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Biochemical composition and nutritional value of promising purple-leaved hazelnut (*Corylus avellana* L.) genotypes developed in Ukraine

Abstract. This study presented the biochemical composition and nutritional value of three promising hazelnut (*Corylus avellana* L.) genotypes with anthocyanin colouration: 'Profesorskyi', 'Aspirantskyi', and 'Akademichnyi', developed at the National University of Life and Environmental Sciences of Ukraine (NULES). This study aimed to compare the content of key nutrients, such as protein, sugars, and fats, as well as the fatty acid profile, in these genotypes. Nut samples from the 2023-2024 harvests, collected from the orchard of the Educational and Production Laboratory of Genetic Resources, Introduction and Breeding of Non-Traditional Fruit and Ornamental Plants at NULES, were analysed using standard methods (Kjeldahl for protein, Bertrand for sugars, Rushkovskyi for fatty acids, and FAME-GC for fatty acid profiling). All three genotypes exhibited high oil content (66.2%-68.2%) and a predominance of oleic acid (79.8%-80.8%). A high content of monounsaturated fatty acids (averaging 81.1%) and a low level of saturated fatty acids (averaging 9.2%), together with the presence of essential fatty acids, indicate a favourable lipid profile similar to that of traditional high-quality hazelnut cultivars. The protein content ranged from 11.7% to 12.8%, while total sugars varied between 1.6% and 1.9%, reflecting good nutritional balance.

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The homogeneity of the genotypes in terms of sugar, protein, and oil content can be attributed to their common genetic origin. The results highlighted the genetic potential of purple-leaved hazelnuts for food and nutraceutical applications. These genotypes may serve as a basis for further breeding programmes targeting both aesthetic and nutritional traits

Keywords: hazelnut oil; oleic acid; essential fatty acids; forest-steppe of Ukraine; nut crops

INTRODUCTION

The hazelnut (*Corylus avellana* L.) is one of the world's most important nut crops. It is highly valued for its nutritional profile and its versatility in food and industrial applications. Despite being native to Ukraine and providing significant ecological benefits, domestic hazelnut production falls short of national demand. This has led to growing interest in industrial hazelnut cultivation and the development of new, high-quality varieties. While traditional breeding has focused on green-leaved genotypes, recent research is exploring forms with anthocyanin colouration, which offer aesthetic appeal and promising nutritional characteristics. Understanding the biochemical composition of these purple-leaved hazelnuts is crucial for advancing breeding programmes, expanding their use in the food and nutraceutical industries, and ultimately enhancing Ukraine's domestic supply.

The hazelnut (*Corylus avellana* L.), native to the forest zone of Ukraine, grows naturally in the understorey of oak-birch and oak-hornbeam forests (Moroz & Terletskyi, 2023). According to V. Sliusarchuk (2006), *Corylus avellana* performs protective functions in steppe forestry; in phytomelioration plantations, it protects the soil from water erosion and improves the hydrological regime and soil fertility. As a pioneer species, it is valuable for forest restoration and succession.

In horticulture, hazelnuts are among the five most important nut crops, alongside cashews, walnuts, almonds, and chestnuts. Hazelnuts are highly nutritious: they are consumed fresh, dried, or roasted and are widely used in cooking and the confectionery industry. The oil extracted from the kernels is important for both nutrition and technology and is also used in painting and perfumery (Goluch *et al.*, 2019; Motti *et al.*, 2022). B. Olas (2024) notes that nut consumption plays an important role in preventing cardiovascular disease, one of the leading health challenges facing modern society. A. Allegrini *et al.* (2022) regard hazelnuts as a multipurpose crop that enhances the sustainability of agro-ecosystems. However, Ukraine's domestic supply does not meet national demand, with consumption per person per year reaching only 21.5% of the optimal nutritional standard (Weisfeld *et al.*, 2018). This situation could be improved by increasing domestic production. In recent years, there has been a significant increase in interest in industrial hazelnut cultivation in Ukraine (Mezhenskyj, 2022). Researchers have pointed out considerable variations in the economic traits and biochemical composition of hazelnuts, depending on the geographical region in which they are grown and their varietal composition. The industrial hazelnut varieties cultivated internationally are largely based on typical green-leaved genotypes. However, in Europe, genotypes with anthocyanin colouration of organs – particularly leaves and fruit husks – have been identified, giving the plants a distinctive decorative effect (Holstein *et al.*, 2018). These characteristics have led to the incorporation of redpigmented mutants in the development of new varieties with exceptional ornamental qualities in Europe and North America (Johnson & Moore, 2023). These varieties have gained considerable popularity, yet the use of purple-leaved hazelnuts for nut production has remained limited. More recently, they have been introduced into breeding programmes aimed at improving hazelnuts as a nut crop (Kosenko *et al.*, 2023). In 2021-2022, the State Register of Varieties of Ukraine included two purpleleaved hazelnut varieties for the first time (Ministry..., n.d.). Similar forms promising for nut production have also been developed at the National University of Life and Environmental Sciences of Ukraine (NULES). This study aimed to analyse the biochemical composition of nuts from the most promising purple-leaved hazelnut genotypes developed at NULES.

MATERIALS AND METHODS

Orchard disposition and plant materials. The experimental study was conducted in the collection orchard of the Educational, Research and Productive Laboratory of Genetic Resources, Introduction and Breeding of Rare Fruits and Ornamental Plants of Prof. V.L. Symyrenko Department of Horticulture of NULES, located at the Agronomic Research Station in Pshenychne Village, Bila Tserkva District, Kyiv Region. The region is part of the forest-steppe natural zone. According to the Köppen climate classification scheme, the area is characterised by a typical warm-summer humid continental climate. The soil is meadow chernozem with artificial irrigation. The three best selections of *Corylus avellana* L., named 'Profesorskyi', 'Aspirantskyi', and 'Akademichnyi', were used. The adult, multistemmed shrubs were grown at a planting distance of 5×4 m, and standard cultural practices were applied, including inter-row cultivation and mechanical weed control, with the exception of irrigation. The study was conducted in accordance with the ethical standards of the Convention on Biological Diversity (1992), which ensures the conservation and sustainable use of biological diversity, as well as the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1973). The ripe nuts were harvested in mid-August, once they had begun to separate easily from the husk.

Determination of protein content. Determination of nitrogen content was carried out by digesting organic matter with sulphuric acid in the presence of a catalyst, according to the Kjeldahl method. All the nitrogen released in this process is converted into ammonium sulphate $(NH_4)_2SO_4$. In an alkaline medium, this compound releases ammonia, which is distilled into a receiving flask containing boric acid via steam distillation. The final measurement involves titration with a standard acid solution, which changes colour at the end point. The nitrogen content is determined by the amount of ammonia produced. The crude protein content is calculated by multiplying the measured nitrogen value by the corresponding coefficient (K=1.754). The determination was carried out using an automatic distillation unit, Kjeltec 8200 TM Foss (Methodology..., 2023).

Determination of sugar content. The Bertrand method for the quantitative determination of sugar content is based on the ability of reducing sugars – those with a free aldehyde or ketone group – to reduce copper(II) sulphate to copper(II) oxide in an alkaline medium. The resulting copper oxide precipitate is then dissolved in iron sulphate in the presence of sulphuric acid. Copper oxide is oxidised by iron, reducing it to copper oxide, which is subsequently oxidised by potassium permanganate solution. This method can also be used to determine the content of disaccharides, but only after hydrolysis with diluted mineral acids. However, the amount of sugar in the solution is not directly proportional to the mass of copper oxide precipitate formed, as some decomposition of Fehling's solution occurs upon heating (with the formation of copper oxide), and some monosaccharides decompose due to the alkalinity of Fehling's solution. Therefore, Bertrand's tables, which show the relationship between the mass of precipitate, copper oxide, and glucose concentration in the solution, are compiled empirically. Deviations from the recommended methodological conditions (temperature, heating duration, solution concentration, degree of alkalinity, etc.) may lead to inaccuracies in the results (Methodology..., 2023).

Determination of fatty acid content. The Rushkovskyi method for assessing kernel oil content is based on measuring the oil remaining in the defatted residue. Samples of dried, ground nuts were placed in filter paper bags and extracted with diethyl ether in a Soxhlet apparatus until complete defatting was achieved. The extracted fat content was calculated by subtracting the mass of the defatted residue from the initial sample mass (Methodology..., 2023).

Determination of the fatty acid composition of oil. The Fatty Acid Methyl Ester (FAME) GC method involves converting fatty acid triglycerides into methyl esters, followed by gas chromatographic analysis using a Nexis GC-2030 Shimadzu gas chromatograph (DSTU ISO 5509-2002, 2003).

Statistical analyses. Experimental data were expressed as me-an ± standard deviation. The effects of genotype, harvest year, and their interaction on fatty acid composition were analysed using ANOVA. When a significant main effect of genotype or a significant interaction effect was detected ($p < 0.05$), Tukey's HSD post-hoc test was performed to identify specific differences between means. All statistical analyses were conducted using SPSS software (Version 17.0). The non-parametric Kruskal-Wallis test was also applied to determine the statistical significance of differences in fatty acid content between hazelnut varieties. This method was chosen due to the small sample size (two years for each variety) and the inability to reliably verify the assumptions of normal distribution and homogeneity of variance, which are prerequisites for parametric tests.

RESULTS AND DISCUSSION

The studied genotypes were characterised by large nuts with a high kernel content, comparable to that of registered purple-leaved hazelnut cultivars. The nut weights of 'Profesorskyi', 'Aspirantskyi', and 'Akademichnyi' were 3.0-3.4 g, 2.7-2.8 g, and 2.3-2.6 g, respectively. Their corresponding kernel percentages were 46.7%-49.3%, 49.4%-52.6%, and 51.3%-52.2% (Mezhenskyj *et al.*, 2025). The first purple-leaved varieties, 'Barbakan BSI' and 'Bahrianyi', listed in the State Register of Varieties of Ukraine, had nut weights of 4.6 g and 2.4 g and kernel percentages of 35.0% and 47.0%, respectively (Vishtak, 2021; Vishtak, 2022). The seeds of fruit crops differ significantly in biochemical composition from the pulp, containing high levels of protein and oil; therefore, they are particularly valuable in human nutrition. The nuts of the studied purple-leaved hazelnut genotypes contained substantial amounts of essential nutrients that determine their nutraceutical value: sugars (1.6%-1.9%), protein (11.7%-12.8%), and oil (66.2%-68.2%) (Table 1).

Table 1. Oil, protein, and carbohydrate content of nuts, average 2023-2024 (x ± SD)

Content	'Profesorskyi'	'Aspirantskyi'	'Akademichnyi'
Oil, %	68.15 ± 0.919	66.15 ± 1.626	67.75 ± 0.636
Crude protein, %	12.25 ± 0.778	11.70 ± 0.566	12.85 ± 1.202
Total sugar, %	1.82 ± 0.240	1.86 ± 0.287	1.64 ± 0.190

Source: compiled by the authors

These results are consistent with previous studies indicating the limits of variation in protein, carbohydrate, and kernel oil content (Rondanelli *et al.,* 2003; Bignami *et al.,* 2005; Król & Gantner, 2020). However, the biochemical composition is also influenced by varietal characteristics and growing conditions. While the protein content of the studied genotypes (11.7%-12.8%) falls within the average range reported for *Corylus avellana* cultivars globally (7.0%-24.6% according to K. Król & Gantner, 2020), it is slightly lower than that of the recently registered purple-leaved Ukrainian cultivars 'Barbakan BSI' (17.0%) and 'Bahrianyi' (14.8%) (Vishtak, 2021; Vishtak, 2022).

This difference is offset by the exceptionally high oil content observed in 'Profesorskyi', 'Aspirantskyi', and 'Akademichnyi', which averaged 66.2%-68.2%. This range not only aligns with but often surpasses the upper limits reported for many commercial hazelnut varieties cultivated across Europe, Asia, and North America (Król & Gantner, 2020), which typically contain 56.3%-67.5% oil. Notably, these genotypes exhibit oil levels comparable to, or even exceeding, those of highly prized Italian cultivars such as 'Nocchione', 'Tonda Gentile Langhe', 'Tonda Gentile Romana', and 'Tonda di Giffoni', which accumulate 66.3%-67.2% oil under Italian conditions (Bignami *et al.*, 2005). At the same time, according to A. Müller *et al.* (2020), 'Tonda di Giffoni' contains 62.7% oil under German conditions. The superior oil content of these genotypes, especially when compared with other purple-leaved varieties, underscores their significant potential for industrial processing and use in high-value products. The registered purple-leaved cultivars 'Barbakan BSI' and 'Bahrianyi' contain lower amounts of oil: 63.0% and 54.0%, respectively (Vishtak, 2021; Vishtak, 2022). The European purple-leaved 'Red Lambert' contains 64.8% oil (Müller *et al.*, 2020).

The sugar content of the kernels of the studied genotypes is approximately half that of the Italian varieties mentioned above, which accumulate 3.9%-4.8% under Italian conditions (Bignami *et al.*, 2005). The lower sugar content of the studied genotypes may be related not only to varietal characteristics but also to differences in soil and climatic conditions, as well as to the methodology applied: in this case, the Bertrand method. In contrast, Italian researchers determined sugar content using the more accurate gasliquid chromatography method. On the other hand, lower sugar content is advantageous for individuals with diabetes. The genotypes studied are relatively homogeneous in terms of their nutraceutical content, which can be explained by their shared genetic origin (Mezhenskyj *et al.*, 2025). Nevertheless, due to small sample sizes and limited replication in biochemical analyses, the study has certain constraints. These factors may reduce the statistical power of the tests and affect the interpretation of the results. When analysing mean data over two years, no significant differences in sugar, protein, or oil content were observed. However, a significant interaction was observed between genotypes and years. In 2023, 'Aspirantskyi' had a statistically higher sugar content than 'Akademichnyi' and 'Profesorskyi', while 'Akademichnyi' and 'Profesorskyi' did not differ significantly from each other. In 2024, however, 'Profesorskyi' had a statistically higher sugar content than 'Akademichnyi' and 'Aspirantskyi', whereas 'Akademichnyi' and 'Aspirantskyi' again did not differ significantly. Thus, the interaction between genotype and year is statistically significant, meaning that the effect of genotype on sugar content varies depending on the year, and vice versa. The qualitative composition of hazelnut oil in the studied genotypes is shown in Table 2.

Table 2. Fatty acid composition of hazelnut oil (%), average 2023-2024 (x ± SD)

Acid		'Profesorskyi'	'Aspirantskyi'	'Akademichnyi'
Myristic	C14:0	0.033 ± 0.001	0.020 ± 0.002	0.0275 ± 0.005
Palmitic	C16:0	6.592 ± 0.226	6.072 ± 0.486	5.350 ± 0.086
Palmitoleic	C16:1	0.402 ± 0.008	0.347 ± 0.080	0.262 ± 0.001
Stearic	C18:0	2.735 ± 0.086	3.190 ± 0.165	2.836 ± 0.057
Oleic	C18:1	79.816 ± 0.358	80.759 ± 1.281	80.413 ± 0.404
Linoleic	C18:2	9.784 ± 0.035	8.038 ± 0.816	10.230 ± 0.660
Linolenic	C18:3	0.152 ± 0.007	0.263 ± 0.201	0.278 ± 0.110
Arachidic	C20:0	0.133 ± 0.016	0.154 ± 0.012	0.145 ± 0.040
Gondoic	C20:1	0.145 ± 0.014	0.281 ± 0.236	0.189 ± 0.025
Eicosadienoic	C20:2	0.001 ± 0.0b	0.006 ± 0.001a	0.002 ± 0.001ab
Behenic	C22:0	0.087 ± 0.010b	0.145 ± 0.020a	0.111 ± 0.005ab
Erucic	C22:1	0.004 ± 0.006	0.571 ± 0.805	0.001 ± 0.001
Docosadienoic	C22:2	0.001 ± 0.001	0.001 ± 0.000	0.001 ± 0.001
Nervonic	C24:1	0.005 ± 0.004	0.004 ± 0.005	0.001 ± 0.001

Note: different letters indicate values that are significantly different within a row, according to the results of Tukey's test ($P \leq 0.05$)
Source: compiled by the authors

The main fatty acids present in the oil of the studied genotypes are oleic acid (79.8%-80.8%), linoleic acid (8.0%-10.2%), palmitic acid (5.4%-6.6%), and stearic acid (2.7%-3.2%), while other fatty acids occur only in small amounts. When the genotypes are compared with one another and with the average values across two years, no statistically significant differences are observed. This similarity is attributable to their common genetic origin. The results are consistent with the typical order of fatty acid contribution in hazelnuts: oleic acid > linoleic acid > palmitic acid > stearic acid > linolenic acid. As reported in previous studies, oleic acid remains the predominant fatty acid (Król & Gantner, 2020; Gardeli *et al.*, 2025).

Over the two-year period, the average proportions of oleic acid in the kernels of 'Profesorskyi', 'Aspirantskyi', and 'Akademichnyi' were 79.8%, 80.8%, and 80.4%, respectively. These levels are similar to those of popular Italian varieties, whose oil contains between 80.7% and 82.1% oleic acid under Italian conditions (Bignami *et al*., 2005). Among the 15 European varieties studied, the Italian cultivar 'Tonda di Giffoni' had the highest content (81.7%) under German conditions, while the purple-leaved 'Red Lambert' had a moderate content (80.3%) (Müller *et al.,* 2020). P. Benitez-Sanchez *et al*. (2003) and C. Gardeli *et al*. (2025) point out the similarity between hazelnut oil and olive oil, both of which are characterised by a high oleic acid content when different vegetable oils are compared. Its high similarity means that hazelnut oil can even be used to adulterate extra virgin olive oil (Ordoudi *et al*., 2022; Pereira *et al*., 2023).

A high oleic acid concentration is known to lead to a longer shelf life and greater oxidative stability (Król & Gantner, 2020; Sun *et al*., 2022). On average, the proportion of monounsaturated fatty acids (MUFAs), including oleic acid, in the oil of the studied genotypes is 81.1%; polyunsaturated fatty acids (PUFAs) account for 9.6%, and saturated fatty acids for 9.2%. The low level of saturated fatty acids in hazelnut kernels compared with other food sources is advantageous (Sun *et al*., 2022; Rondanelli *et al*., 2023). According to E. Whitney & S. Rolfes (2007), only two fatty acids are essential for humans: α-linolenic acid (ω-3) and linoleic acid (ω-6). The content of these polyunsaturated fatty acids in the kernel oil of the studied genotypes is 0.15%-0.28% and 8.0%-10.2%, respectively. Linoleic acid ranks second after oleic acid, which highlights the valuable composition of the oil from these genotypes.

ANOVA of the kernel oil composition showed that, for the majority of fatty acids, there were no statistically significant differences between the genotypes or harvest years. This suggests a high degree of homogeneity in the fatty acid profiles of the studied genotypes, as well as stability across the two growing seasons for most components. This is likely due to their common genetic origin. However, statistically significant findings were observed for eicosadienoic acid and behenic acid. Both the main effect of genotype and the interaction effect between genotype and year were statistically significant. This interaction indicates that differences in acid content between genotypes varied depending on the harvest year. 'Aspirantskyi' had a significantly higher average content of both acids compared with 'Profesorskyi'. 'Akademichnyi' did not differ significantly from the other two genotypes. It is also noteworthy that, although the main genotype effects were not statistically significant ($p > 0.05$), gondoic acid and erucic acid exhibited highly significant interaction effects between genotype and year. This implies that, although these genotypes may not differ significantly in their overall average content of these fatty acids across both years, their performance or accumulation patterns for these acids were strongly influenced by the environmental conditions of the individual harvest year. Further in-depth analysis would be beneficial to fully elucidate these genotype responses dependent on the harvest year. In summary, the statistical analysis confirms the overall genetic uniformity of the developed hazelnut genotypes with regard to their major fatty acid profiles; however, specific fatty acid compositions can be modulated by environmental conditions. This is consistent with the findings of R. Gianferri *et al*. (2023), who demonstrated that the chemical composition of hazelnuts is significantly influenced by the pedoclimatic conditions of the growing site and the variety.

In the Kruskal-Wallis test, no statistically significant differences were found between the genotypes at the p-value threshold of < 0.05 for any of the fatty acids. Despite the absence of statistically significant differences confirmed by the Kruskal-Wallis test and Dunn's post-hoc comparison for most fatty acids in the limited dataset, some genotypes demonstrated notable compositional trends that may be biologically relevant. For instance, oleic acid was consistently the predominant fatty acid across all three cultivars, contributing over 79.8% to the total oil content. The lack of significant differences underscores its stability and suggests that oleic acid content is a robust varietal trait. Linoleic acid varied among genotypes, with 'Akademichnyi' exhibiting the highest average content (10.230% ± 0.660%) and 'Aspirantskyi' the lowest (8.038% ± 0.816%). Although the difference was not statistically significant, it may influence oxidative stability and nutritional value. Linolenic acid, an omega-3 fatty acid, showed higher average levels in 'Akademichnyi' (0.278% ± 0.110%) and 'Aspirantskyi' (0.263% ± 0.201%), which may enhance their nutritional profile. Despite the lack of statistical significance, these differences may be biologically or technologically important, suggesting the need for further studies with larger sample sizes.

CONCLUSIONS

The hazelnut genotypes 'Profesorskyi', 'Aspirantskyi', and 'Akademichnyi', developed at the NULES, were found to have a high content of essential nutrients, indicating their high nutritional value and suitability for dietary supplementation. The protein content ranged from 11.3% to 13.7%, the sugar content from 1.5% to 2.1%, and the oil content from 65.0% to 68.8%. Notably, the oil content in these genotypes is particularly high, with oleic acid (79.6%-81.7%) being the predominant fatty acid. This is a characteristic feature of high-quality vegetable oils, such as olive oil. The high content of monounsaturated fatty acids (averaging 81.1%) and the low level of saturated fatty acids (averaging 9.2%) highlight the health benefits of these nuts, particularly in the prevention of cardiovascular disease. The presence of linoleic and α-linolenic acids, the two main essential fatty acids, indicates the oil's valuable composition. Despite some fluctuations in biochemical composition over the years of cultivation, the studied genotypes show relative homogeneity, which is explained by their common genetic origin. A comparison with existing registered hazelnut varieties (in particular the registered red-leaved cultivars 'Barbacan BSI' and 'Bahrianyi' and Italian cultivars used in industrial plantations in Ukraine shows that the NULES of Ukraine genotypes have competitive or even superior performance in terms of key biochemical parameters, especially oil content. This suggests significant potential for increasing the industrial production of hazelnuts in Ukraine, which could reduce dependence on imports and boost nut consumption among the population. Further research could focus on other bioactive compounds in these genotypes to better assess their value.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Біохімічний склад і харчова цінність перспективних пурпуроволисткових генотипів фундука (*Coryllus avellana* L.) дібраних в Україні

Анотація. Дослідження представило біохімічний склад та харчову цінність трьох перспективних генотипів фундука (*Corylus avellana* L.) з антоціановим забарвленням: 'Професорський', 'Аспірантський' та 'Академічний', створених у Національному університеті біоресурсів і природокористування України (НУБіП України). Дослідження мало на меті порівняти вміст ключових поживних речовин, таких як білки, цукри та жири, а також профіль жирних кислот у цих генотипів. Зразки горіхів урожаю 2023-2024 років, зібрані з саду Навчально-виробничої лабораторії генетичних ресурсів, інтродукції та селекції нетрадиційних плодових та декоративних рослин НУБіП України, аналізували стандартними методами (К'єльдаля для білків, Бертрана для цукрів, Рушковського для жирних кислот та FAME-GC для профілювання жирних кислот). Усі три генотипи показали високий вміст олії (65,0-68,8 %) та переважання олеїнової кислоти (від 79,8 % до 80,8 %). Високий уміст мононенасичених жирних кислот (в середньому 81,1 %) і низький рівень насичених жирних кислот (в середньому 9,2 %) та наявність незамінних жирних кислот свідчить про сприятливий ліпідний профіль, подібний до профілю традиційних високоякісних сортів ліщини. Уміст білка коливався від 11,7 % до 12,8 %, тоді як загальний вміст цукрів становив від 1,6 % до 1,9 %, демонструючи хороший харчовий баланс. Однорідність генотипів за вмістом цукру, білка та олії пояснюється їхнім спільним генетичним походженням. Результати підкреслили генетичний потенціал пурпурнолисткових ліщин для харчових та нутрицевтичних застосувань. Ці генотипи можуть слугувати основою для подальших селекційних програм, спрямованих як на естетичні, так і на харчові ознаки

Ключові слова: фундукова олія; олеїнова кислота; незамінні жирні кислоти; лісостеп України; горіхоплідні культури