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Original scientific paper

EARLY ASSESSMENT OF GROWTH AND SURVIVAL RATE OF EUROPEAN BEECH (*Fagus sylvatica* L.) IN PROVENANCE TRIAL ON GOČ MOUNTAIN

Vladan POPOVIĆ¹, Sanja JOVANOVIĆ¹, Aleksandar LUČIĆ¹,
Ljubinko RAKONJAC¹, Danijela MILJKOVIĆ²

Abstract: Different scenarios indicate that macro-climatically suitable areas for European beech will decrease dramatically in the coming decades. Due to climate change, European beech will face a change in phenology, mortality, and reduced tree growth, with a particular tendency to reduce forest productivity in the southern part of its distribution range. Provenance trials represent the research of the adaptation to specific environmental conditions of populations of the same species but with different origins and provide a unique insight into the plant's response to the changed environmental conditions in real-time.

This research aims to determine and describe the growth and survival rate of European beech seedlings from 29 provenances in a trial established on Goč Mountain.

The trial involved 29 European beech provenances selected from their natural distribution areas in Central and Southeastern Europe. The European beech provenance trial was established in the spring of 2021 on Mt. Goč in central Serbia. At the end of the vegetation period in 2021, the height and root collar diameter of seedlings were measured, and the survival rate was recorded. The seedling survival rate ranged from 40.7% to 84%. Statistically significant differences between the provenances were determined for the height and root collar diameter, and the correlation values of the measured traits.

The Mt. Goč provenance trial remains a valuable resource for studying the performance of European beech provenances and can provide guidelines for their tolerance and adaptation.

Key words: beech, provenances, adaptation, survival, seedlings.

РАНА ПРОЦЕНА РАСТА И ПРЕЖИВЉАВАЊА БУКВЕ (*Fagus sylvatica* L.) У ПРОВЕНИЈЕНИЧНОМ ТЕСТУ НА ГОЧУ

Извод: Према различитим сценаријима, у наредним деценијама драматично ће се смањити макроклиматски погодна подручја за букву. Као последица климатских промена доћи ће до промене фенологије, повећања морталитета и умањења раста

¹ Institute of Forestry, Belgrade, Serbia

² University of Belgrade, Institute for Biological Research „Siniša Stanković”, National Institute of Republic of Serbia

*Corresponding author. E-mail: vladanpop79@gmail.com

стабала, са нарочитом тенденцијом смањења продуктивности шума у јужном делу ареала. Провенијенчни тестови представљају управо истраживање прилагођавања популација различитог порекла исте врсте на одређене услове средине и дају јединствен увид у одговор биљке на измењено стање околине, у реалном времену.

Циљ истраживања у овом раду био је да се утврде и опишу подаци раста и преживљавања садница букве из 29 провенијенција у провенијенцијском тесту на Гочу.

За успостављање провенијенцијског теста одабрано је 29 провенијенција букве са подручја ареала у централној и југоисточној Европи. Провенијенчни тест је основан на планини Гоч у централној Србији у пролеће 2021. године. На крају вегетационог периода 2021. године, извршена су мерења висине, пречника кореновог врата и регистровање преживљавања садница. Преживљавање садница се кретало од 40,7% до 84%. Утврђене су статистички значајне разлике између провенијенција за висине и пречник кореновог врата садница, као и за вредности корелационих односа мерених особина.

Провенијенчни тест на Гочу остаје вредан ресурс за проучавање учинака европских провенијенција букве и може дати смернице за њихову толеранцију и адаптацију.

Кључне речи: буква, провенијенције, адаптација, преживљавање, саднице.

1. INTRODUCTION

European beech (*Fagus sylvatica* L.) is one of the most important species of forest trees in Europe, both ecologically and commercially. It is susceptible to spring frosts and extended dry periods (Granier et al, 2007), which makes it very vulnerable to predicted climate scenarios (Piovesan et al., 2008). Projections based on IPCC scenarios indicate that macro-climatically suitable areas for European beech will decrease dramatically in the coming decades (Czúcz et al., 2011). Due to climate change, European beech will face a change in phenology, increased mortality, and reduced tree growth (Gárate-Escamilla et al., 2019), with a particular tendency to reduce forest productivity in the southern part of its distribution range (Del Castillo et al., 2022). The central part of Europe is already suffering the adverse effects of climate change to a certain extent (Zimmermann et al., 2015). It is estimated that an increase in temperature will cause a significant decrease in the number of European beech trees at elevations below 500 m in some southern parts of the range by the end of the 21st century (Pavlović et al., 2019). Additionally, complex disturbances caused by biotic factors occur as a consequence of reduced tree vitality (Langer and Bußkamp, 2023). Understanding key functional indicators of adaptability is especially necessary in mitigating the impact of climate change (Kramer et al., 2010). However, until now, there has not been enough research comparing selected populations from the Western Balkans and Central Europe, especially indicating their potential for growth as a parameter of adaptation to climate change.

One of the main features of the living world is diversity, and the main features of the species are their variability and the ability of different genotypes to adapt to various environmental conditions. Local adaptation enabled the persistence and maintenance of broad distribution areas of particular plant species (Brancalion et al., 2018; Klisz et al., 2023). Provenance trials represent the research of the adaptation to specific environmental conditions of populations of the same species but with

different origins and provide a unique insight into the plant's response to the changed environmental conditions in real-time. They, in effect, represent programs or plans for establishing and restoring forests, enabling the monitoring of various parameters to determine the best-adapted origin to the given conditions (White et al., 2007). Provenance trials involve collecting seeds by selecting mother trees of different origins, producing seedlings, and planting them in a unique, homogeneous area. They also provide subsequent measurements and data analysis of various plant characteristics (Atiken, 2004).

Provenance trials have been established in forestry since ancient times, when they were primarily used to increase production capacity (Mátyás, 1996). Today, climate change is at the epicenter of environmental research, so provenance trials are established for selecting future reproductive material for maintaining existing forest ecosystems and establishing new, more resistant ones. Data such as growth and survival rate, resistance to diseases and pests, flowering, phenological data, as well as the characteristics of the trunk essential for the utilization in the industry (Potts, 2004) are very significant as they represent the basis for the selection of adequate genetic material, greatly facilitating forest management in the future. Climate changes are happening rapidly, and their effects are becoming visible and measurable through the increasing number of rehabilitation plans for damages caused by wind-breaks, ice-breaks, droughts, floods, fires, or pest attacks. Plant organisms cannot keep up with this rate of change in environmental conditions or the rate of natural migration of species, so human assistance is mandatory to prevent adverse predictions (Loreto and Atzori, 2024).

Beech is, in addition to particular oak species, the most important forest species in the Serbian growing stock. European beech forests are the most widespread in Serbia and have the largest share of wood volume. They inhabit a wide range of elevations, ranging from very low (70 m near Negotin) to over 1500 m (Stojanović et al. 2005). One of the models that predict climate change in Serbia, taking extreme values into the calculations, predicts a decrease in the area of European beech forests by 90% by the end of the 21st century (Stojanović et al., 2013). European beech provenance trials have been established throughout Europe, and the data are monitored even today (Muhs and von Wuehlisch, 1993; von Wuehlisch, 2004; von Wuehlisch et al., 2010; Stojnić et al., 2010; Horvath et al., 2016; Mohytych et al., 2024). A new European beech provenance trial covering 29 provenances from distribution areas in Central and Southeastern Europe was established on Goč Mountain in Central Serbia, and this research aims to determine and describe the growth and survival rate of these beech seedlings. The findings will be a valuable resource for future research on the performance of European beech populations and may provide insights into their adaptation abilities.

2. MATERIAL AND METHODS

Experimental site

The trial involved 29 European beech provenances selected from their natural distribution areas in Central and Southeastern Europe, and their general

characteristics are shown in Table 1. In the fall of 2018, about 1 kg of visually healthy seeds were collected from each provenance. The collected seeds were processed in the laboratory of the Institute of Forestry in Belgrade. After analyzing their quality and health status, a nursery test was established in the spring of 2019 at the nursery of the Institute of Forestry in Belgrade.

Table 1. *Data on the studied provenances of European beech*

Provenance label	Provenance name	Latitude	Longitude	Elevation (m)
BG1	Centralni Balkan	42.86444	24.24941	1100
BG2	Rila	42.26417	23.28333	1280
SRB1	Mali Jastrebac	43.39092	21.65006	830
SRB2	Rudnik	44.10531	20.6136	700
SRB3	Povlen	44.16111	19.69861	870
SRB4	Javor	43.44913	20.06806	1350
SRB5	Goč	43.56351	20.75001	920
SRB6	Fruška Gora	45.14194	19.62289	370
SRB7	Severni Kučaj	44.12941	21.79868	730
SRB8	V. Jastrebac	43.36242	21.56092	810
SRB9	Južni Kučaj	44.07015	21.75708	700
SRB10	Stara Planina	43.38065	22.60313	1260
SRB11	Dubašnica	44.10063	21.88801	900
SRB12	Miroč	44.57029	22.37021	450
SRB13	Kukavica	42.79124	21.97133	1200
SRB14	Boranja	44.38997	19.28981	650
SRB15	Kačer-Zeleničje	42.82314	22.21206	1180
MNE1	Borak	42.82738	19.99544	1250
MNE2	Kovač	43.40833	19.11611	960
BIH1	Javor	44.15611	18.94333	1010
BIH2	Lisina	45.02522	17.00861	400
HR1	Bukovača	45.34747	15.22334	435
HR2	Građevačka Biogora	45.79191	17.12667	185
HR3	Južni Papuk	45.50722	17.63802	685
HR4	Bublen	45.23139	15.84747	205
SI1	Hrastovec	46.35667	15.96667	300
SI2	Osankarica	46.45325	15.38333	1240
CZ1	Malužin	49.27334	16.66171	360
DE1	Harz	51.78503	10.51716	820

Country abbreviations: BG-Bulgaria; SRB-Serbia; MNE-Montenegro; BIH-Bosnia and Herzegovina; HR-Croatia; SI-Slovenia; CZ-Czech Republic; DE-Germany.

The European beech provenance trial is situated on Goč Mountain (Latitude 43.56139 Longitude 20.80056) at 980 m.a.s.l., a northeast exposition in the central part of Serbia, in Management Unit “Gračac“, department 20a, Public Enterprise “Šume Goč“ Vrnjačka Banja. The climate on the mountain is temperate continental. Mean air temperature is 7.5°C, and annual precipitation is 856 mm. The trial was established in spring 2021 by planting two-year-old seedlings. The seedlings were planted with a spacing of 2×1 m, resulting in a density of 4350 plants in 1 ha (50 seedlings per provenance $\times$ 3 replicates (blocks) $\times$ 29 provenances = 4350 seedlings). The experimental design is a randomized complete block with three replicates, which was used for all trials in this series. One replicate of each provenance consisted of 50 plants planted in five rows of 10 planting sites (10×10 m plot). According to von Wühlisch (2004), the plots are large enough to maintain the trials for 60 years. At the end of the vegetation period in 2021, the height and root collar diameter of seedlings aged 2+1 (two-year-old seedlings after one year of growth in the field trial) were measured, and the survival rate was recorded. The height was measured with a ruler with an accuracy of 0.5 cm, and the root collar diameter with a vernier caliper with an accuracy of 0.1 mm.

Statistical methods

The measured morphometric traits of the seedlings included the root collar diameter (**d**, in mm) and seedling height (**h**, in cm), which were analyzed using the SAS statistical package (SAS Institute, Inc. 2011). The mean values of all analyzed seedling traits were calculated using the MEANS procedure. The significance of the differences between the mean values of the provenances for the analyzed parameters was confirmed using one-way ANOVA (GLM Procedure). Correlations between **d** and **h** were obtained in the CORR Procedure. To examine the differences between the provenances, a multivariate statistical analysis, Agglomerative hierarchical clustering (AHC), was performed, which grouped the provenances based on the differences in the analyzed seedling characteristics using the pair-group average method.

3. RESULTS AND DISCUSSION

Provenance BIH2 (Lisina) with 84% surviving plants proved to be the best, followed by provenance HR4 (Bublen) with 82% surviving plants, HR2 (Građevačka Biogora) with 74.7% surviving plants, HR3 (Južni Papuk) with 74% surviving plants, and SRB13 (Kukavica) with 70.7% surviving plants. The worst survival rate had the provenances CZ1 (Malužin) with 40.7% surviving plants, SRB6 (Fruška Gora) and SRB14 (Boranja) with 48% surviving plants, and SRB10 (Stara Planina) with 49.3% surviving plants. The plant survival rate above 60% was determined in 19 out of 29 provenances, while in 6 provenances the plant survival rate was between 50% and 60% (Figure 1).

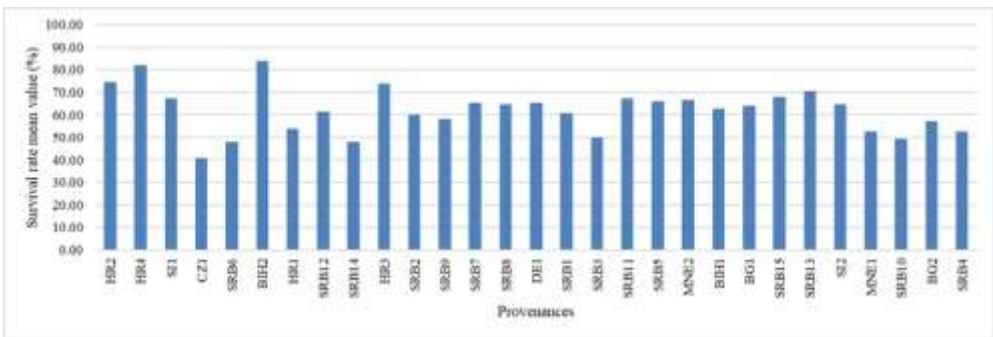


Figure 1. Survival rate at the provenance trial

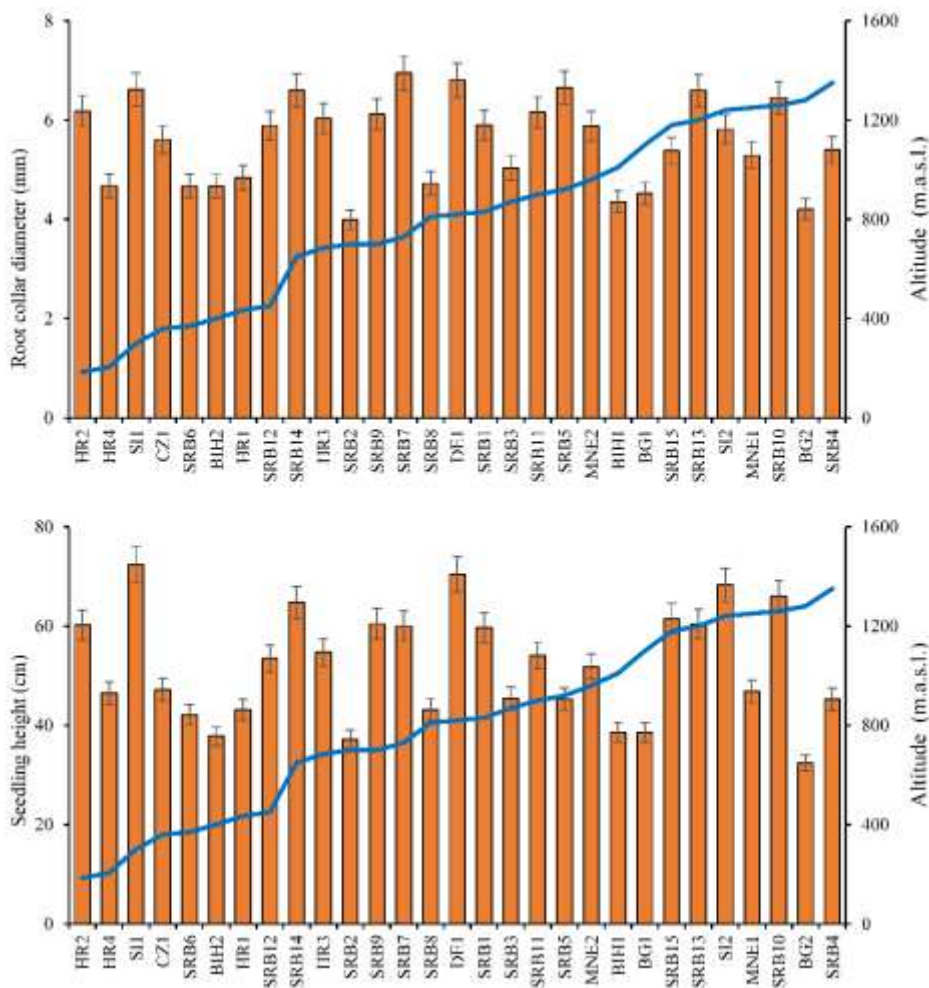


Figure 2. Histogram showing the mean values of root collar diameter (mm) and seedling height (cm) (bars with standard error) from 29 provenances in a provenance trial set on Goč Mountain across elevation (m.a.s.l.) (blue line).

The mean values of root collar diameter and seedling height were not correlated with the elevation of the provenance origin. Root collar diameter values ranged from 3.99 mm SRB2 (Rudnik) to 6.94 mm SRB7 (North Kučaj). For the seedling height trait, the values ranged from 32.38 cm BG2 (Rila) to 72.37 cm SI1 (Hrastovec) (Figure 2). The results of one-factor ANOVA confirmed statistically significant differences between provenances for both analyzed traits (all $p < 0.0001$).

The correlation values of the measured traits were statistically significant (all $p < 0.0001$) in the range from 0.77 SRB1 (Mali Jastrebac) to 0.29 BIH2 (Lisina) (Figure 3).

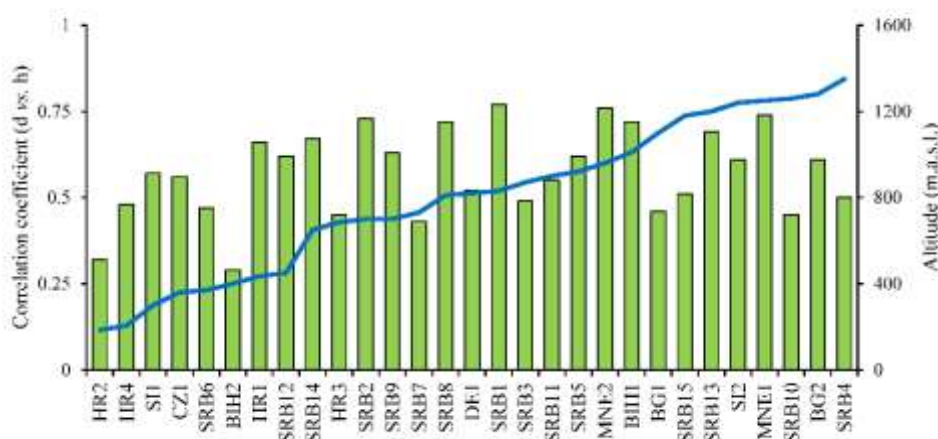


Figure 3. Histogram showing the correlation coefficient values (*d* - root collar diameter vs. *h* - seedlings height (green bars) from 29 provenances in a provenance trial set on Goč Mountain across elevation (m.a.s.l.) (blue line).

Following the results of the applied multivariate statistical cluster analysis (AHC) for the analyzed traits, the provenances are divided into three clusters based on differences. The first cluster includes 10 provenances, the second has five with more similar differences, and the third contains 14 provenances (Figure 4).

Despite their demands on time and establishment costs, provenance trials are still very important and informative when selecting a planting site and seeds of suitable origin (Risk et al., 2021). The higher percentage of survival rate of specific provenances can be interpreted through better adaptation to local environmental conditions. However, the cause of the lower percentage of survival rate of other provenances may be rodent attack, issues of planting microsite conditions, or ecological effects of transplanting (Horváth et al., 2016). Mohytych et al. (2024) also highlighted the impact of the microenvironment on the survival of beech trees in their 28-year-old provenance trial in the Ukrainian trial site.

Unterholzner et al. (2024) studied, among other things, tree-ring width (TRW), diameter at breast height (DBH), and climate-growth relationships of 24

beech provenances at three trial sites in Germany along the latitudinal gradient. Despite greater differences between trial sites, the differences between provenances within one field were minor, indicating the remarkable plasticity of beech as a species. Our work showed statistically significant differences between the traits studied and the provenances. Therefore, the observed variances represent differences in the genotypes of the studied provenances. Significant differences between the tested provenances of beech for the height and root collar diameter were reported by I. Ballian, Zukić (2011), and I. Stojnić et al. (2010). However, grouping provenances into three clusters, in which each group is mutually heterogeneous in terms of elevation of origin, indicates a similar strategy of phenotypic plasticity.

Additionally, Unterholzner et al. (2024) also indicated the greater importance of climate conditions in habitat conditions compared to seed origin. This aligns with our research findings, which show no correlation between the elevation of provenance origin and height and root collar diameter values.

Although the goal of such trials is to select provenances that will best adapt to the targeted environmental conditions and show the best performance, which is also associated with stronger physiological resistance of seedlings, Hoffman (1961) indicates that the measured height of seedlings at a younger age cannot be a reliable parameter in assessing the growth of provenances, because differences are manifested at a later age. On the other hand, these studies are necessary in the selection process and represent initial steps in the long-term monitoring of provenance adaptations.

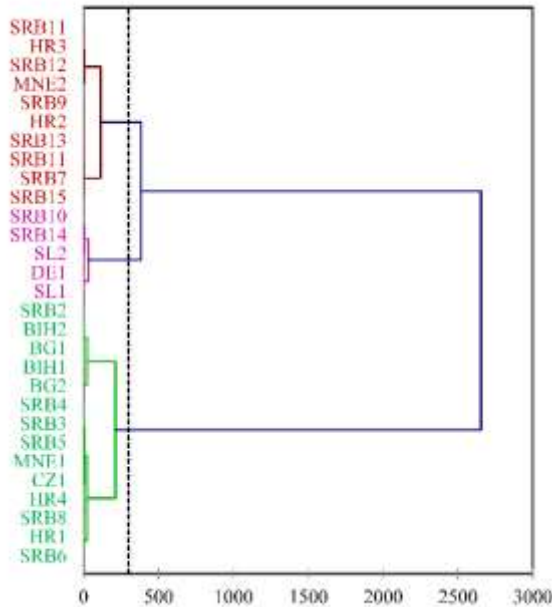


Figure 4. Dendrogram illustrating hierarchical clustering of 29 provenances in a provenance trial set on Goč Mountain based on ACH dissimilarity. The height of each branch indicates the level of dissimilarity between clusters, with shorter branches representing more similar ACH profiles.

4. CONCLUSION

This research provides valuable information about the qualitative and quantitative traits of beech seedlings, which result from possible adaptation to naturally drier and warmer or colder and wetter environmental conditions. The adaptive potential of beech seedlings plays a key role in adapting to projected climate changes and will enable the survival of this species.

The seedling survival rate ranged from 40.7% to 84%. The root collar diameter values ranged from 3.99 mm to 6.94 mm, while seedling heights ranged from 32.38 cm to 72.37 cm. Statistically significant differences between the provenances were determined for the height and root collar diameter, as well as for the correlation values of the measured traits.

The provenance trial conducted on Mt. Goč showed significant variability in survival rate and growth among different European beech provenances. This variability and adaptive potential of beech seedlings provide opportunities for further research and breeding programs that will enable the survival and reproduction of this species in the face of predicted rapid climate change.

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EARLY ASSESSMENT OF GROWTH AND SURVIVAL RATE OF EUROPEAN BEECH (*Fagus sylvatica* L.) IN A PROVENANCE TRIAL ON GOČ MOUNTAIN

Vladan POPOVIĆ, Sanja JOVANOVIĆ, Aleksandar LUČIĆ, Ljubinko RAKONJAC,
Danijela MILJKOVIĆ

Summary

European beech (*Fagus sylvatica* L.) is one of the most important species of forest trees in Europe, both ecologically and commercially. Projections based on different scenarios indicate that macro-climatically suitable areas for European beech will decrease dramatically in the coming decades. Due to climate change, European beech will face a change in phenology, increased mortality, and reduced tree growth, with a particular tendency to reduce forest productivity in the southern part of its distribution range. Understanding key functional indicators of adaptability is especially necessary in mitigating the impact of climate change. Provenance trials represent the research of the adaptation to specific environmental conditions of populations of the same species but with different origins and provide a unique insight into the plant's response to the changed environmental conditions in real-time.

They represent guidelines for programs/plans for establishing and restoring forests, enabling the monitoring of various parameters to determine the best-adapted origin to the given conditions. Until now, there has not been enough research comparing selected populations from the Western Balkans and Central Europe, especially indicating their potential for growth as a parameter of adaptation to climate change.

This research aims to determine and describe the growth and survival rate of European beech seedlings from 29 provenances within this provenance trial established on Goč Mountain.

The provenance trial involved 29 European beech provenances selected from their natural distribution areas in Central and Southeastern Europe. It was established on Mt. Goč in spring 2021 by planting two-year-old seedlings. The seedlings were planted with a spacing of 2×1 m, resulting in a density of 4350 plants in 1 ha (50 seedlings per provenance $\times$ 3 replicates (blocks) $\times$ 29 provenances = 4350 seedlings). One replicate of each provenance consisted of 50 plants planted in five rows of 10 planting sites (10×10 m plot). At the end of the vegetation period in 2021, the height and root collar diameter of seedlings were measured, and the survival rate was recorded.

The seedling survival rate ranged from 40.7% to 84%. The root collar diameter values ranged from 3.99 mm to 6.94 mm, while seedling heights ranged from 32.38 cm to 72.37 cm. Statistically significant differences between the provenances were determined for the height and root collar diameter, as well as for the correlation values of the measured traits.

This research provides valuable information on the qualitative and quantitative traits of beech seedlings, which result from possible adaptation to naturally drier and warmer or colder and wetter environmental conditions. The adaptive potential of beech seedlings plays a key role in adapting to projected climate changes and will enable the survival of this species. The provenance trial conducted on Mt. Goč showed significant variability in survival rate and growth among different European beech provenances. This variability and adaptive potential of beech seedlings provide opportunities for further research and breeding programs that will enable the survival and reproduction of this species in the face of predicted rapid climate change. The Mt. Goč provenance trial remains a valuable resource for studying the performance of European beech provenances and can provide guidelines for their tolerance and adaptation.

РАНА ПРОЦЕНА РАСТА И ПРЕЖИВЉАВАЊА БУКВЕ (*Fagus sylvatica* L.) У ПРОВЕНИЈЕНИЧНОМ ТЕСТУ НА ГОЧУ

Владан ПОПОВИЋ, Сања ЈОВАНОВИЋ, Александар ЛУЧИЋ, Љубинко РАКОЊАЦ,
Данијела МИЉКОВИЋ

Резиме

Буква (*Fagus sylvatica* L.) је једна од најважнијих састојинских врста шумског дрвећа у Европи, како у еколошком тако и у комерцијалном смислу. Према различитим сценаријима, у наредним деценијама драматично ће се смањити макроклиматски погодна подручја за букву. Као последица климатских промена доћи ће се промене фенологије, повећања морталитета и умањења раста стабала, са нарочитом тенденцијом смањења продуктивности шума у јужном делу ареала. Познавање кључних функционалних показатеља адаптивности је посебно неопходно у ублажавању утицаја климатских промена. Провенијенични тестови представљају управо истраживање прилагођавања популација различитог порекла исте врсте на одређене услове средине и дају јединствен увид у одговор биљке на измењено стање околине, у реалном времену. Представљају својеврсне водиче програма/планова за подизање и обнову шума, омогућавајући да се кроз праћење различитих параметара одреди порекло које се најбоље адаптира на дате услове. До сада није било довољно истраживања која су вршила поређење одабраних популација из Западног Балкана и Централне Европе, нарочито као показатеља њиховог потенцијала за раст као параметра прилагођавања насталим климатским променама.

Циљ истраживања у овом раду био је да се утврде и опишу подаци раста и преживљавања садница букве из 29 провенијенција у провенијеничном тесту на Гочу.

За успостављање провенијеничног теста одабрано је 29 провенијенција букве са подручја ареала у централној и југоисточној Европи. Провенијенични тест је основан на планини Гоч у централној Србији у пролеће 2021. године садњом двогодишњих садница. Саднице су засађене са размаком од 2×1 м, што је резултирало густином од 4350 биљака на површини од 1 ха (50 садница по провенијенцији $\times$ 3 понављања (блок) $\times$ 29 провенијенција = 4350 садница). Једно понављање сваке провенијенције састојало се од 50 биљака засађених у пет редова на 10 места за садњу (парцела 10×10 м). На крају вегетационог периода 2021. године, извршена су мерења висине, пречника кореновог врата и регистравање преживљавања садница.

Преживљавање садница се кретало од 40,7% до 84%. Вредности пречника у кореновом врату су биле у опсегу од 3,99 мм до 6,94 мм, док су се вредности висине саднице кретале 32,38 цм од 72,37 цм. Утврђене су статистички значајне разлике

између провенијенција за висине и пречника кореновог врата садница, као и за вредности корелационих односа мерених особина.

Резултати овог истраживања дају корисне информације о квалитативним и квантитативним особинама садница која је резултат могуће адаптације на природно сувље и топлије или хладније и влажније услове. Адаптивни потенцијал садница букве има кључну улогу у прилагођавању пројектованим променама климатских фактора и омогућиће опстанак ове врсте. Истраживања у провенијеничном тесту на Гочу показује значајну варијабилност у преживљавању и расту међу европским провенијенцијама букве. Добијена варијабилност и адаптивни потенцијал садница букве отвара могућности за даља истраживања и програме оплемењивања који ће омогућити опстанак и репродукцију врсте у новоствореним пројекцијама брзих климатских промена. Провенијенични тест на Гочу остаје вредан ресурс за проучавање учинака европских провенијенција букве и може дати смернице за њихову толеранцију и адаптацију.