Morphological assessment of plus trees progeny as a basis for establishing a sessile oak seed orchard

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Abstract

In the context of variable climate conditions, selecting high-quality Sessile oak (*Quercus petraea* (Matt.) Liebl.) reproductive material is crucial for sustainable forestry. This research aimed to assess the genetic potential of 86 selected plus trees by analyzing seedling morphological characteristics and quality indices. The ultimate goal was to identify the most promising genotypes for establishing seed orchards. Root collar diameter (D), seedling height (H), stem dry mass (SDM), and root dry mass (RDM) were measured under uniform nursery conditions. The following derived indices were calculated: seedling height to root collar diameter ratio (H/D), stem dry mass to root dry mass ratio (SDM/RDM), and Dickson's quality index (DQI). Descriptive statistics, one-factorial analysis of variance (ANOVA) and Pearson correlation analysis were performed as well. The results showed significant variability in all observed morphological characteristics and quality indices among half-sib families, confirming a strong genetic influence. Correlation analysis indicated strong positive relationships between DQI and all primary morphological characteristics (r≤0.94), confirming DQI as the most effective integrative indicator of seedling quality. The combined ranking of the half-sib families, based on DQI, H/D, and SDM/RDM, identified those with optimal morphological characteristics, including an optimal H/D ratio, balanced SDM/RDM, and a high DQI value. The identified superior half-sib families represent valuable genetic material for the establishment of future seed orchards, thereby contributing to the production of better-quality seedling material and to improved forest ecosystem resilience under climate change.

Keywords

Quercus petraea; Selection; Progeny; DQI; SDM/RDM; H/D; seed orchard

Contents

1 Introduction

Modern strategies for conserving forest ecosystems and improving reproductive material production face the challenges of climate change, habitat degradation, and the need for long-term adaptation of genetic resources. In Europe, especially in valuable broadleaf species such as Sessile oak (*Quercus petraea* (Matt.) Liebl.), the selection and production of quality planting material have always been key elements of sustainable forest management. Research in recent decades has shown that the variability in growth, morphology, and adaptability of these species differs significantly between populations and provenances (Arend et al. 2011; Sáenz-Romero et al. 2016; Girard et al. 2022; Ufimov et al. 2025), which highlights the importance of selecting reproductive material with proven genetic potential.

Traditionally, selection of Sessile oaks has been based mainly on phenotypic (morphological) characteristics, i.e., variations in leaf shape, stem structure, bark and root characteristics, growth and phenology. As a result, during the 20th and 21st centuries, numerous provenance and progeny tests were established across different European regions, aimed at identifying genotypes best suited for regeneration and reforestation (Arend et al. 2011; Sáenz-Romero et al. 2016; Girard et al. 2022). These tests have provided valuable information on the differential adaptability of populations, confirming that specific provenances stand out for better survival, growth, and resistance to climatic stress (Girard et al. 2022; Benito Garzón et al. 2019).

Climate change has increasingly highlighted the need to revise traditional principles of genetic selection. The integration of genetic, climatic, and ecological criteria is necessary in response to forced range shifts, prolonged droughts, extreme temperatures, and phenological changes Authors like Sáenz-Romero et al. (2016) and Benito Garzón et al. (2019) emphasize that merely classifying provenances by geographical origin is no longer adequate. Instead, we need climate suitability models to predict which populations will maintain their adaptive potential under future conditions.

In efforts to simultaneously conserve existing genetic resources, maintain the principle of using local provenances, and provide reproductive material suitable for future climate conditions, the establishment of seed orchards plays a central role. Seed for these purposes is sourced from carefully selected plus trees exhibiting exceptional morphological traits, larger diameter and height, straight stems, late first branching, stable crowns, and good health (Kumar and Mohammad 2023). During selection, it is essential to ensure sufficient spatial distance between trees to avoid relatedness and preserve genetic diversity. Collecting seed from these trees and evaluating it through progeny tests verifies the heritability of desired traits. Long-term studies (Girard et al. 2022) show that populations subjected to multi-generational selection in managed forests exhibit better survival, growth, and structural stability. Classical estimates of selection gain indicate that plus trees can provide 10–15% greater height and diameter growth, and up to 35% higher volume (Cornelius 1994), justifying their use in modern forest improvement programs. Beyond their productive function, seed orchards play a significant role in the ex-situ conservation of the gene pool, making them an important component of national genetic resource conservation programs.

In selecting Sessile oak seedlings, the dimensions and morphological characteristics of the seedlings serve as reliable indicators of the genetic potential of their parent trees. Research has demonstrated that factors such as the height-to-diameter ratio (H/D), leaf area, root development, and shoot-to-root ratio are strongly correlated with early growth and survival in the field (Dey et al. 2010; Grossnickle and MacDonald 2018). These characteristics allow for a quick assessment of seedling quality, which is essential when choosing the progeny of plus trees.

This research aimed to determine for the better morphological characteristics of seedlings can reliably reflect the genetic potential of selected Sessile oak plus trees and to identify the most promising trees for establishment of a seed orchard.

2 Material and method

The research was conducted on Sessile oak seedlings obtained from the progeny of 86 selected plus trees. These trees were sourced from natural populations across various ecological conditions and habitat types. Acorns were collected individually from each plus tree, allowing each tree to be treated as a separate half-sib family.

The seeds were sown in the "Mišljenovac" nursery of the Public Enterprise (PE) "Srbijašume"-Forest Units (FU) "Severni Kučaj" in the city of Kučevo. The sowing took place in November 2020, under conditions designed to ensure a uniform environmental regime. Each seed half-sib family was planted in a separate bed that measured 1 meter by 6 meters, with a row spacing of 15 centimeters. The rows were oriented parallel to the long side of the bed.

At the end of the first growing season in October, each bed was divided into three equal sections. A random sample of 30 seedlings was taken from each section, resulting in a total of 90 samples per half-sib family. The seedlings were carefully removed from the substrate to minimize damage to the root system, ensuring the reliability of morphological measurements.

The following morphological characteristics were measured on the samples:

- seedling height (H, cm),
- root collar diameter (D, mm),
- stem dry mass (SDM, g),
- root dry mass (RDM, g).

The height was measured using a ruler with an accuracy of 0.1 cm, while the root collar diameter was measured with a digital vernier to an accuracy of 0.01 mm. After separating stems and roots, the material was dried in a laboratory dryer (Binder) at 105°C for 48 hours. The mass of both components was then measured using an electronic balance with an accuracy of 0.01 g.

Based on the measured values, standard morphological indices used in assessing the quality of forest species seedlings were calculated, as follows:

- Seedling height-to-diameter ratio (H/D) – a strength coefficient (Roller 1977),
- Stem dry mass to root dry mass ratio (SDM/RDM),
- Dickson Quality Index (DQI), as calculated by the formula from Dickson et al. (1960).

For selecting "plus trees" for seed orchard, a combined ranking of all 86 half-sib families was performed based on these three key quality indices:

- Dickson Quality Index (DQI): this quality index ranks half-sib families from highest (best) to lowest. The family with the highest DQI is ranked number 1.
- Height-to-Diameter Ratio (H/D): this sturdiness coefficient is ranked from lowest (best, indicating a sturdier and more stable seedling) to highest. The half-sib family with the lowest H/D ratio is ranked number 1.

- Stem dry mass to root dry mass ratio (SDM/RDM): this ratio is ranked based on the absolute difference from the ideal value of 1 (1 - SDM/RDM). The half-sib family with the ratio closest to 1, i.e., which has the smallest absolute difference, is ranked number 1, indicating more balanced development.

For each half-sib family, the individual ranks for DQI, H/D, and SDM/RDM were added together to create a Combined Rank Score. The half-sib families with the lowest Combined Rank Score are considered the best, as they consistently exhibit favorable traits across all three measures.

For all measured characteristics, fundamental descriptive statistics were calculated (mean, minimum, maximum, standard deviation, and coefficient of variation). To determine whether half-sib families differ significantly, a one-factorial analysis of variance (ANOVA) was used, with half-sib family as the factor. Pearson's correlation coefficient was used to examine linear relationships among seedling morphological characteristics.

Statistical analyses were carried out using software packages Microsoft Office 2021 (Microsoft Corp.) and SPSS 27 (IBM Corp.).

3 Results

The morphological characteristics of Sessile oak seedlings showed a pronounced variability among half-sib families (Table 1). The analyzed characteristics (root collar diameter – D, seedling height – H, stem dry mass – SDM, and root dry mass – RDM) revealed notable differences in mean values across half-sib families. This observation suggests the influence of half-sib family effects and genetic differentiation.

Table 1. The basic descriptive statistics of seedlings' morphometric characteristics.

C	Mean value	Standard deviation	Coefficient of variance
D	4.70	1.20	25.60
H	28.40	10.79	37.99
SDM	3.80	0.56	14.73
RDM	4.29	0.57	13.36
DQI	1.20	0.38	31.81
SDM/RDM	0.91	0.31	34.50
H/D	6.01	1.66	27.60

The results of a one-factor analysis of variance (ANOVA) demonstrated statistically significant differences among half-sib families for all assessed seedling morphometric characteristics. This confirms a high level of intraspecific variability and suggests the potential for selecting trees with desirable morphometric traits (Table 2).

The mean values for root collar diameter ranged from 3.17 mm in half-sib family 31 to 6.33 mm in half-sib family 72. Similarly, seedling height varied from 15.64 cm in half-sib family 2 to 41.18 cm in half-sib family 21. These differences were also reflected in biomass variations, where stem dry mass (SDM) and root dry mass (RDM) were significantly greater in half-sib families with larger root collar diameters and heights. Specifically, SDM ranged from 1.34 g in half-sib family 31 to 8.05 g in half-sib family 73, while RDM varied from 1.94 g in half-sib family 33 to 7.65 g in half-sib family 59 (Table S1).

Table 2. The influence of half-sib family on various quality characteristics of sessile oak seedlings.

Tested characteristic	Degrees of freedom	Mean square	F-value	Significance
D	85	2.256	1.802	< 0.001
H	85	200.0	2.088	< 0.001
SDM	85	9.232	1.567	0.002
RDM	85	8.180	1.311	0.048
DQI	85	0.7783	1.563	0.002
SDM/RDM	85	0.2008	2.727	< 0.001
H/D	85	5.48	2.641	< 0.001

The H/D ratio, which indicates mechanical stability and seedling sturdiness, showed moderate variability. The mean H/D values ranged from 3.91 for half-sib family 4 to 8.30 for half-sib family 29. Families with lower H/D values, such as family 4 (H/D = 3.91), demonstrated more compact and mechanically stable growth. In contrast, the higher H/D values found in family 29 (8.30) suggested more elongated growth, which poses a potential risk of lodging.

The ratio of stem dry mass (SDM) to root dry mass (RDM) displayed significant differences among the families studied. The mean SDM/RDM values ranged from 0.59 in half-sib family 68 to 1.49 in half-sib family 22. The half-sib families with SDM/RDM ratios closer to one—such as half-sib families 17, 25, 38, and 82, which had values around 1.00—demonstrated a more balanced allocation of resources between stems and roots. This balance is considered a desirable trait for improving seedling establishment after planting. In contrast, half-sib family 68's markedly low ratio of 0.59 and half-sib family 22's high ratio of 1.49 indicated a dominance of one plant part over the other, suggesting potentially weaker adaptation to stress conditions.

The DQI emerged as the most informative integrative quality indicator. The DQI values effectively distinguished between half-sib families, ranging from 0.52 for half-sib family 19 to 2.11 for half-sib families 13 and 59. The top-performing genotypes exhibited significantly higher index values, such as half-sib families 13 and 59, both with a DQI of 2.11, and half-sib family 73, which had a DQI of 2.04. These higher values were attributed to balanced mass allocation, a stable root system, and a favorable height-to-diameter (H/D) ratio.

A correlation analysis was performed to assess the strength and direction of the linear relationship between seedling morphological characteristics and derived quality indices. The analysis included the following characteristics: root collar diameter (D), seedling height (H), stem dry mass (SDM), root dry mass (RDM), the seedling height-to-diameter ratio (H/D), the ratio of stem dry mass to root dry mass (SDM/RDM), and Dickson's quality index. The results of this analysis can be found in Table 3.

There is a strong positive correlation between root collar diameter (D) and seedling height (H), suggesting that taller seedlings tend to have larger root collar diameters. Similar significant ($p<0.01$) positive correlations were observed among D, H, stem dry mass (SDM), and root dry mass (RDM). For instance, D has a high correlation with SDM ($r = 0.82$) and RDM ($r = 0.75$), indicating that larger and more developed seedlings tend to be heavier on average. Additionally, SDM and RDM are also strongly positively correlated ($r = 0.78$), which supports the idea of coordinated growth between the above-ground and below-ground parts of the seedlings.

The Dickson Quality Index (DQI) demonstrates a strong positive correlation with all basic morphological characteristics: diameter (D) with a correlation coefficient of r =

0.89, height (H) at r = 0.87, stem diameter measure (SDM) at r = 0.94, and root collar diameter measure (RDM) also at r = 0.94. This indicates that the DQI is a comprehensive indicator that effectively reflects the overall morphological quality of seedlings).

Table 3. Pearson correlation among morphological characteristics and seedling quality indices.

Tested characteristic	D	H	SDM	RDM	H/D	SDM/RDM
H	0.77	-				
SDM	0.82	0.77	-			
RDM	0.75	0.69	0.78	-		
H/D	0.40	0.76	0.54	0.43	-	
SDM/RDM	0.22	0.21	0.55	-0.06	0.22	-
DQI	0.89	0.87	0.94	0.94	0.71	0.38

Note: All correlations are statistically significant at the $p < 0.001$ level, except for the SDM/RDM ratio with RDM, which is very weak and not statistically significant

The height-to-diameter (H/D) ratio is strongly positively correlated with seedling height (H) at r = 0.76, which is expected due to the influence of dominant height on this ratio. There is a positive, but moderate correlation with root collar diameter (D) at r = 0.40. Additionally, the H/D ratio is positively correlated with the DQI at r = 0.71, but this should be interpreted with caution. Generally, a higher DQI value is desirable; however, a high H/D ratio, indicating a slender seedling, is not preferable. This correlation suggests that seedlings with higher DQI values tend to be slender, emphasizing the importance of achieving optimal values, rather than merely maximizing the individual characteristics that contribute to the DQI.

The SDM/RDM ratio exhibits a moderate positive correlation with shoot dry mass (SDM) (r = 0.55), which is expected since an increase in above-ground biomass directly influences this ratio. In contrast, the correlation with root dry mass (RDM) is very weak and negative (r = -0.06), indicating that the growth of root dry mass does not linearly affect the increase in the SDM/RDM ratio. The correlation between the SDM/RDM ratio and the Dickson Quality Index (DQI) is positive but moderate (r = 0.38). This corresponds with the idea that an optimal DQI signifies balance, rather than simply a high SDM/RDM value.

A clear ranking of seedling quality among plus trees was achieved by comparing the means of half-sib families on key indicators such as DQI, SDM/RDM, and height-to-diameter ratio (H/D) (Table 4). Several half-sib families emerged as significantly superior across most characteristics, showcasing high biomass (SDM and RDM), a favorable SDM/RDM ratio (indicating substantial root mass), medium or lower H/D values, and the highest scores on Dickson's Quality Index.

For instance, half-sib family 4 achieved the highest combined rank score of 24, largely due to its exceptionally low H/D ratio of 3.91 (ranked 1st) and a high DQI of 1.97 (ranked 4th). Half-sib family 8 had a combined rank score of 42, characterized by a high DQI (ranked 8th) and a medium H/D ratio of 4.97 (ranked 11^{th}). Meanwhile, half-sib family 10 garnered a combined rank score of 53, showcasing a high DQI of 1.97 and a good balance between SDM/RDM at 0.90 (ranked 10th). Other notable half-sib families include family 37, which earned a combined rank score of 60, demonstrating a high DQI of 1.50 (ranked 19th) and a good SDM/RDM balance of 0.88 (ranked 16th). Additionally, half-sib family 73 achieved a combined rank score of 62, exhibiting a high DQI of 2.04 (ranked 2nd) and a good SDM/RDM balance of 1.08 (ranked 9th).

Based on the analysis of three key indices—DQI, SDM/RDM, and H/D—we can conclude that there are significant differences among the half-sib families. Several half-sib families are clearly distinguished as genetically superior progeny. These half-sib families should be recommended for inclusion in the seed orchard, as they possess desirable genotypic traits for seedling development.

Table 4. Ranking of a total of 86 sessile oak half-sib families based on the mean values of seedling quality indices.

Total of ranking	Half-sib families	Mean DQI	Rank DQI	Mean H/D ratio	Rank H/D	Mean SDM/RDM ratio	1 – Mean SDM/RDM	Rank SDM/RDM	Combined rank score
1	4	1.97	4	3.91	1	0.82	0.18	19	24
2	8	1.84	8	4.97	11	0.81	0.19	23	42
3	10	1.97	4	5.27	39	0.90	0.10	10	53
4	37	1.50	19	5.33	25	0.88	0.12	16	60
5	73	2.04	2	6.14	51	1.08	0.08	9	62
6	41	1.70	12	5.96	44	1.09	0.09	9	65
7	55	1.83	8	6.02	47	1.10	0.10	10	65
8	14	1.82	9	4.03	3	0.66	0.34	54	66
9	84	1.04	42	5.13	15	0.90	0.10	10	67
10	11	1.76	10	4.52	7	0.67	0.33	52	69
11	13	2.11	1	4.70	8	0.62	0.38	60	69
12	56	1.83	8	6.54	54	0.94	0.06	7	69
13	64	1.05	40	5.11	14	0.85	0.15	17	71
14	78	1.40	23	5.67	38	0.87	0.13	16	77
15	50	1.51	18	5.88	40	0.83	0.17	19	77
16	7	1.35	25	4.72	9	0.75	0.25	44	78
17	52	1.32	29	5.91	42	0.93	0.07	8	79
18	61	1.73	11	5.19	16	0.67	0.33	52	79
19	25	0.93	59	5.24	19	1.00	0.00	1	79
20	59	2.11	1	6.67	61	0.86	0.14	17	79
21	51	1.52	17	6.67	61	1.05	0.05	1	79
22	28	1.61	15	6.14	49	0.86	0.14	16	80
23	72	1.86	7	5.33	24	0.67	0.33	52	83
24	82	0.90	65	5.23	18	1.00	0.00	1	84
25	36	1.01	44	5.58	34	0.94	0.06	7	85
26	12	1.59	16	4.48	5	0.60	0.40	65	86
27	54	1.07	37	5.93	43	1.03	0.03	6	86
28	9	1.35	25	5.49	27	1.21	0.21	35	87
29	39	1.27	31	5.37	22	0.79	0.21	35	88
30	45	1.41	22	5.54	32	0.79	0.21	35	89
31	34	1.39	23	5.44	29	0.77	0.23	38	90
32	32	1.62	14	5.46	28	0.68	0.32	51	93
33	71	1.01	44	3.95	2	0.71	0.29	49	95
34	18	1.37	24	7.03	62	1.09	0.09	9	95
35	60	1.18	39	5.90	41	0.87	0.13	16	96
36	66	1.21	38	5.46	30	0.80	0.20	29	97
37	2	0.77	79	4.37	4	0.92	0.08	15	98
38	76	1.21	35	6.33	56	1.04	0.04	7	98
39	30	1.42	21	6.86	61	0.88	0.12	16	98
40	49	1.34	28	4.53	6	0.60	0.40	65	99
41	53	1.20	35	6.72	60	0.98	0.02	4	99
42	58	1.49	20	5.25	23	0.63	0.37	58	101

43	80	1.21	35	6.53	59	0.94	0.06	7	101
44	67	0.96	52	5.04	12	0.76	0.24	40	104
45	75	0.98	52	6.02	46	0.97	0.03	6	104
46	24	1.26	34	4.89	10	0.61	0.39	62	106
47	70	0.91	63	5.49	33	1.10	0.10	10	106
48	69	1.07	37	7.00	62	1.08	0.08	9	108
49	1	0.95	55	5.43	31	0.81	0.19	23	109
50	3	1.07	37	5.22	21	0.69	0.31	51	109
51	35	0.73	83	5.18	17	0.91	0.09	9	109
52	46	1.33	27	6.42	45	0.78	0.22	37	109
53	26	1.27	30	5.53	31	0.71	0.29	49	110
54	6	0.98	52	5.70	36	0.81	0.19	23	111
55	57	1.31	29	7.24	66	1.13	0.13	16	111
56	68	1.35	25	5.24	20	0.59	0.41	68	113
57	81	1.01	44	7.48	65	0.93	0.07	8	117
58	74	1.15	36	6.85	55	0.80	0.20	29	120
59	79	1.02	47	8.03	69	1.02	0.02	4	120
60	5	0.88	68	5.69	35	0.82	0.18	19	122
61	48	0.81	71	5.01	13	0.76	0.24	40	124
62	38	0.81	71	6.23	52	1.00	0.00	1	124
63	15	0.89	67	6.16	48	0.90	0.10	10	125
64	21	0.96	52	8.08	69	1.13	0.13	16	137
65	17	0.86	69	8.13	68	1.00	0.00	1	138
66	65	0.93	59	7.18	64	1.14	0.14	17	140
67	63	1.28	33	7.39	64	1.26	0.26	45	142
68	31	0.56	88	5.66	37	0.84	0.16	18	143
69	77	1.40	23	7.18	65	1.38	0.38	60	148
70	47	0.71	86	5.54	33	0.80	0.20	29	148
71	43	0.98	52	7.13	63	0.77	0.23	38	153
72	27	1.35	25	6.86	61	1.41	0.41	67	153
73	29	0.80	71	8.30	73	1.09	0.09	9	153
74	42	0.77	79	5.36	26	0.72	0.28	48	153
75	83	0.98	52	6.57	60	1.27	0.27	46	158
76	44	0.81	71	6.51	53	0.79	0.21	35	159
77	86	0.73	83	7.65	67	0.89	0.11	13	163
78	40	0.75	81	8.22	72	1.10	0.10	10	163
79	19	0.52	88	8.03	68	1.09	0.09	9	165
80	85	0.85	69	6.42	56	0.76	0.24	40	165
81	23	0.82	71	6.17	50	0.70	0.30	50	171
82	16	0.65	87	5.87	37	0.73	0.27	47	171
83	62	0.91	63	7.44	66	1.28	0.28	48	177
84	33	0.55	89	6.21	53	1.21	0.21	35	177
85	20	0.68	85	7.77	67	1.24	0.24	40	192
86	22	0.80	71	6.50	58	1.49	0.49	72	201

4 Discussion

The results from the morphological assessment of sessile oak seedlings, obtained from the progeny of selected plus trees, showed significant variability among the half-sib families. This finding aligns with previous research indicating considerable genetic diversity within natural populations of Quercus petraea (Rebrean et al. 2023; Müller Starck et al. 1992; Bruschi et al. 2003; Gömöry et al. 2001; Vemić et al. 2025).

The uniform conditions in the forest nursery allowed us to attribute the observed differences primarily to genetic factors, rather than environmental variability. This conclusion is supported by studies highlighting the importance of root development for seedling survival (Grossnickle 2005; Grossnickle and MacDonald 2018). The pronounced variability suggests a strong hereditary potential, which can be leveraged through selection to improve seedling quality and forest adaptability.

The significant variations in root collar diameter (D), seedling height (H), and stem and root dry mass (SDM, RDM) indicate different growth strategies among genotypes. The half-sib families that demonstrated larger diameters and more robust root biomass also generally exhibited higher values of the Dickson Quality Index (DQI), aligning with the original characterization of this index (Dickson et al. 1960; Grossnickle 2005). Our findings, which show that the half-sib families with the highest DQI also possess above-average values for D, H, SDM, and RDM, further support the conclusion that larger seedlings with well-developed root systems are reliable predictors of future outplanting success (Villar Salvador et al. 2012; Grossnickle and MacDonald 2018).

Root collar diameter is a morphological characteristic that reflects root system development and is considered the most reliable predictor of seedling growth in the field (South 1987). This relationship is supported by numerous studies, which have consistently shown a positive correlation between root collar diameter and seedling growth (Grossnickle and MacDonald 2018b). A larger root collar diameter enhances nutrient flow throughout the plant, increasing the chances of survival and enhancing growth performance (Grossnickle MacDonald 2018). Popović et al. (2019) noted that root collar diameter is the best single indicator of seedling quality, as it always correlates positively with seedling survival.

Seedling height (ranging from 15.64 to 41.18 cm) shows significant variability, which is typical for species that exhibit strong early apical growth. This height serves as an important growth indicator during field transplantation, as taller seedlings have a competitive advantage over surrounding vegetation. Increased height allows for greater light access, resulting in higher photosynthetic rates. This is particularly crucial during transplant shock, a phase in which seedlings adjust to their new environment and integrate into the ecosystem's cycles of water and nutrients. Sessile oak is a heliophilous species, meaning it thrives in sunlight, and competition from overtopping vegetation can significantly hinder its habitat. Seedling height is the primary criterion for assessing tree performance during the initial stand development phase (Buriánek et al. 2011). However, the seedling height-to-diameter (H/D) ratio offers a more reliable basis for estimating seedling stability. Low H/D values suggest compact, mechanically stable seedlings, which are often more favorable for outplanting and surviving transplantation (Roller 1977; Haase 2008; Girard et al. 2022). In contrast, higher H/D values indicate a more developed stem, providing a competitive advantage in the field, while lower values denote better anchoring and a more developed root system, which are beneficial for transplantation and integration into ecosystem processes. Therefore, lower H/D values may indicate a greater potential for seedlings to endure transplantation stress (Ivetić et al. 2016).

The stem to root dry mass ratio (SDM/RDM) reflects the different adaptive strategies among half-sib families. Half-sib families with an SDM/RDM ratio close to 1 demonstrate balanced biomass allocation, which is generally more beneficial for seedlings intended for transplantation (Grossnickle 2005; Grossnickle and MacDonald 2018; Benito Garzón et al. 2019). Research on seedling survival under abiotic stress often indicates that both root biomass and the optimal structure of seedlings influence planting success (Villar Salvador et al. 2012; Yang et al. 2025; Walters et al. 2023).

In many studies, the Dickson Quality Index (DQI) has proven to be a reliable measure that integrates height, thickness, and root system attributes, allowing for the selection of seedlings with favorable morphological and physiological characteristics (Dickson et al. 1960; Grossnickle 2005; Villar Salvador et al. 2012). The positive correlations between DQI and morphological characteristics—such as root collar diameter, root mass, and stem mass—support the notion that DQI is a strong indicator of seedling potential for survival and growth (Grossnickle and MacDonald 2018).

Based on the analysis of three key indices—DQI, SDM/RDM, and H/D—and their combined ranking scores, significant differences among half-sib families can be observed. These combined ranking indicators (DQI, SDM/RDM, H/D) allow us to identify half-sib families whose progeny show the highest potential (Grossnickle & MacDonald, 2018; Villar-Salvador et al., 2012). Several half-sib families distinctly stand out as genetically superior and should be recommended for inclusion in seed orchards as carriers of desirable genotypic traits for seedling development.

In addition to other highly ranked half-sib families, those that demonstrate favorable values for these indicators are logical choices for establishing seed orchards and promoting sustainable forest regeneration (Ufimov et al. 2025). The half-sib families with high DQI values, favorable SDM/RDM ratios, and low H/D ratios should be prioritized. Evidence suggests that such genotypes maintain their advantageous traits in future generations, exhibiting a high degree of heritability for morphological traits (George et al. 2025; Sampaio et al. 2021).

Despite the advancements in molecular genetics and the acceleration of information acquisition, these methods still do not provide critical information, such as the expected growth rate of plus-tree progeny or the straightness of stems (Baliuckas, 2004). Consequently, progeny tests remain essential for understanding genetic and morphological changes, as demonstrated by the observable growth and performance of the studied plants under consistent environmental conditions. Based on this understanding, new models for dynamic and genetically improved forest stand management are being developed, utilizing measured growth characteristics from the plants' earliest stages (Zeltiņš et al. 2023; Zeltiņš et al. 2025).

5 Conclusion

The morphological assessment of sessile oak seedlings derived from the progeny of plus trees revealed significant variability among half-sib families. This variability was observed in terms of root collar diameter, seedling height, stem dry mass (SDM), root dry mass (RDM), the ratio of SDM to RDM, and Dickson's quality index values. The uniform conditions in the nursery allowed us to attribute these differences primarily to genetic factors, highlighting the considerable selection potential within the analyzed population.

The most valuable indicator of seedling quality was Dickson's Quality Index (DQI), which assesses growth stability and biomass allocation. The half-sib families with the highest DQI values exhibited a favorable SDM/RDM relationship, as well as lower H/D ratios. This makes them the most promising candidates for inclusion in the seed orchard. These findings confirm that early morphological assessments of seedlings serve as reliable indirect indicators of genetic potential, providing a solid basis for the rational selection of superior trees.

The results have practical implications for establishing first-generation sessile oak seed orchards and for the long-term conservation and improvement of genetic resources. By using morphological indices in the selection process, it is possible to improve the quality of reproductive material and ensure the stability and productivity of future generations of sessile oak forests.

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