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Interakcija između efekata genetske strukture i stanišnih uslova na rast zelene duglazije u testovima provenijencija u Bosni i Hercegovini

Interaction between the effects of genetic structure and habitat conditions on douglas fir growth in provenance tests in Bosnia and Herzegovina

Mirzeta Memišević Hodžić[1], Dalibor Ballian[1], Emina Šehović[2]

[1] University of Sarajevo, Faculty of Forestry, Zagrebačka 20, 71000 Sarajevo
[2] Šumarstvo "Ljuta" Osik 861, 71210 Ilidža

ABSTRACT

Douglas fir (*Pseudotsuga menziesii* (Mirbel) Franco) is the most important and most productive species in Europe, outside its natural range. This study aimed to examine the presence of interaction between the effects of the genetic structure of provenances from the United States and Canada and three localities of provenance tests in Bosnia and Herzegovina.

For this research, we measured diameters at breast height of all trees, and heights of 10 trees per provenance in three tests of Douglas fir at the age of plants 32 years. Four provenances are represented in all three tests and additional two provenances in two tests. We examined the variance between provenances and habitats using multivariate analysis, for four provenances in all three habitats, and six provenances in two habitats (Bosanska Gradiška and Zavidovići).

Multivariate analysis of variance for four provenances at all three localities showed that there were no statistically significant differences in diameters at breast height and heights caused by the interaction of provenances x localities. Multivariate analysis for six joint provenances at Bosanska Gradiška and Zavidovići tests showed that there were no statistically significant differences for diameter at breast height caused by interaction locality x provenance, and there were statistically significant differences caused by interactions of locality x provenances for height.

The obtained results can be used for the introduction of Douglas fir on predefined habitats that correspond to the conditions of the experimental plots, as well as for the selection of the best provenances for raising clone plantations or seed plantations.

Key words: *Douglas fir, provenances, interaction provenance x habitat*

INTRODUCTION - *Uvod*

Douglas fir is a species of rapid height and thickness growth and is very interesting for introduction to areas where the production potential of the habitat is not sufficiently used, and which are suitable for its growth. There are many such areas in Bosnia and Herzegovina, especially in the Bosna river basin, but also in the hilly part of Bosanska Posavina, and the area of Sprečko polje, and Majevica.

Douglas fir originated from the western United States and Canada and was introduced to Europe in the 19th century (Kleinshmit and Bastien 1992). It is currently one of the most important foreign tree species in Western and Central Europe, and it is the most represented in France and Germany (Bastien and Sanchez 2013; Krumm and Vitkova 2016; Konnert et al. 2018). In addition to good growth, Eilman and Rigling (2011) state that Douglas fir has a high level of resistance to long-term droughts, which was confirmed in a study conducted by Montwe et al. (2015).

As it is one of the most productive species of trees in Europe, works on its breeding have been done for a long time. The greatest attention was paid to the correct choice of provenances for raising forest plantations. These activities began at the beginning of the 20th century, and numerous provenance trials were raised in many European countries. In the territory of Bosnia and Herzegovina, the first experimental plots were raised in 1966, near Sarajevo (Batalovo Brdo and Rosulje near Rakovica) with five different provenances. In the early 1970s, a series of provenance tests were established throughout Bosnia and Herzegovina within the IUFRO program with Douglas fir. Thus, experiments were raised on the site of Crna Lokva (Bosanska Gradiška), Blinje (Kreševo), Gostović (Zavidovići), Dubrave (Visoko), which was destroyed very soon after the construction, and the largest of them on the site of Goleš (Travnik).

Previous results on experimental areas with Douglas fir in Bosnia and Herzegovina indicate very high productivity of this species (Pintarić 1973, 1979, 1989, 1991). In the experimental plot Batalovo Brdo, Ballian et al. (1999) determined the productivity of the best provenance in 37 years 235 m^3/ha. Ballian et al. (2002, 2003), Govedar et al. (2003) also defined the high productivity of provenances in experimental plots Bosanska Gradiška, Zavidovići, and Kreševo.

In this study, the interactions between the effects of the genetic structure of provenances from the United States and Canada and the locations of provenance tests in Bosnia and Herzegovina were analyzed. The results will be used in the selection of best provenances in terms of productivity for further use in wood production.

MATERIAL AND METHODS - *Materijal i metode*

For this study, the heights and diameters at breast height (DBH) of Douglas fir trees were measured in three provenance tests. Provenances are shown in Table 1, Figure 1.

Provenance tests were raised on areas based on climatic analogs of provenances, and are located in different ecological conditions, at the sites Zavidovići Gostović, Bosanska Gradiška Crna Lokva, and Kreševo Blinje (Table 2, Figure 2).

In all three provenance tests, DBH of all trees were measured, and the height of 10 trees by provenance in each block for all common provenances, at the age of plants 32 years. For the above traits, we examined the interaction between provenances and habitats using multivariate analysis, for four provenances for all three habitats and six provenances for two habitats.

RESULTS - *Rezultati*

The highest average value of DBH in all tests had the provenance of Alberni from Canada (1036), from an altitude of 150 m (Table 2). The lowest average value of DBH in Bosanska Gradiška and Kreševo had the provenance Grand Ronde from Oregon (1100) from an altitude of 170-230 m, while in Zavidovići this provenance was at the top in terms of average DBH, and the lowest value had provenance Cougar Washington (1090) from an altitude of 500-600 m.

Table 1. List of provenances with main information

Tabela 1: Lista provenijencija sa osnovnim podacima

Provenance label	Country	Locality	Latitude	Longitude	Altitude	Included in provenance tests
1029	British Columbia (Canada)	Thasis	49°47'	-126°38'	17	Bos. Gradiška, Kreševo, Zavidovići
1036	British Columbia (Canada)	Alberni	49°19'	-124°51'	150	Bos. Gradiška, Kreševo, Zavidovići
1099	Washington (USA)	Pine Grove	45°06'	-121°23'	800	Bos. Gradiška, Kreševo, Zavidovići
1100	Oregon (USA)	Grand Ronde	45°06'	-123°36'	170-230	Bos. Gradiška, Kreševo, Zavidovići
1060	Washington (USA)	Sequim	48°02'	-123°02'	33-100	Bos. Gradiška, Zavidovići
1090	Washington (USA)	Cougar	46°05'	-122°18'	500-600	Bos. Gradiška, Zavidovići

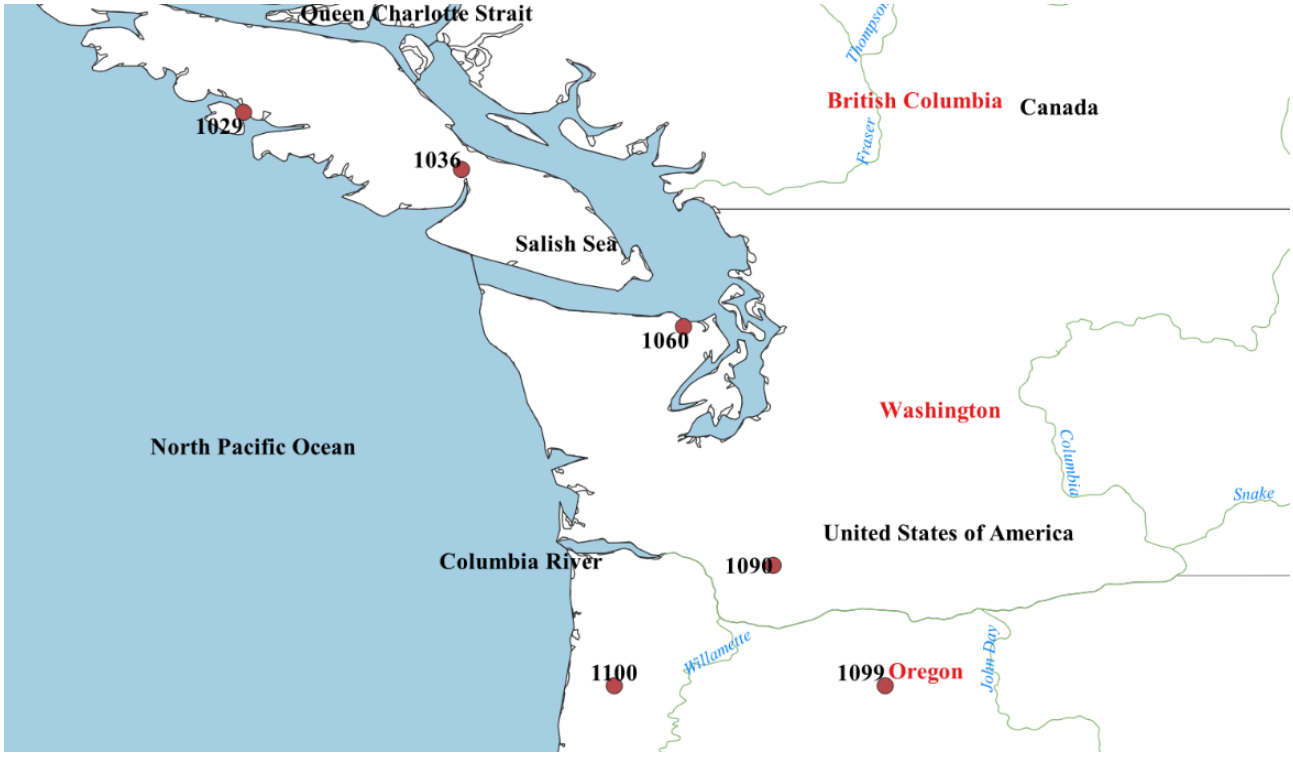

Figure 1. Distibution of researched provenances

Slika 1. Raspored istraživanih provenijencija

Table 2: Basic information on provenance test sites

Tabela 2: Osnovni podaci o lokalitetima testova provenijencija

Provenance test	Locality	Latitude	Longitude	Altitude
Bosanska Gradiška	Crna Lokva	44° 59'	16° 51'	665
Kreševo	Blinje	43° 50'	18° 03'	951
Zavidovići	Gostović	44° 23'	18° 08'	411

Figure 2: Distribution of provenance tests

Slika 2: Raspored testova provenijencija

Table 2: Average values of DBH and height by provenances and localities

Tabela 2: Prosječne vrijednosti prsnog prečnika i visine po provenijencijama i lokalitetima

Provenance	Average DBH (cm) in provenance tests			Average height (m) in provenance tests		
	B. Gradiška	Kreševo	Zavidovići	B. Gradiška	Kreševo	Zavidovići
1029	26.0	23.8	27.9	20.3	18.6	18.7
1036	27.9	25.9	29.7	22.2	20.4	19.1
1060	25.3	-	23.5	21.5	-	17.5
1090	25.7	-	23.0	21.2	-	17.6
1099	27.2	25.8	25.5	21.0	20.9	18.6
1100	25.3	23.1	27.8	21.5	19.8	20.4
Total	26.2	24.7	26.3	21.3	20.0	18.7

Table 3: Multivariate analysis for diameter at breast height (Test of Between-Subject Effects) for four provenances for three localities

Tabela 3: Multivarijantna analiza za prsni prečnik (Test of Between-Subject Effects) za četiri provenijencije za sva tri lokaliteta

Source of variability	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3798.774a	35	108.536	1.961	0.001
Intercept	421415.515	1	421415.515	7615.533	0.000
Locality	1109.427	2	554.714	10.024	0.000
Provenance	123.367	3	41.122	0.743	0.527
Locality * provenance	511.983	6	85.330	1.542	0.162

Table 4: Multivariate analysis for height (Test of Between-Subject Effects) for four provenances for three localities

Tabela 4: Multivarijantna analiza za visinu (Test of Between-Subject Effects) za četiri provenijencije za sva tri lokaliteta

Source of variability	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	928.839a	34	27.319	3.591	0.000
Intercept	134885.653	1	134885.653	17731.237	0.000
Locality	239.777	2	119.888	15.760	0.000
Provenance	65.274	3	21.758	2.860	0.037
Locality * provenance	77.082	6	12.847	1.689	0.123

The highest average value of height in Bosanska Gradiška provenance test had Alberni provenance from Canada (1036), from 150 m above sea level (Table 2). In Kreševo test, Pine Grove provenance (1099) from Washington from 800 m above sea level had the highest average height, while in Zavidovići test, Grand Ronde provenance (1100) had the highest average height. The lowest average value of height in Bosanska Gradiška and Kreševo had provenance Thasis from Canada (1029) from 17 meters above sea level). In Zavidovići, provenance Sequim Washington (1060) had the lowest average height. Multivariate analysis of variance for diameter at breast height for four provenances (1029, 1036, 1099, and 1100) and three localities (Table 3) showed that there were statistically significant differences caused by provenance test localities (Sig. = 0.000), but no significant differences caused by provenances (Sig. = 0.527), nor by interactions locality x provenance (Sig. = 0.162).

Multivariate analysis of variance for height for four provenances (1029, 1036, 1099, and 1100) and three localities (Table 4), showed that there were statistically significant differences caused by the localities of provenance tests (Sig. = 0.000), by provenances Sig. = 0.037), while there were no statistically significant differences caused by interactions locality x provenance (Sig. = 0.123).

The results of multivariate analysis for six common provenances at Bosanska Gradiška and Zavidovići (Table 5) for DBH showed that there were no statistically significant differences caused by localities (Sig. = 0.997), there were statistically significant differences caused by provenances (Sig. = 0.003), and there were no statistically significant differences caused by interactions locality x provenance (Sig. = 0.108).

The results of the multivariate analysis for height for six common provenances in Bosanska Gradiška and Zavidovići (Table 6) showed that there were statistically significant differences caused by localities (Sig. = 0.000), by provenances (Sig. = 0.005), and interactions locality x provenance (Sig. = 0.030).

The registered interaction between provenances and habitat for the trait of height is visible in the graph (Figure 3), where all provenances changed order depending on the locality where they were introduced. Thus, provenance 1036 (Alberni, British Columbia 150 m above sea level) showed better growth in height at the locality Bosanska Gradiška than provenance 1100 (Grand Ronde, Oregon 170-230 asl), while at the locality Zavidovići provenance 1100 showed better growth in height. Provenance 1060 (Sequim Washington 33-100 asl) grew better in the Bosanska Gradiška locality than

Table 5: Multivariate analysis for diameter at breast height (Test of Between-Subject Effects) for six provenances for two localities

Tabela 5: Multivarijantna analiza za prsni prečnik (Test of Between-Subject Effects) za šest provenijencija za dva lokaliteta

Source of variability	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1101.293a	11	100.118	2.362	0.008
Intercept	237179.830	1	237179.830	5595.727	0.000
Locality	0.001	1	0.001	0.000	0.997
Provenance	782.634	5	156.527	3.693	0.003
Locality * provenance	386.061	5	77.212	1.822	0.108

Table 6: Multivariate analysis for height (Test of Between-Subject Effects) for six provenances for two localities

Tabela 6: Multivarijantna analiza za svojstvo visine (Test of Between-Subject Effects) za šest provenijencija za dva lokaliteta

Source of variability	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	798.343b	11	72.577	9.443	0.000
Intercept	137404.951	1	137404.951	17878.226	0.000
Locality	589.672	1	589.672	76.724	0.000
Provenance	131.013	5	26.203	3.409	0.005
Locality * provenance	96.514	5	19.303	2.512	0.030

Provenance 1090 (Cougar Washington 500-600 m asl), 1099 (Pine Grove Washington, 800 m asl) and 1029 (Thasis British Columbia 17 m asl)), while at the Zavidovići site all these provenances preceded it in growth in height.

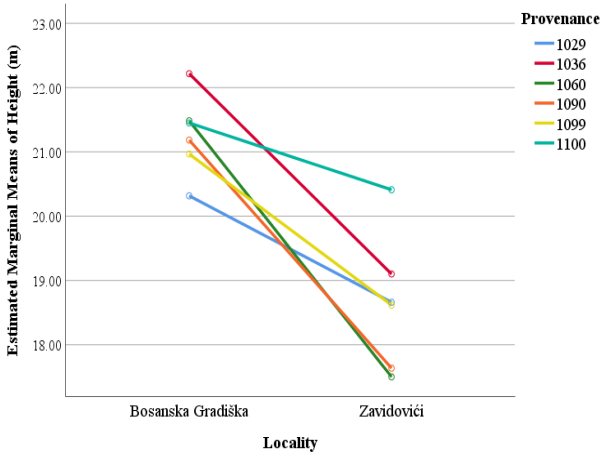

Figure 3: Estimated marginal means of height per provenances and localities

Slika 3: Procijenjene granične srednje visine po provenijencijama i lokalitetima

DISCUSSION AND CONCLUSIONS – *Diskusija i zaključci*

In this study, we did not obtain a statistically significant difference among provenances caused by the interaction of locality and provenances for the four provenances represented in all three provenance tests. This can be explained by large differences among the sites of provenance tests (Bosanska Gradiška test is located at an altitude of 665 m, Kreševo at 951 m, and Zavidovići at 411 m), and also differences arising from soil type, as well as climate. According to climatic indicators given in ecological vegetation zoning (Stefanović et al. 1983), all experimental areas are located in different areas and regions. Since the differences in heights by provenances are statistically significant, in all localities, in the future planning of raising Douglas fir plantations, provenances that grow better in these localities are recommended.

Statistically significant differences among provenances caused by the interaction provenance x locality were found for six provenances represented in the Bosanska Gradiška and Zavidovići provenance tests for the trait of height. Thus, provenance 1036 (Alberni, British Columbia 150 m asl) shows better growth in in Bosanska Gradiška than provenance 1100 (Grand Ronde, Oregon 170-230),

while in Zavidovići provenance 1100 showed better growth in height. Provenance 1060 (Sequim Washington 33-100) grew better in Bosanska Gradiška than provenance 1090 (Cougar Washington 500-600 m asl), 1099 (Pine Grove Washington, 800 m asl) and 1029 (Thasis British Columbia 17 m asl)), while in Zavidovići test all these provenances preceded it in growth in height.

The influence of interactions between the genetic structure of provenances and localities of provenance tests for Scots pine was investigated by Memišević Hodžić et al. (2020) and Memišević Hodžić and Ballian (2021). In both studies (interactions between the Kupres and Žepče provenance tests and between the Glasinac and Gostović provenance tests), statistically significant differences were found for the traits of diameter at breast height and height caused by interactions of locality x provenance.

In Bosnia and Herzegovine, the growth of different provenances of Douglas fir was investigated by Ballian et al. (1999, 2002, 2003), Govedar et al. (2003), and statistically significant differences among provenances for certain traits were found.

Research on the provenance of Douglas fir was also conducted in neighboring countries. Orlić and Ocvirek (1994), Perić et al. (2009, 2011), Orlić and Perić (2015) found statistically significant differences among provenances in provenance tests in Croatia.

Smolnikar et al. (2021), in research of fifteen Douglas fir provenances in the IUFRO provenance test established in 1966/67 in Slovenia, found significant differences among provenances in terms of survival rate, growth, and quality. They also found a positive and significant correlation between tree height in 1985 and average diameters measured in 2017. They determined that provenances from the west coast of Washington from low altitudes have the greatest potential for western Slovenia (Central Europe).

The lack of interaction between the provenances and the localities for the four common provenances for three localities is probably caused by the distance among the original populations that are larger than the differences among the localities where the provenance tests were set.

As six common provenances in the tests Bosanska Gradiška and Zavidovići showed statistically significant differences for height, it is recommended to choose provenances that grow better in height at given localities, ie localities with similar ecological conditions. Specifically, provenance 1036 should be favored at the Bosanska Gradiška locality, and 1100 at the Zavidovići locality.

The obtained results can be used for the introduction of Douglas fir on predefined habitats that correspond to the conditions of the experimental plots, as well as for the selection of best provenances for raising clone plantations or seed plantations.

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SAŽETAK

Duglazija (*Pseudotsuga menziesii (Mirbel) Franco)* je najvažnija i najproduktivnija vrsta u Evropi izvan svog prirodnog areala. Stoga je na području Bosne i Hercegovine od 1966. godine postavljeno nekoliko testova provenijencija, u cilju provjere njene proizvodnosti. Cilj ovog istraživanja je utvrditi da li postoji interakcija između efekata genetske strukture provenijencija iz Sjedinjenih Američkih Država i Kanade i lokaliteta na kojima su postavljeni testovi provenijencija. Rezultati će poslužiti prilikom selekcije najboljih provenijencija po proizvodnosti u svrhu daljeg korištenja u proizvodnji drvne mase.

Za potrebe ovog istraživanja mjerene su visine i prečnici stabala duglazije različitih provenijencija u tri provenijencijska testa, koji se nalaze u različitim ekološkim uslovima, i to na lokalitetima Zavidovići Gostović (411 m), Bosanska Gradiška Crna Lokva (665 m), Kreševo Blinje (951 m). Za procjenu interakcija za sva tri provenijencijska testa korištene su sljedeće provenijencije: 1029 (Thasis, Britanska Kolumbija, Kanada, NV 17m), 1036 (Alberni, Britanska Kolumbija Kanada, NV 150 m), 1099 (Pine Grove, Washington, USA, NV 800 m) i 1100 (Grand Ronde, Oregon, USA, NV 200 m), koje su zajedničke za sva tri testa. Za procjenu interakcija između testova Bosanska Gradiška i Zavidovići korištene su još dvije provenijencije (1060 Washington Sequim 33-100 m NV i 1090 Washington Cougar 500-600 m NV). Terenski testovi su postavljeni u proljeće 1972. godine sadnicama starosti 2 + 2 po blok sistemu sa tri ponavljanja, sa razmakom sadnje 2.5x2.5m. Na sve tri eksperimentalne površine izvršen je premjer prečnika svih stabala, te visine 10 stabala po provenijenciji u svakom bloku, za četiri zajedničke provenijencije u tri testa, te dodatno za dvije zajedničke provenijencije u dva testa. Mjerenje je vršeno pri starosti biljaka 32. godine. Za navedena svojstva pomoću multivarijantne analize ispitivane su interakcije između provenijencija i staništa, i to za četiri provenijencije na sva tri staništa, te za šest provenijencija na dva staništa.

Multivarijantna analiza varijanse za četiri provenijencije na sva tri lokaliteta pokazala je da ne postoje statistički značajne razlike u prečnicima i visinama uzrokovane interakcijom provenijencija x lokalitet.

Rezultati multivarijantne analize za šest zajedničkih provenijencija na lokalitetima Bosanska Gradiška i Zavidovići pokazali su da za svojstvo prečnika ne postoje statistički značajne razlike uzrokovane interakcijama lokalitet x provenijencija, dok za svojstvo visine postoje statistički značajne razlike.

Dobijeni rezultati mogu se koristiti pri introdukciji na unaprijed definiranim staništima koja odgovaraju uslovima koje imaju eksperimentalne plohe, kao i pri selekciji najboljih provenijencija za podizanje klonskih nasada ili sjemenskih plantaža.