Growth Dynamics and Tree Shape of Common Beech (*Fagus sylvatica* L.) in the International Provenance Test

Mirzeta Memišević Hodžić[1],*, Dalibor Ballian[1]

(1) University of Sarajevo, Faculty of Forestry, Zagrebačka 20, BA-71000 Sarajevo, Bosnia and Herzegovina

* Correspondence: e-mail: m.memisevic-hodzic@sfsa.unsa.ba

ABSTRACT

Provenance tests of forest tree species are important experiments in silviculture and tree breeding. Their results provide information about provenances' growth, adaptability, and other features. The research aimed to determine the dynamics of growth and tree shape of common beech plants per provenances in the international provenance test in Bosnia and Herzegovina to choose the best provenances considering wood production and quality. Research was conducted in the provenance test containing eight provenances from Bosnia and Herzegovina, four from Germany, three from Serbia, two each from Croatia, Romania, and Switzerland, and one from Hungary. Provenance test was established in 2007 by planting 2-year-old and 3-year old seedlings. Height and root collar diameter were measured, and tree shape was assessed in 2019. Data were processed in SPSS 26.0. Descriptive statistics, variance analysis, multiple Duncan's test for all traits, and Pearson's coefficient of corelation among morphological traits and tree shape were calculated. Variance for the height and root collar diameter showed statistically significant differences among different ages of plants and among provenances. Provenance from Croatia (Dilj Čaglinski) had the highest, and provenance from Romania (Alba-Iulia) had the lowest average height. The highest average value of root collar diameter had provenance Dilj Čaglinski, and the lowest value had provenance Sihlwald (Switzerland). The highest percentage of category 10 (ideal tree form) had provenance Bad Wildbad (Germany), and categories 1-4 (no silviculture value) had provenance Alba-Iulia (Romania). Pearson's coefficient showed that height, root collar diameter, and tree shape are highly correlated. Considering all the above, when planning forest-breeding works, it is recommended to continue the research and favor provenances with the best growth and tree shape.

Keywords: *Fagus sylvatica*; selection of provenances; wood productivity; wood quality

INTRODUCTION

Common beech (*Fagus sylvatica* L.) is the most common tree species in the total area of forests and forest lands in Bosnia and Herzegovina (Fukarek 1970), and researches on this species are especially significant. Studies of common beech provenances in different parts of its range indicated significant intra-population and inter-population variability (Kajba 2003).

Due to its importance, beech has been the subject of research by numerous scientists and researchers (Barriere et al. 1984, Kleinschmit 1985, Brus et al. 1990, Comps et al. 1991, 1998, Muhs and von Wuhlisch 1992, Gömöry et al. 1999, 2003, 2007, Gračan and Ivanković 2001, Gračan et al.

2006, Ivanković et al. 2008, 2011, Ballian and Zukić 2011, Ballian et al. 2012, Ballian et al. 2015, Ballian et al. 2019, Memišević Hodžić and Ballian 2021).

International experiments with common beech have been established intensively in recent decades due to the need to preserve the genetic resources of the species. In the early 1980s, the establishment of a network of field trials began (Muhs 1985). During that period, 15 experiments with 188 provenances were established. During the 1990s, new experiments were established and included the eastern part of the common beech range. Muhs et al. (1992) proved morphological, phenological, and genetic variability of common beech among and within populations. Muhs (1985) found that geographical variability is ecotypic rather than clinal.

Hussendörfer et al. (1996) investigated phenotypic traits (branching type, forkiness) in a 12-year-old common beech stand in Switzerland. They concluded that there was no correlation between these traits and that it was not possible to identify their genetic determinants.

This research aimed to determine the dynamics of growth and the shape of the tree of common beech provenances in the international provenance test in Bosnia and Herzegovina, to select provenances with the best characteristics in terms of wood mass production and wood quality for further afforestation with this species. The aim was also to determine whether there were statistically significant differences in morphological traits of provenances according to the age of the seedlings at the time of establishing the provenance test.

MATERIALS AND METHODS

Plants from the international provenance test of common beech in Bosnia and Herzegovina were measured and assessed in this research. The test includes 22

provenances, eight from Bosnia and Herzegovina, four from Germany, three from Serbia, two from Croatia, two from Romania, two from Switzerland, and one provenance from Hungary (Table 1, Figure 1).

The test was established in a randomized block system with three replications, planting seedlings aged 2+0 and 3+0 with a planting interval of 2x1 m. The provenance test was erected in the spring of 2007 on a surface with average coordinates of 44°04'15'' N 18°11'32''E. Administratively, it belongs to the forest management area "Kakanjsko", forest management unit "Donja Trstionica - Goruša", department 41, section c. It is located at 510 to 540 m above sea level. The average slope of the terrain is 7%, and the exposure is mostly northeastern. Rendzina and acid brown soil complex, and a complex of acid brown and ilimerized soil predominate. Brown soils are present on a small part of the surface. The area is influenced by a temperate continental climate, characterized by cold winters and moderately warm summers with abundant precipitation.

In the spring of 2019, plant heights and root collar diameters were measured, and tree shape was assessed. Heights were measured using a stick meter and root collar

Table 1. Data of studied provenances.

| No	Label	Provenance	Country	Latitude	Longitude	Altitude	Seedlings' age at the time of establishing the test	Plants age at the time of measuring
1	9661	B. Krupa Baštra Čorkovaća	BiH	44°45'	16°14'	720	2+0	14
2	9659	Bugojno Vranica - Bistrica	BiH	43°33'	17°49'	750	2+0	14
3	9662	Dinara	BiH	44°06'	16°30'	950	2+0	14
4	9633	Grmeč - Jasenica	BiH	44°16'	16°18'	450	3+0	15
5	9631	Konjuh - Kladanj	BiH	44°16'	18°34'	840	3+0	15
6	9630	Tajan – Zavidovići	BiH	44°23'	18°03'	700	3+0	15
7	9632	Tešanj - Crni Vrh I	BiH	44°33'	17°59'	500	3+0	15
8	9660	Tešanj - Crni Vrh II	BiH	44°33'	17°59'	500	2+0	14
9	9624	Dilj Čanglinski	HR	45°17'	18°01'	350	3+0	15
10	9625	Vran kamen	HR	45°37'	17°19'	600	3+0	15
11	9646	Bad Wildbad	D	48°46'	08°35'	700	3+0	15
12	9642	Valkonya	H	46°30'	16°45'	300	3+0	15
13	9649	Hasbruch	D	53°08'	08°26'	35	3+0	15
14	9648	Hoellerbach	D	49°01'	13°14'	755	3+0	15
15	9647	Schwäbisch Alb	D	48°00'	10°00'	650	3+0	15
16	9663	Alesd	RO	46°10'	22°15'	490	2+0	14
17	9664	Alba-Iulia	RO	46°10'	23°05'	860	2+0	14
18	9666	Avala	SRB	44°12'	20°45'	745	2+0	14
19	9669	Cer	SRB	44°12'	19°50'	745	2+0	14
20	9668	Fruška gora	SRB	45°10'	19°47'	360	2+0	14
21	9643	Herzogenbuchsee	CH	07°40'	47°11'	500	3+0	15
22	9665	Sihlwald	CH	47°12'	07°21'	1050	2+0	14
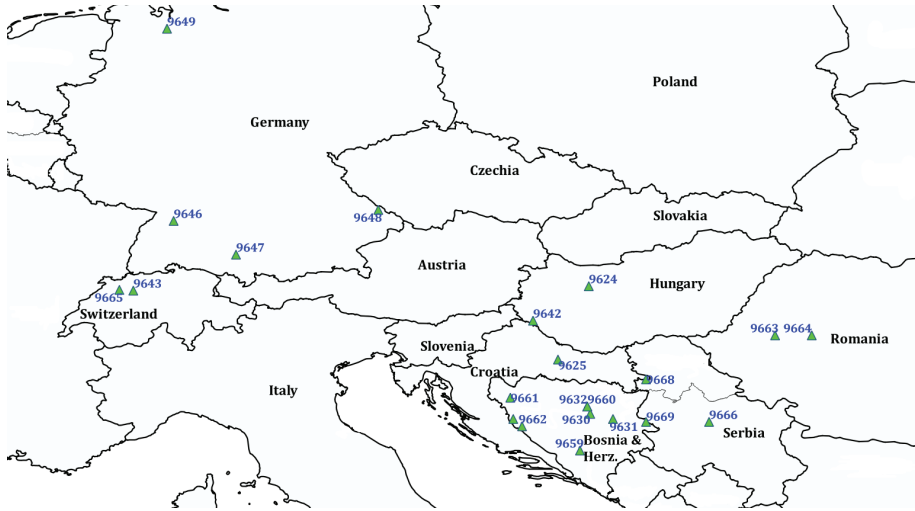
Figure 1. Researched provenances.

diameter using an electronic moving scale. Tree shape was evaluated according to the scoring system for beech and oak as shown in Figure 2 (Ducci et al. 2012). Trees that did not meet the criteria of cultivation value were marked by a common designation 1-4.

Data on height and root collar diameters were processed by the statistical program SPSS 26.0. Descriptive indicators, variance analysis, and Duncan's test were calculated according to the provenances and ages of the plants. Tree shape data were also processed in the SPSS 26.0 program. Frequencies of categories were calculated per provenances. The Pearson's correlation coefficient for height, root collar diameter, and tree shape was calculated.
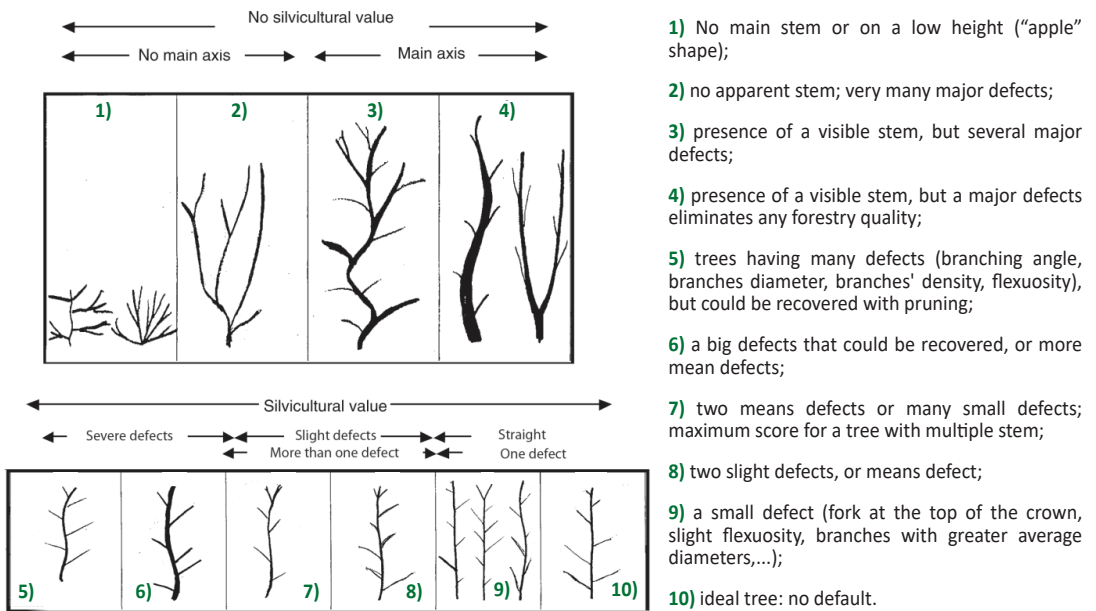

1) No main stem or on a low height ("apple" shape);

2) no apparent stem; very many major defects;

3) presence of a visible stem, but several major defects;

4) presence of a visible stem, but a major defects eliminates any forestry quality;

5) trees having many defects (branching angle, branches diameter, branches' density, flexuosity), but could be recovered with pruning;

6) a big defects that could be recovered, or more mean defects;

7) two means defects or many small defects; maximum score for a tree with multiple stem;

8) two slight defects, or means defect;

9) a small defect (fork at the top of the crown, slight flexuosity, branches with greater average diameters,...);

10) ideal tree: no default.

Figure 2. The scoring system used for beech and oak (Ducci et al. 2012).

RESULTS

Heights

Average values of heights according to plant ages are shown in Table 2.

The average height of provenances whose seedlings were 2+ 0years old when establishing the provenance test was lower than the average height of those whose seedlings were 3 + 0 years old. T-test according to plant age (Table 3) showed that the differences caused by differences in seedlings' age were statistically significant (Sig. <0.05).

Average values of heights by provenances are shown in Table 4.

Provenance from Croatia (Dilj Čanglinski) had the tallest trees, the average height of 262.9 cm, while provenance from Romania (Alba-Iulia) had the lowest trees, and the average height of 161.3 cm. The second-highest average height had provenance Vran Kamen (Croatia) with 243.4 cm, and the third Konjuh - Kladanj (Bosnia and Herzegovina) with 241.80 cm.

When it comes to provenances with lower average heights, after Alba-Iulia, another provenance from Romania (Alesd) had a low average height (165.0 cm) and provenance from Switzerland (Sihlwald) (172. 4 cm). Plants of provenances with higher average heights at the time of measurement were 15 years old, and plants of provenances with lower heights were 14 years old.

Analysis of variance for height (Table 5) shows statistically significant differences among provenances (F calculated > F in the table, Significance < 0.005).

The results of the Duncan's test for height showed a grouping of provenances into six groups that overlap (showed in Table 4).

Root Collar Diameter

Table 6 shows the average values of root collar diameter according to plant ages in the provenance test.

As for the heights, average values of root collar diameters of 14 year-old plants were lower than the average values of provenances with 15 years old plants. T-test according to plant age (Table 7) showed statistically significant differences per plants' age (Sig. <0.05).

Table 8 shows the average values of root collar diameter (mm) per provenances.

The highest average value of the root collar diameter had the provenance from Croatia (Dilj Čanglinski) with 48.9 mm. The second highest value had provenance Vran Kamen with 45.8 mm and the third Tešanj Crni Vrh I with 45.4 mm. The lowest average size of root collar diameter had provenance Sihlwald from Switzerland with 29.5 mm, then provenances from Romania, Alba-Iulia 30.7 mm, and Alesd 32.6 mm. As for the root collar diameter, provenances with 14 year-old plants had lower values of root collar diameter than provenances with 15 year-old plants.

Variance analysis for root collar diameter (Table 9) showed statistically significant differences among provenances (F calculated > F in the table, Significance <0.005).

Duncan's test for root collar diameter showed a grouping of provenances into eight groups, which overlap each other.

Tree Shape

Figure 3 shows the percentages of plants with tree shape categories for all provenances together. The highest number of trees belong to category 10 (perfectly flat tree), and shapes without significance for forest cultivation occupy 9.8% of plants (Categories 1-4) .

Table 2. Descriptive statitstics for height according to plants' age.

Plants' age (years)	Average height (cm)	Standard deviations (cm)	Standard error (cm)	Minimum (cm)	Maximum (cm)
14	206.0	75.9	4.6	55	420
15	230.4	82.1	3.0	55	530
Average	223.7	81.1	2.5	55	530

Table 3. T-test for height per plants' age.

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Equal variances assumed	553.599	0.000	-14.952	3066	0.000	-59.20579	3.95962	-66.9696	-51.4420
Equal variances not assumed			-15.299	2937.144	0.000	-59.20579	3.86981	-66.7936	-51.6180

Table 4. Descriptive statitstics for height per provenances.

Provenance	Age	Average height (cm)	Standard deviation (cm)	Standard Error (cm)	Minimum (cm)	Maximum (cm)	Group by Duncan's test
9624	15	262.9	99.9	10.9	70	530	6
9625	15	243.4	86.8	9.8	65	440	5/6
9630	15	238.3	81.3	9.7	110	440	5/6
9631	15	241.8	99.5	17.9	55	450	5/6
9632	15	239.9	93.1	14.2	85	420	5/6
9633	15	230.8	73.9	9.5	95	390	4/5/6
9642	15	235.3	73.2	8.0	80	395	4/5/6
9643	15	232.0	80.9	10.1	70	410	4/5/6
9646	15	178.4	49.8	10.0	100	290	1/2/3
9647	15	216.8	68.4	7.6	60	400	3/4/5
9648	15	209.9	67.3	9.9	85	360	2/3/4/5
9649	15	200.6	69.5	8.0	70	350	1/2/3/4/5
9659	14	217.9	85.9	16.2	105	420	3/4/5
9660	14	240.6	101.8	20.0	60	410	5/6
9661	14	193.1	47.9	10.4	100	280	1/2/3/4
9662	14	221.4	65.3	10.1	100	370	4/5/6
9663	14	165.0	53.8	10.6	55	330	1
9664	14	161.3	73.3	18.9	60	280	1
9665	14	172.4	64.9	12.3	80	305	1/2
9666	14	230.3	69.0	12.8	90	350	4/5/6
9668	14	212.7	75.2	14.2	60	400	2/3/4/5
9669	14	210.9	76.0	13.0	70	340	2/3/4/5
Average		223.7	81.1	2.5	55	530	-

Table 5. Variance analysis for height of the provenances.

Source of variability	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	578576.925	21	27551.282	4.486	0.000
Within Groups	6122980.590	997	6141.405		
Total	6701557.515	1018			

Table 6. Descriptive statitstics for root collar diameter according to plants' age

Plants' age (years)	Average root collar diameter (mm)	Standard deviations (mm)	Standard error (mm)	Minimum (mm)	Maximum (mm)
14	7.5	16.2	0.4	0.01	80.4
15	19.0	23.1	0.6	0.01	89.5
Average	13.7	21.0	0.4	0.01	89.5

Table 7. T-test for root collar diameter per plants' age.

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Equal variances assumed	632.107	0.000	-15.854	3098	.000	-11.54696	.72832	-12.9750	-10.1189
Equal variances not assumed			-16.278	2985.931	.000	-11.54696	.70934	-12.9378	-10.1561

Table 8. Descriptive statistics of root collar diameter per provenances.

Provenance	Age (years)	Average root collar diameter (mm)	Standard deviation (mm)	Standard error (mm)	Minimum (mm)	Maximum (mm)	Group according to Duncan's test
9624	15	48.9	13.5	1.5	22.9	80.5	6
9625	15	45.8	13.6	1.5	20.4	81.7	5/6
9630	15	44.4	15.7	1.9	18.4	89.5	5/6
9631	15	43.9	12.9	2.3	19.1	73.0	4/5/6
9632	15	45.5	16.8	2.6	19.9	83.4	5/6
9633	15	42.6	13.7	1.8	17.7	82.8	4/5/6
9642	15	44.2	13.0	1.4	21.3	75.0	4/5/6
9643	15	40.7	13.0	1.6	16.6	81.7	5/6/7
9646	15	33.2	7.2	1.4	18.3	50.4	1/2/3/4
9647	15	40.0	12.3	1.4	22.3	77.6	5/6/7
9648	15	37.2	11.1	1.6	18.4	56.8	2/3/4/5/6
9649	15	39.4	10.4	1.2	20.6	73.8	4/5/6/7
9659	14	41.1	13.8	2.6	25.3	68.9	5/6/7
9660	14	40.8	16.4	3.2	14.7	80.4	5/6/7
9661	14	34.4	6.8	1.5	22.8	46.2	1/2/3/4/5
9662	14	45.4	12.4	1.9	25.6	70.3	5/6
9663	14	32.6	7.2	1.4	24.5	52.4	1/2/3
9664	14	30.7	9.0	2.3	18.5	42.9	1/2
9665	14	29.5	9.4	1.8	13.5	52.0	1
9666	14	43.0	12.0	2.2	20.4	64.0	4/5/6
9668	14	40.1	10.5	2.0	19.6	61.4	5/6/7
9669	14	39.1	12.2	2.1	18.3	71.6	3/4/5/6/7
Average		41.6	13.4	0.4	13.5	89.5	

Table 9. Variance analysis of root collar diameter per provenance.

Source of variability	Sum of Squares	df	Mean Square kvadrata	F	Sig.
Between Groups	21155.683	21	1007.413	6.216	0.000
Within Groups	161568.944	997	162.055		
Total	182724.627	1018			

Figure 4 shows the percentages of tree shape categories per provenances.

The highest percentage of category 10 had provenance 9646 (Bad Wildbad, Germany). Provenance 9664 (Alba-Iulia, Romania) had the highest share of categories 1-4 (no cultivation value).

If we analyze only categories 8, 9, and 10, as categories of trees with good shape, Baštra Ćorkovača from Bosnia and Herzegovina stands out with 76.2% of plants in these categories, Bad Wildbad from Germany with 72.0%, Dilj

Čaglinski from Croatia with 69.0%, and Herzogenbuchsee from Switzerland with 68.8%.

Correlation of Tree Shape, Height, and Root Collar Diameter

Table 10 presents the values of the Pearson's correlation coefficient of investigated traits: tree shape, height, and root collar diameter.

Pearson's correlation coefficient showed high values of correlation among all three examined properties (height, root collar diameter, and tree shape).
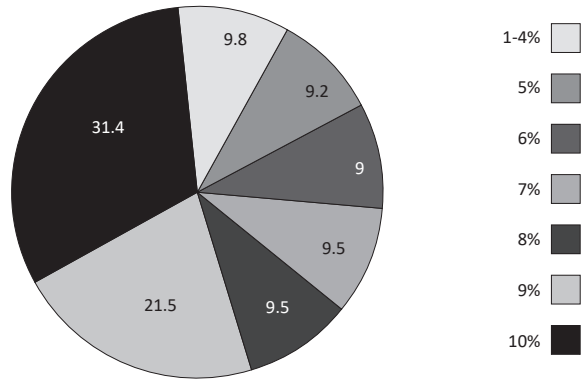
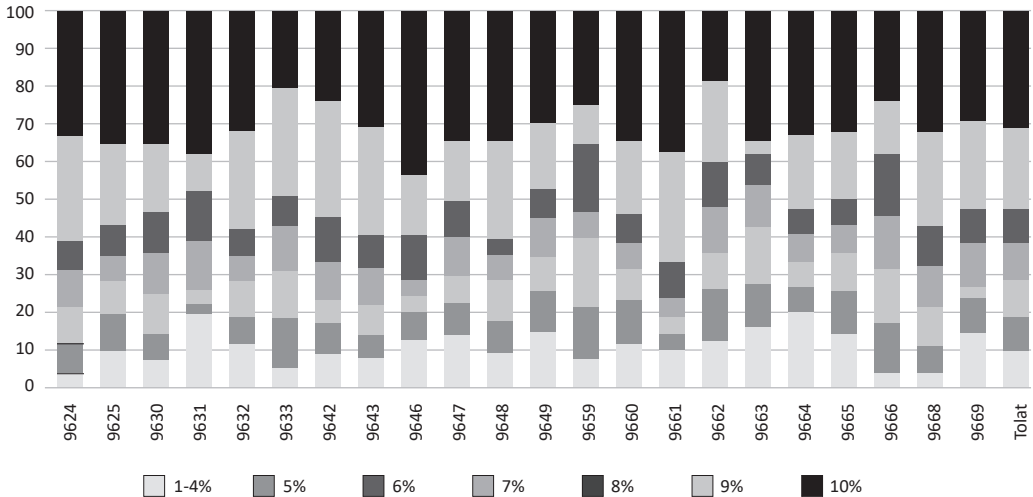**Figure 3.** Percentages of plants per tree shapes categories for all provenances.

Figure 4. Percentages of plants per tree shape categories per provenance.

Table 10. Pearson's correlation coefficient of tree shape, height, and root collar diameter.

Traits	Pearson's correlation coefficient	Tree shape	Height	Root collar diameter
Tree shape	Pearson's Correlation	1	0.931[**]	0.929[**]
	Sig. (2-tailed)		0.000	0.000
	Sum of Squares and Cross-products	46864.699	1220252.887	228498.360
	Covariance	15.627	410.860	76.192
	N	3000	2971	3000
Height	Pearson's Correlation	0.931[**]	1	0.975[**]
	Sig. (2-tailed)	0.000		.000
	Sum of Squares and Cross-products	1220252.887	39376906.780	7033261.658
	Covariance	410.860	12838.900	2293.206
	N	2971	3068	3068
Root collar diameter	Pearson's Correlation	0.929[**]	0.975[**]	1
	Sig. (2-tailed)	0.000	0.000	
	Sum of Squares and Cross-products	228498.360	7033261.658	1368664.902
	Covariance	76.192	2293.206	441.647
	N	3000	3068	3100

DISCUSSION

Almost all previous research of common beech provenances treated morphological characteristics, especially height, diameter, and survival of plants, and results showed statistically significant differences among provenances (Ballian and Zukić 2011, Ballian and Jukić 2014-15, Bogunović et al. 2020, Memišević Hodžić and Ballian 2021, Popović et al. 2021). Ivanković et al. 2008 identified statistically significant differences among provenances in a provenance test in Slovenia, but in the same research, in a provenance test in Croatia, the effects of provenances were not statistically significant. Hoffman (1961) stated that the heights that reached a younger age cannot be taken as a reliable measure for determining the growth of provenances because changes in growth rate often occur at a later age. Some authors stated that conclusions about the growth of provenances are not reliable up to the age of 40 or one-third of the production period (Vidaković and Krstinić 1985, Kleinschmit 1985). Therefore, given the age of the provenances in this research, we still cannot reliably talk about the productivity of individual provenances, but the results are significant for the juvenile-adult correlation of investigated traits. Larsen (1985), based on an early test, stated that it is possible to predict that individual beech populations will maintain good growth at a later age. Therefore, this research results could help to obtain a general picture of all provenances and to predict their growth at a later age.

The highest values of the investigated traits had provenance from Croatia Dilj Čanglinski and the lowest Alba-Iulia from Romania, which is in accordance with the results of the research by Memišević Hodžić and Ballian (2021).

This study also showed statistically significant differences between different ages of provenances.

In this paper, tree shape as an important indicator of the quality of the produced wood mass was also evaluated. The results showed statistically significant differences among the investigated provenances. The best tree shape had the provenance from Bosnia and Herzegovina (Baštra Čorkovaća). Also, provenances from Croatia and Germany had a large percentage of plants with good tree shape.

Correlation results among the growth properties (height and root collar diameter) and tree shape showed high values of the correlation among all three traits. Although there were no many studies on the correlation among morphological traits in common beech, Hussendörfer et al. (1996) investigated different types of branching and forkiness in 12-year-old common beech stand in Switzerland. They found no correlation among the traits and concluded that it is not possible to identify their genetic determinants.

Memišević Hodžić and Ballian (2020) investigated the shape of the pedunculate oak tree in Bosnian-Herzegovinian provenance test. The share of tree shape categories was less favorable, and only 14% of the total number of plants had the form of tree 10 according to the protocol of Ducci et al. (2012).

CONCLUSIONS

Analysis of variance for researched morphological traits (root collar diameter and height) showed statistically significant differences among the provenances, which was confirmed by Duncan's test. T-test showed statistically significant differences between plants of different ages.

Provenances whose plants were 15 years old at the time of the study had higher average values of traits, which implies that the age of seedlings is an important factor to consider for artificial afforestation. The highest average plant height in 2019 had the provenance from Croatia (Dilj Changlinski) with 262.90 cm, while the lowest average height had provenance from Romania (Alba-Iulia) with 161.30 cm. The highest average value of root collar diameter had the provenance from Croatia (Dilj Čanglinski) with 48.9 mm, while the lowest average value had the provenance from Switzerland (Sihlwald) with 29.5 mm. The provenances of Baštra Ćorkovača from Bosnia and Herzegovina, Bad Wildbad from Germany, and Dilj Čaglinski from Croatia have the best ratio of the percentage of trees of different categories of tree shapes. The correlation coefficient showed values of approximately 1, which indicates a positive correlation, i.e., provenances with higher increments in height and thickness also have a better tree shape. The results of this research are important for having a general picture of provenances' growth, and should be continued to determine the juvenile-adult correlation of these traits in common beech.

Author Contributions

MMH and DB conceived and designed the research; DB carried out the field measurements; MMH and DB processed the data and performed statistical analysis; MMH and DB supervised the research; MMH and DB wrote the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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