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Preliminary assessment of genetic gain through the selection of different pedunculate oak populations in provenance test

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Abstract

The distribution of pedunculate oak in Bosnia and Herzegovina is important in connecting the southern and eastern provenances of the Balkan Peninsula with provenances from Central Europe. However, due to over-exploitation, pedunculate oak is almost extinct in Bosnia and Herzegovina. This research aims to determine the heredity and production potential of the pedunculate oak from 28 provenances in the Bosnian-Herzegovinian provenance test through the genetic gain of thickness and height growth. The results will be used in selection of best provenances in terms of genetic gain. For this research, height and root collar diameter of pedunculate oak plants in Bosnian-Herzegovinian provenance tests were measured in 2012, 2016 and 2020. The provenance test was established in 2009. It contains 28 provenances from Bosnia and Herzegovina. Heredity and selection differential were assessed using analysis of variance. Possible genetic gain if using five best and one best provenance were determined. The results of the genetic gain for height obtained using data from 2012 and 2020 were low. The results obtained for 2016 indicate that the genetic gain for height, using five best provenances would be 7.62%, and using the best provenance 9.98%. Results of the genetic gain for root collar diameter obtained for 2016 and 2020 were low. For 2012, the genetic improvement using five best provenances would be 4.28%, and using the best provenance 6.32%. The results indicate that by selecting the best provenances of pedunculate oak and their propagation, we can achieve a significant increase in plant height and thickness, i.e., the yield of wood mass. As research concerns juvenile material, it is necessary to continue systematic monitoring, to determine the actual heredity and genetic age, when the trees reach their physiological maturity, and when the annual value oscillations become uniform.

Keywords

Pedunculate oak, selection, genetic gain

Introduction

Oaks (*Quercus* spp.) belong to the most widely distributed genus of forest trees (Kremer et al. 2004). Pedunculate oak (*Quercus robur* L.) is a large deciduous tree that reaches 30–40 m in height and lives 800 years and more (Ducousso and Bordacs, 2004). The species is tolerant to soil conditions and the continental climate but prefers fertile and well-watered soils (Ducousso and Bordacs, 2004). It is widely distributed in Europe from northern Spain to southern Scandinavia and from Ireland to Eastern Europe (Ducousso and Bordacs, 2004). Oak timber is traditionally used for building, ships and furniture (Ducousso and Bordacs, 2004).

In Bosnian-Herzegovinian forests, pedunculate oak used to be an economically important species (Memišević 2008; Ballian and Memišević Hodžić 2016), but as early as 1907, Beck von Mannagetta (1907) stated that in Bosnia and Herzegovina, there were only the remains of once large forest complexes. Begović (1960, 1978) confirmed these claims in his research on the historical forestry development in Bosnia and Herzegovina. He stated that pedunculate oak forests were marginalized in scientific and economic activities after the devastation from 1839 to 1913.

The distribution of pedunculate oak in Bosnia and Herzegovina, builds a specific connection of southern and eastern provenances of the Balkan Peninsula with provenances from Central Europe. Because of that, Bosnian-Herzegovinian pedunculate oak has an important role in gene movement from south to north and vice versa, and west to east and vice versa (Slade et al., 2008; Ballian and Memišević Hodžić 2016).

According to the data from the inventory of forests in large areas from 1964-1968 (Matić et al., 1971), "other high forests" covered 32,368 ha, and 31.7% of that area (10,261 ha) were pedunculate oak forests. Klepac (1988) stated that pedunculate oak forests in Bosnia and Herzegovina covered about 30,000 ha.

Klepac (1988) stated that the highest quality pedunculate oak forests were in Bosanski Šamac, Bosanska Gradiška, Brčko, and Bijeljina, on about 14,000 ha. The oldest pedunculate oak forests were in Bosanska Gradiška, with an average wood stock of about 315 m^3/ha. The rest were private, small, mostly coppice pedunculate oak forests throughout Bosnia and Herzegovina.

Researches on the provenances of tree species are important for knowing their variability and ability to thrive and produce in different ecological conditions. In Europe, provenance tests with pedunculate oak were raised at the beginning of the 20th century (Hauch 1909; Cieslar 1921). There are numerous of data on provenance tests of pedunculate oak in Europe, from southern Europe to Scandinavia. In neighboring Croatia, there are several pedunculate oak provenance tests. Gračan (1995, 1996) conducted the first significant morphological studies of pedunculate oak. Gračan (1995) analyzed pedunculate oak from several provenances at two localities, and obtained significant variability among provenances. All provenances had better growth in one locality, indicating that ecological conditions highly influenced the growth of pedunculate oak (Gračan, 1995). Further research continued at the same sites by other authors (Perić 2001a, Perić 2001b; Perić et al., 2000, 2003, 2006, 2007, 2008). Their results showed better growth of some provenances in both localities and confirmed the importance of the origin of seeds for the success of pedunculate oak forest plantations.

In Bosnia and Herzegovina, the first studies of pedunculate oak provenances were conducted in 2007 (Ballian et al., 2011), followed by Ballian and Memišević Hodžić (2016), Memišević Hodžić and Ballian (2016, 2018, 2019, 2020), and

Memišević Hodžić et al. (2016, 2019). The results showed high interpopulation and intrapopulation variability for all traits. Ballian and Kajba (2010) stated the heritability of height for *Quercus robur* was 0.14 – 0.32 in the 5th year and 0.52 in the 13th year.

This research aims to determine the heredity and production potential of the pedunculate oak from 28 provenances in the Bosnian-Herzegovinian provenance test through the genetic gain of thickness and height growth. The results will be used in selection of best provenances in terms of genetic gain.

Material and methods

For this research, pedunculate oak plants in Bosnian-Herzegovinian provenance tests were measured. The provenance test contains 28 provenances from Bosnia and Herzegovina (Figure 1).

The provenance test was established by planting one-year-old seedlings in 2009. The seedlings were planted in 30 cm × 30 cm × 30 cm holes, with a planting distance of 2 m × 2 m. The seedlings were planted in three blocks, with 36 plants per provenance in one block. Two rows of seedlings were planted around each block to reduce the edge effects on the experimental plot. Ameliorative measures or cleaning was not carried out from planting to conducting the research.

At the end of the growing seasons 2012, 2016, and 2020, root collar diameter and height on all plants were measured.

Using analysis of variance heredity (formula 1) and selection differential assessment (formula 2) were assessed, which determined the genetic gain (formula 3) or possible improvement if using five best and one best provenance.

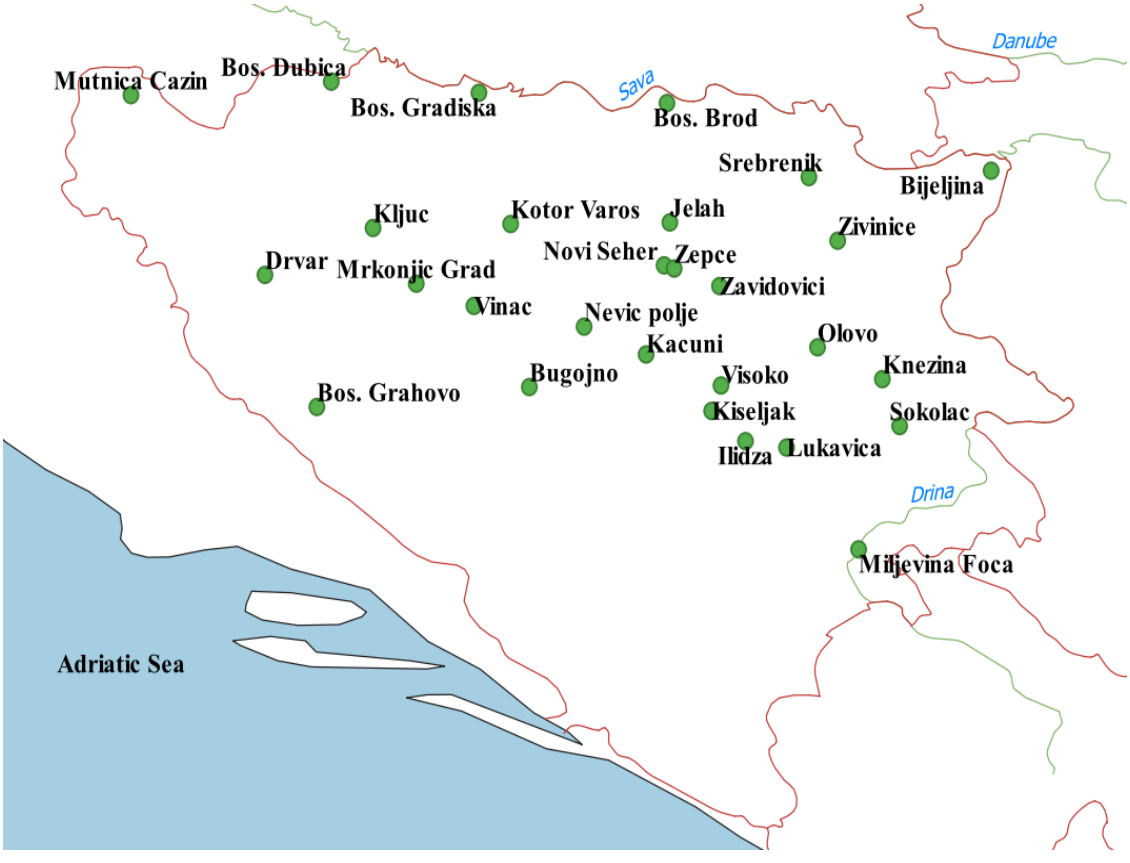

Figure 1. Geographic distribution of pedunculate oak provenances included in the provenance tests

$$h^2 = \frac{\delta_p^2}{\frac{\delta_g^2}{r} + \delta_p^2}$$

formula 1) broad sense heritability (according to Wright, 1976):

δ_g^2 - error variance component

δ_p^2 - provenance variance component

r – number of repetition

$$i = \bar{x}_s - \bar{x}$$

formula 2) selection differential

i - the average for the selected part of the provenances reduced by the average of all the provenances

$$\Delta G = i \times h^2$$

formula 3) genetic gain

$$\%GG = \frac{\Delta G}{\bar{x}} * 100$$

formula 4) percentage of genetic gain for selected provenances in relation to the average value for all provenances

Results and Discussion

Predicting the evolutionary potential of natural tree populations requires an assessment of the heritability and genetic correlation among traits affected by selection, as differences in evolutionary success between species may rely on differences in these genetic parameters (Alexandre et al. 2020). Toda et al. (1959) stated thar large variation had been observed in the growth and other characteristics within a population of forest trees, and the problem has been how much of this variation is determined by environmental factors and how much by the inherent nature of the trees (Toda et al. 1959). Toda et al. (1959) suggested the solution of this problem by using the concept of "heritability" i.e. the relative amount of heritable variance in the total variance of the population.

In this research the heritability of traits of pedunculate oak in the Bosnian-Herzegovinian provenance test was investigated using the data of heights and root collar diameters from 2012, 2016, and 2020. Table 1 shows the average heights and root collar diameters per provenance and year.

Jelah provenance had the highest average heights in 2012 and 2016 and root collar diameter for all three years, while in 2020, Drvar provenance had the highest average height. Thus, data from these provenances were used for genetic gain calculating for researched traits.

The five best provenances for height in 2012 were: Jelah, Žepče, Bosanska Dubica, Drvar, and Bugojno. In 2016 five best provenances were: Jelah, Drvar, Kaćuni, Mutnica Cazin, and Bosanski Brod, and in 2020: Drvar, Jelah, Kaćuni, Bijeljina, and Hrgovi Srebrenik.

The five best provenances for root collar diameter in 2012 were: Jelah, Drvar, Kaćuni, Bijeljina, and Mutnica Cazin. In 2016 five best provenances were: Jelah, Drvar, Mutnica Cazin, Bosanska Dubica, and Živinice, and in 2020: Jelah, Živinice, Drvar, Mutnica Cazin, and Kaćuni.

Results of heritability for height and root collar diameter of pedunculate oak for three different years (2012, 2014, and 2016) are shown in table 2.

Table 2. Heritability and genetic improvement for the trait of height

Year	Heritability of height	Heritability of root collar diameter
2012	0.02150	0.27029
2016	0.34379	0.03290
2020	0.01154	0.05853

The results of heritability of heights and root collar diameters of four-year-old pedunculate oak plants in this research are low compared to results of heritability for different forest tree species in Bosnia and Herzegovina. Ballian (2000a) obtained

Table 1. Average values of height and root collar diameter per provenances and years with the highest data marked in red, and the other four highest averages in green

No	Provenance	Height 2012 (cm)	Height 2016 (cm)	Height 2020 (cm)	Root collar diameter 2012 (mm)	Root collar diameter 2016 (mm)	Root collar diameter 2020 (mm)
1	Bijeljina	44.5	181.2	385.9	14.5	45.3	92.5
2	Bos.Dubica	52.5	193.9	353.0	14.2	48.2	94.5
3	Bos.Gradiška	38.9	151.7	308.6	12.4	40.0	82.7
4	Bos.Brod	40.8	194.4	344.3	13.1	47.3	91.7
5	Bos.Grahovo	43.2	153.8	297.5	13.9	40.2	79.2
6	Bugojno	50.0	183.5	328.3	13.0	43.3	75.4
7	Drvar	52.2	206.4	433.8	15.5	51.9	97.6
8	Hrgovi Srebrenik	42.7	179.7	379.7	13.0	42.6	91.6
9	Jelah	69.5	214.5	425.4	16.0	52.1	101.5
10	Kaćuni	43.3	205.1	394.7	14.7	44.4	96.2
11	Kiseljak	42.6	143.9	314.6	12.9	40.1	76.8
12	Ključ	33.8	158.1	349.6	11.6	40.5	81.4
13	Knežina	42.5	153.4	304.2	11.4	39.1	81.6
14	Kotor Varoš	42.7	163.4	339.8	13.5	43.2	81.6
15	Lukavica	36.4	132.1	279.1	12.8	36.0	76.1
16	Miljevina Foča	32.0	130.8	315.9	11.5	33.8	73.8
17	Mrk.Grad	37.2	159.5	337.3	12.2	40.8	87.2
18	Mutnica Cazin	41.7	194.9	335.9	14.5	50.3	97.4
19	Nević Polje	35.1	134.2	296.3	11.5	34.8	67.4
20	Novi Šeher	39.8	157.9	331.6	12.8	43.2	90.1
21	Olovo	44.4	150.9	299.4	13.3	42.2	84.5
22	Sokolac	42.4	151.5	319.8	11.7	38.3	75.9
23	Stojčevac	38.0	136.6	278.4	11.3	32.0	73.4
24	Vinac	37.2	154.9	369.1	10.9	40.4	76.3
25	Visoko Muhaš.	40.0	123.6	259.5	12.3	32.8	74.3
26	Zavidovići	43.8	172.8	341.3	12.0	42.2	75.8
27	Žepce	53.1	178.7	359.3	13.4	45.5	85.1
28	Živinice	47.9	191.7	361.5	13.5	47.8	101.0

values of heritability from 0.78 for seed width to 0.84 for seed length for wild cherry populations.

The heritability of height of silver fir plants obtained by Ballian (2000b) was higher and amounted to 0.69 for one-year-old and 0.56 for two-year-old plants. For four-year-old silver fir plants, Ballian and Halilović (2016) obtained a heritability of height of 0.74. The heritability of root collar diameter for silver fir one-year-old plants was 0.77, for two-year-old plants 0.54 (Ballian 2000b), and for four-year-old plants 0.64 (Ballian and Halilović 2016).

Research on heritability has been previously conducted on some of the traits of *Quercus* species

in Europe. Rink et al. (1995) got the narrow-sense heritability for height in progeny tests of *Quercus alba* 0.36. Jensen et al. (1997) found heritability for open-pollinated families of *Quercus robur* assumed half-sibs was 0.46 for height, and 0.10 for diameter at breast height. Vidaković et al. (2000) found heritability in a progeny test of *Quercus robur* in Croatia ranged from 0.74 to 0.87. Bogdan et al. (2004) estimated heritabilities in an open-pollinated progeny test in Croatia from 0.62 to 0.78 for height and from 0.28 to 0.65 for diameter at breast height. Barzdajn (2008), found heritability of pedunculate oak trees from five provenances 0.19−0.80 for height, and 0.59−0.87 for diameter at breast height. Ballian and Kajba (2010) stated the heritability of height for *Quercus robur* was 0.14 – 0.32 in the 5th year and 0.52 in the 13th year.

Results of genetic improvement for height and root collar diameter if using five best provenances and one best provenance of pedunculate oak for three different years (2012, 2014, and 2016) are shown in table 3.

4.28% compared to the average value for all provenances, for 2016 0.62% and 2020 0.99 %. If we select the best provenance, data from 2012 indicate that the genetic gain would be 6.32%, 2016 0.78%, and 2020 0.2%.

Rink et al. (1995) obtained expected gains in tree height from an early selection of the tallest trees in the fastest-growing families of *Quercus alba* 30% at age 5. In this research, genetic gain of 9.98 % at age seven could be obtained if using one best provenance.

Bogdan et al. (2004) estimated genetic gains varied from 9.7 to 22.3% for height and 6.8 to 17.3% for diameter at breast height.

Root collar diameter showed the highest values genetic improvement for 2012, in contrast to the result for height when the highest values were for 2016. As quantitative traits are concerned, environmental factors play an important role in determining heredity, especially the competition between trees in the fight for light. The heredity of root collar diameter could be less influenced by climatic conditions and more related to the soil

Table 3. Genetic improvement for the height and root collar diameter

Year	Genetic improvement of height if using the five best provenances		Genetic improvement of height if using the one best provenance		Genetic improvement of root collar diameter if using the five best provenances		Genetic improvement of root collar diameter if using the one best provenance	
	(cm)	(%)	(cm)	(%)	(mm)	(%)	(mm)	(%)
2012	0.26	0.61	0.56	1.31	0.56	4.28	0.82	6.32
2016	12.67	7.62	16.59	9.98	0.26	0.62	0.33	0.78
2020	0.77	0.23	1.11	0.33	0.84	0.99	3.1	0.2

Thus, taking into account the data for 2012, the genetic improvement for height when using the five best provenances, compared to the average value for all provenances, would be 0.61%, for 2016 7.62%, and for 2020 0.23 %. If we select the best provenance, results for 2012 indicate that the genetic gain would be 1.31%, for 2016 9.98%, and for 2020 0,33%.

The genetic improvement for root collar diameter when using the five best provenances would be

structure and the adaptability of the provenance to grow on heavy soils.

Such a low heritability indicates a number of alleles that determine this trait. Thus, in similar 80-year-old research on spruce in Sweden, Eriksson and Ekberg (2001) and Eriksson et al. (2006) found that eight alleles determine this trait. Otherwise, in 2016, when the conditions were favorable, heritability was high. As this research is long-term, these are preliminary results for now,

and the best will be when the plants reach physiological maturity.

Conclusion

The results of the genetic gain for height and root collar diameter were different by years of plants' age. Results for the genetic gain of height obtained using data from 2012 and 2020 were low, but data from 2016 indicated that the genetic gain using the five best provenances would be 7.62% and using the best provenance 9.98%. The results of genetic gain for root collar diameter obtained using data for 2016 and 2020 were low. For 2012, the genetic improvement using the five best provenances would be 4.28% and 6.32%compared if using the best provenance.

These results indicate that by selecting the best individuals and their propagation, we can achieve a significant increase in height and thickness increment, and thus, the yield of wood mass.

As research have concerned juvenile material, it is necessary to continue systematic monitoring, to determine the actual heredity and genetic age, when the trees reach their physiological maturity, and when the annual value oscillations become uniform.

Conflict of interest

Authors declare no conflict of interest.

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