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Microenvironment Impact on Survival Rate, Growth and Stability Traits, in a Half-Sib Test of *Pendula* and *Pyramidalis* Varieties of Norway Spruce

Emanuel Besliu [1], Marius Budeanu [1,*], Ecaterina Nicoleta Apostol [2] and Raul Gheorghe Radu [1]

[1] National Institute for Research and Development in Forestry "Marin Drăcea", Brașov St., 13 Closca Street, 500040 Brașov, Romania
[2] National Institute for Research and Development in Forestry "Marin Drăcea", 128 Eroilor Boulevard, 077190 Voluntari, Romania
* Correspondence: marius.budeanu@icas.ro

Abstract: Norway spruce (*Picea abies*) is a tree species with low resistance to wind storms and breakage from snow. In this study, we analyzed the microenvironmental impact on the survival rate (Sr), growth, and stability traits of 25-year-old narrow (*pendula*)- and normal-crowned (*pyramidalis*) spruce varieties in the Măneciu half-sib trial. The replication factor had a highly significant influence ($p < 0.001$) on the growth and stability traits and a significant influence ($p < 0.05$) on the Sr, which confirms the microenvironmental impact. The average Sr was 85% and was 5% higher for the *pendula* variety ($p < 0.05$). For normal-crowned trees, a negative correlation ($r = -0.26$ ***) between the crown diameter and Sr was found, while for *pendula* trees, the correlations were 31% lower, suggesting the *pendula* variety's high adaptation potential to a denser planting scheme. The edge effect affected the Sr of both varieties almost equally, with a 3% superiority for *pendula*. The Sr variations in relation to the slope position indicated that the narrow-crowned variety was less affected by the slope position, while the normal variety showed significant slope variation. The *pendula* variety of Norway spruce could be promoted in afforestation because of its high adaptation plasticity to a denser planting scheme.

Keywords: breeding strategy; global warming; half-sib trial; edge effect; *Picea abies*; microenvironment factors; survival rate

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1. Introduction

Norway spruce (*Picea abies* (L.) Karst.) is considered as one of the most important tree species of Europe [1–6] and has been highly influenced by climate change in recent years [7–11].

Provenance tests are one of the most important forestry techniques that allow breeders to test and select valuable provenances, especially for adaptation capacity [12]. One of the adaptation traits that can be evaluated in trials under different site conditions is the survival rate. To better understand the ecology of an organism, it is essential to understand what factors and processes have influenced its survival [13]. Studies in this area are more focused on finding explanations for mortality, which is considered as one of the most important and least understood processes that are present in forest ecosystems [14] and is an underlying process of forest succession [15]. Tree mortality is directly influenced by inter-tree competition, which leads to a gradual decrease in growth until the death of some trees [15] and tends to affect forest processes and structure even at old ages [16]. However, even if the tree mortality process is clearly influenced by tree competition, only in rare cases is it the main cause of tree mortality [17–19]. Regarding the survival of trees, Bravo-Oviedo et al. [20] observed that the trees' dimensions, competition amongst them, and environment quality conditioned the survival of *P. sylvestris* and *P. pinaster*, but in different ways. Another study revealed that a large diameter, as in the case the of Pyrenean

oak, indicates a lower probability of mortality and thus a high probability for survival [14]. In the case of Norway spruce, studies have shown that the mortality of this species is influenced by intraspecific competition, growth rate [16,21], age [22], fungal infection [23], insect attack [24], and environment-disturbing factors such as windstorms and breakage from snow [25–27]. It is recommended to replace spruce monocultures with spruce–beech–fir mixed forests because of the potential of this type of forest to resist windstorm [26] and also to increase the water availability in the soil [28].

In recent decades, the problem of climate change and how these changes will affect forestry species has been one of the most studied subjects [8,9,11,29]. Therefore, in a changing climate, it is crucial to find and promote provenances and intraspecific varieties that show superior resistance to disturbance factors [30–38]. Current genetic research has shown that one of the necessary conditions for populations to adapt to changing climatic conditions is a high genetic diversity [39–41]. In recent decades, numerous studies have investigated the resistance, recovery, and resilience of tree species to drought [42–47]. In most cases, Norway spruce showed the lowest resilience, compared to beech, fir, and pine.

Studies that show the superiority of the narrow-crowned Norway spruce ideotype (*Picea abies* f. *pendula*) compared to the normal-crowned (*pyramidalis*) variety regarding the growth traits, wood quality, and resistance to windstorms and breakage from snow have been carried out mostly in Finland [48–50] and Romania [26,36,40,51,52].

In Romania, these varieties of spruce were tested in full-sib and half-sib trials [26,36,51], and the results showed that the *pendula* form is superior to the *pyramidalis* variety for most of the investigated traits (tree height, tree slenderness, survival rate, number of branches in a whorl, branch thickness, and crown diameter), with the highest inheritance rate registered for tree slenderness. The results obtained from laboratory tests regarding the mechanical wood resistance revealed the superiority of narrow-crowned spruce, both for old (Stâna de Vale, 140 years) and juvenile (Comandău trial, 23 years) populations, but the differences were significant ($p < 0.001$) only in the old natural population (Porojan and Budeanu, personal communication).

Considering these results, in this study, we aimed to assess the influence of the microenvironment on the survival rate, growth, and stability traits in a Măneciu half-sib trial of the normal- and narrow-crowned ideotypes of Norway spruce from Romania. The objectives were: (1) to reveal if there are any differences between the two forms of spruce regarding survival rate and (2) to show whether the microenvironment condition affects the survival rate, growth and stability traits.

2. Materials and Methods

The Măneciu half-sib comparative trial was established in the spring of 1994 in the Curvature Carpathians of Romania (Figure 1) under the optimum environmental conditions for Norway spruce [51]. This trial is part of two comparative trials of maternal descendants, installed at Măneciu and Soveja, using seeds harvested from 48 trees (24 *pendula* and 24 *pyramidalis*) that correspond to the eight provenances situated in the Carpathians Mountains. From the eight selected populations, seven are natural and one, Bozovici, is an artificial population planted outside the spruce's natural distribution range [26]. The Stâna de Vale provenances (1 and 2) are located in the western part of the Apuseni Mountains at an altitude of 1200 m (a.s.l.); additionally, the Cetățile Ponorului provenance (5) originates from the same part of the Apuseni Mountains, but from an altitude of 1050 m. The other two provenances from the Apuseni Mountains (Izbuc 3 and 4) are located in the eastern part, at an altitude of 1250 m. The Bozovici provenance (6) is situated in the Banat Mountains at the lowest altitude, at 600 m, outside the natural distribution range of spruce. The Horoaba (7) provenance is located in the southern part of the Curvature Carpathians at the highest altitude (1675 m), while the last provenance, Cucureasa (8), is situated at the altitude of 935 m in the Eastern Carpathians [26,51]. The descendants of *pendula* spruce from provenance 1 were given codes from 1 to 3, while the *pyramidalis* descendants of the same provenance (1) were assigned codes from 25 to 27. The experimental design used in

this trial was an incomplete balance design with four replications and 4–12 seedlings per block that were planted with spacings of 2 by 2 m [51]. Regarding the trial site conditions, the Măneciu trial is situated at an altitude of 820 m, on a slope with a southern exposition that has a surface of 1.1 ha and a 10° incline. The soil is typical eutricambosoil, and the natural forest type is normal beech with mull flora of superior productivity [53].

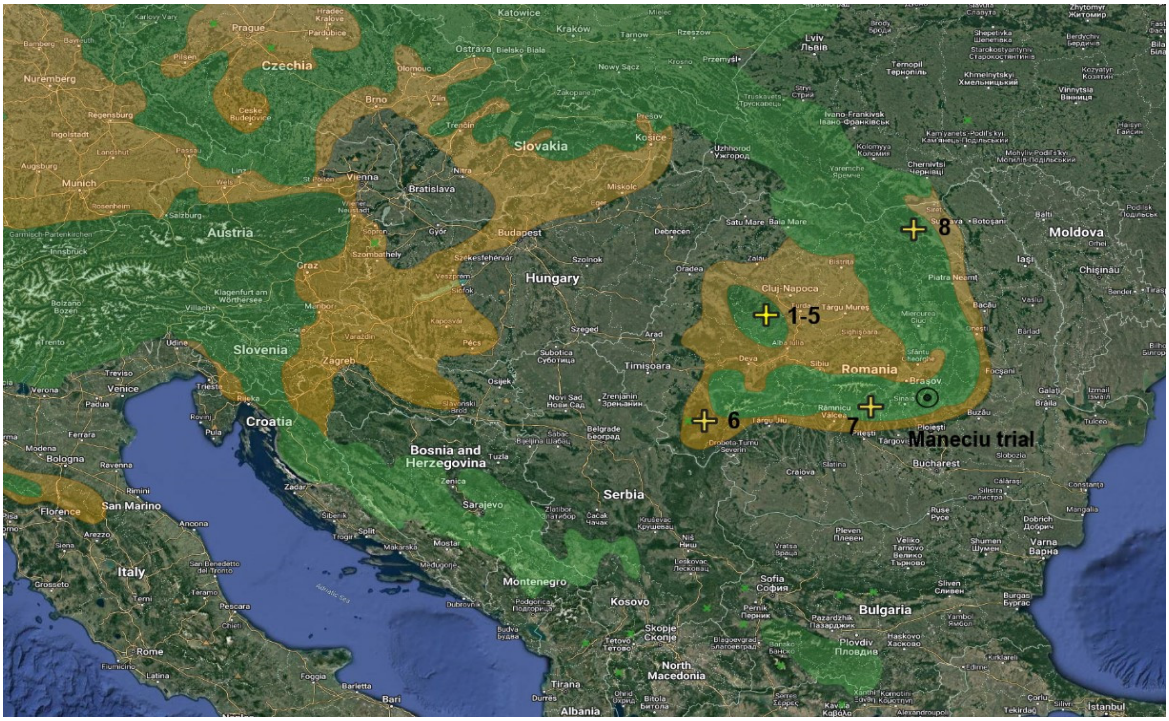

Figure 1. Natural (green) and artificial (yellow) distribution map of Norway spruce [54], origins of *pendula* provenances, and the location of the Măneciu trial.

The survival rate (Sr), tree height (Th), diameter at breast height (Dbh), tree slenderness (Ts), and crown diameter (Cd) were measured for 24 families of the *pendula* variety and for 24 families of the *pyramidalis* variety; both varieties were 25 years of age. In addition, we used a cross validation mortality check using capture images (Figure 2) with an unmanned aerial vehicle (UAV) processed in Qgis software (version 3.24) [55].

In the case of survival, the number of trees that were alive was counted, and the survival rate (Sr) was calculated at the family level as a percentage between the initial number of trees that was planted and the number of the trees that had survived until the age of 25 years. The results were analyzed separately for the two spruce varieties at the replication level, at the provenance level, at the family level, and for the entire trial in the R environment [56]. Pearson's correlation was applied to determine any links between the Sr and growth traits.

We attempted to capture the microenvironment impact by analyzing the results of the Sr in terms of the edge effect and slope position. Regarding the edge effect, we considered that the influence of this factor affected the families that were positioned at the edge of the trial area and had less than two outline rows with trees. The percent of the affected perimeter was measured, and the families that were situated in the edge area of the trial were assigned the code 1 (affected families); the families that were not affected by the edge effect were assigned the code 0 (unaffected families). The effect of slope position was divided into three categories: inferior slope position (1), represented by the inferior third part of the slope (where the terrain has no incline and a plain surface); middle slope position (2), characterized by an incline of 20° and an undulate surface; and superior slope position (3), with a 20° incline and a strongly undulate surface.



Figure 2. The spatial distribution of families (yellow), replication (blue), perimeter affected by marginal effect (orange), and the slope position (red).

The families that had a low Sr, and, thus, more space for development, were compared with those that had high values for the Sr, and, thus, a small space in which to grow and have strong competition. This comparison was made in order to highlight the influence of competition on the growth and stability traits and to show differences between narrow- and normal-crowned spruce regarding the ability to use the growing space.

3. Results

3.1. Survival Rate

The Pearson correlation between the Sr and growth-stability traits (Dbh, Th, Cd, and Ts) for the two varieties of spruce showed that Cd was the only trait highly significantly correlated with Sr. Regarding the correlation of the Sr with Cd for normal-crowned spruce, we identified a negative correlation ($r = -0.26$ ***), meaning that a lower Sr tends to increase the crown diameter. In the case of *pendula* trees, the correlations were 31% lower, suggesting a high potential of adaptation to a denser planting scheme, but also a better utilization of a larger space.

The trial mean of the Sr was 85%, and the difference between the two varieties of spruce was distinctly significant ($p = 0.006$), with a clear superiority (5%) for *pendula* trees. Regarding the four replications, it was observed that the narrow-crowned spruce showed a high homogeneity and had Sr values above the trial mean in all four replications, while the normal-crowned spruce had Sr values above the trial mean only in two replications (Figure 3). In addition, it was observed that the replication factor had a highly significant influence ($p < 0.001$) on the growth and stability traits and a distinctly significant influence ($p < 0.01$) on the Sr (Table 1). The best results for the Sr were recorded in the third replication for the *pendula* variety (91%), and the lowest Sr was observed in the first replication for the *pyramidalis* variety (76%).

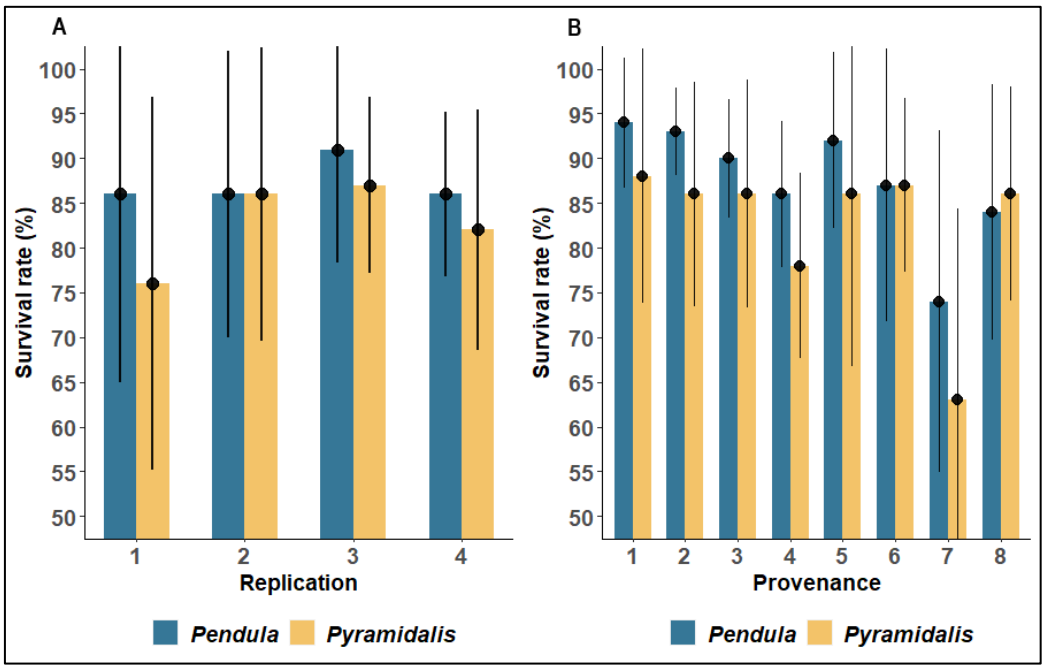

Figure 3. The variation of Sr in the four replications (**A**) and among provenances (**B**). The black vertical lines represent the standard deviation.

Table 1. ANOVA for Sr in the Măneciu trial.

	Survival Rate (%)			
Factors	**DF**	**SS**	**MS**	***p***
Replication	3	1824	608.1	0.005 **
Crown form	1	1069	1068.8	0.006 **
Provenance	7	8792	1256.0	0.000 ***
Marginal effect	1	932	931.6	0.010 *
Slope position	2	3990	1995.2	0.000 ***
Error	177	24,633	139.2	-

DF = degrees of freedom, SS = sum of squares, MS = mean square. Significant differences ($p < 0.05$, *), distinctly significant ($p < 0.01$, **), and highly, significant ($p < 0.001$, ***).

The initial observation from the results of the Sr recorded for the provenances (Figure 3) concerned the low values obtained for provenance 7 (Horoaba), which originates from the highest-altitude area. The provenance analyses revealed that narrow-crowned spruce was superior to normal-crowned spruce (highly significant differences) and obtained values over the trial mean for almost all of the provenances. The only provenance where *pyramidalis* spruce was superior was Cucureasa (8). In the case of provenance 6 (Bozovici), from outside of the natural distribution range of Norway spruce, *pendula* and *pyramidalis* spruce had the same value for Sr (87%), which was higher than that of the trial average.

At the family level, *pendula* spruce had the same superiority to *pyramidalis* regarding Sr. The narrow-crowned spruce family with the best results was family 14 (Sr = 97%), and for normal spruce, this was family 33 (Sr = 94%). On the other hand, the families with the lowest Sr values were family 19 (69%) for the *pendula* variety and family 44 (54%) for the *pyramidalis* variety, both from the Horoaba (7) population.

The survival rate influences on the growth traits (Dbh and Th) showed that narrow-crowned spruce could better use the growth space because for both traits, we found almost the same values for low survival rates (25–50%) where there was more space to grow like for the high survival rates (100%), where the competition between trees was much more intense. A higher homogeneity was registered for Th than for Dbh (Figure 4).

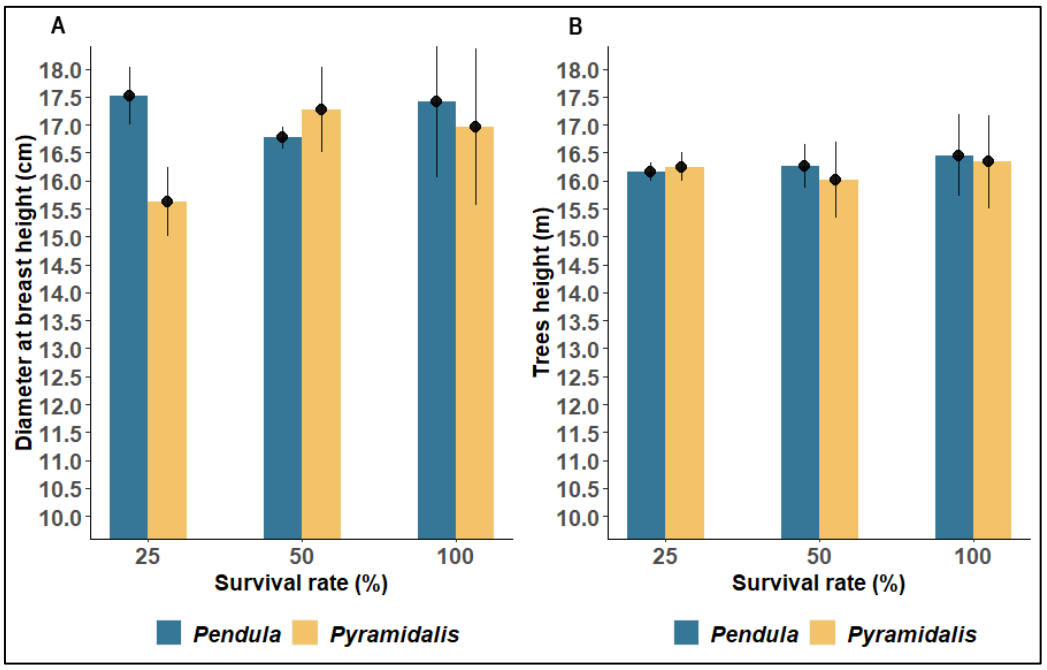

Figure 4. Variation in the growth traits: diameter at breast height (**A**) and tree height (**B**) by survival rate. The black vertical lines represent the standard deviation.

In the case of the crown diameter, at the age of 25 years, the *pendula* variety had smaller crowns than the *pyramidalis* variety (highly significant differences, $p < 0.001$) at both low and high survival rates. Regarding Ts, the *pendula* trees seemed to be more stable than the *pyramidalis* trees at both low and high survival rates, but with no significant differences (Figure 5).

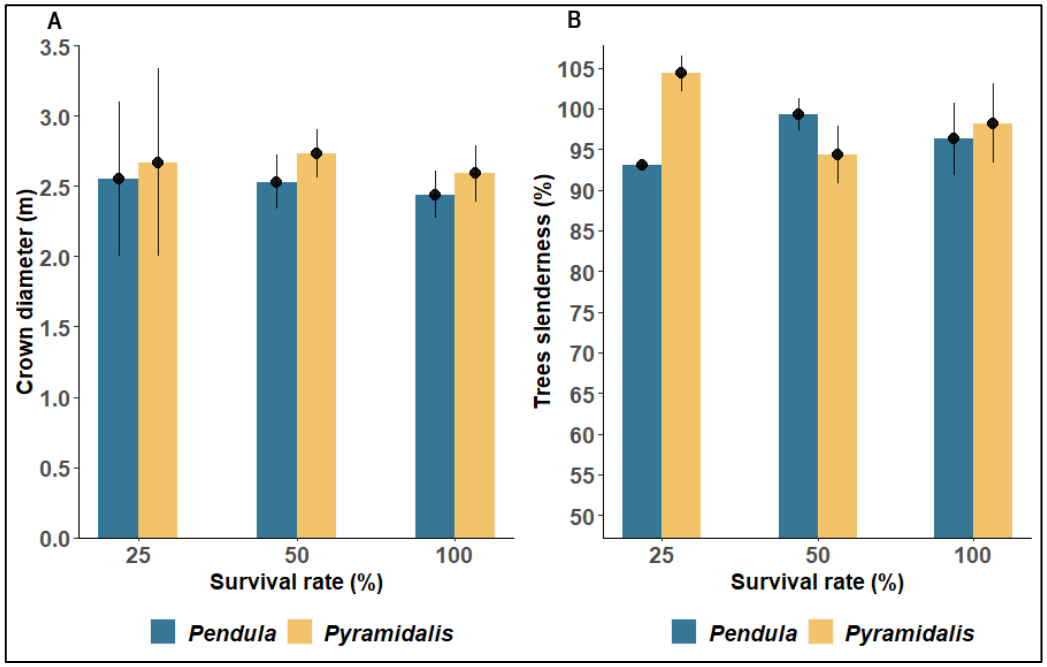

Figure 5. Variation in stability traits: crown diameter (**A**) and tree slenderness (**B**) by survival rate. The black vertical lines represent the standard deviation.

3.2. Edge Effect

The edge effect had different impacts on the Sr of the four replications in the Măneciu trial. The first and fourth replications that had 28% of their perimeter situated in the edge showed an Sr that was 6% lower than that of the other two replications (second and third) that had only 5% of their perimeter affected by the edge effect. Additionally, the number of families with an Sr = 100% was 18% higher in the second and third replications than in the first and fourth replications. The *pendula* variety had a 4% higher number of families with Sr = 100% than the *pyramidalis* variety (no significant differences, $p > 0.05$) in the edge areas.

On average, the *pendula* variety showed a 3% higher adaptability to the edge effect (Figure 6) than normal spruce as well as higher Sr for the unaffected families ($p > 0.05$). Differences between the affected and unaffected families were distinctly significant ($p < 0.01$), and it was found that the Sr of the unaffected families was higher.

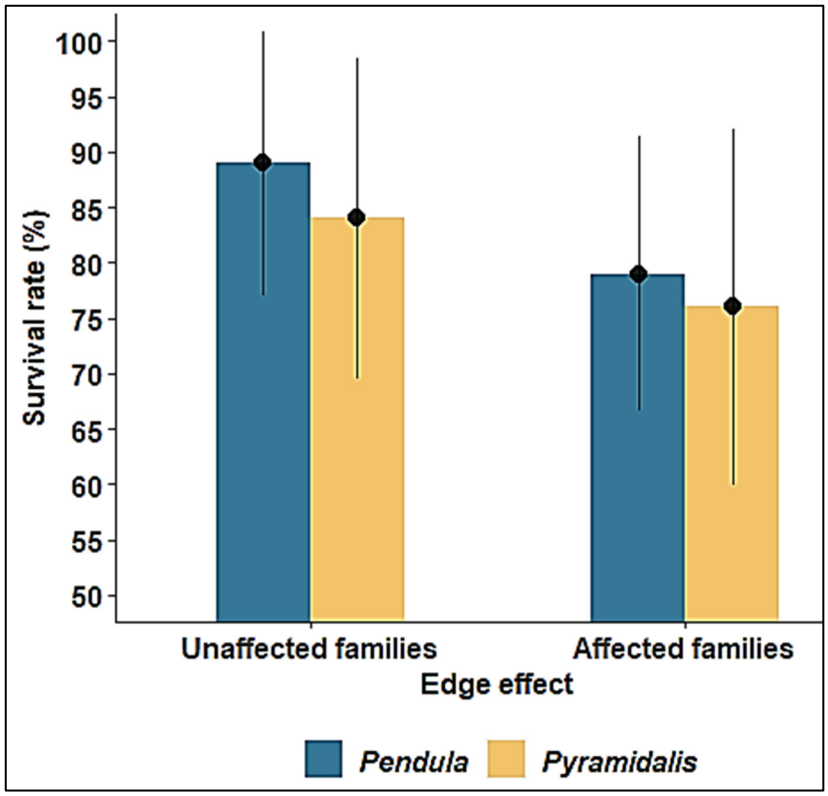

Figure 6. The influence of the edge effect on the survival rate of the two spruce varieties. The black vertical lines represent the standard deviations.

The families situated at the edge of the trial area obtained lower values for growth traits than families that were not influenced by the edge effect for both varieties of spruce. The *pendula* variety showed slightly superior (statistically insignificant) results for both growth traits in comparison to the *pyramidalis* variety within the group of families affected by the edge effect (Figure 7).

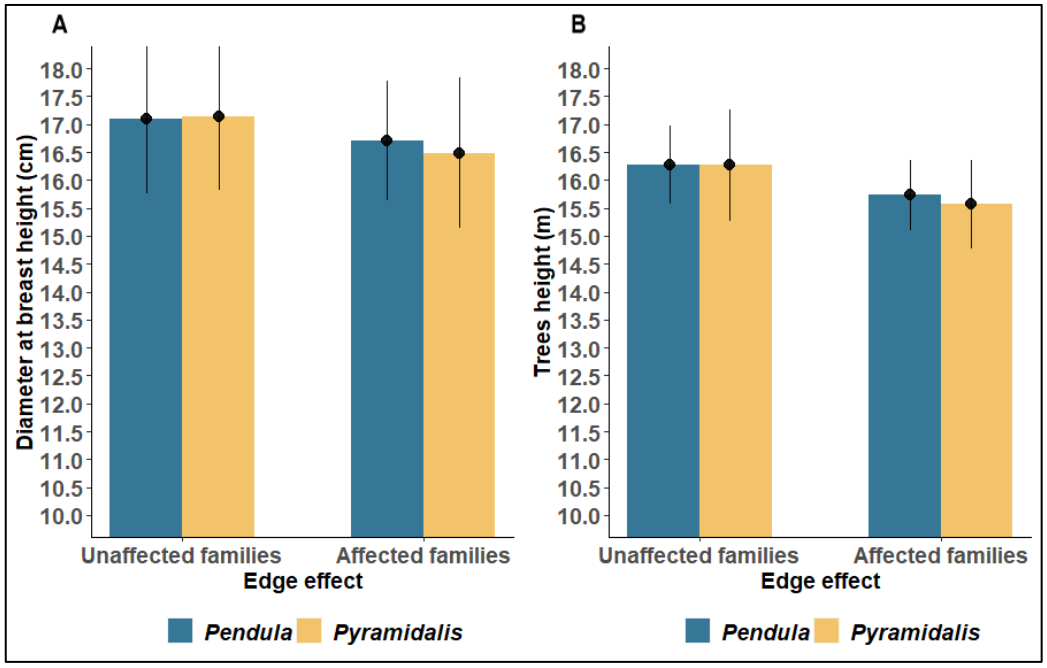

Figure 7. Variation in the growth traits: diameter at breast height (**A**) and tree height (**B**) by the edge effect. The black vertical lines represent the standard deviation.

Regarding the stability traits (Figure 8), highly significant differences ($p < 0.001$) between the two varieties of spruce were found for Cd in the case of the unaffected families, and the *pendula* trees recorded almost the same crown diameter and tree slenderness in both the affected and unaffected families. This again shows the high adaptative capability of this variety of spruce to variations in the microenvironment conditions.

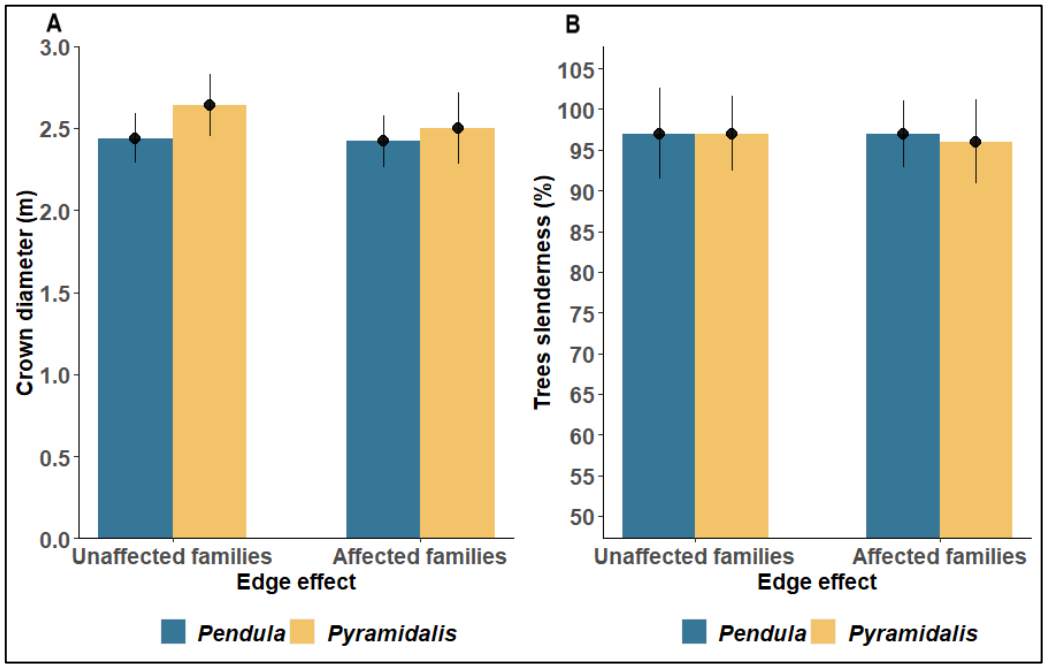

Figure 8. Variation in the stability traits: crown diameter (**A**) and tree slenderness (**B**) by the edge effect. The black vertical lines represent the standard deviation.

3.3. Slope Position

Slope position was one of the microenvironmental factors that influenced the survival of the trees in the Măneciu trial, and the Sr differed significantly between the three slope positions for both varieties of spruce ($p < 0.001$).

At the base of the slope (the inferior third of it), the Sr of *pendula* was 12% superior to that of the normal-crowned variety (significant differences, $p < 0.05$). The influence of the middle slope position on the Sr of the *pendula* and *pyramidalis* spruce varieties illustrated that the two varieties of spruce did not differ significantly, but in the case of the superior slope position, once again, the *pendula* spruce had a significant advantage over the *pyramidalis* variety (Figure 9).

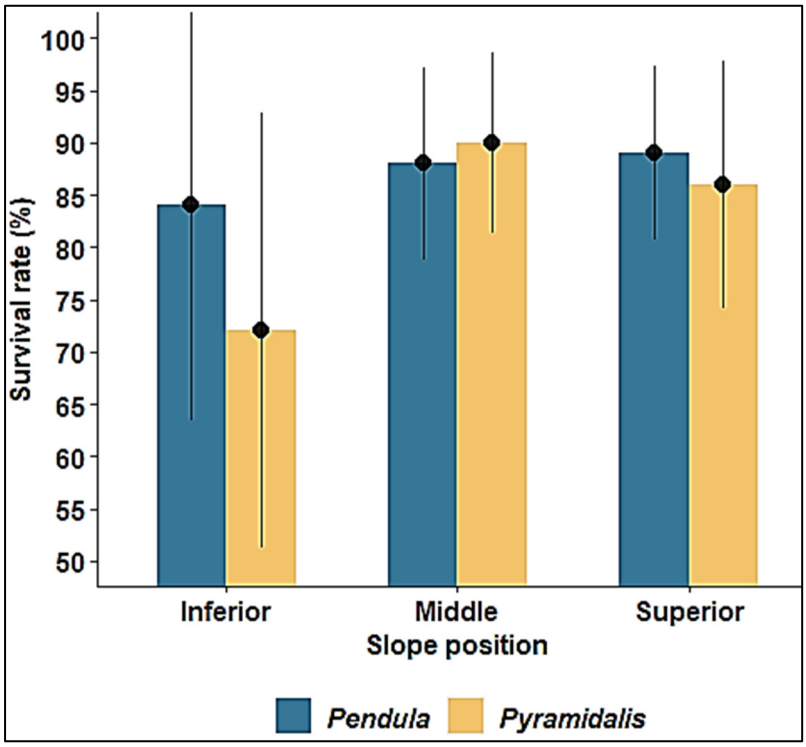

Figure 9. The influence of the slope position on the survival of the two spruce variety. The black vertical lines represent the standard deviation.

The growth traits of both varieties of spruce seem to have values below the trial mean in the case of superior slope positions, so this position on the slope seems to be less convenient for both varieties of spruce (Figure 10). In general, the *pyramidalis* spruce obtained slightly superior values for growth traits in comparison to the *pendula* trees (insignificant differences, $p > 0.05$).

The variations in the stability traits by slope positions (Figure 11) show that the *pendula* variety had smaller crown diameters in all slope positions ($p < 0.001$), so this trait is unaffected by the environment conditions, thus being a genetically controlled trait. For the tree slenderness, both varieties obtained lower values and a high stability in the middle slope position, with no clear differences between them.

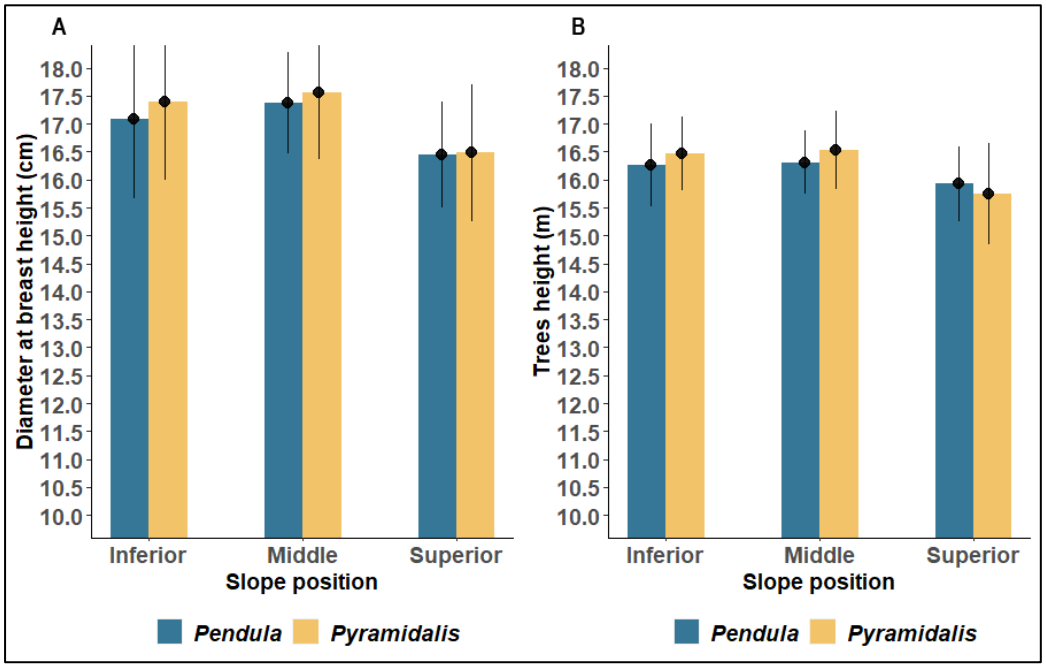

Figure 10. Variation in the growth traits: diameter at breast height (**A**) and tree height (**B**) by the slope position. The black vertical lines represent the standard deviation.

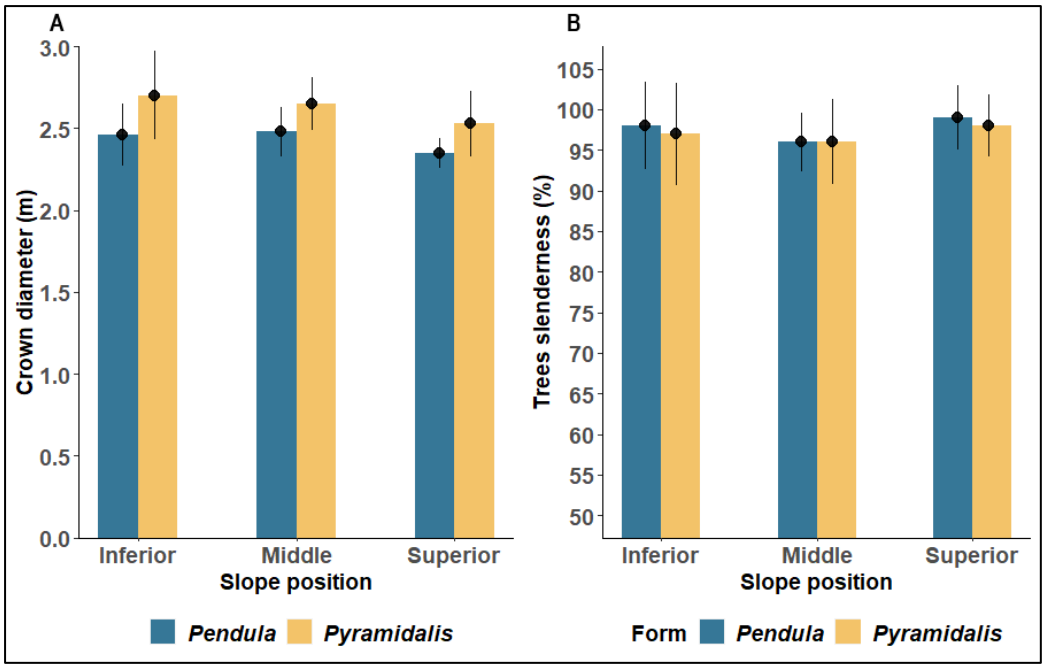

Figure 11. Variation in the stability traits: crown diameter (**A**) and tree slenderness (**B**) by the slope position. The black vertical lines represent the standard deviation.

4. Discussion

In this study, we evaluated the microenvironmental factors that influence 48 families of the *pendula* and *pyramidalis* varieties of Norway spruce by analyzing the results of the Sr at the trial level and between replications, variety, and family as well as in terms of the edge effect and slope position. The results showed that both varieties of spruce obtained a good level of survival, but the *pendula* variety was superior to the *pyramidalis* variety and obtained a 5% higher Sr (results confirmed from orthophoto images). We also observed that the narrow-crowned spruce was less affected by the microenvironmental factors compared

to the normal spruce, and this can be considered as a remarkable ability if we consider the actual problems of global climate change.

In the case of *pendula* trees, we observed that at lower Sr values, the Ts tended to become closer to the stability values described by Popa [25], meaning that this variety can better resist windstorms and breakage from snow.

For the selection of provenances for the next generation of trees with good survival abilities, *pendula* varieties with provenances from the Apuseni Mountains, especially Stâna de Vale (1 and 2) and Cetățile Ponorului (5), must be included. The lower Sr values obtained for provenance 7 (Horoaba) in the highest-altitude area confirmed the fact that the transfer of a forest's reproductive materials requires maximum caution because the incorrect use of these materials can produce serious disturbances in forest ecosystems and can lead to reduced productivity of the forests [36,52,57]. The result for the replications showed that this factor had a highly significant influence on the growth and stability traits, and this fact confirms the necessity of establishing a trial with replications in order to reduce the microenvironmental influence [26,36,40].

The survival of Norway spruce trees has been described as being linked to growth traits, thus, trees with a small diameter and slow growth increases have a greater probability of dying, so trees with a larger diameter are more likely to survive [21]. In our study, we observed that the Sr was higher in spruce with a small crown diameter than in spruce with larger crowns, so narrow-crowned spruce has an advantage in terms of the Sr because it is known to have smaller crowns. In addition, our findings are in contrast to the results obtained by Sterck et al. [58] in a tropical forest, where the Sr was higher when the number of leaves and crown diameter were larger.

Ruiz-Benito et al. [59] mentioned that the tree dimensions and competition were the most important factors that influenced tree mortality, but that the temperature and soil proprieties also played an important role in this process. If we analyze the potential of narrow-crowned spruce to survive better than normal spruce in conditions of high competition, we can sustain the idea of using the narrow-crowned spruce in afforestation because of the high potential of the *pendula* variety to use the growing space, to better cope with the competition, and because this variety of spruce is less affected by the microenvironmental factors. Additionally, these findings are in agreement with the results obtained by Zubizarreta Gerendiain et al. [49], who observed that narrow-crowned spruce was less affected by competition and could better utilize the growing space.

The edge effect increased the probability of mortality due to trees being vulnerable to wind damage when they were situated at the edge of the trials or where there was no protection from other trees [60]. In accordance with this, we observed that families situated at the edge of the trial area, and without protection from other trees, had a lower Sr than the other families. Another important finding is that the *pendula* spruce obtained slightly superior Sr results in the case of families affected by the edge effect. The growing conditions in the edge perimeter were influenced by wind, but also by other factors such as snow, high temperatures, insolation, poor water reserves, and different anthropogenic activities that lead to significant losses in the case of trees from this area. Considering these results, we recommend using border rows (a minimum of two rows), especially for Norway spruce comparative trials, in order to reduce the influence of disturbance factors that affect trees at the edge of trial areas.

Balazy et al. [61] studied the influence of slope position on the height increments of Norway spruce, and found that the height increment of spruce trees was higher when the slope increased from 0° to 15°, but after this point, no differences in the height increment between slope positions were recorded. These results are in accordance with our findings because we observed the same differences in the growth traits between the part of the slope with a plain surface and the part with a 20° incline (in the case of the higher slope position, we recorded a decrease in the growth traits). In addition to these findings, we also observed that the Sr of the normal-crowned spruce was clearly lower in the case of lower slope positions than the Sr obtained in the narrow-crowned spruce, so the normal spruce seemed

to be more affected by the inferior position of the slope where growth is conditioned by factors such as cold air and excess water. It is worth noting that the narrow-crowned spruce seemed to be less affected by the slope position because this variety had Sr values close to those of the trial average in all slope positions; therefore, this result reveals the strong adaptability of this variety of spruce. In contrast, it appeared that the normal-crowned spruce was clearly affected by a lower slope position. However, the *pyramidalis* variety obtained the highest Sr in the middle slope position, which seems to be the preferred position for this variety of spruce.

Future research will be focused on long-term observations and on developing an algorithm to automatically process data captured by UAV sensors regarding the survival rate of the two varieties of spruce in multisite trials in order to increase our knowledge regarding the influence of microenvironmental factors on the survival rate of Norway spruce.

5. Conclusions

Some microenvironmental factors that condition the growth and stability of Norway spruce in the Măneciu comparative trial include the edge effect and slope position. The survival rate of the entire trial was 85%, and the *pendula* variety of spruce obtained Sr values 5% higher than those of the *pyramidalis* variety. For normal-crowned trees, a negative correlation ($r = -0.26$ ***) between the crown diameter and Sr was found, while for *pendula* trees, the correlations were 31% lower, suggesting the *pendula* variety's high adaptation potential to a denser planting scheme.

Regarding the edge effect and slope position, the narrow-crowned spruce obtained slightly superior results in comparison to normal spruce, being less affected by the microenvironmental factors. This capability allows the *pendula* spruce to cope with different disturbance factors and increases the value of the growing space.

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