DETERMINATION OF THE MORPHOMETRIC PARAMETERS AND REPRODUCTIVE ABILITY OF BEECH SEEDS (*Fagus sylvatica*) OF SLOVAK ORIGIN

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Abstract. Screening beech seeds of various origins to identify their reproductive and adaptive capabilities is important for the restoration of beech forests in Europe, especially in conditions of climate change. The aim of this study was to evaluate the morphometric characteristics and viability of beech seeds from five populations, collected in different years in the Slovak Republic. In this research, the seeds from Nitra-19; Detva-22; Orava-22 and two population of Roznava-22 were involved. The length of the seed ranged from 13.00 to 19.50 mm, and the width - from 5.50 to 12.50 mm. The eccentricity index varied from 1.74 to 1.81. The average weight of a thousand seeds in the populations, collected in different years, did not differ significantly, and modified in limits from 237.40 to 311.10 g. According to the Pearson correlation coefficient (0.7127), the closest relationship was found between the weight of seed and their width. The relationship between seed weight and length was less strong (0.6450). The viability of seeds, determined by two tests using 2.3.5-triphenyltetrazolium chloride and hydrogen peroxide solutions, ranged from 61.75 to 92.00%. The seeds from the Roznava-22 (2) and Detva-22 populations had the highest viability. There was no strong correlation between seed weight and viability (0.3639), as well as between seed weight and the altitude above sea level where the seeds were collected (0.2088). At the same time, a close correlation was found between seed viability and the altitude above sea level where the seeds were collected (0.6802). Thus, the data showed that beech seed populations from the Slovak Republic had homogeneous morphometric parameters, but differed significantly in terms of viability, which depended on the height of the beech plant growth.

Keywords: *Fagus sylvatica*, morphometric parameters, reproductive ability, viability.

Rezumat. Determinarea parametrilor morfometrici și a capacității de reproducere a semințelor de fag (*Fagus sylvatica*) originare din Slovacia. Screening-ul semințelor de fag de diverse origini pentru a le identifica capacitățile de reproducere și adaptare este important pentru restaurarea pădurilor de fag din Europa, în special în condițiile schimbărilor climatice. Scopul acestui studiu a fost de a evalua caracteristicile morfometrice și viabilitatea semințelor de fag de la cinci populații, colectate în diferiți ani în Republica Slovacă. Semințele din Nitra-19; Detva-22; Orava-22 și două populații din Roznava-22 au fost implicate în această cercetare. Lungimea semințelor a variat de la 13,00 la 19,50 mm, iar lățimea - de la 5,50 la 12,50 mm. Indicele de excentricitate a variat de la 1,74 la 1,81. Masa medie a unei mii de semințe în populații, colectate în ani diferiți, nu s-a deosebit semnificativ și s-a modificat în limite de la 237,40 la 311,10 g. Conform coeficientului de corelație Pearson (0,7127) cea mai strânsă relație a fost găsită între masa semințelor și lățimea acestora. Corelația dintre masa semințelor și lungimea a fost mai puțin pronunțată (0,6450). Viabilitatea semințelor, determinată prin două teste folosind soluții de clorură de 2,3,5-trifeniltetrazoliu și peroxid de hidrogen, a variat de la 61,75 la 92,00%. Semințele din populațiile Roznava-22 (2) și Detva-22 au avut cea mai mare viabilitate. Nu a existat o corelație puternică între masa semințelor și viabilitate (0,3639), precum și între masa semințelor și altitudinea deasupra nivelului mării la care au fost colectate semințele (0,2088). În același timp, s-a constatat o corelație strânsă între viabilitatea semințelor și altitudinea deasupra nivelului mării la care au fost colectate semințele (0,6802). Așadar, datele au arătat că populațiile de semințe de fag din Republica Slovacă au avut parametri morfometrici omogeni, dar s-au deosebit semnificativ în gradul de viabilitate, care depindea de altitudinea de creștere a plantelor de fag.

Cuvinte-cheie: *Fagus sylvatica,* parametri morfometrici, capacitate de reproducere, viabilitate.

INTRODUCTION

The importance of European beech (*Fagus sylvatica* L.), which is a significant forest-forming species and a characteristic component of broad-leaved forests in Europe, cannot be overestimated from both economic and environmental points of view (GLATTHORN et al., 2017; RUKH et al., 2023). In the Republic of Moldova, natural beech forests extend up to 400 m above sea level in the central part of the country, in the north-west of the Codrii natural reserve forests and represent the easternmost geographical area in Europe (POSTOLACHE & POSTOLACHE, 2011; CHETREAN, 2022). It is known that species at the edge of their ranges are most sensitive to environmental changes (ROIBU et al., 2022). The global warming currently occurring covers almost the entire territory of the globe and its pace has no analogues over the period spanning the last 2000 years. According to the European Centre for Medium-Range Weather Forecasts, 2023 was the warmest year in the last 174 years of records (***. PROVISIONAL STATE OF THE GLOBAL CLIMATE, 2023). A similar forecast is being built for 2024.

As a result of such climatic changes, a reduction will be seen in the ranges of natural beech forests, and the most endangered habitats will be those located at lower altitudes in the southern and south-eastern parts of the species' distribution area (GAVRANOVIĆ et al., 2018). For this reason, the climate fluctuations observed in the last two decades in Europe can directly affect the structure of forests – eventually, forest stands dominated by oak and hornbeam can completely replace the current beech forests of the Republic of Moldova (DONICA & GRIGORAȘ, 2018).

Historically, beech forests in the Republic of Moldova were restored naturally. To preserve and maintain the forest gene pool, in particular relict beech forests, several natural reserves were created and are currently operating in the Republic of Moldova, among which the leading place belongs to the “Plaiul Fagului” reserve. Every year the demand for artificially obtained beech seedlings is growing, which requires the collection of a sufficient quantity of high-quality seeds and the creation of a reserve seed fund (CUZA et al., 2006; POSTOLACHE & POSTOLACHE, 2011; ELISOVEȚCAIA et al., 2023). However, for beech, annual seed collection is problematic, because the most productive years occur once every 3-7 years, sometimes much less often – once every 15-20 years (ÖVERGAARD et al., 2007; MÜLLER-HAUBOLD et al., 2015; GAVRANOVIĆ et al., 2018; NUSSBAUMER, 2020). Moreover, the proportion of seeds that are defective or damaged by pests and diseases can reach from 15 to 75% and even up to 100% of seeds. According to some authors, despite the fact that fruiting in beech stands can provide about 850 thousand seedlings per hectare, the amount of beech undergrowth in terms of 4-8 years of age, as a rule, does not reach even one tenth of one percent of viable seeds (7 .96 thousand seeds/ha) (STANDOVÁR & KENDERES, 2003).

Even in the productive years, the quality of seed material can vary significantly. Beech seeds are seriously damaged by the beech moth *Cydia fagiglandana* (Zeller, 1841), Lepidoptera, Tortricidae (HACKET-PAIN & BOGDZIEWICZ, 2021), and are also eaten by birds, rodents and artiodactyls. A serious threat is posed by infection of seeds by pathogenic fungi of the genera *Fusarium*, *Alternaria*, *Penicillium* and some others (KRÓL et al., 2015). Therefore, it is advisable to create seed banks at nature reserves and nurseries for storage and exchange both within and between countries.

When choosing seed material, on the one hand, it is desirable to take into account the similarity of climatic and soil conditions in the regions of growth and introduction. On the other hand, genetic diversity is also important, which can ensure better adaptation of plants to a changing climate and biotic and abiotic factors (AUÑÓN et al., 2011). According to some authors, marginal populations of beech have greater plasticity, providing better adaptation to climate change (ROSE et al., 2009). This plasticity may be explained by the time delay between initial distribution and range expansion of the European beech population. However, this theory cannot yet be confirmed or refuted due to the lack of genetic data on beech populations during the Holocene (HOFFMAN, 2022). Therefore, screening beech seeds of various origins to identify their reproductive and adaptive capabilities at this stage is extremely relevant and of paramount importance for the restoration of beech forests in Europe in the face of climate change, and especially in conditions of a significant increase in temperature and decreased precipitation in summer.

The aim of our research was to study the morphometric parameters and reproductive capacity of beech seeds from five populations of the Slovak origin.

MATERIAL AND METHODS

The experiments were carried out in the Natural Bioregulators laboratory, in the solarium of the Institute of Genetics, Physiology and Plant Protection of the Moldova State University and in the Slovak University of Agriculture in Nitra, Faculty of Agrobiology and Food Resources during 2019-2024.

The study involved beech seeds from 5 populations collected in the fall of 2019 and 2022 from 4 locations in the Slovak Republic, located in the western, northwestern, central and eastern parts of country (Table 1; Fig. 1).

Table 1. Characteristics of beech (*Fagus sylvatica*) seed collection sites in Slovakia.

Name population	Location / Forest management unit	Part of Slovakia	Altitude (above sea level), m	Year of collection
Nitra	Nitra Region	western	350-580	2019
Roznava (two populations)	Nižná Slaná, Rožňava District, Košice Region (2 populations)	eastern	570	2022
Detva	village Vígľaš, Detva District, Banská Bystrica Region	central	580	2022
Orava	Biely Váh, Liptovský Mikuláš, Dolný Kubín District, Žilinský Region	North-western	875	2022

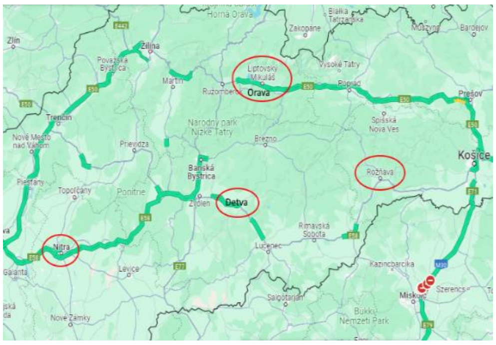


Figure 1. Regions in Slovakia (https://www.mapsofindia.com/world-map/slovakia/).

The morphometric parameters of beech seeds.

The length, width of the seed, the eccentricity index (aspect ratio), the weight of the seeds and the coefficients of variation (for length, width and weight separately) were used by us for the comparative characteristics of beech seeds from different locations. Random samples of 40 seeds per collection were taken for morphometric (length and width parameters) analysis. The length (L) and width (W) of the seeds were measured with an electronic caliper accurate to the first decimal place. Weight of 1000 seed was determined using analytical balance with readability of 0.0001 g.

In general, seed shape can be scored as a combination of values, or by a single value that indicates the percentage of similarity to a given geometric object. Seed shape can be determined by the ratio of length and width. Although this does not accurately describe seed shape, it is the simplest metric to evaluate and is often used by many authors (IWATA et al., 2010; BALKAYA & ODABAS, 2002) called the eccentricity index (EI) (Formula 1):

$$EI = \frac{L}{W} \quad (1), \text{ where}$$

L – length of beech seeds, cm;
W – width of beech seeds, cm.

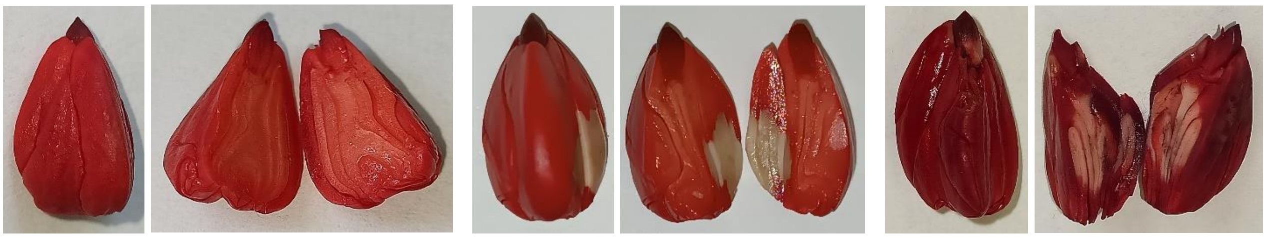
The variation coefficient is a quantity used in statistics, equal to the ratio of the standard (mean square) deviation of a random variable to its mathematical expectation. It is used to compare the variability of the same characteristic in several populations with different arithmetic averages.

Seed moisture was measured using the RADWAG moisture analyser by gradual drying with a halogen lamp at a temperature of 160 °C to a constant weight (if the change in weight does not exceed 1 mg in 10 sec) (ELISOVEȚCAIA et al., 2023). For each determination, 3 grams of seeds were used. Three determinations were made for each lot of seeds (population).

The viability of F. sylvatica seeds was determined by two tests, using the 2.3.5-triphenyltetrazolium chloride (TTC) solution (KERKEZ et al., 2018) and hydrogen peroxide (HP) solution (SHARMA & SIBI, 2020). The root length (in cm) of germinated seeds in the HP test was measured.

The tetrazolium test (TTC) determines the percentage of viable seeds within a sample, even if the seeds are dormant (FRANÇA-NETO & KRZYZANOWSKI, 2019). The results of the TTC test indicate the number of viable seeds in a sample that are capable of producing normal plants under suitable germination conditions.

The beech seeds (100 seeds for four replications of 25 seeds each selected using random sampling techniques) are pre-soaked in Petri dishes in 50 ml distilled water for 18-24 hours at temperature 20-25 ºC. The pericarp was then removed, and the seeds are again soaked in distilled water for 6 hours at temperature 20-25 ºC. After this, the brown seed coat is carefully removed and cleaned beech seeds are immersed in a 0.5% solution of 2,3,5-triphenyltetrazolium chloride (TTC) for 10-12 hours in the dark at 25-30 ºC (ISTA, 2006). For correct interpretation, seeds must be cut lengthwise to observe all stained parts of the seed. The viability of seeds in TTC test was classified (distributed into three groups) according to standard methods, depending on seed staining (KERKEZ et al., 2018; ELISOVEȚCAIA et al., 2021): a) the seeds with bright red staining, which are ***completely viable*** and give normal seedlings; b) partially stained seeds (with at least two-thirds of the basal part of the cotyledons stained) that may produce either normal or abnormal seedling – ***conditionally viable seeds***; c) greyish stained or black seeds indicate the presence of a dead tissue in the seed; seeds with an unpainted radicle, with cotyledons in which the unpainted area occupies a third or more of the area – they are ***non-viable*** (Photo 1).



a b c

Photo 1. Determination of the viability of *Fagus sylvatica* seeds depending on the degree of staining using the tetrazolium test (TTC): a – *viable seeds*; b – *conditionally viable seeds*; c – *non-viable* seeds (original).

Hydrogen peroxide test (HP). Each variant contained 100 seeds, in four replications of randomly selected 25 seeds. Seeds were soaked in 100 ml of 1.0% hydrogen peroxide solution at temperature 25 °C for 24 hours. The pericarp tip of the seed was cut deep enough to expose and seeds were immediately placed in 150 ml of 1.0% hydrogen. Incubation was carried out in a thermostat in the dark at 25 °C for 7 days, changing the hydrogen peroxide solution to a fresh one every three days. On the 7th day, all seeds were evaluated and the test was completed. Seeds were divided into three classes: evident – radicle > 2 mm long; slight – radicle ≤ 2 mm long and none – no radicle protrusion. Data were expressed as the proportion of "evident" and "slight evident" germinates to the total number of seeds used in the test (SHARMA & SIBI, 2020; ELISOVETCAIA et al., 2021) (Photo 2).

a b c

Photo 2. The degree of germination of radicle in *Fagus sylvatica* seeds in the HP test (a – completely viable; b – conditionally viable; c – non-viable seeds) (original).

Statistical analysis. The results were processed with the use of Statgraphics Plus 5.0 software based on general statistical procedures, including one-way ANOVA and Multiple Range Tests (Tukey Honestly Significant Difference) (RABIEJ, 2012). Statistical calculations were performed at the significance levels of 0.05; 0.01 and 0.001. Values of the seed viability were presented as the mean and standard deviation. Pearson correlation analysis was conducted using the CORR procedure to determine the relationships between the studied traits (seed length, width, and weight) and to assess the relationship between viability and seed weight.

RESULTS

The moisture content of the beech seeds of the Slovak populations before storage ranges from 8.78±0.18 to 9.50±0.10% of fresh weight (Table 2). The morphometric parameters of the weight, length and width of beech seeds of the European beech *F. sylvatica* L. (Fagaceae) from five populations of Slovakia and their statistical analysis are presented in Tables 2 and 3. The average values, standard derivations, minimum, and maximum, eccentricity index and coefficient of variation were taken into account. A statistical analysis of the data on the length and width of beech seeds did not reveal significant differences in the indicators between populations of seeds, collected in the same year in one location (Roznava-22 (1) and Roznava-22 (2)), as well as collected in different years in various locations – Nitra-19, Roznava-22, Orava-22 and Detva-22 (Table 2).

The smallest seeds were observed in the Roznava-22 (2) and Detva-22 populations. Seeds of the Nitra-19 and Orava-22 showed identical morphometric parameters of seed length, width and weight (Table 2; 3). The seeds of the Roznava-22 (1) population showed the maximum weight, despite the fact that the length of the seeds was in third place among the five populations. However, the seed width of Roznava-22 (1) was ranked first, EI was the lowest – 1.74 (Table 2). This suggests that mature healthy seeds, with almost the same length, but wider, have more weight. This fact is also confirmed by the obtained Pearson coefficients. Thus, rounder seeds tend to weigh more and therefore have better germination potential.

A statistical analysis of the data showed that, at three levels of significance for both morphometric indicators – length and width, the beech seeds of all Slovak populations are homogeneous. The coefficient of variation for length of seeds in all populations did not exceed 10% (and amounted from 7.67 to 8.63%), which indicates an insignificant degree of data dispersion (Table 2). The coefficient of variation for width of beech seeds for four populations (Nitra-19, Roznava-22 (1), Roznava-22 (2) and Orava-22) exceeded 10% (and amounted from 11.56 to 12.95%), which indicates a moderate degree of data dispersion. The highest coefficient of variation was observed in the Roznava-22 population (2), as seed width varied from 5.50 to 11.50 mm. For the Detva-22 population, the coefficient of variation did not exceed 10%, which indicates an insignificant degree of data dispersion of beech seed width (Table 2).

Table 2. Morphometric parameters of beech seeds of different origins.

Populations	Seed moisture, %	Length, mm			Width, mm			Eccentricity Index	Coefficient of variation, %	
		min	max	average	min	max	average		L	W
Nitra-19	9.50±0.10	14.00	19.00	16.39±1.34	7.50	12.50	9.30±1.09	1,76	8.16	11.73
Roznava-22 (1)	9.49±0.11	13.50	19.50	16.38±1.41	7.00	11.50	9.43±1.09	1,74	8.63	11.56
Roznava-22 (2)	9.07±0.15	13.50	18.50	15.75±1.35	5.50	11.50	9.00±1.17	1,75	8.57	12.95
Orava-22	8.78±0.14	14.00	19.00	16.40±1.32	7.50	12.50	9.31±1.11	1,76	8.03	11.89
Detva-22	9.37±0.15	13.00	18.00	15.98±1.22	7.00	10.00	8.81±0,76	1,81	7.67	8.59

Based on weight, the five studied seed populations from Slovakia were divided into three homogeneous groups for all three levels of significance (Multiple Range Tests, Method 95.0; 99.0 and 99.9 percent Tukey HSD) (Table 3). Beech seeds were significantly larger (by weight) in the Roznava-22 (1) population, the smallest (light) seeds were in the Roznava-22 (2) population. Seeds in the Nitra-19 and Orava-22 populations were identical in weight (with an extremely low coefficient of variation – 2.84 and 2.74% respectively). The weight of seeds from the Detva-22 population was at the level of seeds from Roznava-22 (2) and at the same time comparable to the weight of seeds from Nitra-19 and Orava-22 (Table 3).

Table 3. Weight of beech seeds and its distribution in the studied populations into groups depending on the confidence levels of different origins.

Populations	Weight 1000 seeds, g			Coefficient of variation, %	Distribution of variants into groups depending on the confidence levels*								
					α = 0.05 +/- limits 8.56008			α = 0.01 +/- limits 10.4161			α = 0.001 +/- limits 12.1521		
	min	max	average		1	2	3	1	2	3	1	2	3
Nitra-19	249.90	271.80	261.72±7.44	2.84		X			X			X	
Roznava-22 (1)	285.20	311.10	295.81±7.38	2.49			X			X			X
Roznava-22 (2)	237.40	257.60	247.68±6.20	2.50	X			X			X		
Orava-22	249.80	273.80	262.43±7.18	2.74		X			X			X	
Detva-22	247.00	265.20	256.01±5.19	2.03	X	X		X	X		X	X	

*Note: three homogeneous groups without significant differences within each group

Twin (double) seeds were found in all populations, but their proportion was extremely low and amounted to 0.5-1.0% of the total number of seeds studied. There was no relationship between weight and the proportion of twin seeds.

The viability of European beech seeds in Slovak populations varied from 61.75 to 92.00% depending on population and TTC and HP test (Table 4). The highest viability was found in seeds of the Roznava-22 (2) and Detva-22 populations – the average between both methods (TTC and HP) was 91.14 and 90.50%, respectively. The seeds of the Nitra19 population showed the lowest viability – the average between both methods was 60.65%, respectively. The average viability of seeds from Roznava-22 (1) and Orava-22, determined by the two methods TTC and HP, was 78.92 and 82.54%, respectively.

Table 4. Quality of *Fagus sylvatica* seeds of Slovak populations.

Variants	Seed viability seeds, %		Difference between					
			TTC			HP		
	TTC	HP	max[1]	min[2]	average[3]	max[4]	min[5]	average[6]
Nitra-19	69.55	61.75	-27.71*	3.55	-13.85*	-34.88*	11.02*	-14.15*
Roznava-22 (1)	81.83	76.00	-15.43*	15.83*	-1.57	-20.63*	25.27*	0.10
Roznava-22 (2)	92.00	90.27	-5.26	26.00*	8.60	-6.36	39.54*	14.37*
Orava-22	87.53	77.54	-9.73*	21.53*	4.13	-19.09*	26.81*	1.64
Detva-22	93.00	88.00	-4.26	27.00*	9.60*	-8.63	37.27*	12.10*
$LSD_{0.05}$	8.86	9.57						

Note: * significant difference noted

A high degree of positive correlation (0.9703) was noted between various methods (TTC and HP) for determining seed viability (Table 5). While no direct significant relationship was found between weight and seed viability values (in both methods) - the value of the Pearson coefficient of correlation between weight and the TTC and HP methods ranged from -0.3508 to -0.3700, which indicates the presence of a moderate negative relationship. A strong negative relationship was found between viability and such morphometric indicators as the length and width of the seed, because Pearson's correlation coefficient was in the limits -0.6662 – - 0,8238 (Table 5).

A high degree of correlation was found between the length and width of beech seeds in the studied populations of Slovakia, the Pearson coefficient was 0.8330, while correlations between the weight of the seeds and the morphometric parameters of the length and width of the seed were 0.6450 and 0.7127, respectively (Table 5). As follows from the data obtained, the correlation between the weight and width of the seed was higher than the one between the weight and length of the seed.

Table 5. Pearson correlation coefficients.

Pearson correlation coefficients between	TTC	HP	Weight of 1000 seeds	Length	Width	Altitude
TTC	1					
HP	0.9703	1				
Weight of 1000 seeds	-0.3508	-0.3700	1			
Length	-0.6917	-0.8238	0.6450	1		
Width	-0.6662	-0.7199	0.7127	0.8330	1	
Altitude	0.6979	0.6559	-0.2088	0.4380	0.7714	1
Average viability (TTC+HP)	0.9912	0.9938	-0.3639	-0.7690	-0.7005	0.6802

DISCUSSIONS

The length of the seed in the populations we studied ranged from 13.00 to 19.50 mm, and the width from 5.50 to 12.50 mm. Analysis of the data showed that populations from Slovakia had seeds that were quite similar in shape. The eccentricity index ranged from 1.74 to 1.81. It is known that the morphometric parameters of *F. sylvatica* seeds can vary depending on the agroclimatic conditions of growth, on the altitude (above sea level) of tree growth, the age of the trees, genetic factors and some other reasons (DRVODELIC et al., 2011; KALINIEWICZ et al., 2018). Beech seeds typically reach a length of 15 to 20 mm and a width of 7 to 10 mm, but seed sizes can vary considerably and extend beyond this range (TYLEK & WALCZYK, 2002; DRVODELIC et al., 2011). For example, according to TYLEK & WALCZYK (2002), the length of seeds collected in Bielsko Forest Division, Forest Section – Salmopol, Poland; the crop year 2000 varied from 14.93±0.06 mm to 16.29±0.10 mm, and the width from 7.22±0.04 mm to 8.36±0.04 mm. The seeds of the Slovak populations we studied were significantly larger (Table 2).

The analysis of the variability of morphometric features showed that beech seeds in the population limits are highly dimensionally uniform – a low coefficient of variation for length, width and weight (Tables 2; 3). Correctly formed seeds have the least variability, which was evident in the studied Slovak populations. At the same time, deviations from the average values in some populations (for example, the width of the seeds of population Roznava-22 (2) varied widely from 5.50 to 11.50 mm) indicate a high degree of heterogeneity, which is an important quality for the formation of new populations.

It should be noted that the populations we studied were distinguished by a greater degree of homogeneity than the three seed populations from Poland in which the coefficient of variation for width ranged within 11.5-11.6%, and for length – within 19.3-20.3% (TYLEK & WALCZYK, 2002).

Data analysis showed a high degree of correlation between seed length and width in the 5 studied populations from Slovakia (0.8330). At the same time, as our data showed, there was a closer correlation between the width and mass of seeds than between the length and mass of seeds. Our data on the close connection between the width (thickness) of a seed and its mass are confirmed by other studies, which found that there is a direct relationship between seed mass and seed size (KALINEVICH et al., 2018; GAVRANOVIC et al., 2018). KALINEVICH et al. (2018) found that the correlation coefficient between seed weight and seed width is higher (0.666) than the one between seed weight and seed length (0.557). Using correlation analysis, GAVRANOVIC et al. (2018) showed that there is a positive and statistically significant correlation between the weight of a beech seed sample and the width of the seeds (R^2 = 0.5875), while no significant correlation was found between the weight and length of the seeds. In our studies, a direct correlation was found both between the width of the seed and their weight, and between the length of the seed Slovak populations and their weight (Table 3).

According to previous research (RATAJCZAK & PUKACHKA, 2005), beech seeds best retain their viability and germination (up to 3-4 years) if their moisture content is within 8–9% when stored at a temperature of +3-4 °C. MULLER & LAROPPE (2003) showed that beech seeds stored for 3 years at 7 or 9% moisture content germinate well under the influence of ethephon with short-term (3 weeks) prechilling. In this case, a humidity regime of 45% is preferable to 75%. Other authors have recommended an optimum humidity of 15-16% for beech seed storage at +5°C (HONG & ELLIS, 1996). These parameters made it possible to maintain maximum germination of beech seeds for at least one to two years (HONG & ELLIS, 1996). Our earlier studies (ELISOVETCAIA et al., 2021, ELISOVETCAIA et al., 2023) confirmed that seeds with a moisture content in the range of 8.6-9.2% reduced their viability after two years of storage by 1.0-2.3 %, while seeds with higher humidity decreased their viability more significantly (ELISOVETCAIA et al., 2021; ELISOVETCAIA et al., 2023). To preserve their quality, seeds should be stored in sealed plastic bags without access to air. Thus, the seeds of the studied Slovak populations with moisture content in limits from 8.78±0.14 to 9.50±0.10 met the requirements for long-term storage.

The average weight of a thousand seeds in the five studied Slovak populations, collected in 2019 and 2022 at an altitude of 350-875 meters above sea level, ranged from 237.40 to 311.10 g. Our data are in good agreement with the data of other authors. KALINIEWICZ et al., (2018) found that the weight of 1000 seeds collected in Poland from trees aged from 105 to 130 years (seven locations) varied from 185.7 to 217.2 g. Other authors, when analysing six populations collected in 2007 in Bosnia and Herzegovina (Bužim, Bugojno, Banja Luka, Bosansko Grahovo, Posušje and Olovo) also identified a wide range weight fluctuation, from 143.2 g (Bosansko Grahovo) to 274.8 g (Banja Luka) (MEKIĆ et al., 2010). Serbian populations collected in 2004 in Avala, Fruska Gora, Ger and Boranja had smaller differences in the average weight of 1000 seeds, which ranged from 241.14 to 336.54 g, and the average reached 299.38 g (ŠIJAČIĆ-NIKOLIĆ et al., 2007). Similar studies conducted in Croatia (seeds were collected from several localities at different altitudes in the area of North Velebit) recorded weights of 1000 seeds ranging from 210 to 310 g, with an average of 240 g (DRVODELIC et al., 2011). The weight of 1000 beech seeds collected in 2001 and 2003 from two regions of the Czech Republic (Stredomoravske Karpaty and Luzicka piskovcova vrchovina, at an altitude of 400-550 and 600-700 meters above sea level, respectively) after storage during 2 and 4 years in sealed plastic bags at –7°C with a moisture content of 8.6–9.0% ranged from 241.4 to 277.4 g (KOLAŘOVA et al., 2010).

We did not find a close correlation between the weight of the seeds and their viability (0.36391), or between the weight of the seeds and the altitude above sea level where the seeds were collected (0.2088). At the same time, a close correlation was found between seed viability and the altitude above sea level where the seeds were collected (0.6802). Moreover, seed viability increased with increasing altitude. For example, TYLEK & WALCZYK (2002) reported a significant correlation between seeds weight and germination, which could be explained by the high percentage of heavy and well-developed seeds. However, the size of the embryo does not always correlate with the linear dimensions of the length and width of the beech seed (KALINIEWICZ et al., 2018). Therefore, there are no discrepancies in the relationships we have described. The weight and quality of beech seeds can be influenced by various factors, primarily the climatic conditions of the year of ripening, as well as the year of flower bud formation.

CONCLUSIONS

Our studies showed that populations of Slovak origin beech seeds with significantly homogeneous morphometric parameters (length, width) differed significantly in the degree of viability. No direct positive relationship was found between the weight of seeds and their viability. A high positive correlation between seed viability and the altitude of European beech above sea level may indicate a greater adaptive potential of such populations. Thus, for estimation of the quality and reproductive capabilities of *F. sylvatica* seed populations, it is impossible to reliably rely only on basic morphometric indicators. Parameters of seeds as their moisture content, viability and germination, as well as the agroclimatic conditions of beech tree growth, should be taken into account. This will allow us to predict the shelf life of each batch of collected seeds.

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