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Adaptation stability of European beech *Fagus sylvatica* L. after five years of g owth

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Abstract. This study was focused on the evaluation of beech adaptation on test plots in the Góra Śląska and Świebodzin Forest Districts. For this purpose, we examined offspring from seed stands of beech growing in the Regional Directorates of State Forests in Szczecin, Szczecinek, Piła, Zielona Góra and Poznań, which were brought to both test plots. The aim was to determine the adaptive response of the offspring from these stands after five years of growth with respect to the changed environmental conditions compared to the site of origin. Our analysis revealed a relatively low survival rate, which was 60.8% and 72.2% in Góra Śląska and Świebodzin respectively. Interestingly, beeches grown on the plot in Góra Śląska were about 40% higher than those grown in Świebodzin (77.6 cm). The trees from both plots were significantly different from each other in terms of the analysed features and a significant interaction was observed between the test plot and the site of origin. However, the variability in the adaptive response of the seedlings was large. Using a regression coefficient and the average height value, we determined the seedlings' stability, which indicated high quality in offspring from the beech stand in the Łopuchówko Forest District (Buczyna forest range, sub-compartment 95n) and a high degree of adaptation to growth in adverse environmental conditions. Our results also indicate a low survival rate and reduced height of beech offspring from commercial seed stands (local standard).

Keywords: Progeny testing, selected seed stand, survival, height, heritability, genotype stability

1. Introduction and study aim

In Poland, the issues related to the enhancement of forests and their productivity have been given a lot of attention by the State Forests, the example of which is the 'Program of conserving forest genetic resources and breeding of trees in Poland for the years 2011–2035' (Chałupka et al. 2011) – a continuation of the Program implemented in the years 1991–2010. An important aspect of the activities undertaken has been testing the progeny of selected forest stands, maternal trees and plantations in different environmental conditions in order to gain knowledge of intraspecific variability as a source of adaptation to climate change and other environmental factors (Alfaro et al., 2014). Better understanding of these aspects is of great importance in view of progressive degradation of the natural environment and the adverse effects of numerous biotic and abiotic factors, which locally may threaten the existence of forests. Increasing demand for wood as the most environmentally friendly product, necessitates intensification of the production of this raw material. On the other hand, despite the ever-increasing forested area, in many forest stands, intensive management activities or logging are restricted (e.g., Natura 2000 sites).

Poland is divided into the so-called test regions designated within the Regional Directorates of the State Forests for observations on important forest-forming species included in the testing program, that is: European beech *Fagus sylvatica* L., pedunculate oak *Quercus robur* L. and sessile oak *Q. petraea* (Matt.) Liebl., birch *Betula pendula* Roth, black alder *Alnus glutinosa* Gaertn., silver fir *Abies alba* Mill., Norway spruce *Picea abies* (L.) H. Karst, European larch *Larix decidua* Mill. and Scots pine *Pinus sylvestris* L. For

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European beech, taking into account its range of occurrence and capability of the seed base, there were designated 4 test regions (Banach et al. 2012; Skrzyszewska et al. 2016). In 2006, first comparative beech provenance trials (8 test areas) were established in the test regions: III and IV. Two years later, another 20 test areas were established in the regions I and II: 8 for testing progenies of beech stands and 12 for testing progenies of beech maternal trees (Banach et al. 2012).

By 2019, the testing areas have been established to study not only the European beech progenies, but also those of Scots pine, silver fir and Norway spruce selected stands and maternal trees. A relatively short duration of the testing program (launched in 2006) resulted in fairly small amount of published test data. The majority of scientific papers have been so far published as regards the results obtained in the studies on European beech offspring (Barzdajn 2009; Banach et al. 2015; Buraczyk et al. 2016; Szeligowski et al. 2019). Klisz et al. (2018) published the results on silver fir and Kowalewski et al. (2017) – on Scots pine.

The aim of this study was to evaluate the European beech adaptation on 2 experimental plots established in test region II. On both plots, there were tested the progenies of the same set of selected seed stands from the test regions: I and II. Beech progeny survival, height and stability were assessed in view of the environmental conditions in the test plots. The experimental trees were examined 5 years after planting in the experimental plots, that is, in the first term determined in the general principles of the 'Program of testing the progeny of basic forest material' (Zarządzenie [*Regulation*] 2004).

2. Research material and methodology

Experimental plots were established at the turn of April and May 2008, in the Góra Śląska Forest District (Góra Śląska FD) and the Świebodzin Forest District (Świebodzin FD) (Table 1). The Góra Śląska FD (the Poznań Regional Directorate of State Forests) is located in the Nizina Wielkopolska (*Wielkopolska Lowland*), and the Świebodzin FD (the Zielona Góra Regional Directorate of State Forests) is located within in the Pojezierze Łagowskie (Łagowskie *Lakeland*) region.

On both experimental plots, there were planted the European beech progenies from 27 selected seed stands – designated in 5 Regional Directorates of State Forests (Piła, Poznań, Szczecin, Szczecinek and Zielona Góra). As a local standard, within each plot, there were planted seedlings developed from seeds obtained in the production seed stands growing in a given area (Table 2).

In the Góra Śląska FD, the plot for testing European beech progeny was established on 180 m × 180 m clear area, divided into five experimental blocks. The progenies of the selected seed stands were planted in 4 blocks (I, II, III, IV), and the fifth block was used to plant seedlings intended for replenishing losses in the experimental material in the first year subsequent to planting. Each block (replication) comprised of 28 provenance sub-plots (Fig. 1). On each sub-plot, 100 beech trees (10 × 10 seedlings) were planted at a density 1.5 m × 1.5 m. In the Świebocin FD, the test plot was established in a former ground nursery, within two divisions (approx. 50 m × 350 m), separated with 38 m-wide Scots pine stand (Fig. 2).

On both plots, the observations were carried out in September 2012. Seedling survival and height (measured with the use of a telescopic rule) was evaluated. For each studied population, the mean value of the trait examined was determined. The results were tabulated together with the standardised units (JS), which were calculated as the difference between the mean for the progeny of a given stand and the mean for the experimental plot, divided by the standard deviation. Calculations and statistical analyses were carried out separately for each study plot. The mean value, standard deviation and coefficient of variation were determined for each plot. The results were arranged in a table form, comprising measuring units [cm] and standardised units [JS]. The used model of multivariate analysis of variance was:

$$y_{kjn} = \mu + B_j + P_k + PB_{kj} + E_{n(jk)},$$

where:
y_{kjn} – value of observation *kjn*,
μ – overall mean,
B_j – effect of experimental block *j*,
P_k – effect of provenance *k*,
PB_{kj} – effect of interaction *k x j*,
$E_{n(jk)}$ – error.

Table 1. Location of experimental plots with offspring of European beech in the middle region of testing

Experimental plot ID	Forest District	Forest range, sub-compartment	Geographical coordinates		Altitude m a.s.l.
			longitude (N)	latitude (E)	
15/Bk/P/I/3/WDN1	Góra Śląska	Wronki, 119m	16°37’33”	51°41’11”	121
16/Bk/P/I/4/WDN1	Świebodzin	Dolina, 138ab	15°13’33”	52°19’48”	124

Table 2. Location of beech stands, whose offspring is tested on plots Góra Śląska and Świebodzin (SR – regional standard, SL – local standard)

No	Progeny number	Regional directorate of the State Forest	Forest District	Forest Subdistrict	Subcompartment	Geographical coord.		Altitude m a.s.l.	Type of forest site
						longitude (E)	latitude (N)		
1	464/ZP/06	Poznań	Łopuchówko	Buczyna	95m	16°58'	52°41'	119	Lśw
2	476/ZP/06	Szczecin	Bierzwnik	Radachowo	405a	15°30'	53°01'	117	Lśw
3	506/ZP/06	Zielona Góra	Świebodzin	Długoszyn	30a	15°19'	52°22'	205	Lśw
4 (SR)	514/ZP/06	Piła	Krucz	Goraj	15g	16°30'	52°52'	111	Lśw
5	521/ZP/06	Poznań	Pniewy	Dąbrowa	226c	16°18'	52°29'	104	Lśw
6	522/ZP/06	Szczecin	Dobrzany	Kielno	467i, 468b	15°29'	53°23'	127	Lśw
7	538/ZP/06		Myślibórz	Grzybno	170c	14°37'	53°04'	93	Lśw
8	541/ZP/06	Szczecinek	Czaplinek	Sikory	58ah	16°15'	53°35'	161	Lśw
9	557/ZP/06		Świerczyna	Jeleni Stok	31b, 32a, 33a	16°12'	53°25'	179	Lśw
10	581/ZP/06	Piła	Okonek	Węgorzewo	21a	16°54'	53°36'	164	Lśw
11	582/ZP/06	Szczecinek	Leśny Dwór	Podwilczyn	191a	17°11'	54°19'	123	LMśw
12	585/ZP/06		Damnica	Wolinia	89a	17°33'	54°36'	34	Lśw
13	609/ZP/06		Szczecinek	Dalęcino	355f	16°34'	53°46'	150-160	Lśw
14	610/ZP/06		Szczecinek	Janowo	137f	16°38'	53°40'	172	Lśw
15	611/ZP/06		Szczecinek	Janowo	138o	16°37'	53°40'	185	Lśw
16	659/ZP/06	Szczecin	Gryfino	Śmierdnica	153b, 154a, 155a, 172b	14°44'	53°19'	99	Lśw
17	660/ZP/06		Gryfino	Kołowo	317ab	14°39'	53°20'	159	Lśw
18	661/ZP/06		Gryfino	Kołowo	213b, 227a, 214b, 212ac	14°42'	53°18'	91	Lśw
19	662/ZP/06		Gryfino	Kołowo	161b, 160b, 159a	14°42'	53°20'	117	Lśw
20	664/ZP/06		Gryfino	Osetno	30b	14°46'	53°19'	86	Lśw
21 (SR)	665/ZP/06		Gryfino	Glinna	206i, 211d	14°43'	53°18'	106	Lśw
22	666/ZP/06		Gryfino	Osetno	171d	14°44'	53°19'	117	Lśw
23	739/ZP/06		Gryfino	Klęskowo	163c	14°41'	53°20'	101	Lśw

No	Progeny number	Regional directorate of the State Forest	Forest District	Forest Subdistrict	Subcompartment	Geographical coord.		Altitude m a.s.l.	Type of forest site
						longitude (E)	latitude (N)		
24	741/ZP/06	Szczecinek	Świerczyna	Jeleni Stok	83c	16°12'	53°20'	101	Lśw
25	742/ZP/06		Świerczyna	Jeleni Stok	42c, 43c	16°12'	53°25'	151	Lśw
26	758/ZP/06		Gościno	Bagicz	25a	15°41'	54°11'	30	Lśw
27	827/ZP/06		Połczyn	Kluczewo	399f	16°10'	53°41'	203	Lśw
28 (SL)	Góra Śląska	Poznań	Łopuchówko	Bartków	164a	17°08'	52°34'	123	Lśw
	Świebodzin	Zielona Góra	Świebodzin	Długoszyn	14a	15°20'	52°23'	195	Lśw

Type od forest site: Lśw – decidous forest, fresh variant; LMśw – mixed decidous forest, fresh variant

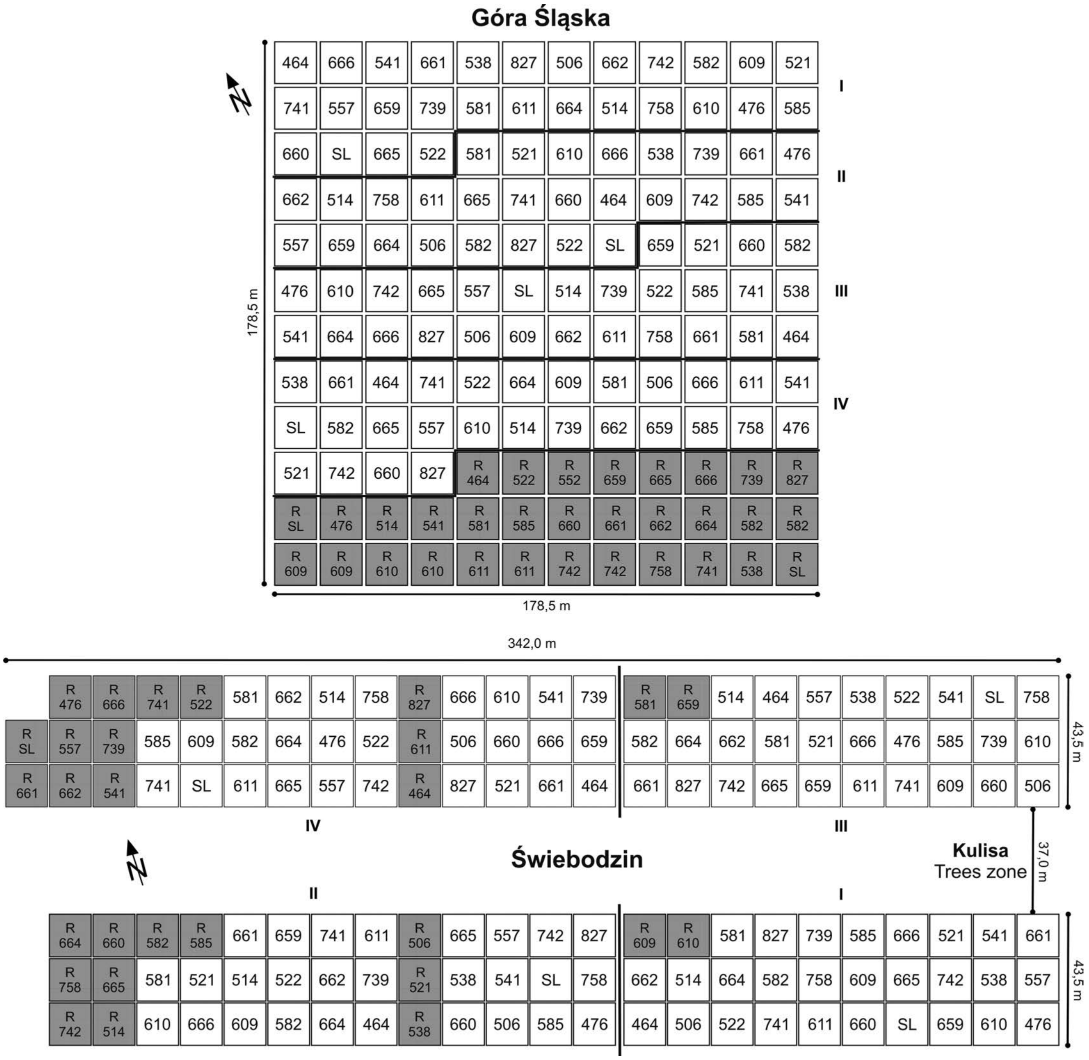

Figure 1. Plan of experimental plots with offspring of selected seed stands of the European beech, located in the Góra Śląska and Świebodzin forest districts; I–IV – block numbers (replications), SL – local standard, R – reserve

The same analytical model was used to assess the effect of the location of the study plot. In the above formula, the effect of block (*Bj*) was replaced by the effect of the *i-th* location. In order to determine the possibility of effective selection, provenance heritability was calculated with the use of variance components obtained in the analysis of variance for each trait examined. Heritability was calculated based on variance components, and this was associated with a mixed data analysis model. The expected mean squares for the used data analysis scheme (Żuk 1989) are given in Table 3.

To calculate provenance heritability (h_p^2), the following general formula was used (Giertych 1991):

$$h_p^2 = \frac{\sigma_p^2}{V_p}$$

where:
σ_p^2 – provenance variance component,
V_p – provenance variance.

General formula was transformed into heritability formula, using in the two-factor analysis of variance: provenance variance and provenance variance component divided by the coefficient k_3. The following formula was obtained (Banach et al. 2015):

$$h_p^2 = \frac{\sigma_p^2}{\frac{\sigma_e^2}{k_3} + \frac{k_2\sigma_{pb}^2}{k_3} + \sigma_p^2}$$

where:
σ_p^2 – provenance variance component,
σ_{pb}^2 – variance component for interaction provenance x block,
σ_e^2 – variance component for error,
k_2 – mean number of trees in block and provenance
k_3 – mean number of trees in provenance

Calculations and statistical analyses were carried out with the use of the functions in Statistica software: General Linear Models (means, statistical analyses) and Variance Components (variance components and coefficients for the components) (StatSoft 2014). For the obtained values of trait heritability on individual plots, a standard error of heritability estimation (se_{h^2}) was calculated in line with the formula by Falconer and Mackay (1996). The stability of each analysed provenance was determined by the method of Finlay and Wilkinson (1963). It consists in calculating the regression coefficient b between the trait values on individual crops for each analysed origin and the averages for experimental plots. The average stability is determined by a factor of 1.0. The value of regression coefficient *b* lower than 1.0 indicates better adaptation to adverse environmental conditions, whereas the higher value – only adaptation to the favourable environment. The provenance with higher regression coefficient values usually adapt well only in one specific environment (Giertych, 2000). In the present study, the stability was analysed in relation to two traits: height and survival, the mean values of which were transformed using the logarithm function (Finlay, Wilkinson, 1963). Regression coefficients were compared to the mean trait values for provenances, jointly for both test plots. The progenies with regression coefficient values close to 1.0 and the value of trait above the overall mean were classified as well adapting to all environments. The progenies well adapted to favourable and adverse environments were also determined. To determine the relationship between the analysed traits, the Pearson's linear correlation coefficient was used ($p < 0.05$). Calculations were carried out with the use of Statistica 12 software (StatSoft 2014).

Table 3. Expected average squares in the analysis of measurement data

Source of variance	Degree of freedom	Expected mean square
Block (B)	$b - 1$	$\sigma_e^2 + k_5\sigma_b^2$
Provenance (P)	$p - 1$	$\sigma_e^2 + k_2\sigma_{pb}^2 + k_3\sigma_p^2$
Interaction (P×B)	$pb - p - b + 1$	$\sigma_e^2 + k_1\sigma_{pb}^2$
Error	$n... - pq$	σ_e^2

σ_x^2 – variance component for the *x* source of variance, $k_1 ... k_5$ – coefficients for individual components

3. Results

After 5 years of growth, the survival of European beech seedlings on the plot established in the Świebodzin FD was 72.2%, and in the Góra Śląska FD – 60.8%. Overall (plots analysed jointly), on average, the highest survival values were observed in the progenies of the following selected seed stands: 464 – Łopuchówko (78.8%), 611 – Szczecinek (76.7%), 741 – Świerczyna (74.4%) and 660 – Gryfino (72.6%). The lowest survival values were observed in the progenies of the stands: 585 – Damnica (57.0%), 557 – Świerczyna (58.0%), 514 – Krucz (58.4%), 661 – Gryfino (60.2%), 739 – Gryfino (60.3%). When the experimental plots were analysed separately, in the Góra Śląska FD, the highest survival values were observed in the progenies of the stands: 464 – Łopuchówko (76.4%), 611 – Szczecinek (72.5%), 741 – Świerczyna (69.3%). In the plot established in the Świebodzin FD, the highest survival was observed in the progenies of the stands: 660 – Gryfino (84.0%), 464 – Łopuchówko (81.2%), and 611 – Szczecinek (81%) (Table 4).

Multi-factor analysis of variance showed a significant effect of provenance on the European beech survival only in the plot established in the Świebodzin FD. On both test plots,

Table 4. Average survival of European beech on plots in Świebodzin and Góra Śląska with regression coefficient *b*

Provenance No.	Forest District	Świebodzin + Góra Śląska			Świebodzin		Góra Śląska		*b*
		mean [%]	stand. unit	rank	mean [%]	rank	mean [%]	rank**.**	
464	Łopuchówko	78.8	2.28	1	81.2	2	76.4	1	0.36
476	Bierzwnik	66.5	0.00	17	75.3	13	57.6	20	1.56
506	Świebodzin	66.8	0.06	15	79.1	5	54.6	23	2.16
514	Krucz	58.4	–1.50	25	64.8	23	52.0	26	1.29
521	Pniewy	67.0	0.09	14	75.6	10	58.3	17	1.51
522	Dobrzany	67.9	0.26	8	68.1	20	67.8	5	0.02
538	Myślibórz	69.8	0.61	6	75.5	11	64.2	9	0.95
541	Czaplinek	67.3	0.15	10	67.8	21	66.8	7	0.08
557	Świerczyna	58.0	–1.57	26	63.3	24	52.6	25	1.09
581	Okonek	65.4	–0.20	18	72.8	17	58.0	18	1.32
582	Leśny Dwór	64.6	–0.35	19	77.4	7	51.8	27	2.34
585	Damnica	57.0	–1.76	27	57.3	27	56.7	21	0.06
609	Szczecinek	67.3	0.15	10	76.0	9	58.5	16	1.53
610	Szczecinek	67.3	0.15	10	73.3	16	61.4	13	1.03
611	Szczecinek	76.7	1.89	2	81.0	3	72.5	2	0.65
659	Gryfino	62.6	–0.72	21	69.8	18	55.5	22	1.34
660	Gryfino	72.6	1.13	4	84.0	1	61.1	14	1.85
661	Gryfino	60.2	–1.17	24	56.4	28	64.0	10	–0.74
662	Gryfino	61.2	–0.98	22	57.6	26	64.8	8	–0.69
664	Gryfino	70.0	0.65	5	77.2	8	62.8	11	1.20
665	Gryfino	64.6	–0.35	19	74.7	14	54.6	24	1.83
666	Gryfino	67.2	0.13	13	65.5	22	68.9	4	–0.30
739	Gryfino	60.3	–1.15	23	69.1	19	51.6	28	1.70
741	Świerczyna	74.4	1.46	3	79.4	4	69.3	3	0.80
742	Świerczyna	67.4	0.17	9	73.9	15	61.0	15	1.12
758	Gościno	66.6	0.02	16	75.4	12	57.8	19	1.55
827	Połczyn	69.8	0.61	6	78.0	6	61.6	12	1.37
Local standard		–	–	–	58.6	25	67.6	6	–
Mean		66.5	–	–	72.2	–	60.8	–	–
Standard deviation		5.4	–	–	7.5	–	6.6	–	–
Coefficient of variability		8.1	–	–	10.4	–	10.9	–	–

there were found significant effects of other sources of variation (‘block’ and interaction ‘block × provenance’) (Table 5).

The analysis of the heights of European beech trees (the experimental plots jointly) showed that the average height was 97 cm. At a level of individual progenies, the highest were those of the selected seed stands: 538 –Myślibórz (114.9 cm), 742 – Świerczyna (107.6 cm), 660 – Gryfino (106.5 cm), 464 – Łopuchówko (106.3 cm), 827 – Połczyn (106.2 cm) and 611 – Szczecinek (104.4 cm). Comparatively, the lowest height values were shown by the progenies of the stands from: 581 – Okonek (85.2 cm), 541 – Czaplinek (87.9 cm), 506 – Świebodzin (88.9 cm), 582 – Leśny Dwór (89.2 cm) and 585 – Damnica (89.5 cm). The average height of the trees examined after 5 years of growth in Świebodzin was 69.6 cm, and in Góra Śląska – 103.2 cm. On the plot established in Świebodzin, the highest were the progenies of the stands: 665 – Gryfino (94.5 cm), 660 – Gryfino (90.8 cm) and 464 – Łopuchówko (90.2 cm), and in Góra Śląska – those from 538 – Myślibórz (142.3 cm), 741 – Świerczyna (131.4 cm), 610 – Szczecinek (127.5 cm) and 827 – Połczyn (127.4 cm). In both experimental plots, tree height increment in the progenies of local production seed stands was comparatively the smallest (Table 6).

The results achieved by the best provenances in terms of tree height obtained in the plot Góra Śląska did not correspond to those obtained in the plot Świebodzin. In general, European beech heights varied considerably, even though the experimental plots were located in the same test region and the same experimental material was planted at the same time in the experimental plots.

Analysis of variance showed no effect of site of origin on the height of the beech trees studied; however, a significant effect of ‘block × provenance’ interaction on both experimental plots was found. Significant differences between blocks were also found in the case of the plot established in the Świebodzin FD (Table 5).

Analysis of variance performed for individual traits, including the effect of the location of the experimental plot, showed a significant differentiation between the plots, with no effect of the site of origin on beech height and survival. The effect of interaction ‘provenance × plot’ was significant, which proves different response of individual beech provenances to changed environmental conditions for their growth (Table 7).

On both experimental plots, the provenance 464 – Łopuchówko – was the best in terms of survival (the first ranking position in the Góra Śląska FD and the second – in the Świebodzin FD). The progenies of the following selected seed stands also ranked high: 611 – Szczecinek and 741 – Świerczyna. On the other hand, the provenances from: 557 – Świerczyna, 514 – Krucz and 585 – Damnica achieved the lowest scores. The response showed by the progenies of seed stands representing local standards was differentiated: on the experimental plot established in the Świebodzin FD, beech seedling survival was one of the poorest, and the Góra Śląska FD was at the forefront in the ranking of this trait. On both test plots, similar mean survival values were shown by the progenies from the following origin sites: 538 – Myślibórz, 609 – Szczecinek and 581 Okonek. The remaining progenies tested were characterised by varied survival values and reached differentiated positions in the ranking (Fig. 2).

On both experimental plots, the progenies of the selected seed stands: 538 – Myślibórz, then 464 – Łopuchówko and 660 – Gryfino, showed the uppermost values in terms of tree height. Irrespective of the experimental plot, the progenies of beech provenances: 581 – Okonek as well as seedlings representing both local standards showed low height growth values. On both test plots, similar average height values were shown by the progenies of the stands: 476 – Bierzwnik, 662 – Gryfino and 557 – Świerczyna. Likewise, in the case of seedling survival, the remaining beech progenies tested showed diverse values of their height and reached considerably different scores in the ranking (Fig. 2).

Table 5. Results of multivariate variance analysis of beech survival and height on experimental plots in Świebodzin and Góra Śląska

Trait	Source of variance	Świebodzin		Góra Śląska	
		F-test	significance level (*p*)	*F*-test	significance level (*p*)
Survival	block	39.2905	< 0.001	12.2606	< 0.001
	provenance	**2.0545**	**0.007**	1.1483	0.310
	block × provenance	6.5248	< 0.001	9.1453	< 0.001
Height	block	**17.8604**	**< 0.001**	1.4503	0.235
	provenance	1.7901	0.024	1.0728	0.392
	block × provenance	15.9772	< 0.001	2.4977	< 0.001

Table 6. Average height of European beech on plots in Świebodzin and Góra Śląska with regression coefficient *b*

Prove-nance No.	Forest District	Świebodzin + Góra Śląska			Świebodzin		Góra Śląska		*b*
		mean (cm)	stand. unit	rank	mean (cm)	rank	mean (cm)	rank.	
464	Łopuchówko	106.3	1.29	4	90.2	3	122.4	5	0.76
476	Bierzwnik	97.7	0.10	11	78.5	13	116.8	14	1.00
506	Świebodzin	88.9	–1.13	25	76.8	14	100.9	26	0.68
514	Krucz	93.5	–0.49	19	73.9	20	113.0	17	1.06
521	Pniewy	94.0	–0.42	18	68.4	26	119.6	12	1.40
522	Dobrzany	90.0	–0.97	21	75.2	16	104.7	23	0.83
538	Myślibórz	114.9	2.49	1	87.5	4	142.3	1	1.22
541	Czaplinek	87.9	–1.26	26	60.3	28	115.4	15	1.63
557	Świerczyna	91.2	–0.81	20	73.7	21	108.7	21	0.97
581	Okonek	85.2	–1.64	27	69.8	24	100.5	27	0.91
582	Leśny Dwór	89.2	–1.08	24	78.9	12	99.4	28	0.58
585	Damnica	89.5	–1.04	23	61.1	27	117.9	13	1.65
609	Szczecinek	96.3	–0.10	14	80.4	10	112.1	18	0.83
610	Szczecinek	101.1	0.57	8	74.7	18	127.5	3	1.34
611	Szczecinek	104.4	1.03	6	87.0	5	121.8	7	0.84
659	Gryfino	102.2	0.72	7	84.6	7	119.7	11	0.87
660	Gryfino	106.5	1.32	3	90.8	2	122.1	6	0.74
661	Gryfino	95.6	–0.19	15	70.8	23	120.3	9	1.33
662	Gryfino	95.0	–0.28	17	75.1	17	114.8	16	1.06
664	Gryfino	95.5	–0.21	16	79.7	11	111.2	19	0.83
665	Gryfino	98.2	0.17	9	94.5	1	101.9	25	0.19
666	Gryfino	96.7	–0.04	12	71.7	22	121.7	8	1.33
739	Gryfino	90.0	–0.97	21	74.0	19	105.9	22	0.90
741	Świerczyna	107.6	1.47	2	83.7	8	131.4	2	1.13
742	Świerczyna	96.6	–0.06	13	82.2	9	110.9	20	0.75
758	Gościno	97.9	0.13	10	75.9	15	119.8	10	1.14
827	Połczyn	106.2	1.28	5	84.9	6	127.4	4	1.02
Local standard		–	–	–	69.6	25	103.2	24	–
Mean		97.0	–	–	77.6	–	115.5	–	–
Standard deviation		7.2	–	–	8.4	–	10.3	–	–
Coefficient of variability [%]		7.4	–	–	10.8	–	8.9	–	–

Table 7. Results of multivariate analysis of variance of analyzed European beech traits for both test plots

Trait	Source of variance	df	*F*-test	Significance level (*p*)
Survival	plot	1	63.0507	< 0.001
	provenance	27	0.9365	0.567
	provenance × plot	27	11.0028	< 0.001
Height	plot	1	337.9014	< 0.001
	provenance	27	1.6655	0.097
	provenance × plot	27	4.1256	< 0.001

The experimental plots differed in terms of the conditions for survival and height growth of the examined European beech progenies. On the plot established in the Świebodzin FD, the pressure of various environmental factors was somewhat lesser, and so, the average values of seedling survival were higher as compared to those achieved in the Góra Śląska FD. At the same time, the average height of the progenies growing in the Świebodzin FD was lower when compared to those observed in the Góra Śląska FD, where the experimental plot was established within clear cut area, hence a higher-quality site. Survival stability analysis showed that the progeny of European beech population from 464 – Łopuchówko (b = 0.36), followed by those from 611 – Szczecinek (b = 0.65) and 74 – Świerczyna (b = 0.80) indicated high survival values and adaptation to unfavourable environmental conditions (Table 5). In the case of tree height, the progeny of the regional standard in the test region I, that is, stand 665 – Gryfino (b = 0.19), was the best adapted to adverse environmental conditions. Populations 660 – Gryfino (b = 0.74) and 464 – Łopuchówko (b = 0.76) showed high values in terms of tree height and low values of regression coefficients. On average, the progeny of the stand 538 – Myślibórz – was the best in terms of height of trees achieved in both experimental plots. In this case, the high coefficient b value (1.22) indicated good adaptation to favourable growth conditions. The progeny of the stand 827 – Połczyn, characterised by very good height values and a regression coefficient close to 1.0 was well adapted to the analysed environments (Table 6).

On individual experimental plots, the values of heritability of the studied beech traits showed a lot of differences. The highest heritability values (0.513 and 0.441 for survival and height, respectively) were observed in the case of survival European beech trees growing within the plot established in the Świebodzin FD. The trees observed on the plot established in the Góra Śląska FD, achieved much lower heritability values (0.129 and 0.068 for survival and height, respectively) (Table 8).

Differences were observed between the values of linear correlation coefficients for the traits tested obtained within the experimental plots. A significant correlation between tree survival and height (r = 0.437) was found in Góra Śląska. In Świebodzin, this correlation was stronger (r = 0.668). No correlation was found between the survival of the seedlings examined in Głóra Śląska and Świebodzin (r = 0.090). In the case of the average beech heights, the positive correlation was weak (r = 0.240) and not statistically significant (Table 9).

4. Discussion and conclusions

The study was carried out to evaluate the European beech adaptation examined on two experimental plots located in the test region II, in the Forest Districts: Góra Śląska and Świebodzin. The aim was to determine the adaptive response in the studied provenances, in view of their stability in changed environmental conditions. The progenies of the selected seed stands growing in 5 Regional Directorates of State Forests (Szczecin, Szczecinek, Piła, Zielona Góra and Poznań) were observed. The results obtained after five years of observations showed a large diversity in beech survival and height and different response to environmental conditions in the test plots. The testing program assumes 10-year-long tree survival assessments in established experimental areas. The results of the present study confirmed that preliminary

Table 8. Provenance heritability of the analyzed traits of European beech, tested on plots in Góra Śląska and in Świebodzin

Trait	Heritability ± for test plot	
	Świebodzin	Góra Śląska
Survival	0,513 ± 0,120	0,129 ± 0,035
Height	0,441 ± 0,108	0,068 ± 0,019

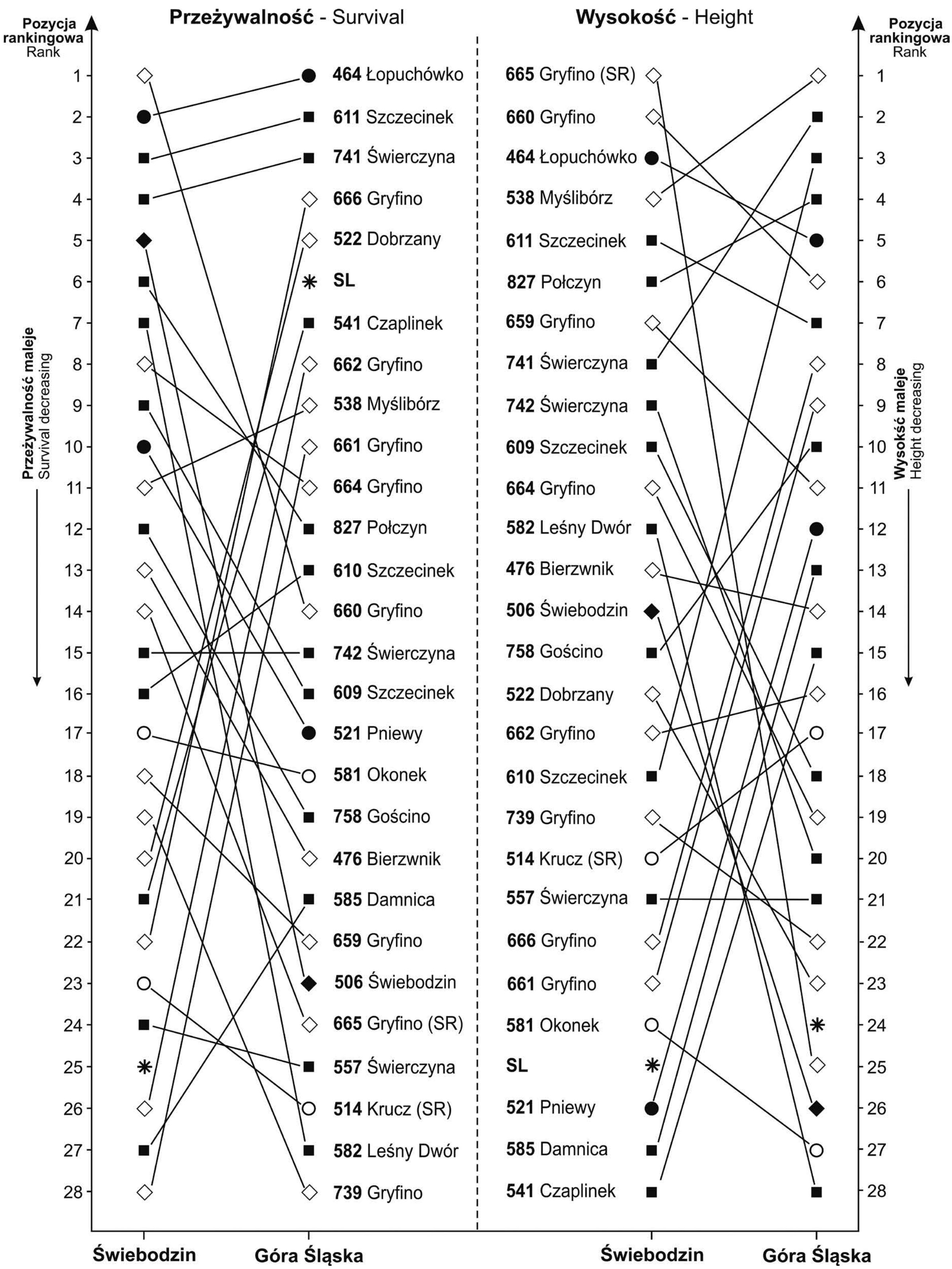

Figure 2. Change in ranking positions of provenances for analyzed traits on both test plots; SR – regional standard, SL – local standard (✱), regional directorate of State Forests: Piła (○), Poznań (●), Szczecin (◇), Szczecinek (■), Zielona Góra (◆)

Table 9. Correlation coefficient between traits of European beech, tested on plots in Góra Śląska and in Świebodzin (* significant value for *p*<0,05)

Trait / plot		Survival		Height	
		Świebodzin	Góra Śląska	Świebodzin	Góra Śląska
Survival	**Świebodzin**	×	0.090	*0.668	0.189
	Góra Śląska		×	0.138	*0.437
Height	**Świebodzin**			×	0.240
	Góra Śląska				×

assessment was possible after a shorter, 5-year-long period. The average values of European beech survival, obtained in the experimental plots in Góra Śląska and Świebodzin, were 60.8% and 72.2%, respectively. This difference between the plots may be related to environmental conditions. In the Góra Śląska FD, the experimental plot was established on a clear cut area, covered by intensively developing vegetation (natural regeneration) that was competing with the tested seedlings. In the Świebodzin FD, the plot was established within the area of a former forest nursery. The majority of the tested European beech provenances showed different responses when examined on the experimental plots separately. This was evidenced by the differences in the rankings of provenance survival and height prepared for the plots, as well as significant interaction origin 'provenance × plot'. Similar results were obtained by Barzdajn (2009) in the study on progenies of seed stands in Złotoryja and Lądek Zdrój, in the south-western region of European beech testing, as well as by Banach et al. (2015) in the south-eastern region – experimental plots in Rymanów and Nawojowa. In the Świebodzin FD, some European beech provenances were characterised by relatively high survival rates when compared to the other provenances tested. This indicates their better adaptation to local conditions. A similar relationship was demonstrated by Kowalkowski (2013), in the study on the progenies of various European beech provenances carried out on the testing areas established in the Łobez Forest District. The results of the tests on European beech, carried out by Sabor and Stanuch (2009) indicated a different adaptation response to planting conditions. The authors showed that the soil could play an important role in seedling growth in the first few years after planting. In the experimental plot in Świebodzin, in general, relatively high inheritance values were obtained, both for European beech survival and height, and the values obtained did not differ considerably from those reported by Galoux (Giertych 2000). It means that the results obtained in this study can enable effective selection of desirable population in terms of both traits. The heritability observed in Góra Śląska achieved considerably lower values, which could be influenced by hard growth conditions due to weed overgrowth, which outweighed adaptation capability of individual beech progenies. Observations carried out in Góra Śląska indicated that the tested seedlings had to compete for access to light, with, for example, common hornbeam *Carpinus betulus* L. and bushgrass *Calamagrostis epigejos* (L.) Roth. These species were left behind in the experimental plot so as to protect the newly planted beech seedlings against late frost. Subsequently, they were gradually removed from the plot, as their effects on beech adaptation became negative (when compared to Świebodzin, there were observed more dead beech seedlings and lower average survival rates).

The correlations between mean values of the tested provenance traits obtained in the two experimental plots were not significant, whereas the relationship between the survival rate and tree height within an individual plot was positive and statistically significant. This indicates that beech trees that achieved high survival values also grew well in height.

The assessment of European beech adaptation did not show that the progeny of the local seed stands achieved the best results. This is confirmed by the results obtained by Banach et al. (2015) and Szeligowski et al. (2019) obtained in the southeast beech test region. A similar conclusion was drawn by Sułkowska (2004). On the other hand, however, Giertych (1990) stated that local populations are best adapted to environmental conditions. In the present study, relatively poor adaptation of local provenances (local standard) may be related to the category of the seed stand, as in both experimental plots, there were observed European beech progenies of the production seed stands.

The progenies of local European beech populations growing in the same region (Forest District) were tested in the present study, yet their adaptive response differed considerably between each other as depending on the experimental plot, they were among the best and the worst provenances in terms of both traits studied. This indicates European beech ecotypic variation, confirmed by other authors (Giertych 2000; Sułkowska 2010; Szeligowski et al. 2019).

As a result of the analyses of the progeny of the European beech examined on the test plots in the Góra Śląska and Świebodzin Forest Districts, the following conclusions were drawn:

1. The European beech progenies examined significantly differed in terms of tree survival and height assessed on the two experimental plots. A significant difference between the two locations and the significant interaction 'provenance × plot' were found, which demonstrated strong response of European beech to the change of growth conditions.

2. When compared to the experimental plot established in the Góra Śląska FD, European beech trees achieved higher average survival values within the experimental plot established in the Świebodzin FD. However, the trees growing in Góra Śląska were on average approximately 40% higher than those growing in Świebodzin.

3. On both experimental plots, the progeny of the selected seed stand 464 – Łopuchówko was the best in terms of survival, and the progeny of the stand 538 – Myślibórz achieved the top average height value.

4. European beech stability evaluated on the basis of regression coefficients and the average survival and height values, indicated that the progeny of the European beech stand in the Łopuchówko Forest District (Forest Sub-District Buczyna, sub-division 95n) adapted well, especially to adverse environmental conditions.

5. The progeny of the regional standard 514 – Krucz showed low survival and height values on both experimental plots, whereas the progeny of the regional standard 665 – Gryfino showed average values. These results can enable choosing European beech progenies with better adaptive traits.

6. Within both experimental plots, the local standards ranked among the worst populations in terms of tree height. In the case of survival, the local standards showed the best values in Góra Śląska, whereas in Świebodzin – the worst when compared to other progenies tested.

7. The highest values of heritability of the analysed traits was observed within the plot established Świebodzin: 0.441 for height and 0.513 for survival. This indicates the possibility of effective selection of progenies in terms of both adaptive traits. The values of heritability obtained in Góra Śląska were much lower, which indicates a greater impact of environmental factors.

Conflict of inte est

The authors declare no potential conflicts.`

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Authors' contribution

J.J. – field studies, analysis of measurement data, tabular summaries, manuscript writing; J.B. – research concept, verification of analyses, preparation of graphs, manuscript edition/revision; K. S. – tabular summaries, description of the results.

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