

Evaluation of ‘Esterhazy II’ Persian walnut (*Juglans regia* L.) genotypes from Hungary, Austria, and Switzerland

Géza Bujdosó

bujdosogeza@uni-mate.hu

Hungarian University of Agriculture and Life Sciences

Alina Ratiu

Hungarian University of Agriculture and Life Sciences

Andreas Spornberger

BOKU University

Daniela Noll

BOKU University

Klára Cseke

University of Sopron

Short Report

Keywords: historic variety, local population, nut pomology, selection, SSR analysis

Posted Date: July 15th, 2025

DOI: <https://doi.org/10.21203/rs.3.rs-7068639/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Version of Record: A version of this preprint was published at Genetic Resources and Crop Evolution on August 7th, 2025. See the published version at <https://doi.org/10.1007/s10722-025-02590-x>.

Abstract

The historic Persian walnut genotype, known as 'Esterhazy II' and derived from Hungary, is well-known in the German-speaking countries; however, there are only a few specimens showing significant variability in traits in its native country. In this current study, the aim was to evaluate our genotype, labelled 'Esterhazy II', which is planted in the ex-situ gene bank of the Hungarian University of Agriculture and Life Sciences, and compare it to other true-to-type ones. During the examination, the SSR analysis confirmed that the Hungarian 'Esterhazy II' is exactly identical to the true-to-type Austrian and Swiss varieties. The Austrian and the Swiss 'Esterhazy II' differed significantly in nut height from the control 'Chandler'. There was no further significant difference in the nut parameters. All Esterhazy genotypes, except 'Esterhazy II' from Hungary, as well as 'Milotai 10', 'Chandler', were significantly different from 'Alsószentiváni 117' and 'Tizacsécsi 83' in shell thickness. The Hungarian 'Esterhazy II' reached the heaviest dried nut weight; there wasn't any significant difference in this parameter among the study's varieties. The Swiss 'Esterhazy II' and 'Esterhazy kesei' had the heaviest kernel weight. Kernel weight of the Austrian 'Esterhazy II' differed from the Swiss 'Esterhazy II' and 'Esterhazy kesei'. The Austrian 'Esterhazy II' had a significantly smaller cracking rate compared to Swiss 'Esterhazy II', 'Alsószentiváni 117', and 'Tizacsécsi 83' and a higher rate of halves compared to 'Esterhazy kesei' and 'Alsószentiváni 117'.

Introduction

The Persian walnut (*Juglans regia* L.) is a well-known and widespread nut tree species in the Carpathian Basin, including Hungary. The backyard gardens should have at least one walnut tree in the countryside. This nut tree species might be native to the Pannonian basin, and this population was mixed with other populations (located in Anatolia) through human-mediated activity (Pollegioni et al., 2015, 2017, Vahdati 2014), which provides a wide range of variability. Accessions with a certain geographical origin, such as walnut derived from Milota and Tarpa (both villages are from Northeast Hungary), Eszterháza, located in Northwest Hungary (today Eszterháza is part of Fertőd, merged in 1950), as well as from Sebesel and Baia Mare (located in Romania), had good renown on the markets during the 18th century. Furthermore, the relative frequency of genotypes with red kernels was very high in the Western or Southwestern Transdanubia. In Transylvania, it was very frequent to find cluster-bearing genotypes. Others, such as genotypes with stone shell, paper shell, thin shell, soft shell, and large nut size did not have special geographic locations, but were typical for the Pannonian Basin (Dochstuhl, 1860, Schneiders 1899, Mohácsy – Porpácz 1951, Porpácz et al. 1955). All previously bred, so-called historic genotypes were lost because of a lack of vegetative propagation. This xenovegetative propagation method started in the 1970s in Hungary; therefore, there are some specimens labelled under historic variety names having different traits on the market.

The mindful breeding activity started after the strong winter in 1928/29, when seedlings, imported from France in 1910, were heavily damaged by the frosts during the dormant period. First, the breeders used selection from the local population, because 1,900,000 walnut trees were registered during the fruit-bearing tree data collection in 1935 (Porpácz et al. 1955). This method is still very popular in lot of

countries such as in China (Luo et al. 2022), India (Sajwan 2022, Shah et al., 2023), Iran (Fallah et al., 2024), Nepal (Khanal et al., 2023), Uzbekistan (Butkov et al., 2020), Türkiye (Keles 2014, Aydemir et al., 2025), Kazahstan (Akca et al., 2020), Russian Federation (Sokolova, 2022), Serbia (Cercovic et al., 2010, Paunović and Rade, 2023), Australia (Sluiter et al., 2014), Czech Republic (Pavliuk et al., 2025), Romania (Botu et al., 2014, Iordănescu et al., 2021), France (Lheureux et al. 2021), and Hungary (Bujdosó et al., 2020).

During the 1930s, the breeding aims were focused on the adaptation of the trees to the local climate conditions and good nut quality (at least 32 mm in diameter, smooth shell surface with light colour, light kernel colour, at least 50% kernel yield, no aftertaste). Furthermore, it was essential to have tolerance to the fungal diseases, and the homogamy was preferred (Porpáczy et al. 1955). Today, homogamy during the blossom period is no longer preferred, but others are accepted by the breeders. Further breeding aims were added to this list, like tolerance to the bacterial diseases (Frutos, 2010, Sun et al., 2025), late leafing (Akca, and Özongun 2004, Kavosi and Khadivi, 2021, Fallah et al., 2022, Sutyemez et al., 2022, Hamidirad et al., 2025), lateral bearing (Botu et al. 2010, 2019, Bernard et al., 2020, Rezaei et al., 2020, Hakimi et al., 2024), and good shell structure (Sarikhani et al., 2018, Sarikhani and Vahdati, 2019, Rezaei et al., 2020). Furthermore, good adaptability to the different environmental factors such as drought tolerance (Lofti et al., 2022, Zheng et al., 2024, Gao et al., 2025), low-temperature stress (Zhang et al. 2020, Zhao et al., 2024), salt tolerance (Ji et al., 2022, Zheng et al., 2024) is needed.

During the early stage of breeding, some candidates were prepared for approval. At that time, a candidate had to pass the DUS examination and the Value of Cultivation and Use Test. This later-mentioned test took a long period (15–30 years), in the case of walnut. Furthermore, novel-bred genotype had to have at least one positive value compared to the reference cultivar. During this period, there were some genotypes under evaluation, such as ‘Alsószentiváni 117’, ‘Milotai 10’, ‘Tiszacsécsi 83’, ‘Fertődi 1’, ‘Eszterhazy II’. Among these, the Esterhazy genotypes appeared with various synonyms (Eszterházi, Eszterházy, Eszterházai, Eszterházy), and are still very popular in Switzerland, Germany, and Austria (Solar et al., 1997). Unfortunately, many of the historic walnut genotypes were putatively lost due to the use of generative propagation.

In this study, our goal was to evaluate the genotypes/varieties, selected from the local populations, with special regard to the ‘Esterhazy II’ genotypes.

Materials and methods

Plant material

There were some specimens labelled ‘Esterhazy II’ in the ex situ gene bank collection of the Hungarian University of Agriculture and Life Sciences, but those were not true-to-type ones (Bujdosó et al., 2021, 2022). Continuing this research, we went back to that site, from which this genotype was described and selected. Around Eszterháza (part of Fertőd today), the walnut accessions were checked, and senior colleagues were asked about the true-to-type ‘Esterhazy II’ genotype. Finally, we found one tree, which

was identified on the old maps of the trials. Samples were collected to check the nut characteristics and the genetic identity of this tree. To add additional true-to-type ‘Esterhazy II’ specimens, the Nut Tree Working Group of European Fruit Research Institute was asked to provide the requested material. BOKU from Austria, and a Swiss nursery (located in Hörhausen) sent us nut and leaf samples to check and compare them with our selected tree. It is important to mention that we do not have any knowledge about having any ‘Esterhazy II’ in the herbaria now. So, the specimen labelled true-to-type ‘Esterhazy II’ from Hungary (marked as ‘Esterhazy II (H)'), and further two true-to-type ‘Esterhazy II’ accessions from Austria (marked as ‘Esterhazy II’ (A)), and Switzerland (marked as ‘Esterhazy II’ (CH)), the most grown varieties, selected from the Hungarian local population, ‘Milotai 10’, ‘Tiszacsécsi 83’ and ‘Alsószentiváni 117’, another Esterhazy-type variety, ‘Esterhazy kesei’, as well as the most grown cultivar on the Earth, the US-bred ‘Chandler’ as control, were added to the trial (Table 1).

Table 1
Some nut characters of the examined varieties, involved in the trial

Name of the cultivar	Origin	Nut diameter (mm)	Nut shape	Nut weight (g)	Kernel colour	Kernel yield (%)
Alsószentiváni 117	selected from the Hungarian population	33 to 36	elongated	11 to 14	yellowish brown	48 to 51
Chandler	cross between Pedro and UC 56–224	28 to 30	round	13	light yellowish brown	49
Esterhazy II	derived from a French population, selected in Hungary	37 to 45	ovate with medium-long tip	13 to 15	ivory white	49
Esterhazy kesei	selected from the Hungarian population	35 to 37	ovate	13 to 16	light yellow	45
Milotai 10	selected from the Hungarian population	33 to 35	round	13 to 17	straw yellow	47 to 52
Tiszacsécsi 83	selected from the Hungarian population	32 to 34	elongiated	11 to 14 2	light yellowish brown	48 to 52

sources: Böllersen, (2017), Szentiványi, P. and Kállay T. (2006), Ramos, 1998, Aleta, et al., 2005, Connell et al., 2010, Bujdosó et al., 2019, 2022.

Observed traits

The Hungarian samples were from a rainfed experimental orchard was established in Érd, Hungary (lat. 47°20'11"N, long. 18°51'53"E; elevation, 127 m above sea level), in 1990. All trees were grafted on selected *J. regia* seedlings, and plated in five replications in 10 m inter-row and between the row spacing, trained as a central leader canopy. The Table 2. contains climate and soil conditions of the different sites.

Table 2
Climate and soil conditions of the sites involved in the trial

	Érd (Hungary)	Vienna (Austria)	Hörhausen (Switzerland)
average yearly temperature (°C)	11.5	10.2	5.8
average yearly temperature during the growing season (between March and September) (°C)	18.3	16.9	13.8
average yearly precipitation (mm)	538	550	990

During this research period of 2010 to 2024 the nut tree characters (nut height, nut diameter, nut width, shell thickness, dried nut and kernel weight, kernel yield: rate of weight of halves compared to the whole nut weight, and rate of halves: rate of weight of halves compared to the weight of whole kernel) of 1 kg samples were checked.

Genetic analysis

To prove the genetic identity of the selected samples, a genetic fingerprinting analysis was conducted applying nuclear microsatellite (or nSSR, nuclear simple sequence repeats) markers. The following 13 markers were selected from the available literature: WGA27, WGA72 (Woeste et al., 2002), WGA001, WGA004, WGA009, WGA089, WGA118, WGA202, WGA276, WGA321, WGA331 (Dangl et al., 2005) and JR1817, JR6160 (Dang et al., 2016). PCR conditions were applied based on the original references.

For SSR data analysis, GenAlEx 6.5 software (Peakall and Smouse, 2006, 2012) was used. The probability of identity (P_{ID}) was calculated for the combination of the 13 analyzed loci, and possible matching genotypes were verified. The Genetic distance (Codom-Genotypic) option was applied for generating a pairwise, individual-by-individual genetic distance matrix. Matrix was used for subsequent PCoA and for constructing UPGMA dendrogram by PAST 4.03 (Hammer et al., 2001).

Results

First, the genetic identity of the analysed samples was confirmed by the fingerprint analysis. The low value of the P_{ID} index (9.54×10^{-9}) indicated the high accuracy and resolution of the applied markers. The three different 'Esterhazy II' specimens involved in the study shared the same genotype; therefore, they can be considered true replicates of the same historical variety. The other five cultivars represented different genetic backgrounds. The 'Esterhazy II' genotype appeared relatively distinct from the other clones in this evaluation (Fig. 1).

The highest nut height was reached by 'Chandler', followed by 'Milotai 10', and 'Esterhazy kesi'. The smallest nut height was measured in the case of 'Alsószentiváni 117', 'Tizacsécsi 83', 'Esterhazy II' harvested in Austria. Nut height of 'Chandler' and 'Milotai 10' differed significantly from the 'Esterhazy II' from Austria and Switzerland, but not from the Hungarian accession.

Regarding the diameter, all measured varieties reached the lowest border of the first grade (32 mm), except the control. The largest nut diameter was measured on 'Milotai 10', followed by 'Esterhazy II' from Switzerland, 'Alsószentiváni 117', and 'Esterhazy kesi'. The smallest nut diameter was measured on the control, 'Chandler'.

The nut width values were similar for all; the largest width was reached by 'Alsószentiváni 117', the smallest one was produced by 'Esterhazy II', derived from Austria, and the control. There wasn't a significant difference in nut diameter and nut width (Fig. 1).

The shell thickness is important during both mechanical harvesting and the post-harvesting. 'Esterhazy kesi' had the thickest shell, followed by 'Esterhazy II' from Austria and 'Milotai 10'. The 'Alsószentiváni 117' and 'Tizacsécsi 83' had the softest shell, which had a significant difference from the other observed varieties (Fig. 2).

The Hungarian 'Esterhazy II' produced the highest dried nut weight, followed by 'Alsószentiváni 117' and 'Esterhazy II' from Switzerland. The lowest dried nut weight was reached by 'Esterhazy II', derived from Austria, Tizacsécsi 83' and the control. There was no significant difference in this parameter.

Regarding the kernel weight, the Hungarian-bred 'Esterhazy kesi' and the Swiss 'Esterhazy II' samples had the heaviest kernels and differed significantly from the other samples. The smallest weight value was reached by 'Chandler' (Fig. 3).

The kernel yield is an important parameter because it shows the harvestable quantity. The 'Tizacsécsi 83' 'Alsószentiváni 117', 'Chandler', and the Swiss 'Esterhazy II' reached the highest values. The lowest was produced by the Austrian 'Esterhazy II', which did not reach the minimum 40% in kernel yield. The Swiss 'Esterhazy II' Tizacsécsi 83', and 'Alsószentiváni 117' showed a significant difference from the Austrian one in kernel yield.

The cracking rate indicates the rate of halves, which is the most important value on the markets. The Swiss 'Esterhazy II' and 'Chandler' had the highest rate of halves, followed by the Austrian 'Esterhazy II'.

The lowest value from this parameter was produced by ‘Esterhazy kесеi’ and ‘Alsószentiváni 117’; both had a significant difference from the other examined varieties (Fig. 4).

Discussion

It is typical for genotypes, accessions derived from the Carpathian Basin, to have large nut sizes (Bujdosó et al. 2020), which was confirmed in this trial. Large nut size is important because the market pays extra for the large nut size categories (premium ≤ 32.0 mm, premium + ≤ 34.0 , premium++ ≤ 36.0 mm in diameter). The large nut size of varieties, derived from the Pannonian Basin (Bujdosó et al. 2020), correlated well to the heavy dried nut weight, as proven in the trial. Beside these two important traits, the selected ‘Esterhazy II’ specimen has a thin shell, which did not have any significant difference from the approved varieties (Fig. 2).

However, it cannot be confirmed with certainty that ‘Esterhazy II’ does not have French origin based on this study; it is clearly visible that this genotype stands closer to the Hungarian-bred cultivars ‘Tiszacsécsi 83’ and ‘Alsószentiváni 117’. These two are local selections from Central Hungary (Mezőföld region) and Northeast Hungary (Bereg region), respectively.

Based on the literature data and the experience collected from German-speaking countries, the ‘Esterhazy II’ is suitable for small-scale cultivation.

Declarations

Acknowledgements

This work was supported by the Research Excellence Programme of the Hungarian University of Agriculture and Life Sciences.

Author contributions

Géza Bujdosó, Klára Cseke, and Andreas Spornberger contributed to the study conception and design. Material preparation was performed by Géza Bujdosó, Alina Ratiu, Daniela Noll, and Andreas Spornberger. Data collection and analysis were performed by Géza Bujdosó, Alina Ratiu, and Klára Cseke. The first draft of the manuscript was written by Géza Bujdosó and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding none

Data availability

Datasets generated and/or analyzed during the current study are available in the general PC under accession number 4/18/2024.

Conflict of interest

The authors declare no competing interests.

Open Access

This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>

References

1. Akca Y, Özongun Ş (2004) Selection of late leafing, late flowering, laterally fruitful walnut (*Juglans regia*) types in Turkey. *New Zeal J Crop Hort* 32:337-342
<https://doi.org/10.1080/01140671.2004.9514313>
2. Akca Y, Yuldaşulu Y, Murad E, Vahdati K (2020) Exploring of Walnut Genetic Resources in Kazakhstan and Evaluation of Promising Selections Introduction. 7:93-102
<https://doi.org/10.22059/ijhst.2020.299930.352>
3. Aydemir Z, Özcan A, Aytekin M (2025) Production and Marketing of Walnut in Çağlayancerit District of Kahramanmaraş Province. *Black Sea Journal of Agriculture* 8:29-30
<https://doi.org/10.47115/bsagriculture.1624433>
4. Aleta N, Rovira M, Ninot A, Vilanova A (2005) 'Chandler' walnut trees trained in three kinds of central leader: Structured, semi-structured and free—results at the age of six. *Acta Hort* 705:479–485
5. Bernard A, Marrano A, Donkpegan A, Brown P, Leslie C, Neale D, Lheureux F, Dirlewanger E (2020) Association and linkage mapping to unravel genetic architecture of phenological traits and lateral bearing in Persian walnut (*Juglans regia* L.). *BMC Genomics* 21 <https://doi.org/10.1186/s12864-020-6616-y>
6. Botu M, Tudor M, Papachatzis A (2010) Evaluation of some walnut cultivars with different bearing habits in the ecological conditions of Oltenia - Romania. *Acta Hort* 861:119-126
<https://doi.org/10.17660/ActaHortic.2010.861.15>
7. Botu M, Achim G, Cosmulescu S, Tsampas T, Botu I (2014) The influence of ecological conditions and genotype on walnut yield north of Oltenia - Romania. *Acta Hort* 1050:271-276.
<https://doi.org/10.17660/ActaHortic.2014.1050.36>
8. Botu M, Alabedallat Y, Buccura F, Geana I, Vladu M (2019) The Productive Capacity and Quality of Several Walnut Cultivars (*Juglans regia* L.) Grown in North Oltenia, Romania. *Not Bot Horti Agrobi* 47(3):574-579 <https://doi.org/10.15835/nbha47311475>

9. Böllersen V (2017) Revival der Walnuss [Revival of Walnut]. Sortenkatalog [Variety Register]; Organischer Landbau Verlag [Organischer Landbau Publisher]: Kevelaer, Germany, 125 p.
10. Bujdosó G, Varjas V, Szügyi-Bartha K, Tóth-Nagy A (2019) Evaluation of the novel bred Persian walnut genotypes. *Agrolife Sci J* 8:60–65
11. Bujdosó G, Izsépi F, Szügyiné Bartha K., Varjas V, Szentiványi P (2020) Persian walnut breeding program at Naric Fruticulture Research Institute in Hungary. *Acta Horti* 1280:89-94 <https://doi.org/10.17660/ActaHorti.2020.1280.13>
12. Bujdosó G, Illes B, Varjas V, Cseke K (2021) Is “Esterhazy II”, an Old Walnut Variety in the Hungarian Gene Bank, the Original Genotype? *Plants* 10:854 <https://doi.org/10.3390/plants10050854>
13. Bujdosó G, Ercisli S, Ratiu A, Cseke K (2022) Walnut ‘Esterhazy kesi’ for Small-scale Cultivation. *HortScience* 57(4):523-524 <https://doi.org/10.21273/HORTSCI16504-22>
14. Butkov E, Mamutov B, Nikolyai L, Kasimkhodjaev A (2020) Study on the selection of the best forms of walnut in Uzbekistan. *IOP Conference Series: Earth and Environmental Science* 614. 012107 <https://doi.org/10.1088/1755-1315/614/1/012107>
15. Bükücü Ş, Özcan A, Bayazıt S, Sutyemez M. (2025) 'Bayındır': A New Cultivar of *Juglans regia* L. *HortScience* 60:822-823. <https://doi.org/10.21273/HORTSCI18552-25>
16. Cerović S, Branislava G, Todorović J, Bijelic S, Ognjanov V (2010) Walnut (*Juglans regia* L.) selection in Serbia. *Hortic Sci* <https://doi.org/37.10.17221/25/2009-HORTSCI>
17. Connell J, Olson W, Limberg J, Metcalf S (2010) Effects of Various Roots on ‘Chandler’ Walnut Catkin And Pistillate Bloom, Tree Growth, Yield, and Nut Quality. *Acta Horti* 861:237–244
18. Dangl GS, Woeste K., Aradhya MK, Koehmstedt A, Simon C, Potter D (2005) Characterization of 14 microsatellite markers for genetic analysis and cultivar identification of walnut. *J Am Soc Hort Sci* 130:348-354 <https://doi.org/10.21273/JASHS.130.3.348>
19. Dang M, Zhang T, Hu Y, Zhou H, Woeste K, Zhao P (2016) De Novo assembly and characterization of bud, leaf and flowers transcriptome from *Juglans regia* L. for the identification and characterization of new EST-SSRs. *Forests* 7:247-263 <https://doi.org/10.1007/s00438-015-1147-y>
20. Dochnahl FJ (1860) Der sichere Führer in der Obstkunde auf botanisch-pomologischem Wege, oder Systematische Beschreibung aller Obstsorten [The reliable guide to fruit science by botanical-pomological means, or systematic description of all fruit varieties]. Vol. 4. W. Schmid, Nürnberg 25-34 p
21. Fallah M, Rasouli M, Hassani D, Lawson S, Sarikhani S, Vahdati K (2022) Tracing Superior Late-Leafing Genotypes of Persian Walnut for Managing Late-Spring Frost in Walnut Orchards. *Horticulturae* 8:1003 <https://doi.org/10.3390/horticulturae8111003>
22. Fallah M, Paizila A, Karc, H, Arab M, Sarikhani S, Suprun I, Rasouli M, Hassani D, Kafkas S, Vahdati K (2024) Validation and implementation of marker-assisted selection (MAS) for the leafing date trait in Persian walnut populations from Iran. *Euphytica* 220. <https://doi.org/10.1007/s10681-023-03281-3>
23. Frutos D (2010) Bacterial diseases of walnut and hazelnut and genetic resources. *J Plant Pathol* 92:79-85

24. Gao Y, Gong F, Ma X, Zhang Z, Wang Y (2025) Functional identification of JrMYBs gene in Walnut (*Juglans regia*) demonstrates it enhances drought stress tolerance. *Physiol Mol Biol Pla* 31:375-387 <https://doi.org/10.1007/s12298-025-01568-4>
25. Hakimi Y, Taheri Z, Rahmani A (2024) Morphological, pomological, and biochemical evaluation of several superior walnut (*Juglans regia* L.) genotypes *Genet Resour Crop Ev* 71:3361-3381 <https://doi.org/10.1007/s10722-023-01836-w>
26. Hamidirad M, Sarikhani S, Nikpendar A, Sheikhi A, Roozban MR, Ghahramanzadeh S, Vahdati K (2025) Unlocking the walnut genetic resources in Northeastern Iran for late-leafling and nut quality. *Genet Resour Crop Ev* 72:6129-6143 <https://doi.org/10.1007/s10722-024-02324-5>
27. Iordănescu O, Radulov I, Buha, I, Cocan I, Berbecea A, Popescu I, Poșta D, Camen D, Lalescu D (2021) Physical, Nutritional and Functional Properties of Walnuts Genotypes (*Juglans regia* L.) from Romania. *Agronomy* 11:1092 <https://doi.org/10.3390/agronomy11061092>
28. Ji X, Tang J, Fan W, Li B, Bai Y, He J, Pe, D, Zhang J, (2022) Phenotypic Differences and Physiological Responses of Salt Resistance of Walnut with Four Rootstock Types. *Plants* 11:1557 <https://doi.org/10.3390/plants11121557>
29. Kavosi H, Khadivi A (2021) The selection of superior late-leafling genotypes of Persian walnut (*Juglans regia* L.) among seedling originated trees based on pomological characterizations. *Scientia Hortic-Amsterdam* 288:110299 <https://doi.org/10.1016/j.scienta.2021.110299>
30. Keles H., Akca Y, Ercisli S (2014) Selection of promising walnut genotypes (*Juglans regia* L.) from Inner Anatolia. *Acta scientiarum Polonorum. Hortorum cultus = Ogródnictwo* 13:167-175
31. Khanal A, Timilsina S, Poon T, Adhikari B (2023) Characterization and selection of thin-shelled walnut (*Juglans regia* L.) genotypes of Mustang, Nepal. *Archives of Agriculture and Environmental Science* 8:86-91 <https://doi.org/10.26832/24566632.2023.0801013>
32. Lheureux F, Dirlewanger E, Anthony B (2021) The French walnut improvement program. *Acta Hort.* 1318:1-8 <https://doi.org/10.17660/ActaHortic.2021.1318.1>
33. Lotfi N, Soleimani A, Çakmakçı R, Vahdati K, Mohammad P (2022) Characterization of plant growth-promoting rhizobacteria (PGPR) in Persian walnut associated with drought stress tolerance. *Sci Rep-UK* 12:12725 <https://doi.org/10.1038/s41598-022-16852-6>
34. Luo X, Zhou H, Cao D, Yan F, Chen P, Wang J, Keith Woeste, Xin Chen, Zhangjun Fei, Hong An, Maria Malvolti, Kai Ma, Chaobin Liu, Aziz Ebrahimi, Chengkui Qiao, Hang Ye, Mengdi Li, Zhenhua Lu, Jiabao Xu, Shangying Cao, Peng Zhao (2022) Domestication and selection footprints in Persian walnuts (*Juglans regia*). *PLoS Genet* 18(12): e1010513 <https://doi.org/10.1371/journal.pgen.1010513>
35. Mohacsy M, Porpaczy A (1951) Dió, mandula, mogyoró, gesztenye. [Walnut, almond, hazelnut, chestnut]. *Mezőgazda Kiadó [Publisher], Budapest.* 19-26 p
36. Paunović M, Rade C (2023) Fruit characteristics of promising walnut genotypes from the region of eastern Serbia. *Genetika-Belgrade* 55:193-202. <https://doi.org/10.2298/GENSR23010193P>
37. Pavliuk L, Marklová M, Krška B, Pech P (2025). Selection of valuable walnut genotypes in the gene pool collections of VŠÚO Holovousy. *Vědecké Práce Ovocnářské* 31:34-40

<https://doi.org/10.60702/7xkw-bj42>

38. Pollegioni P, Woeste KE, Chiocchini F, Del Lungo S, Olimpieri I, Tortolano V, et al. (2015) Ancient humans influenced the current spatial genetic structure of common walnut populations in Asia. *PloS ONE*. 10: e0135980. pmid:26332919
39. Pollegioni P, Woeste K, Chiocchini F, Del Lungo S, Ciolfi M, Olimpieri I, et al. (2017) Rethinking the history of common walnut (*Juglans regia* L.) in Europe: Its origins and human interactions. *PLoS ONE* 12(3): e0172541. <https://doi.org/10.1371/journal.pone.0172541>
40. Porpáczy A, Szentiványi P, Brózik S (1955): A dió. [The Walnut]. Akadémiai Kiadó [Akadémia Publisher], Budapest. 49-63 p
41. Ramos .E (Ed.) *Walnut Production Manual*; University of California: Oakland, CA, USA, 1998; p. 84–89.
42. Rezaei A, Arzani K, Sarikhani S (2020) Morphological evaluation and identification of walnut (*Juglans regia* L.) superior genotypes in north Hamadan province of Iran. *Iranian Journal of Horticultural Science* 51:441-457 <https://doi.org/10.22059/ijhs.2019.277210.1609>
43. Sarikhani S, Arzani K, Karimzadeh G, Shojaeiyan A, Ligterink W (2018) Genome Size; A Novel Predictor of Nut Weight and Nut Size of Walnut Trees. *HortScience* 53:275-282 <https://doi.org/10.21273/HORTSCI12725-17>
44. Sarikhani S, Vahdati K (2019) Determination of Persian walnut yield components and its correlation with phenological, morphological and biochemical traits. *Journal of Horticultural Science* 50:549-560 <https://doi.org/10.22059/ijhs.2018.260251.1474>
45. Sajwan P (2022) Characterization of walnut seedling selection on the bases of non-metric characters. *Journal of Pharmacognosy and Phytochemistry* 9:3082-3087
46. Schneiders E (1899) *Der neuzeitliche Walnussbaum* [The modern walnut tree]. Ulmer Verlag [Publisher], Stuttgart. 15-20 p
47. Shah R, Bakshi P, Jasrotia Wali V, Sharma S, Gupta M, Gupta R, Jamwal M (2023) Comparative morpho-molecular characterization of elite walnut variety Parbat (JWSP-06) with local selections of north-western Himalayan region of Jammu and Kashmir, India. *Scientia Hortic-Amsterdam* 319. 112176 <https://doi.org/10.1016/j.scienta.2023.112176>
48. Sluiter I.R.K, McKenzie L, Mitchell JR. (2014) Walnut rootstock selection for calcareous soils in Southeastern Australia and the potential for expanding the walnut industry in the region. *Acta Hortic* 1050:105-111 <https://doi.org/10.17660/ActaHortic.2014.1050.12>
49. Sokolova, V (2022) Selection of a breeding source material in the collection of the walnut (*Juglans regia* L.) of the Main Botanical Garden RAS. *Pomiculture and small fruits culture in Russia* 70:7-18 <https://doi.org/10.31676/2073-4948-2022-70-7-18>
50. Solar A, Stampar F, Smole J (1997) The degree of heterodichogamy of some walnut cultivars (*Juglans regia* L.) in Slovenia. *Acta Hortic* 442:217-224 <https://doi.org/10.17660/ActaHortic.1997.442.32>

51. Sun H, Yali W, Wang W, Zupaila N, Wang L, Ma R (2025) Study on Influencing Factors and Low-Temperature Treatment of Walnut Canker Disease in Hotan County, Xinjiang. *Forests* 16:728 <https://doi.org/10.3390/f16050728>
52. Sutyemez M, Özcan A, Bükücü Ş (2022) A superior genetic source for late leafing in walnut 'Ahr Nut'. *Hortic Sci* 49:205-212 <https://doi.org/10.17221/22/2022-HORTSCI>
53. Szentiványi P, Kállay T (Eds.) *Dió*. [Persian Walnut]; *Mezőgazda Kiadó* [Mezőgazda Publisher]: Budapest, Hungary, 2006; p. 66–67.
54. Zhang M-H, Wang J-C, Yang H, Zhang D-Y, Deng P-C, Cui Z-J (2020) Physiological response of Xinjiang wild walnut germplasm to low temperature stress. *J Appl Ecol* 31:2558-2566 <https://doi.org/10.13287/j.1001-9332.202008.002>
55. Zhao H, Luo X, Guo C, Zhang Z, Ma K, Niu J-X, Quan S (2025) Transcriptome and MicroRNA Analysis of *Juglans regia* in Response to Low-Temperature Stress. *Int J Mol Sci* 26:1401. <https://doi.org/10.3390/ijms26041401>
56. Zheng X, Nie R, Li A, Wu C, Ji X, Tang J, Zhang J (2024) Integrated physio-biochemical and transcriptomic analysis reveals mechanism underlying salt tolerance in walnut. *Plant Growth Regul* 104:727-743. <https://doi.org/10.1007/s10725-024-01193-3>
57. Vahdati K (2014) Traditions and folks for walnut growing around the Silk Road. *Acta Hort* 1032:19–24 <https://doi.org/10.17660/ActaHortic.2014.1032.1>
58. Woeste K, Burns R, Rhodes O, Michler C (2002) Thirty polymorphic nuclear microsatellite loci from black walnut. *J Hered* 93:58-60 <https://doi.org/10.1093/jhered/93.1.58>

Figures

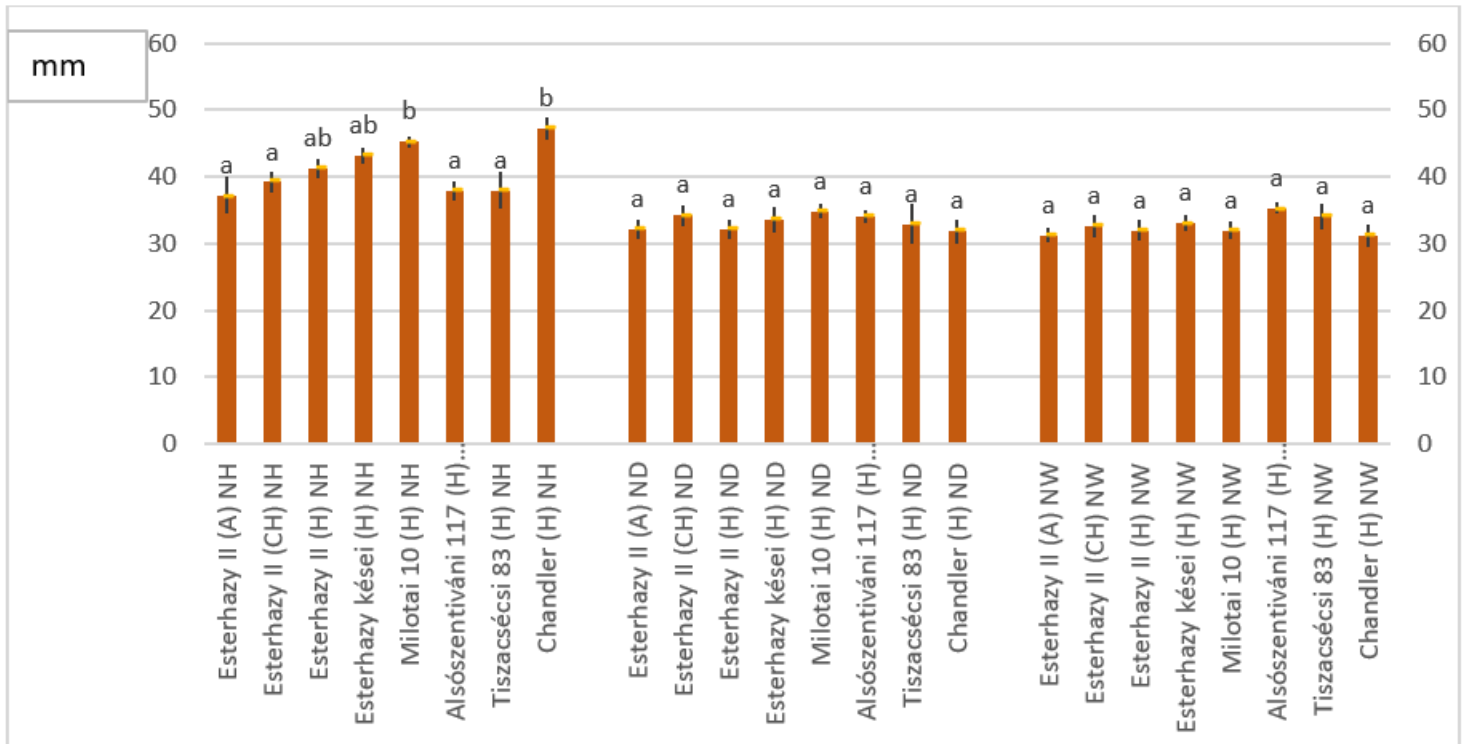


Figure 1

Nut height (NH), nut diameter (ND), and nut width (NW) in mm of the measured varieties ($SD_{5\%NH} = 5.0$, $SD_{5\%ND} = 1.5$, $SD_{5\%NW} = 1.2$)

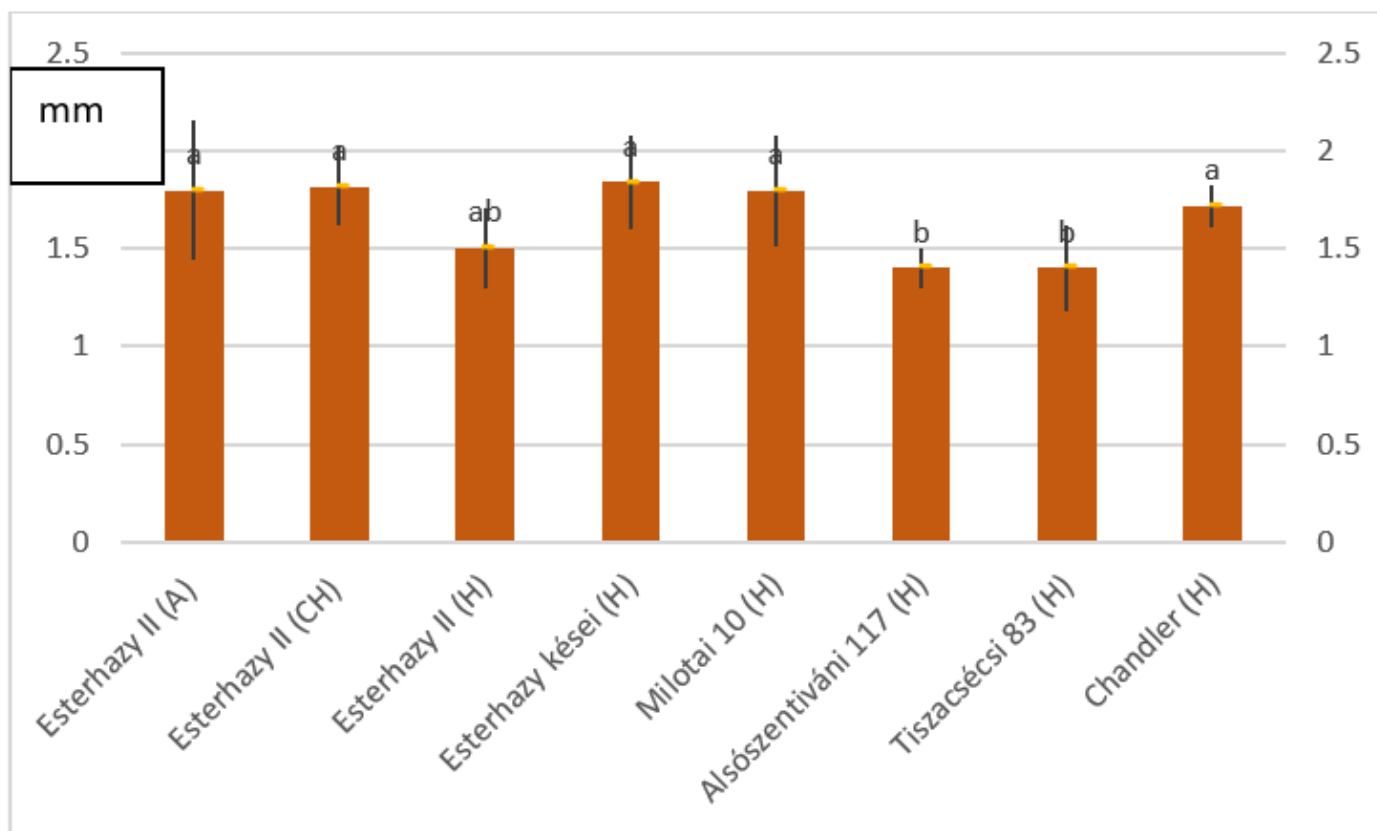


Figure 2

Shell thickness of the studied varieties ($SD_{5\%} = 0.25$)

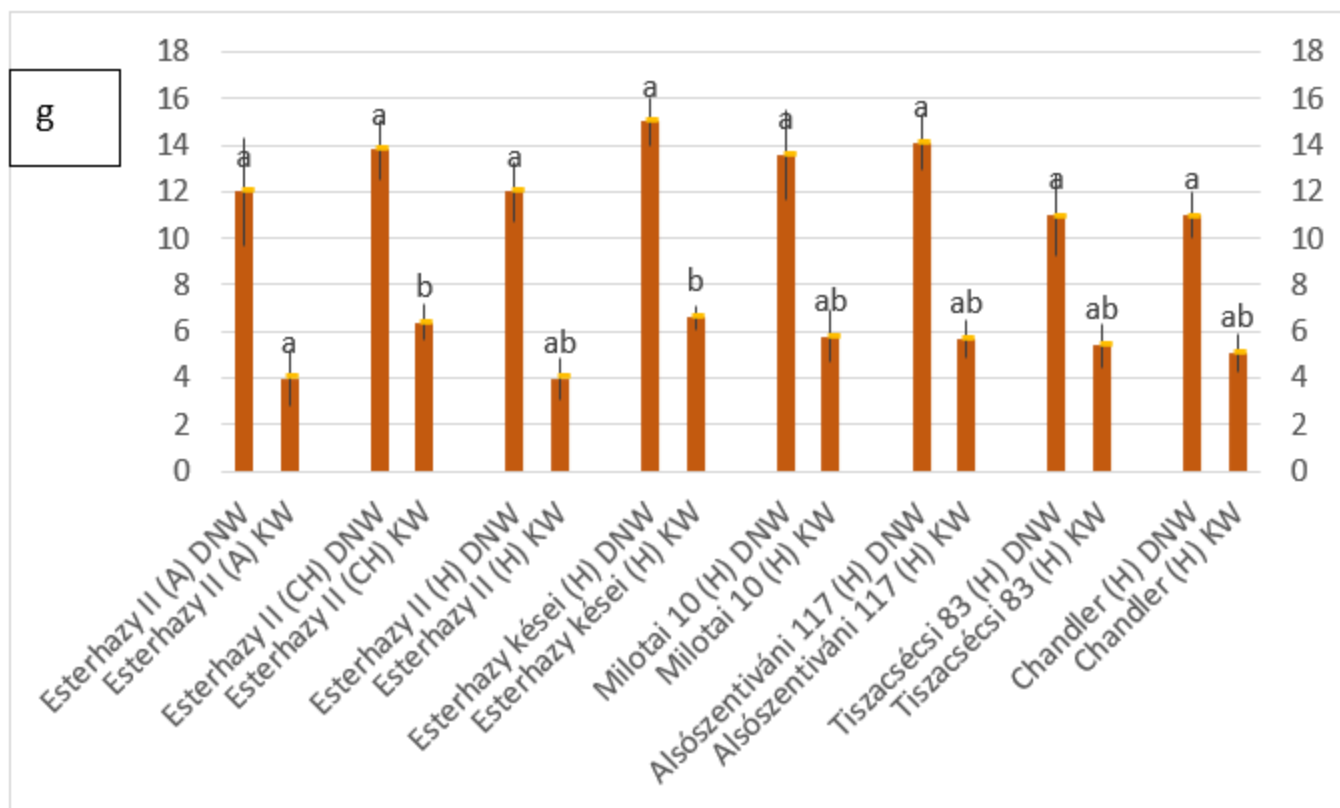


Figure 3

Dried nut weight (DNW) and kernel weight (KW) of the studied varieties ($SD_{5\%DNW} = 1.4$, $SD_{5\%KW} = 0.7$)

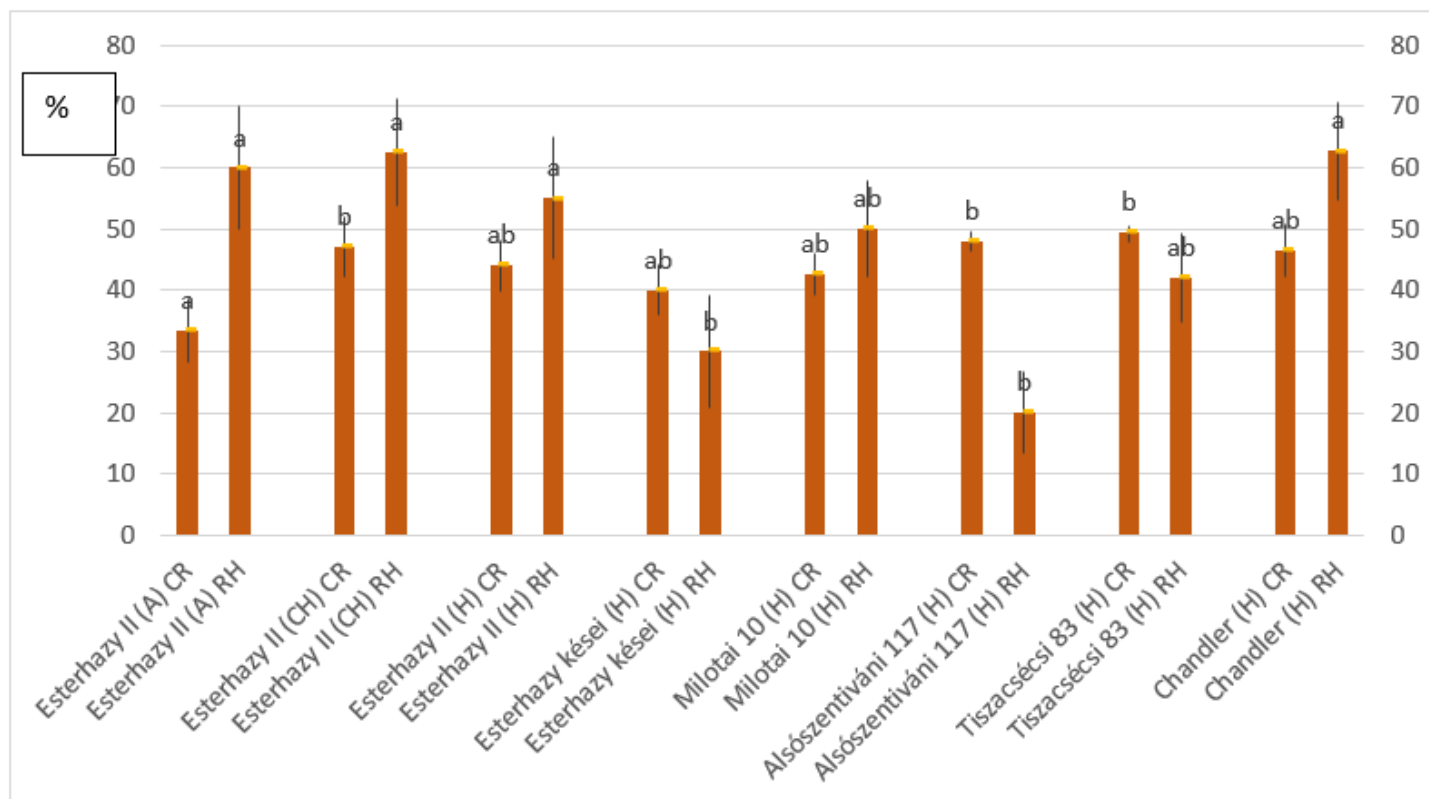


Figure 4

Cracking rate (CR) and ratio of halves (RH) of the studied varieties ($SD_{5\%CR} = 6.5$, $SD_{5\%RH} = 8.0$)