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ANALYZING THE ADAPTIVE REACTION OF EUROPEAN BEECH PROVENANCES FROM THE PERSPECTIVE OF QUALITY TRAITS

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Abstract: *The morphological structure of a tree's stem determines its economic value and can also indicate its level of adaptation to specific environments. Given the current concerns for resilient tree populations, the present survey aims to evaluate the adaptative reaction of European beech in the Carpathian region of Romania from the perspective of quality traits. Four European beech provenance trials, which are part of two international networks, were tested for Stem quality (Sq), Forking (Fk), and Branch diameter (Bd) at the ages of 24 and 27 after planting. The variation of the studied traits across environments and provenances was tested using the Chi-squared test for categorical variables and a linear model for the numerical variables. In the 1995 series, in the more favourable environmental conditions, there was a significantly lower presence of forked trees and lower values for Bd compared to the less favourable site, where the number of trees with severe defects was notably higher. Regarding the 1998 series, there were significantly fewer trees with multiple base stem forks in the warm-humid environment, as well as considerably lower Bd, and a significantly higher number of trees with straight stems, compared with the hot-dry site. The environment significantly conditioned the quality of the stem morphotype of the provenances. The warm-humid and hot-humid environments favoured the adaptation process of the international provenances. Assisted transfer of provenances may be a feasible solution for increasing the quality of Romanian beech stands.*

Key words: *adaptive reaction, assisted migration, Fagus sylvatica, quality traits, provenance trials.*

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1. Introduction

The morphological structure of a tree's stem determines its economic value and can also indicate its level of adaptation to specific environments [15, 19, 27]. Some of the most used traits for scoring the quality of a tree’s stem are forking, stem straightness, and branch diameter. A tree fork is a morphological structure that appears as a result of the bifurcation of the main stem [11]. From a silvicultural point of view, tree forks are considered stem defects resulting from the damage produced to the terminal bud or the last annual increment and can also be genetically inherited [12]. Stem straightness is controlled by environmental factors and can also be a genetic heritage [9]. This trait accounts for the deviations from the centre line of the main axis in any direction and considers the entire stem height [12, 14]. The quality of a tree’s stem is also affected by branch diameter, whose dimensions will condition the area of the knots in the timber [12]. Like the other quality traits, branch diameter is influenced by environmental factors [16], and it is also used to test the provenance performance in different environments [1]. Apart from the genetic inheritance, tree stem morphotypes are affected by climatic conditions [19]. Frosts are one of the main climatic factors associated with the deterioration of stem shape [28]. In general, frosts are linked to forks because of the deterioration of the terminal bud, leading thus to a decrease in growth and economic value [11, 28]. At the same time, forks and the quality of the stems account for the adaptive capacity of tree species [10]. As an example, trees with early phenological activity can be susceptible to late frosts, which will condition their growth and stem shape performance [37]. Therefore, an adapted population will be revealed by the phenotypes with performant stem shapes, which were less affected by environmental factors. European beech (*Fagus sylvatica* L.) is one of the main forest tree species in Europe [22]. Its high ecological and economic importance derives from its large natural distribution range characterized by various environmental conditions [39]. Romania has large areas covered by beech [18] which are emblematic of this land, and their importance has been proven on an international scale [5]. Numerous studies have pointed out the high genetic and phenotypic intrapopulation variability of the beech population across Europe [6, 20, 30]. This variability is considered a sign of a species' ability to adapt to future environmental changes through evolution [8]. Accordingly, it raises the necessity for finding valuable populations which may possess a high ability to cope with predicted disturbances [40] and ensure the future productivity of beech forests [21]. This was the reason for installing several series of international beech provenance trials in Europe [38]. These genetic tests provided the base for many research studies that attempted to evaluate the differences between beech provenances regarding their adaptive capacity [34, 35]. However, in the complex analysis of the adaptive capacity of European beech provenances, less attention has been paid to the impact of the quality traits of tree stems. These traits may have a significant influence on describing the adaptive reaction of provenances to the transfer to various environments. Consequently, the main goal of the study was to assess the European beech's adaptive reaction in the Carpathian region of Romania, focusing on quality traits, to comprehensively understand its adaptive capacity.

2. Materials and Methods
2.1. Trials and Tested Provenances

In the spring of 1995 and 1998, four international beech provenance trials were installed in Romania. These experiments were part of an international network of provenance trials established across Europe for the purpose of testing the adaptive capacity of European beech at the scale of the entire distribution range. These provenance trials were installed using a complete randomized block design with three replications and 50 trees per unitary plot planted using a spacing of two meters between rows and one meter between trees [38].

In Romania, the first series (1995) was represented by two trials installed in Sacele (Brasov County) and Carbunari (Maramures County), where 17 common provenances were planted. Another two trials, which contain 31 common provenances, were installed in Alesd (Bihor County) and Fantanele (Bacau County) in the second series (1998) [26] (Figure 1).

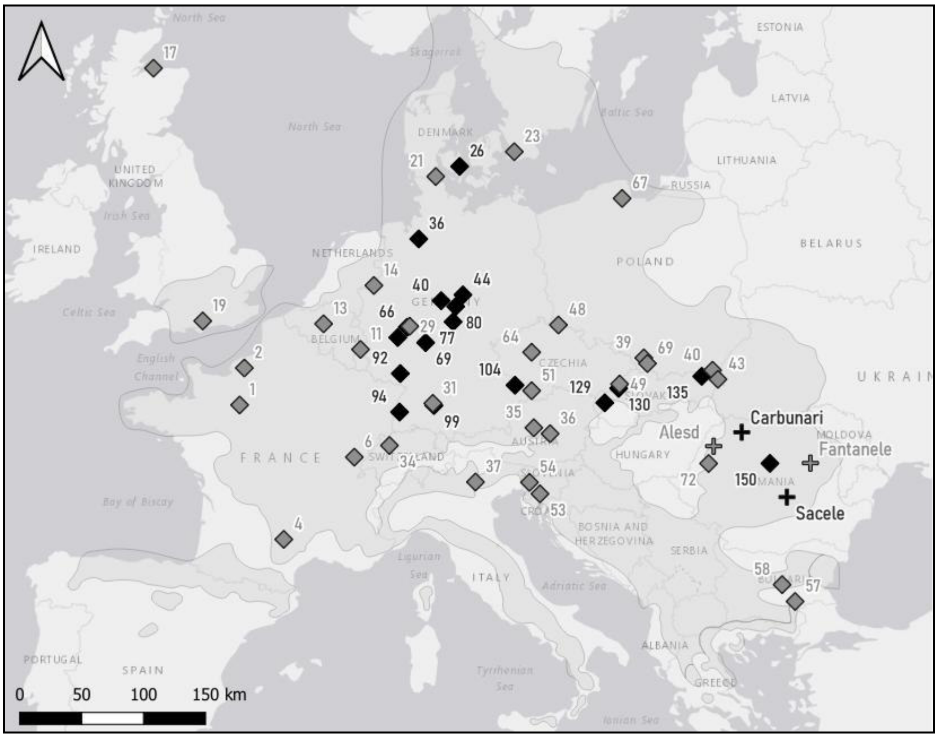

Fig. 1. *Geographic location of the beech provenances (black diamonds for the 1995 series and grey diamonds for the 1998 series) and of the four trials (black crosses for the 1995 series and grey crosses for the 1998 series) [33]; the grey layer represents the natural distribution range of Fagus sylvatica [7]*

2.2. Field Measurements and Site Conditions

The measurements were conducted in the spring of 2022, following 27 years of testing for the 1995 series and 24 years for the 1998 series. The methodology involved the random selection of 15 trees from each provenance in every trial, following a pre-established scheme that required selecting five trees from each replication. The methodology involved randomly selecting 15 trees from each provenance in every trial, following a pre-established scheme that required the selection of five trees from each replication. For these trees, forking (Fk), stem quality (Sq), and branch diameter (Bd) were counted. Fk and Sq were estimated according to the Treebreedex protocol for beech [12], which recommends a 7-class scale for Fk and a 10-class scale for Sq. The Sq scoring was adapted with a focus on stem rectitude. In the case of Bd, the medium branch at the height of 2.2 m was measured (Table 1).

Scoring methodology for Fk and Sq Table 1

Fk classes		**Scoring method**
1	The lowest part of the stem	Tree with several forks (more than one)
2		Tree with one fork
3	The second third of the stem	Tree with several forks (more than one)
4		Tree with one fork
5	The upper third of the stem	Tree with several forks (more than one)
6		Tree with one fork
7	-	Tree without fork
Sq classes		**Scoring method**
1	Severe defects	No main stem or with a low height (“apple” shape)
2		No apparent stem; many major defects
3		Presence of a visible stem, but with several major
4		Presence of a visible stem, but with a major curvature
5		Slight sinuous stem associated with other defects (branch density, flexuosity)
6		Slight sinuous stem
7	Slight defects	Two medium curvatures or many slight curvatures
8		Two slight curvatures
9	Straight	A slight curvature
10		Ideal tree: no defects

To characterize the environmental conditions of the four test sites, climatic data for the testing period (27 years for the 1995 series and 24 years for the 1998 series) were extracted using the Climate downscaling tool [23]. Based on the data, the trials were included in different climatic classes, which enabled a better understanding of the local conditions (Table 2).

The four trials were installed under different site conditions and the climatic classes were selected according to these conditions. In the first series, the ANOVA test revealed significant differences ($p<0.000$***) between sites regarding the no-frost period. The Sacele trial recorded a reduced no-frost period, which means the period with frosts was higher than in the Carbunari trial. Besides, the low mean annual temperature and precipitation were observed in the Sacele trial. Thus, the climatic conditions were characterized as cold-humid for the Sacele site. At the same time, the Carbunari trial was included in the hot-humid class because of the higher temperature and higher precipitation amount. In the second series, the period with no-frost days also differed between test sites ($p= 0.006$**), with a higher frost period in the Alesd trial. In terms of temperature and precipitation, the Fantanele trial was found to be at the limit of beech requirements, while the Alesd trial was installed under optimum conditions. Therefore, the Fantanele trial was distinctly identified as hot-dry, while the Alesd trial was categorized as warm-humid.

Site conditions Table 2

Series	Trial	Altitude [m]	Mean annual temperature [°C]	Mean annual precipitation amount [mm]	Mean of no-frost period [days]	Climatic classes
1995	Sacele	873	7.2	873	231	Cold-humid
	Carbunari	294	9.6	906	265	Hot-humid
1998	Alesd	682	8.3	877	249	Warm-humid
	Fantanele	276	10.0	591	259	Hot-dry

2.3. Data Analyses

Due to the different provenances tested in the two series, the data analyses were made separately for each series using the *R environment* [32]. For testing the variation between test sites and provenances regarding Fk and Sq, the Chi-square test was applied. The mosaic plots were made using the *vcd package* [25], for visualizing categorical relationships between variables. In the analysis of Bd, a linear model was applied, based on the Equation (1), computed with *metan package* [29]:

$$Yijk = \mu + \alpha i + \tau j + (\alpha\tau)ij + \Upsilon jk + \varepsilon ijk \quad (1)$$

where:

Yijk is the response variable (i = provenance, j = environment, k = replication);
μ – the grand mean;
αi – the effect of the provenance;
τj – the effect of the trial;
(ατ)ij – the interaction between provenance and trial;
ϒjk – the replication effect;
εijk – the random error.

The linearity of the data was checked with the Shapiro test, the model's accuracy was tested with residual plots, and a t-test analysis was applied to highlight the levels of significance in the graphs. A simple analysis of variance (ANOVA) was used to test the differences between test sites regarding the no-frost period.

3. Results

3.1. Forking in Relation to the Environment and Provenance

In the evaluation of Fk, the Chi-squared test revealed significant differences (p<0.001***) between the two environments from both series (Figure 2).

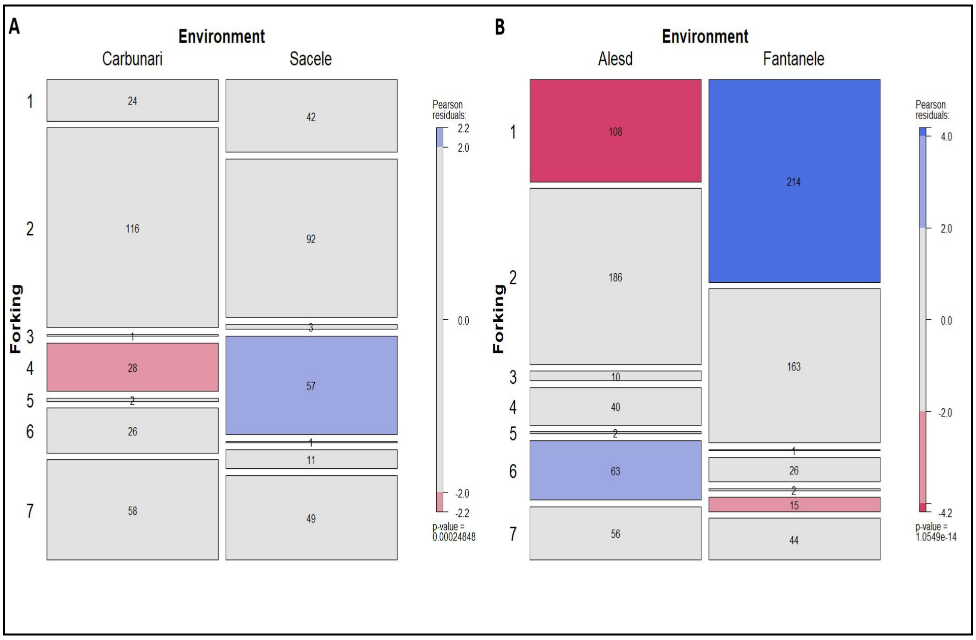

Fig. 2. *Forking (Fk) analysis for the 1995 (A) and 1998 (B) environments; the colours in the graph represent the level of significance: grey = no significance, red = significantly lower values, and blue = significantly higher values; increased colour intensity indicates a higher level of significance*

The differences between the Fk classes and the two environments from the 1995 series (Figure 2a) were marked, especially in the case of the fourth class. This means that in the Carbunari trial, significantly fewer trees, with one fork occurring in the second third of the stem, were observed than in the Sacele trial. Regarding the rest of the Fk classes, similar results were obtained in both environments. However, in the Sacele trial, there was a slightly higher presence of trees with multiple forks in the lowest part of the stem (class 1) and fewer trees with one fork in the upper third of the tree (class 6). The number of trees with no forks (class 7) was higher in the Carbunari trial. Besides, in both environments, the highest number of trees was included in the second Fk class, with one fork in the lowest part of the stem.

In the 1998 series, there was significant variation between environments and Fk classes, which was observed in the first and sixth Fk classes (Figure 2b). Therefore, in the more favourable conditions from the Alesd trial, the number of trees with multiple forks in the lowest part of the stem was significantly lower than in the Fantanele trial. Besides, the number of trees with one fork in the upper third of the stem was significantly lower in the less favourable conditions from the Fantanele trial. The second Fk class was well represented in both trials, and the seventh class (no forks) seemed to be slightly higher in the Alesd trial. In all environments, the first and second Fk classes had the highest representation. This suggests that beech trees were mostly forked in the lowest part of the stem. Besides, the variation of Fk between all environments can be explained by the different climate conditions. In the hot-dry environment (Fantanele), almost half of the beech trees (46%) had multiple forks in the lowest part of the stem. This fact is partly confirmed in the environments from the 1995 series, where a slightly higher number of trees were included in the first Fk class, in the cold-humid site (Sacele). At the same time, the percentage of trees with no forks was higher in the hot-humid (1995 series) and warm-humid sites (1998 series).

In the case of the tested provenances from the 1995 series, no significant differentiation was recorded between provenances in the two test sites (Figure 3). The provenances that obtained the weakest reaction regarding Fk (class 1) were the German provenances 40 (Bovenden) and 99 (Ehingen) together with the Slovakian provenances 129 (Smolenice) and 135 (Medzilaborce), all in the Sacele trial. Oppositely, the highest number of no-forked trees (class 7) was recorded by the German provenance 69 (Budingen) and the Slovakian provenance 130 (Trencin) in the Carbunari trial. In the case of the Romanian provenance 150 (Sovata), a high number of trees with forks that occur in the lowest part of the stem (classes 1 and 2) was recorded in both trials. Similar reactions in the two environments were observed in the German provenances 36 (Osterholz), 66 (Dillenburg), and 92 (Montabaur), which seemed to be less affected by the different environmental conditions. Besides, provenance 69 (Budingen) recorded a high number of no-forked trees in both trials.

No significant differences were observed between the provenances tested in the two trials installed in 1998 (Figure 4). However, in the Fantanele trial, provenances 6 (Plateaux du Jura, France), 11 (Heinerscheid, Luxembourg), 21 (Grasten, Denmark), and 40 (Tarnawa, Poland) recorded the highest number of trees with multiple forks in the lowest part of the stem, so the lowest performance regarding Fk. In contrast, in the Alesd trial, provenances 2 (Bordure Manche, France), 13 (Soignes, Belgium), and 54 (Idrija, Slovenia) recorded the highest number of no-forked trees. Even if the majority of provenances had a weak reaction in the Fantanele environment, the Czech provenances 51 (Horni Plana-Cerny) and 64 (Nizbor) had a slightly higher performance in the Fantanele trial. Provenance 11 (Heinerscheid, Luxembourg) recorded a weak reaction in both environments, and the Romanian provenance 72 (Bihor-Izbuc) performed slightly higher in the Alesd trial.

As an overview of the Fk analysis, it was observed that differences only appeared between environments and not among provenances, indicating that this trait is mostly influenced by site conditions. In the cold-humid (Sacele) and hot-dry (Fantanele) sites, the number of trees with multiple forks in the lowest part of the stem (class 1) was higher than in the hot-humid (Carbunari) and warm-humid (Alesd) sites, but an opposite behaviour between sites was registered in the case of the trees with forks in the upper third of the stem or the no-forked trees. These aspects reveal the connection between extreme sites and less performant tree stems and confirm that the adaptive reaction of provenances may be narrowed by these environments. Provenances 13 (Soignes, Belgium) and 69 (Budingen, Germany) were selected for the highest number of no-forked trees.

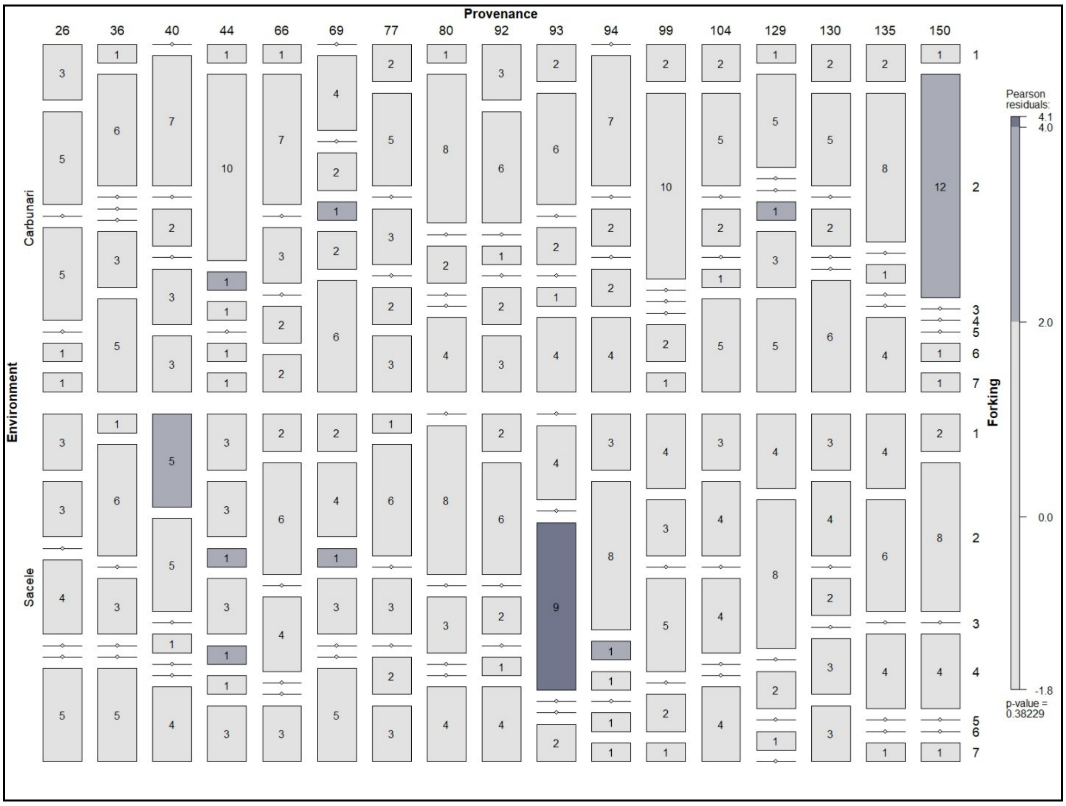

Fig. 3. *Forking (Fk) analysis for the 1995 provenances; the colours from in graph represent the level of significance: grey = no significance, red = significantly lower values, and blue = significantly higher values; increased colour intensity indicates a higher level of significance*

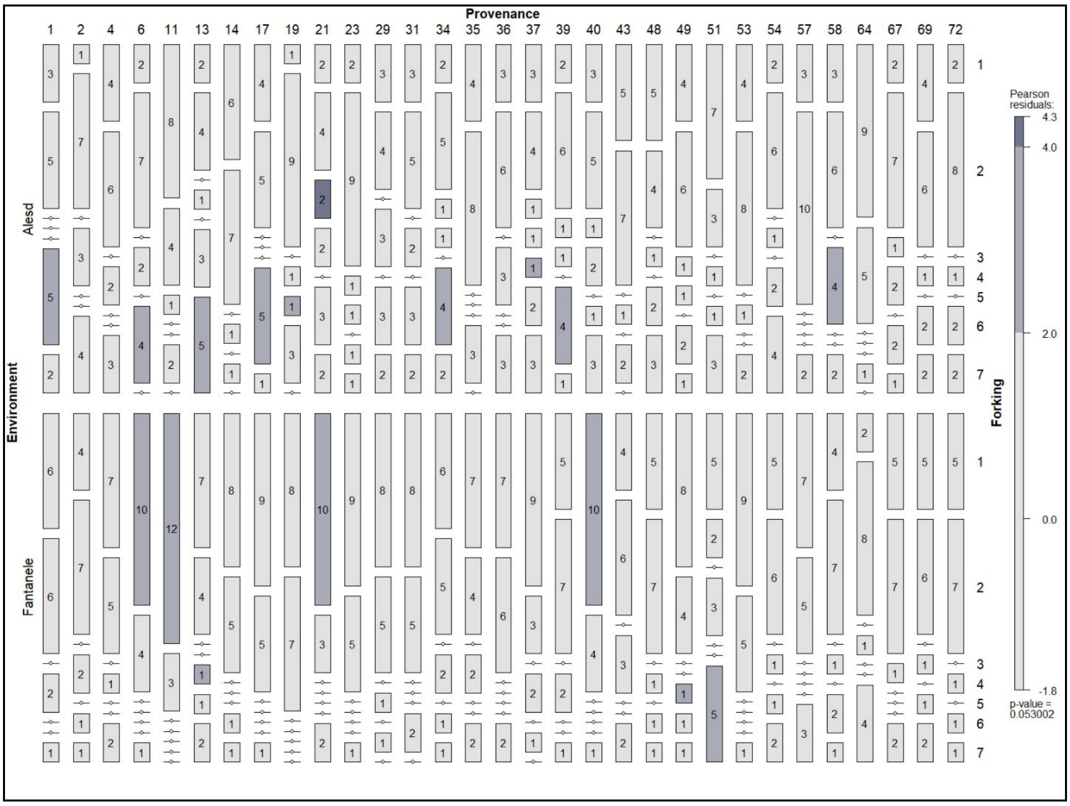

Fig. 4. *Forking (Fk) analysis for the 1998 provenances; the colours in the graph represent the level of significance: grey = no significance, red = significantly lower values, and blue = significantly higher values; increased colour intensity indicates a higher level of significance*

3.2. Stem Quality in Relation to the Environment and Provenance

The variation between the environments, regarding Sq, was significant in both series ($p<0.001^{***}$).

In the 1995 series (Figure 5a), the differences were significant in the fourth, fifth, and seventh classes. In the Sacele environment, there was a significantly higher number of trees with a major curvature (class 4) and slightly sinuous stems (class 5), but a considerably lower number of trees with two medium curvatures (class 7) than in the Carbunari environment. Regarding the trees with a straight stem (classes 9 and 10), no clear differences were recorded between the two sites. Thus, the humid-cold environment, with a higher number of frost days (Sacele), might condition the quality of beech stems due to a higher presence of trees with severe defects (classes 3 to 6).

In the 1998 series (Figure 5b), the significant differences between the environments appeared in the third class. In the Alesd trial, more trees were included in this class than in the other trial. Another significant difference was observed in the number of trees with two medium curvatures (class 7), which was lower in the Alesd trial. The number of beech trees with a straight stem (classes 9 and 10) was significantly higher in the Alesd trial. As a result, the contrasting Sq values in the warm-humid (Alesd) and hot-dry (Fantanele) environments accentuate the influence of the environmental conditions on the quality of the beech stems.

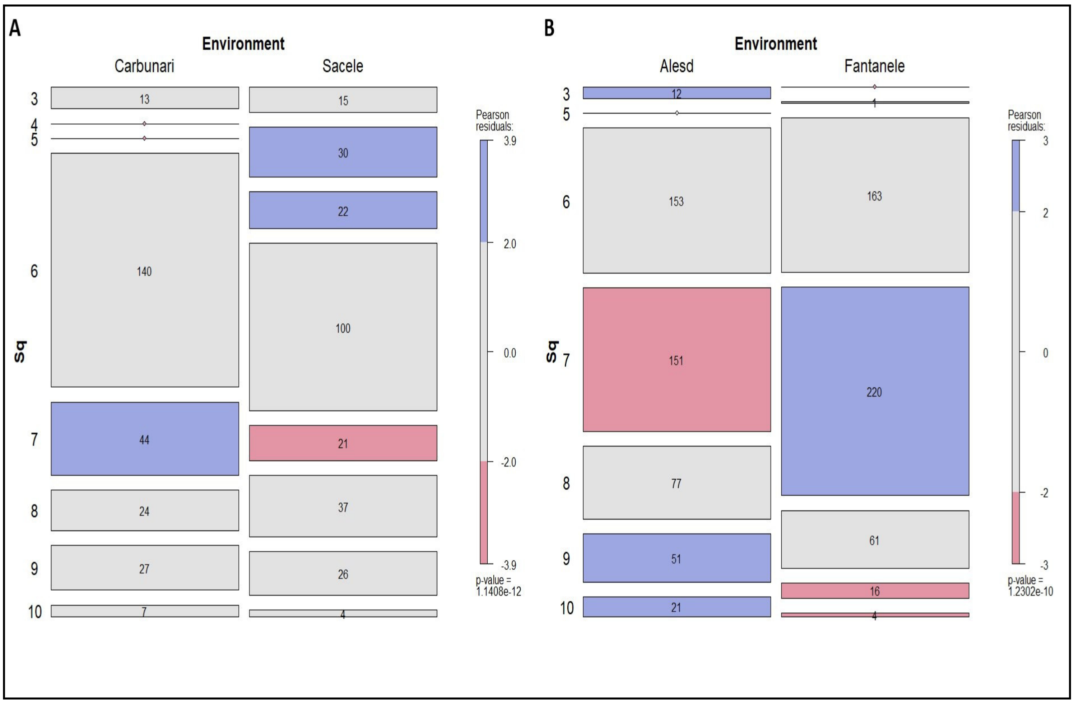

Fig. 5. *Stem quality (Sq) analysis for the 1995 (A) and 1998 (B) environments; the colours in the graph represent the level of significance: grey = no significance, red = significantly lower values, and blue = significantly higher values. Increased colour intensity indicates a higher level of significance*

The provenances from the 1995 series had a significantly different reaction between the two environments (p<0.001***) (Figure 6). In the Sacele environment, the Sq classes from 3 to 5 (severe defects) were significantly better represented than in the Carbunari environment. The Romanian provenance 150 (Sovata) recorded a higher number of trees with a major curvature (class 4) in the Sacele environment, as well as the German provenances 36 (Osterholz), 69 (Budingen), 77 (Eisenah), 92 (Elmstein Sud Appenthal) and 99 (Ehingen). The weakest Sq was recorded in provenances 69 (Budingen) and 150 (Sovata) in the Sacele environment, while provenances with a higher number of trees with straight stems (classes 9 and 10) were the German provenances 77 (Eisenah) in the Carbunari environment, and 104 (Zwiesel) in the Sacele environment. The provenances that were less influenced by the different site conditions were 40 (Bovenden), 66 (Dillenburg), and 93 (Montabaur), because they obtained similar and less performant values for Sq in the two environments.

Regarding the provenances tested in the 1998 trials, the Sq varied significantly between the two trials (p<0.001***) (Figure 7). The highest number of trees with straight stems (classes 9 and 10) was recorded by the Austrian provenance 35 (Hinterstoder) and the Czech provenance 48 (Jablonec) in the Alesd environment with significantly higher quality than in the Fantanele trial. At the opposite pole, the French provenance 2 (Bordure Manche) and the Swedish provenance 23 (Torup) registered the lowest values for Sq in the Alesd trial. Quite similar Sq in the two environments was observed in provenances 14 (Aarnink - Netherlands) and 51 (Horni Plana-Cerny – Czech Republic).

In the case of Sq, both factors, environment and provenance influenced this trait. The higher number of trees with severe defects (classes 3 to 6) that were counted in the cold-humid site (Sacele) and the higher presence of trees with straight stems (classes 9 and 10) in the warm-humid environment (Alesd) suggest that beech manifested a more positive adaptive reaction to the warm-humid (Alesd) and hot-humid (Carbunari) sites. The provenances that obtained the highest number of trees with straight stems (classes 9 and 10) were the German provenances 77 (Eisenah) and 104 (Zwiesel), and the Austrian 35 (Hinterstoder) and Czech 48 (Jablonec) provenances.

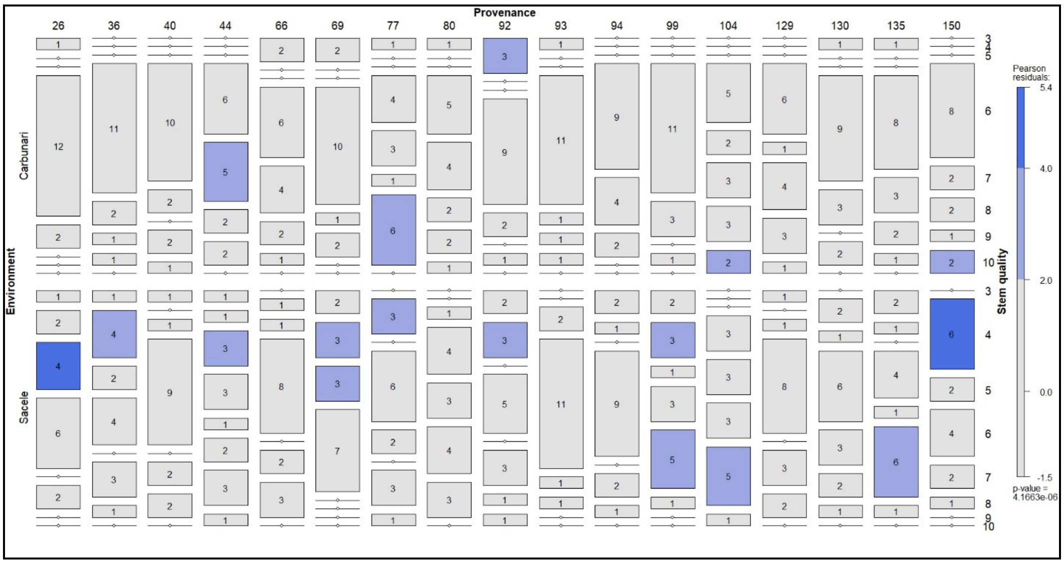

Fig. 6. *Stem quality (Sq) analysis for the 1995 provenances; the colours in the graph represent the level of significance: grey = no significance, red = significantly lower values, and blue = significantly higher values; increased colour intensity indicates a higher level of significance*

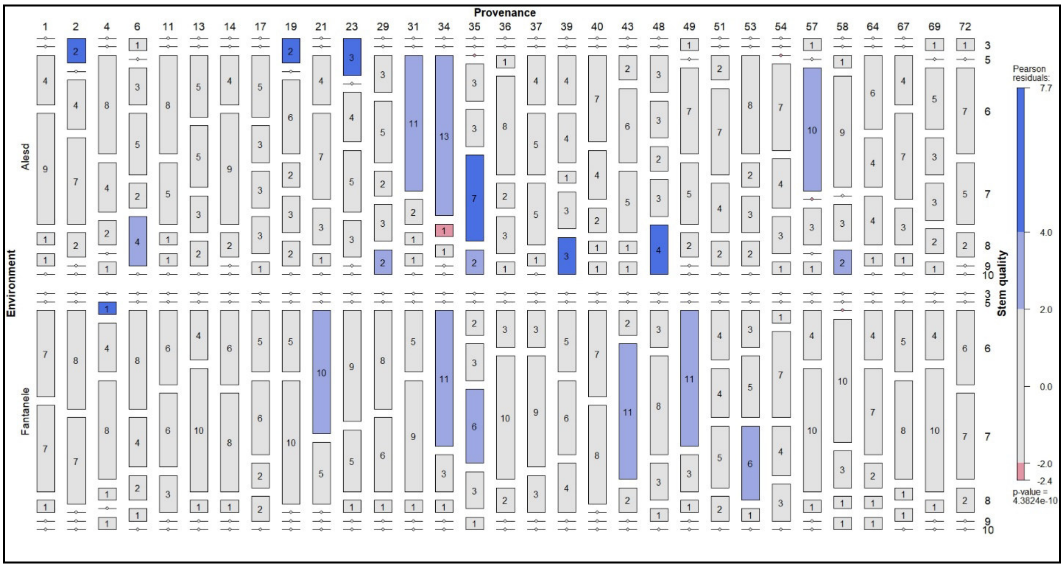

Fig. 7. *Stem quality (Sq) analysis for 1998 provenances; the colours from the graph represent the level of significance: grey = no significance, red = significantly lower values, and blue = significantly higher values; increased colour intensity indicates a higher level of significance*

3.3. Branch Diameter in Relation to the Environment and Provenance

The differences between the environments and provenances, as well as their interaction, were significant in both series (Table 3). Therefore, Bd was influenced by environmental factors, but it was also genetically controlled.

The variation of branch diameter between environments and provenances Table 3

Series	Trait	Influence	Df	Sum sq	Mean Sq	F value	P value
1995	Bd	Environment	1	40.264	40.264	107.894	0.000***
		Provenance	16	11.469	0.717	1.921	0.000***
		Environment: Provenance	16	11.200	0.700	1.876	0.020*
1998		Environment	1	6.542	6.542	13.328	0.000***
		Provenance	30	49.830	1.661	3.384	0.000***
		Environment: Provenance	30	23.044	0.768	1.565	0.028*

The Bd analysis for the 1995 environments (Figure 8) revealed that the provenances had a clearly different reaction. In the Sacele environment, all provenances recorded a higher Bd than in the Carbunari trial, and for the majority, these differences were statistically significant. Therefore, this general reaction of the provenances indicates that the environmental conditions from the cold-humid site (Sacele) influenced the expression of a considerably higher Bd. The lower values of Bd (22%) in the hot-humid site (Carbunari) suggest that provenances are favoured to exhibit a more performant stem in this environment. The Romanian provenance 150 (Sovata) recorded the highest mean Bd in the Sacele trial, and the German provenance 66 (Dillenburg) registered the lowest mean value for this trait in the Carbunari trial. Very close values in the two environments were identified at provenances 92 (Elmstein Sud Appenthal) and 93 (Montabaur), while the provenances with very distinct reactions were 26 (Glorup), 80 (Ebeleben), 94 (Ettenheim), 135 (Medzilaborce), and 150 (Sovata).

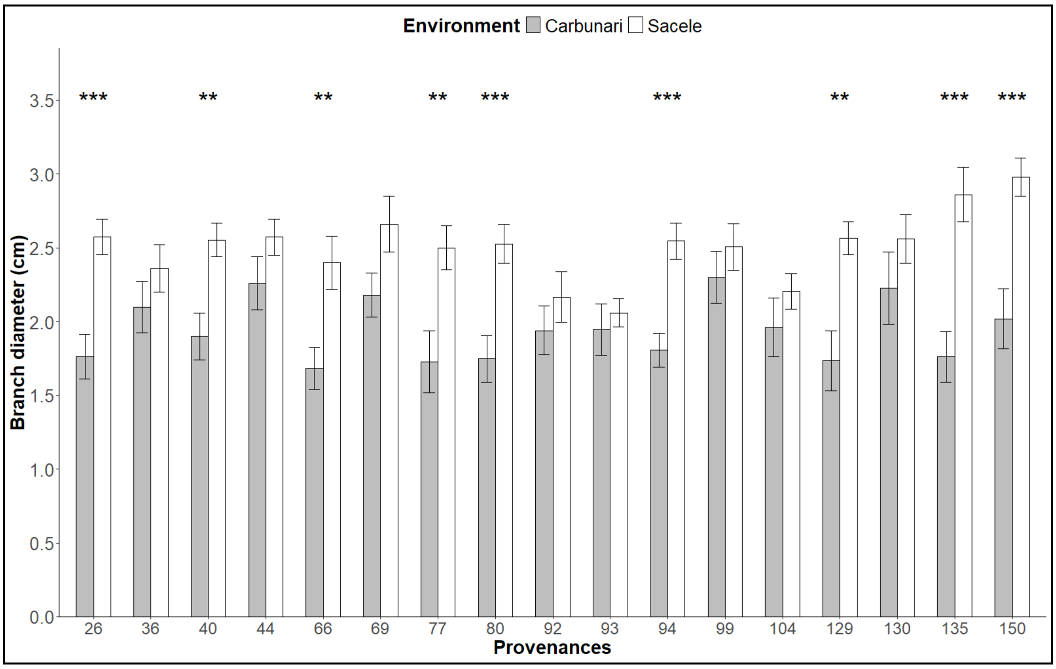

Fig. 8. *Branch diameter analysis for the 1995 provenances; the black stars represent the level of significance revealed by the t-test (* at p < 0.05, ** at p < 0.01, *** at p < 0.001)*

For the 1998 series, Bd was found to have high variability between site and provenances (Figure 9). The majority of provenances obtained high values for this trait in the Fantanele environment (hot-dry), and for some of them, the differences were significant. Thus, the harsh site conditions contribute to the increase in Bd and, at the same time, to a decrease in wood quality. The highest mean value was registered in the Fantanele trial by the French provenance 6 (Plateaux du Jura). Conversely, the lowest Bd was recorded by the Slovenian provenance 54 (Idrija), in the Alesd trial. A contrasting reaction in the two sites was observed in provenances 6 (Plateaux du Jura), 21 (Grasten), 35 (Hinterstoder), 54 (Idrija), 58 (Maglij), and 72 (Bihor-Izbuc), which indicate the high influence of the site conditions in their performance. Apart from provenance 21 (Grasten), which originates from a low altitude (50 m), the rest of the provenances with contrasting reactions were those transferred from altitudes above 600 m. The provenances that were less affected by the change in the environmental conditions were 2 (Bordure Manche), 17 (Westfield), 19 (Chilterns), 31 (Urach), 49 (Brumov-Sidonie), and 67 (Bilowo), which had almost the same mean values for Bd in both environments. Those provenances were transferred from low altitudes sites (50-400 m), except for provenance 31 (Urach). Even if the majority of provenances exhibited a lower Bd in the warm-humid environment (Alesd), provenances like 11 (Heinerscheid), 34 (Oberwil), 36 (Eisenerz), or 64 (Nizbor) recorded lower, but not significant, values in the hot-dry site (Fantanele).

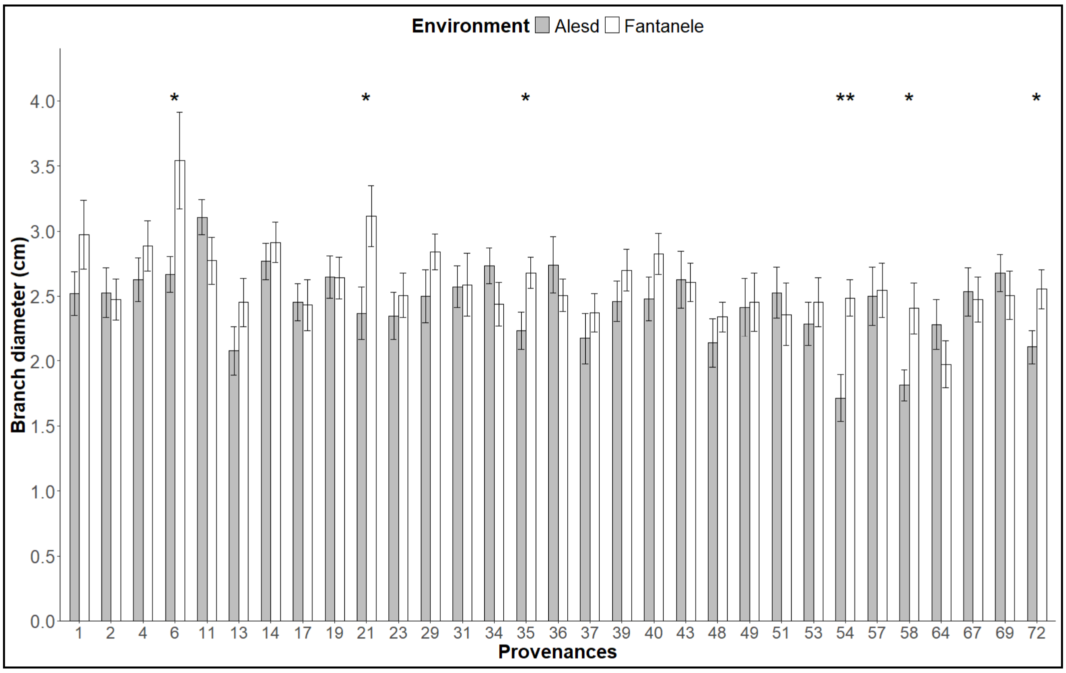

Fig. 9. *Branch diameter analysis for the 1998 provenances. the black stars represent the level of significance revealed by the t-test (* at p < 0.05, ** at p < 0.01, *** at p < 0.001)*

The analysis of Bd revealed that the cold-humid (Sacele) and the hot-dry (Fantanele) sites contributed significantly to the increase of this trait, while in the hot humid (Carbunari) and warm-humid (Alesd) sites, the values were considerably lower. Therefore, the general adaptive response of the provenances regarding Bd can be considered less favourable in the extreme site (Sacele and Fantanele) than in the other two, where the values of this trait indicate a higher level of adaptation (Carbunari and Alesd). The provenances that stood out for the lowest Bd were the German provenance 66 (Dillenburg) and the Slovenian provenance 54 (Idrija).

4. Discussion

4.1. General Discussion

The stem morphotype can be used as a predictor of beech adaptive reaction because it is strongly associated with the other indicators of adaptation [19]. In the present survey, the traits that account for trees' stem morphotypes (forking, stem quality, and branch diameter) were used to quantify the adaptive response of European beech. The fact that the four sites were different in terms of climatic conditions enabled the opportunity to test the variation of the quality traits in relation to site conditions and provenance. Besides, the large number of provenances included in the study, which were transferred from almost the entire distribution range of species, and the testing sites that are comprehensive for the beech distribution range in Romania, allow for an extensive overview of the adaptive reaction of European beech provenances in the Romanian Carpathians.

4.2. Forking in Relation to the Environment and Provenance

In general, tree forks appear as a result of the influence of environmental factors, but they can also be related to the genetic structure of the population [12]. In this study, the environmental influence on tree forking was confirmed in both series of trials, but the differentiation between provenances was not significant. The results indicated that the extreme sites (cold-humid and hot-dry) affected tree stem performance by determining the occurrence of forks in the lowest part of the tree, which directly decreases the economic value of the tree and confirms the lower adaptive reaction. In contrast, the higher number of no-forked trees, or trees with forks in the upper third of the stem, sustains the fact that beech manifested a higher level of adaptation to the hot-humid and warm-humid sites. The differences between the environments used in this study were also reported in previous studies that focused on the growth and stability analysis of international beech provenances [3, 4]. Other studies also pointed out the lower performance of beech provenances in extreme sites [24, 31]. The provenances with the highest number of no-forked trees were 69 (Budingen, Germany), 130 (Trencin, Slovakia) and 13 (Soignes, Belgium). The weakest performance regarding Fk was recorded in provenances 40 (Bovenden, Germany) and 11 (Heinerscheid, Luxembourg). In line with these findings, Bergkvist [2] mentions that provenance 11 (Heinerscheid, Luxembourg) manifested a high predisposition for forking in an international beech trial from Sweden.

4.3. Stem Quality in Relation to the Environment and Provenance

The quality of beech tree stems was highly influenced by the environmental conditions but also by the provenance, as was previously specified by Del Rio et al., [9]. The present results indicated that the environments characterized as cold-humid

(Sacele) and hot-dry (Fantanele) were related to the presence of a significant number of trees with severe defects (Sq classes from 3 to 6) and a considerably lower number of trees with straight stems (Sq classes 9 and 10). Therefore, these remarks can be considered a sign of a lower adaptation to these environments, which seems to have narrowed the performance of beech provenances and are sustained by other similar findings in provenance experiments [17, 24]. Regarding the provenances, the highest Sq was recorded in the German provenances 77 (Eisenah) and 104 (Zwiesel), as well as in the Austrian provenance 35 (Hinterstoder). Contrarily, provenances 69 (Budingen, Germany), 150 (Sovata, Romania), 2 (Bordure Manche, France), and 23 (Torup, Sweden) obtained the lowest Sq. The high stem quality of provenance 35 (Hinterstoder) was also reported in an analysis of beech provenances in Sweden [2]. The surprising fact is that the Romanian provenance 150 (Sovata), which has one of the weakest reactions in Romanian trials, was one of the top rankings in Sweden in terms of Sq [36].

4.4. Branch Diameter in Relation to the Environment and Provenance

The evaluation of Bd showed a significant variation of this trait between provenances and environments. Thus, this trait that determines wood quality [12] seems to be influenced by site conditions and by the genetic inheritance of the provenances. The analysis of this trait in the four environments revealed that harsh climatic conditions lead to an increase in the Bd of beech and, thus, to lower wood quality. To the same extent, the cold-humid (Sacele) and the hot-dry (Fantanele) sites, which favoured the increase of Bd, sustain the lower adaptive reaction of beech provenances in comparison with a higher level of adaptation to hot-humid (Carbunari) and warm-humid (Alesd) environments. The highest Bd, associated with a low adaptation, was recorded in provenances 15 (Sovata, Romania) and 6 (Plateaux du Jura, France). Opposite results were registered in provenances 66 (Dillenburg, Germany) and 54 (Idrija, Slovenia). These results are contrary to those observed in Sweden by Vanícek [36], where the Romanian provenances obtained the highest performance, and the German provenance 66 (Dillenburg) has one of the lowest performances regarding the presence of spike knots. Therefore, these results confirm that genotypes can be represented by distinct phenotypes in different environments [13].

5. Conclusions

The quality traits analysis revealed that common beech provenances were conditioned by the environment during 24 to 27 years of testing. The site conditions characterized as cold-humid and hot-dry significantly affected the stem morphotype quality compared to hot-humid and warm-humid sites.

In general, international common beech provenances exhibit a positive adaptive reaction to the Romanian testing sites. However, the harsh environmental conditions narrowed the performance and indicated a decrease in their adaptive potential.

The variability in the provenances' adaptive response indicated that assisted transfer might be a feasible solution for increasing the quality of the Romanian beech stands and, to the same extent, raising the economic returns from forests. However, in this process, it is important to prioritize the relationship between provenance performance and the environment to avoid ecological imbalances.

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