



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

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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 simple sequence repeat (SSR) analysis confirmed that the Hungarian ‘Esterhazy II’ is exactly identical

to the true-to-type Austrian and Swiss cultivars. 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 ‘Tiszacsécsi 83’ in shell thickness. There wasn’t any significant difference in this parameter among the study’s cultivars on dried nut weight. The Swiss ‘Esterhazy II’ and ‘Esterhazy kesi’ had the heaviest kernel weight. Kernel weight of the Austrian ‘Esterhazy II’ differed from the Swiss ‘Esterhazy II’ and ‘Esterhazy kesi’. The Austrian ‘Esterhazy II’ had a significantly smaller cracking rate compared to Swiss ‘Esterhazy II’, ‘Alsószentiváni 117’, and ‘Tiszacsécsi 83’ and a higher rate of halves compared to ‘Esterhazy kesi’ and ‘Alsószentiváni 117’.

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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 eighteenth 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 (Dochnahl 1860, Schneiders 1899, Mohácsy – Porpáczy 1951, Porpáczy 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 (Porpáczy 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 (Akcan et al. 2008, Keles 2014, Sutyemez et al. 2019, Aydemir et al. 2025, Bükücü et al. 2025), Kazakhstan (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; Sutyemez 2006; Sun et al. 2025), late leafing (Akca, and Özongun 2004, Kavosi and Khadivi 2021 Fallah et al. 2022, Sutyemez et al. 2021, 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. 2025), 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 ‘Alsószeztiváni 117’, ‘Milotai 10’, ‘Tiszacsécsi 83’, ‘Fertődi 1’, ‘Eszterhazy II’. Among these, the Esterhazy genotypes appeared with various synonyms (Eszterházi, Eszterházy, Eszterháyai, 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/cultivars, selected from the local populations, with special regard to of 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 cultivars, 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).

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.

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

Table 1 Some nut characters of the examined cultivars, involved in the trial. *Sources* Böllersen, (2017), Szentiványi and Kállay (2006), Ramos 1998, Aleta, et al. 2005, Connell et al. 2010, Bujdosó et al. 2019, 2022

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

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

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 an unweighted pair group method with arithmetic mean (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 kesei’. The smallest nut height was measured in the case of ‘Alsószentiváni 117’, ‘Tiszacsécsi 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 cultivars 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 kesei’. The smallest nut diameter was measured on the control, ‘Chandler’.

The nut width values were similar for all. There wasn’t a significant difference in nut diameter and nut width (Fig. 2).

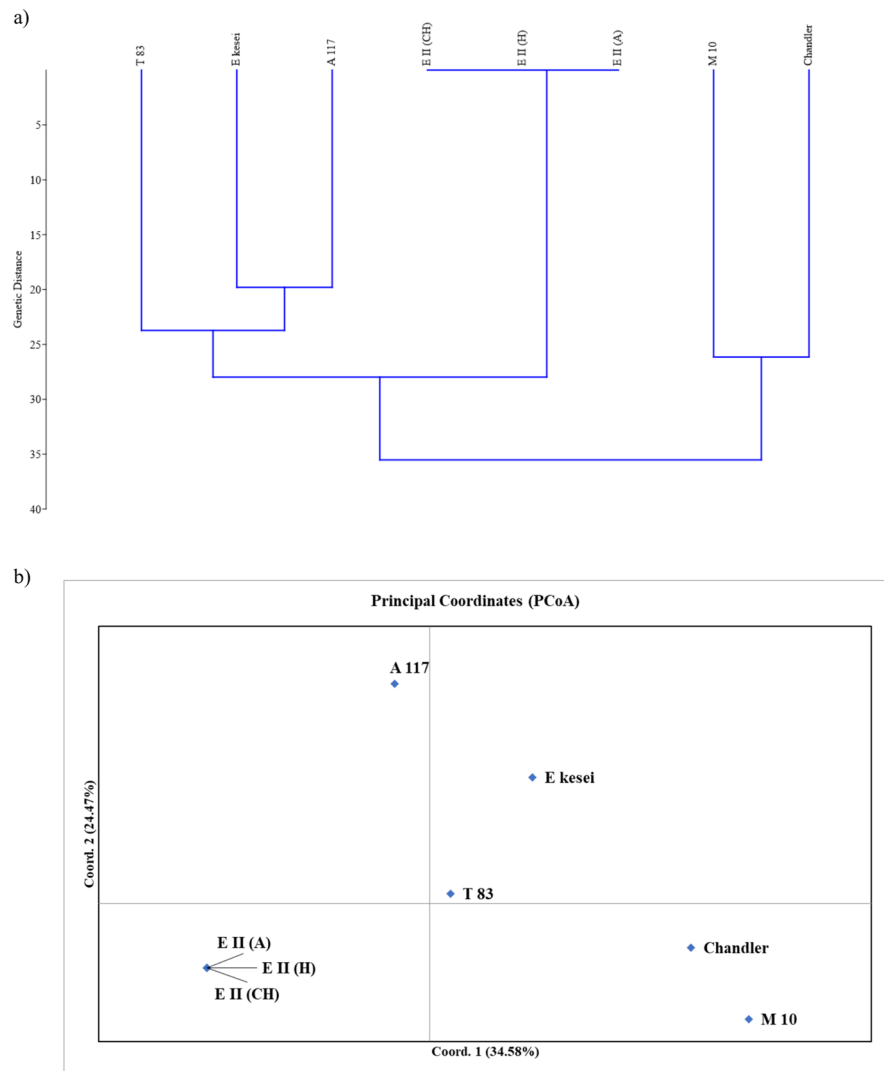
The shell thickness is important during both mechanical harvesting and the post-harvesting. ‘Esterhazy kesei’ had the thickest shell, followed by ‘Esterhazy II’ from Austria and ‘Milotai 10’. The ‘Alsószentiváni 117’ and ‘Tiszacsécsi 83’ had the softest shell, which had a significant difference from the other observed cultivars (Fig. 3).

The Hungarian ‘Esterhazy II’, ‘Alsószentiváni 117’ and ‘Esterhazy II’ from Switzerland represented the first three samples in the sequence in dried nut weight. ‘Esterhazy II’, derived from Austria, Tiszacsécsi 83’ and the control belonged to the lower part in the sequence in dried nut weight. There was no significant difference in this parameter.

Regarding the kernel weight, the Hungarian-bred ‘Esterhazy kesei’ 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. 4).

The kernel yield is an important parameter because it shows the harvestable quantity. The ‘Tiszacsécsi 83’ ‘Alsószentiváni 117’, ‘Chandler’, and the Swiss ‘Esterhazy II’ reached the highest values. The lowest was produced by the Austrian

Fig. 1 Genetic distances of the analysed walnut genotypes represented by a) Unweighted pair group method with arithmetic mean (UPGMA) dendrogram, b) principal component analysis (PCoA) plot (where E II – ‘Esterhazy II’, E kesei – ‘Esterhazy kesei’, M 10 – ‘Milotai 10’, T 83 – ‘Tiszacsécsi 83’, A 117 – ‘Alsószentiváni 117’)



‘Esterhazy II’, which did not reach the minimum 40% in kernel yield. The Swiss ‘Esterhazy II’ Tiszacsécsi 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 kesei’ and ‘Alsószentiváni 117’; both had a significant

difference from the other examined cultivars (Fig. 5).

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 ,

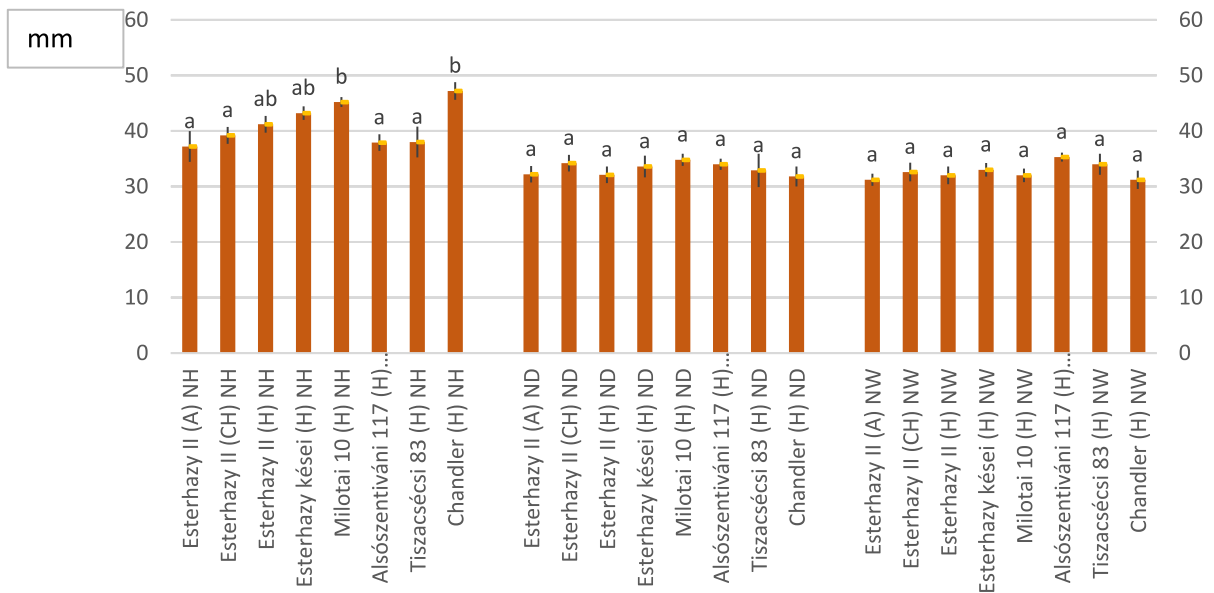


Fig. 2 Nut height (NH), nut diameter (ND), and nut width (NW) in mm of the measured cultivars ($SD_{5\%NH}=5.0$, $SD_{5\%ND}=1.5$, $SD_{5\%NW}=1.2$)

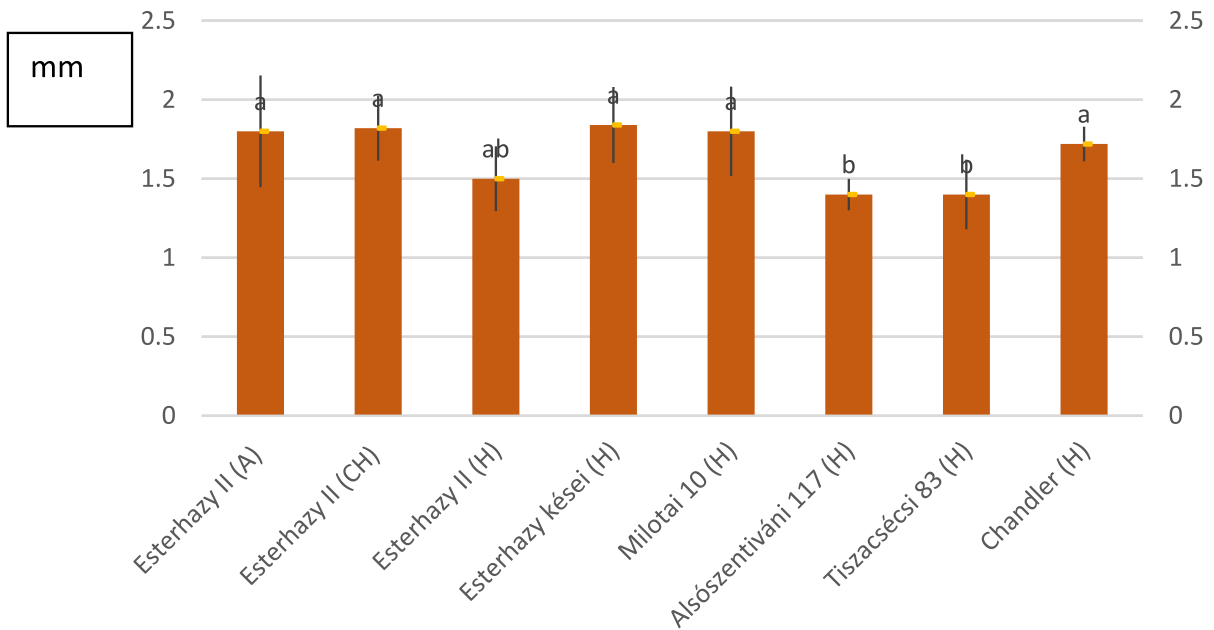


Fig. 3 Shell thickness of the studied cultivars ($SD_{5\%}=0.25$)

premium + + ≤ 36.0 mm in diameter). The large nut size of cultivars, 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 cultivars (Fig. 3).

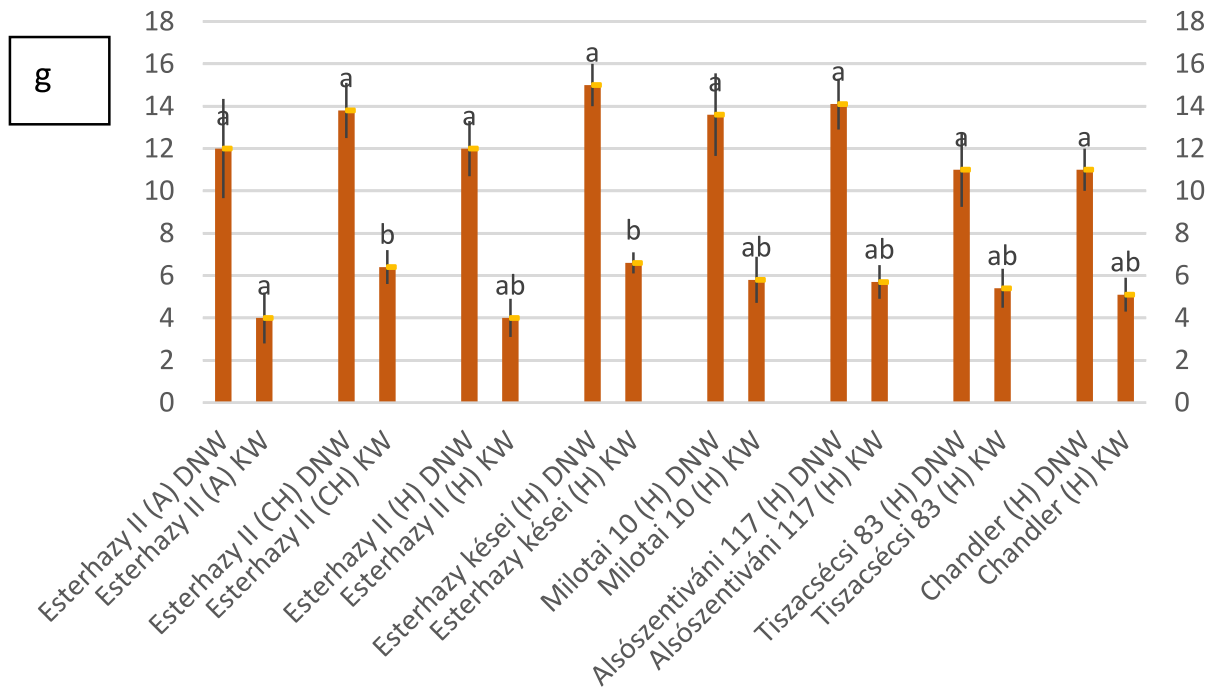


Fig. 4 Dried nut weight (DNW) and kernel weight (KW) of the studied cultivars ($SD_{5\%DNW} = 1.4$, $SD_{5\%KW} = 0.7$)

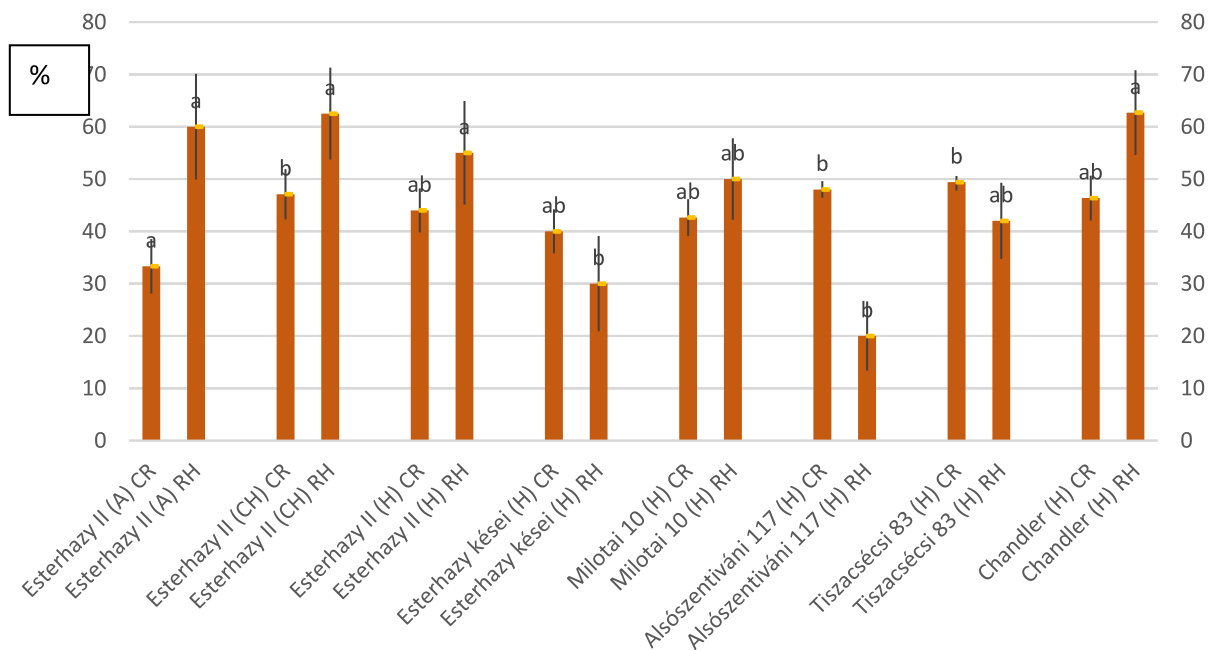


Fig. 5 Cracking rate (CR) and ratio of halves (RH) of the studied cultivars ($SD_{5\%CR} = 6.5$, $SD_{5\%RH} = 8.0$)

All three studied ‘Esterhazy II’ specimens, derived from Hungary, Austria, and Switzerland, were the same genotype. However, it cannot be confirmed with certainty that ‘Esterhazy II’ does not have French origin based on this study, as previously suggested by the literature. 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.

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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.

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

Declarations

Conflict of interest The authors declare no competing interests.

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