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MORPHOMETRIC CHARACTERISTICS OF SWEET CHESTNUT (*CASTANEA SATIVA* MILL.) FRUITS

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ABSTRACT

Aim of this study was to determine morphometric differences of fruits between selected sweet chestnuts *(Castanea sativa* Mill.). The 28 genotypes (referred as CS-01 to CS-28) were introduced by seeds from Czech Republic, Carpathians, Kyrgyzstan. Genotypes of sweet chestnut are grow more than 30 years in Forest-Steppe of Ukraine in the M.M. Gryshko National Botanical Garden of NAS of Ukraine. They are well adapted to the climatic and soil conditions. The fruits were collected at the period of their full maturity (September). The population differs in weight, shape, size and color of fruits. Their morphometric parameters were following: weight from 1.70 g (CS-26) to 18.60 g (CS-20), length from 8.07 mm (CS-28) to 33.39 mm (CS-11), width from 16.34 mm (CS-28) to 40.95 mm (CS-11), thickness from 9.02 mm (CS-26) to 28.70 mm (CS-11) and hilum length from 6.62 mm (CS-26) to 31.30 mm (CS-07), hilum width from 6.50 mm (CS-23) to 19.99 mm (CS-07). The shape index of the fruits was found in the range of 0.81 (CS-20) to 0.98 (CS-12). The shape index of the hilum was found in the range of 1.48 (CS-04) to 2.03 (CS-23). The outcome of the research point to the fact that the genepool Ukrainian sweet chestnut is a rich source of genetic diversity and might be used in selection for creation a new genotypes and cultivars.

Keywords: Sweet chestnuts; Forest-Steppe of Ukraine; fruit; morphometric characteristics; variability

INTRODUCTION

Preservation and growth of biological diversity is of strategic importance for the sustainable development of society. Therefore, the introduction, as a part of experimental botany and plant geography, remains the main direction of activity botanical gardens and other plant growing scientific and research institutions. The urgency of our research is due to the Neglected and Underutilized Plant Species: strategic plan of action the Bioversity International, which provides the stability of ecosystems and conservation of biological diversity **(IPGRI, 2002)**. Nowadays, the awareness is given more and more to underutilized and unusual fruits as Sorbus domestica L. **(Žiarovská and Poláčeková, 2012)**, Cydonia oblonga Mill. **(Monka et al., 2015)**. One of them is Castanea sativa Mill. not only as an endangered species, but as well as a promising and economically usable crop. Especially important is the question about introduction of new plants into cultivation in connection with global climate change, which had started in the last decade. Introduction and acclimatization of rare fruit plants in Ukraine contribute to increase biodiversity of our flora. To promising underutilized fruit plants for Forest-Steppe of Ukraine belongs Castanea sativa **(Klymenko and Grygorieva, 2013)**. Chestnut (Castanea Mill.) has been placed in the Fagaceae family. In total, 13 Castanea species are recognized and are native to the temperate zone of the Northern Hemisphere; five in East Asia, seven in North America and one in Europe **(Burnham et al., 1986)**. The most important of them are: Castanea sativa Mill. (Europe, Asia Minor, North Africa), C. dentata (Marsh.) Borkh. (USA), Castanea mollissima Blume and C. crenata Sieb. et Zucc. (Eastern Asia). C. sativa is the most consumed **(Goulão et al., 2001)**. In common, chestnuts are used as a food, its chemical composition is similar to potatoes or cereals **(Vojtaššáková et al., 2000)**, however chestnuts or chestnuts by-products may be used as a source of energy, nutrients and active substances also in animal nutrition **(Gálik et al., 2014; Šimko et al., 2014)**. Chestnuts posses many characteristics that are used by human for different purposes, not only as a part of the food. One of them is the utilization of the sweet chesnut pollen for its pharmacological benefits **(Žiarovská et al., 2015)**.

There are many authors who have been researching phenotypic diversity among various local populations of sweet chestnut in Italy **(Borghetti et al., 1986; Casini et al., 1993; Jacoboni, 1993; Ponchia et al., 1993; Beccaro et al., 2005)**, in France **(Breisch, 1993)**, in Portugal **(Costa et al., 2005)**, in Spain **(Pereira-Lorenzo et al., 1996; Fernández-López, 2005)**, in Greece **(Alizoti and Aravanopoulos, 2005)**, in Turkey **(Villani, 1992; Serdar, 1999; Serdar and Soylu, 1999; Ertan, 2007; Ormeci et**

al., 2016), in Romania **(Botu et al., 1999)**, in Slovenia **(Solar et al., 1998; Podjavoršek et al., 1999)**, in Slovak Republic **(Bolvanský et al., 2009)**, in Czech Republic **(Haltofová and Jankovsky, 2003)**, in Spain **(Alvarez, 2005; Furones and Fernández-López, 2005; Alvarez-Alvarez et al., 2006)**, in Bosnia and Herzegovina **(Mujić et al., 2010)**, in Iran **(Atefe et al., 2015)** and in India **(Pandit et al., 2011)**. This researches form basis for the selection of the best types from natural populations of sweet chestnut **(Bounous et al., 2000)**. Most of the chestnut cultivars, used in commercial production, were obtained with selection studies from natural chestnut populations **(Ertan et al., 2007; Pandit et al., 2011)**.

The aim of this study was to separate, based on our research, the best genotypes from our collections sweet chestnut, which can be successfully grown on plantations, as well as ornamental trees.

MATERIAL AND METHODOLOGY

Locating trees and data collection

The objects of the research were 30-year-old plants of sweet chestnut from seed origin, which are growing in Forest-Steppe of Ukraine in M.M. Gryshko National Botanical Garden of NAS of Ukraine (NBG). Seeds were brought from Czech, Carpathians, Kyrgyzstan. They are well adapted to the climatic and soil conditions. Observations on the collection's forms of sweet chestnut in the period 2013 – 2015 were performed during mass fruiting. We have described 28 genotypes of sweet chestnut. In autumn, when the nuts began to fall, a sample of one kg with burrs was collected from the marked trees. The harvest time was recorded.

Morphometric characteristics

Pomological characteristics were conducted with four replications on a total 30 nuts per genotypes. In the study only one plant (tree) used for per genotype.

The following measurements were taken: fruit length (FL), in mm, fruit weight (FS), in g, fruit thickness (FT), in mm, fruit width (FW), in mm and hilum length (HL), in mm, hilum width (HW), in mm. The measurements were made in each nut element as shown in Figure 1. Data, we are working with, were tested for normal distribution.

Basic statistical analyses were performed using SAS System v. 9.2 (SAS 2009). The DISTRIBUTION analysis (verification of normal distribution of input data), the CORRELATION procedure, the CLUSTER procedure, the TREE procedure (creating the dendrogram) in SAS 9.2. for further detailed analysis were used. Variability of all these parameters was evaluated using descriptive statistics. Correlation between traits was determined using the Pearson correlation coefficient. Dendrogram clustering the data from the individual experimental genotypes using average linkage using Euclidian distance as metric.

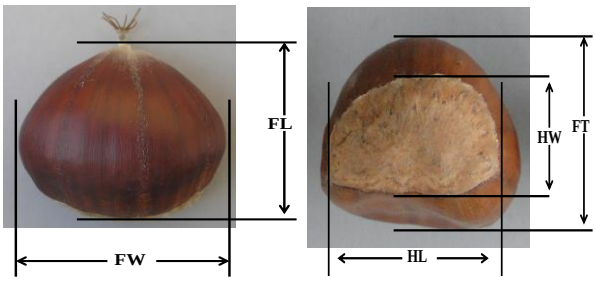

Figure 1 Illustration of measuring process: length, width, thickness and hilum length and width.

Figure 2 Variability in the shape of sweet chestnut *(Castanea sativa* Mill.) fruits.

Figure 3 Variability in the shape of sweet chestnut *(Castanea sativa* Mill.) hilum.

RESULTS AND DISCUSSION

The weight of the whole fruit is one of significant production characteristics of plant species. Further important features of the fruit are shape, size and color. These characteristics of the sweet chestnut fruit varied significantly. The images of sweet chestnut fruits of various genotypes are shown on Figure 2, 3. High variability of the size, shape and color of these fruits are evident.

Fruit weight (g)

The weight of sweet chestnut fruits of present study was in the range of 1.70 to 20.0 g (Table 1).Coefficient of variation was 45.92%, which shows a very high degree of variability of fruit weight. Significant differences in fruit weight were reaffirmed a lot of authors from different countries (Table 2). The fruit weight was determined in range from 2.98 g by **Aravanopoulos et al. (2001)** to 39.73 g by **Ormeci et al. (2016)**. Data comparison shows a high consistency with our results. There are genotypes, which reached minimum and maximum values in these characteristic, in Table 3.

Fruit length (mm)

The fruit length in our analyses was determined in the range of 8.07 to 33.39 mm (Table 1). The value of the coefficient of variation was 13.74%, which documented medium degree of variability of the character within the collection. Significant differences in fruit length were reaffirmed a lot of authors from different countries (Table 2). The fruit length was determined in range from 19.10 mm (Aravanopoulos et al., 2001) to 39.73 mm **(Ormeci et al., 2016)**. In case of data comparison tested genotypes from Ukraine have low values on this characteristic. There are genotypes, which reached minimum and maximum values in these characteristic, in Table 3.

Fruit width (mm)

In our experiments the fruit width was determined in the range of 16.34 to 40.95 mm (Table 1). The variation coefficient (14.98%) confirmed medium degree of variability within the collection. Significant differences in fruit width were reaffirmed a lot of authors from different countries (Table 2). The fruit width was determined in

Table 1 The variability of some morphometric characteristics of fruits for the whole collection of sweet chestnut *(Castanea sativa* Mill.) genotypes from Kyiv.

Characteristics	Unit	*n*	*min*	*max*	*mean*	*CV%*
Fruit weight	**g**	840	1.70	20.0	6.85	45.92
Fruit length	**mm**	840	8.07	33.39	23.74	13.74
Fruit width	**mm**	840	16.34	40.95	26.52	14.98
Fruit thickness	**mm**	840	9.02	28.70	16.62	20.57
Hilum length	**mm**	840	6.62	31.30	21.15	19.58
Hilum width	**mm**	840	6.50	19.99	12.24	20.66

Note: n – number of measurements; min, max – minimal and maximal measured values; mean – arithmetic mean; CV – coefficient of variation (%).

Table 2 Variability of some morphometric characteristics on sweet chestnut fruits according to the authors from different countries.

Authors	Fruit				Hilum	
	Weight (g)	Length (mm)	Width (mm)	Thickness (mm)	Length (mm)	Width (mm)
Borghetti et al., (1986)	9.41 – 16.60	25.89 – 30.41	30.86 – 37.59	19.09 – 23.96	–*	–*
Pereira-Lorenzo et al., (1996)	8.00 – 15.00	24.80 – 32.70	28.20 – 35.90	–*	–*	–*
Aravanopoulos et al., (2001)	2.98 – 6.07	19.10 – 24.90	18.80 – 23.80	10.80 – 14.80	12.90 – 14.50	6.00 – 7.00
Solar et al., (2005)	3.50 – 18.60	20.00 – 37.00	12.00 – 39.00	14.00 – 25.00	12.00 – 32.00	7.00 – 16.00
Alvarez-Alvarez et al., (2006)	–*	25.80 – 31.40	25.20 – 34.40	14.20 – 20.20	–*	–*
Ertan, (2007)	–*	30.39 – 34.31	23.70 – 35.17	18.95 – 23.70	–*	–*
Mujić et al., (2010)	4.32 – 6.67	20.45 – 24.89	23.45 – 27.10	21.26 – 27.29	–*	–*
Odalovic et al., (2013)	4.80 – 10.60	19.60 – 30.60	23.70 – 34.90	13.30 – 23.80	19.00 – 31.00	11.00 – 16.00
Ormeci et al., (2016)	10.26 – 22.32	27.74 – 39.73	26.80 – 42.47	–*	–*	–*
Silva et al., (2016)	9.00 – 18.67	29.30 – 37.90	25.40 – 34.00	16.10 – 23.50	–*	–*
Bolvanský et al., (2012)	2.94 – 13.40	16.41 – 27.75	19.81 – 34.17	–*	–*	–*

range from 12.00 mm **(Solar et al., 2005)** to 42.47 mm **(Ormeci et al., 2016)**. Data comparison shows a high consistency with our results. There are genotypes, which reached minimum and maximum values in these characteristic, in Table 3.

Table 3 The fruits variability of sweet chestnut *(Castanea sativa* Mill.) genotypes from the collection.

Genotypes	*Mean*	*SD*	*CV%*	Genotypes	*Mean*	*SD*	*CV%*
	Lowest values				**Highest values**		
			Fruit weight (g)				
CS-28	2.68	0.42	15.72	**CS-07**	9.12	1.71	18.75
CS-26	2.78	0.78	28.28	**CS-03**	10.29	1.82	17.74
CS-14	3.59	0.65	18.29	**CS-08**	11.95	2.53	21.25
CS-27	3.63	0.68	18.94	**CS-11**	13.58	2.60	19.02
CS-16	4.00	0.75	18.72	**CS-20**	13.61	2.88	21.19
			Fruit length (mm)				
CS-28	16.54	1.85	11.23	**CS-08**	26.83	1.48	5.54
CS-26	17.94	1.38	7.72	**CS-03**	27.12	0.80	2.97
CS-27	18.72	1.09	5.82	**CS-20**	27.83	2.04	7.32
CS-14	20.16	1.03	5.03	**CS-05**	28.17	1.08	3.86
CS-24	22.05	1.23	5.60	**CS-11**	29.90	1.78	5.95
			Fruit width (mm)				
CS-28	19.07	1.35	7.10	**CS-08**	29.75	1.36	4.59
CS-26	20.24	2.02	9.99	**CS-05**	29.94	1.63	5.46
CS-14	21.95	1.24	5.63	**CS-03**	30.54	1.23	4.03
CS-27	22.06	1.83	8.30	**CS-11**	33.44	2.53	7.57
CS-16	23.35	1.49	6.38	**CS-20**	33.96	2.68	7.90
			Fruit thickness (mm)				
CS-26	11.86	1.76	14.83	**CS-01**	19.90	2.45	12.34
CS-28	12.61	1.93	15.33	**CS-07**	20.04	3.56	17.76
CS-27	12.97	1.33	10.30	**CS-11**	20.43	3.25	15.94
CS-14	13.22	1.64	12.40	**CS-03**	21.75	2.46	11.31
CS-16	14.09	1.24	8.84	**CS-20**	23.72	2.11	8.91
			Hilum length (mm)				
CS-12	15.16	2.62	17.34	**CS-21**	24.82	2.29	9.24
CS-28	15.43	2.04	13.26	**CS-01**	25.00	2.15	8.61
CS-26	15.95	2.62	16.42	**CS-20**	26.18	2.62	10.01
CS-09	16.57	3.23	19.54	**CS-07**	26.42	3.39	12.84
CS-14	17.63	1.87	10.65	**CS-03**	26.81	1.97	7.34
			Hilum width (mm)				
CS-12	8.98	0.68	7.67	**CS-01**	14.64	1.79	12.29
CS-28	9.31	1.21	13.08	**CS-04**	15.14	2.03	13.41
CS-26	9.57	1.34	14.03	**CS-20**	15.75	1.65	10.50
CS-09	10.01	1.20	12.00	**CS-07**	15.94	2.15	13.51
CS-24	10.12	0.93	9.22	**CS-03**	15.98	2.06	12.94

Note: mean – arithmetic mean; SD – standard deviation; CV – coefficient of variation (%).

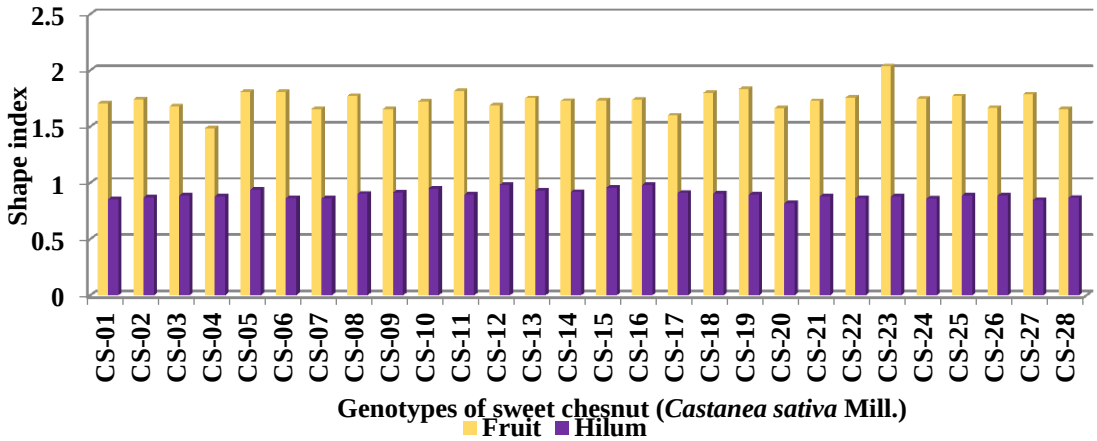

Figure 4 Comparison of the tested sweet chestnut *(Castanea sativa* Mill.) genotypes in the shape index of fruit and hilum.

Fruit thickness (mm)

In evaluated genotypes we determined the fruit thickness in the range of 9.02 to 28.70 mm (Table 1). The value of the coefficient of variation was 20.57%, which documents a high degree of variability of the characteristic within the collection. Significant differences in fruit thickness were reaffirmed a lot of authors from different countries (Table 2). The fruit thickness was determined in range from 10.80 mm **(Aravanopoulos et al., 2001)** to 27.29 mm **(Mujić et al., 2010)**. Data comparison shows a high consistency with our results. There are genotypes, which reached minimum and maximum values in these characteristic, in Table 3.

Hilum length (mm)

Hilum length was identified in range from 6.62 mm to 31.30 mm (Table 1). The value of the coefficient of variation documented a high degree of variability of these characteristic. Significant differences in fruit hilum length were reaffirmed a lot of authors from different countries (Table 2). The hilum length was determined in range 12.00 – 32.00 mm **(Solar et al., 2005)**. Data comparison shows a high consistency with our results. There are genotypes, which reached minimum and maximum values in these characteristic, in Table 3.

Table 4 The linear relationship between of the morphometric characteristics of evaluated genotypes of sweet chestnut *(Castanea sativa* Mill.).

Characteristic		r	sr	Confidence Interval $r_{95\%}$	r^2	*p*
1	**FW/FL**	0.85	1.60	0.70 ≤r ≥0.93	0.73	**
2	**FW/FS**	0.92	1.38	0.83 ≤r ≥0.96	0.85	**
3	**FW/FT**	0.91	1.13	0.83 ≤r ≥0.96	0.84	**
4	**FW/HL**	0.68	2.48	0.42 ≤r ≥0.84	0.47	**
5	**FW/HW**	0.67	1.58	0.39 ≤r ≥0.83	0.45	**
6	**HL/HW**	0.94	0.69	0.88 ≤r ≥0.97	0.89	**
7	**FL/FS**	0.94	1.20	0.87 ≤r ≥0.97	0.88	**
8	**FL/FT**	0.82	1.63	0.64 ≤r ≥0.91	0.67	**
9	**FL/HL**	0.70	2.43	0.44 ≤r ≥0.85	0.49	**
10	**FL/HW**	0.63	1.64	0.34 ≤r ≥0.81	0.40	**
11	**FS/FT**	0.90	1.19	0.80 ≤r ≥0.95	0.82	**
12	**FS/HL**	0.80	2.00	0.62 ≤r ≥0.90	0.65	**
13	**FS/HW**	0.74	1.42	0.51 ≤r ≥0.87	0.55	**
14	**FT/HL**	0.78	2.13	0.57 ≤r ≥0.89	0.61	**
15	**FT/TP**	0.77	1.35	0.55 ≤r ≥0.88	0.59	**

Legend: r – Pearson's correlation coefficient, sr – standard error of the coefficient, r^2 – coefficient of determination, ** $p \leq 0.01$

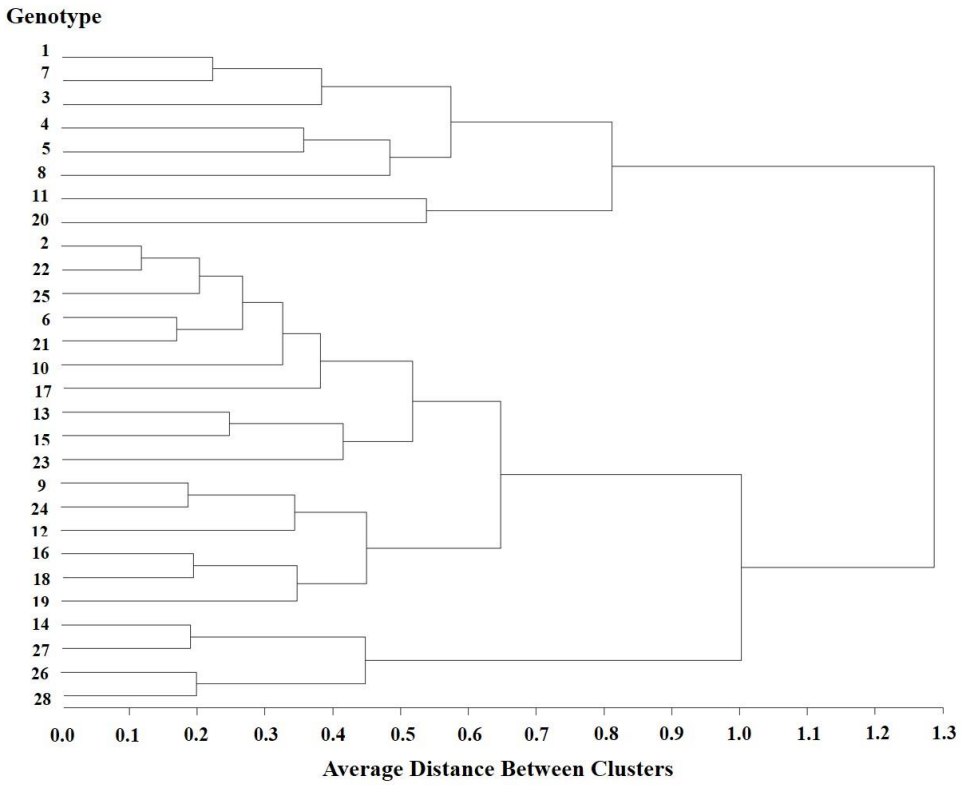

Figure 5 Dendrogram of 28 genotypes of sweet chestnut (*Castanea sativa* Mill.) based on morphometric characteristics of fruits.

Hilum width (mm)

Hilum width was identified in range from 6.50 – 19.99 mm (Table 1). The value of the coefficient of variation documented a high degree of variability of these characteristic. Significant differences in fruit hilum width were reaffirmed a lot of authors from different countries (Table 2). The hilum width was determined in range from 6.00 mm **(Aravanopoulos et al., 2001)** to 16.00 mm **(Solar et. al., 2005; Odalovic et al., 2013)**. Data comparison shows a high consistency with our results. There are genotypes, which reached minimum and maximum values in these characteristic, in Table 3.

Shape index

The shape of each object can be characterized by the shape index, i.e. the length to width ratio. Figure 3 represents the shape indexes of fruits and hilum. The shape index of the fruits was found in the range from 1.48 (CS-04) to 2.03 (CS-23), so the genotype's collection demonstrates significant variability in the shape of the fruit, as seen in Figure 2 and Figure 3. The shape index of the hilum was found in the range from 0.81 (CS-20) to 0.98 (CS-12). This parameter can be used for the identification of the genotypes.

The relationship between specific characteristics

The results of the analysis are given in Table 4. The results indicated high correlations (r = 0.63 – 0.94). The results document that between specific characteristics is positive relationship which is very important in sweet chestnut's breeding.

Clustering of sweet chestnut genotypes based on fruit characteristics

The genetic relationship among the 28 genotypes was examined by cluster analysis. The figure clearly identified significant differences between tested sweet chestnut genotypes. Dendrogram has showed 3 main groups (Figure 5). Eight of the 28 genotypes were included in cluster group A, 16 genotypes in group B, 4 genotypes in group C. The group B had the highest mean for morphological characteristics (fruit weight, fruit length, fruit width, fruit thickness, hilum length, hilum width), that were significantly different with other groups. The results this assessment related to group C had the lowest mean of morphological parameters. Figure confirms the results from the evaluated variability of morphometric characteristics (Table 1).

CONCLUSION

The results of the experiment presented in this work are consistent with the results reported earlier. In evaluating 28 genotypes of sweet chestnut we determined the weight of the fruits in the range from 1.70 g (CS-26) to 18.60 g (CS-20), lenght from 8.07 mm (CS-28) to 33.39 mm (CS-11), width from 16.34 mm (CS-28) to 40.95 mm (CS-11), thickness from 9.02 mm (CS-26) to 28.70 mm (CS-11) and hilum length from 6.62 mm (CS-26) to 31.30 mm (CS-07), hilum width from 6.50 mm (CS-23) to 19.99 mm (CS-07).

The results about relationship between specific characteristics were indicated as a high correlation (r = 0.63 – 0.94).

Presented results also showed that significant differences in the evaluated characteristics were found for the studied sweet chestnut genotypes. Obtained results are important for breeding new varieties of sweet chestnut as well as their practical use.

This study is significant because it is the first selection work in Ukraine. Adaptation studies will also be required for the selected sweet chestnut genotypes. The results of the study are helpful for understanding the variability and attempting the selection of superior desirable sweet chestnut accessions for bringing to commercial cultivation.

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