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Research on the variability of *Picea abies* in Poland: genetic and breeding value of spruce populations in the Polish range of the species

Abstract: The work outlines the directions in the past and present research into the variability of Norway spruce in Poland, and presents the results of provenance experiments concerning the genetic and breeding value of provenances tested in the Polish range of spruce distribution. The Istebna race proved to have a good value, however, so far only the progeny of single stands have been tested. It is thus necessary to determine the range of distribution for this race. The altitude of the location of mother stands significantly correlates with the genetic and breeding value of their progeny cultivated at different altitudes. This suggests that the altitude and exposure of plantations to be established in mountain forest belts should be specified for individual provenances (altitudinal zoning). New inventory provenance tests should be run under varied site conditions to assess both the genetic value and plasticity range of the provenances. In view of the biotic and abiotic threats facing spruce, there is a need to work out detailed programmes designed to preserve its genetic resources in gene banks and *in vivo* archives.

Additional key words: Norway spruce, provenance test, intra-population variability, gene resources, altitudinal zoning

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Introduction

Norway spruce (*Picea abies* (L.) Karst.), along with pine, counts among the economically most important forest tree species in Poland owing to the large area it covers (6% of the total forest area of the country; Forests in Poland 2006), and the substantial volume of timber production. Being as a rule an admixture species, it forms pure stands at higher altitudes, between 1000 and ca. 1500 m a.s.l. Although much effort has been devoted to investigating the intra-population variability of Norway spruce, especially in Germany and Scandinavia, and the results clearly point to its polymorphism (Schmidt-Vogt 1977), the knowledge of the genetic variability of partial populations of spruce is still insufficient. The present work gives a brief overview of the studies in this field in Poland and summarises the results of provenance tests.

Fields of research

The issue of Norway spruce's genetic variability has long attracted interest among Polish scientists. As early as the first half of the 20th century, thanks to the activity of Prof. S. Tyszkiewicz, spruce provenances from Poland (Białowieża, Istebna, Garbatka-Radom, Stolpce, Wilno, and Dolina) were included in the collection of progenies tested in UFRO's first experiment of 1938. Due to the military operations of World War II, however, this trial has not survived in our country. New impetus to the genetic variability studies was given by establishing a

UFRO 1964/68 test site in Krynica. This was done in 1968 by Prof. S. Bałut on the initiative of Prof. T. Krzysik, using 1096 Norway spruce provenances, among them 91 provenances from Poland. Other important developments in this field include international and national provenance trials such as IUFRO 1972 with 20 Polish provenances (Assoc. Prof. S. Kocięcki) and earlier experiments conducted at the Forest Research Institute (Tyszkiewicz 1969) and the Institute of Dendrology, Polish Academy of Sciences, in Kórnik. The results of those provenance tests provide a basis for determining the race variability and the genetic and breeding value of Norway spruce in the Polish range of the species (Kocięcki 1968, 1977).

The IUFRO 1972 trial carried out on the Siemianice site confirmed a high breeding value of the Beskid Mts. spruces, among them the Istebna 149 h population, as well as populations from the area of the dispersed occurrence of spruce (Roztocze, Świętokrzyskie Mts.) and from the Sudetes (Stronie Śląskie) (Barzdajn 1994, 1995a, b, 1996a, b, c, 1997, 2003; Barzdajn and Kowalkowski 2001). As in other studies, the population from the Tatra Mts. (Witów) differed from the others in height growth and phenology. Analyses of the adaptation, height growth, phenological and morphological traits provided evidence to confirm that the spruce in Poland is divided into two distinct groups: Hercyno-Carpathian and boreal. This finding was supported by the results of a morphological analysis of cones: those of spruces from the Hercyno-Carpathian range had mostly scales of *europaea* form, whereas those from the boreal range, exhibited an *acuminata* form of scales. However, one of the Carpathian populations (Tarnawa) showed similarity to the boreal spruces.

The research results on the population variability of spruce in Poland were summarised in monographs worked out by many authors, e.g. Tjoelker et al. (2007), and in conference proceedings. The genetic variability of Polish provenances, studied in provenance experiments, was thoroughly discussed in several joint publications such as the proceedings of the conference devoted to the studies of Norway spruce in Poland, organised by the Institute of Dendrology, Polish Academy of Sciences, in Kórnik in 1967; the work *Population studies of Norway spruce in Poland*, published in 1968 by the Forest Research Institute, Warsaw; monographs on spruce of 1977 and 1998; and a synthesis of the experimental results of IPTNS-IUFRO 1964/68 (Bałut and Sabor 2001, 2002). This list of works is supplemented with the proceedings and proposals from the conferences, taking place in Poland in the years 1994–1998, on the races of mountain spruce in the Carpathians and Sudetes, and the populations of lowland spruce from the northeastern range of the species. The findings included in those publications confirm a good genetic and breeding value of the Polish races of Norway spruce.

Another important field of research comprises physiological and biochemical studies. Those include the long-term investigations of spruce carried out by Chmura (2006) and others at the Institute of Dendrology, Polish Academy of Sciences, in Kórnik; phenological studies of spruce provenances from the Beskid Mts., conducted by Rudawska et al. (2006); research by Trocha et al. (2006) on spruce ectomycorrhiza; investigations by Oleksyn et al. (2006) into the growth response of spruce to climatic altitudinal gradients in the Tatra Mts.; research by Misiorny (2007) on the polymorphism of the generative organs of spruce; studies by Misiorny and Chałupka (2006) on the variation in flowering phenology of spruce in second-generation seed orchards; works by Szczygieł et al. (2007) on somatic embryogenesis; and investigations by Finer et al. (2007) into the variation in the root system.

The establishment of so-called reconstitution and outbreeding orchards for the spruce populations threatened with extinction, and the genetic evaluation of seed orchards comprising clones from geographically distant provenances (Chałupka et al. 2008, 2009) have great significance to the preservation programmes of the Norway spruce gene resources. Yet another examples of recent studies on the genetic structure of spruce stands in Poland are the advanced research conducted by Nowakowska (2004) and Prus-Głowacki et al. (2007), to mention a few.

Many biotic and abiotic factors have predisposed Norway spruce to being one of the most endangered species. Especially in the last years, spruce populations in the Polish range of distribution have suffered from a so-called spiral disease, i.e. forest decay whose symptoms include dead branches, slow growth, and reduced assimilatory apparatus, finally leading to the death of trees. What really concerns foresters is that whole forest stands and even ecosystems are caused to die. The disease has been brought about by environmental pollution, droughts, winds, attack of pathogenic fungi and insects, as well as by the global warming of climate. It is believed that the foreign origin lies at the roots of the weakening of spruces (Barzdajn et al. 2003). The mass decline of spruces in Poland manifested itself in the Sudetes (ecological disasters in the Izerskie Mts. and the Karkonosze Mts.), and more recently in the Silesian Beskid Mts. and the Żywiecki Beskid Mts. (Sierota 2001). The decay process affects also the internationally famous Istebna spruce population of highest genetic value. For example, as a result of the ecological disaster, the Istebna population lost 16% of seed stands and over 35% of plus-trees only in the year 2008 (J. Urbaczka, M.Sc. thesis, UR Kraków 2008). This suggests that effective programmes should be implemented to preserve the genetic resources of the species.

It seems that the results of studies carried out at the Agricultural University in Vienna may provide a reliable basis for preparing a forecast of the future climate changes in Poland. As suggested by Kromb-Kolb (2002), the climate changes in Europe have both a global and local nature, and vary according to time and space. To produce an accurate long-range forecast, it is necessary to consider the trends in temperature and precipitation.

Scientists predict a 0.1–0.4°C rise in air temperature in southern and northeastern Europe, dramatic winter warming in the continental climatic zone, and substantial difference in mean temperature between the North and the South of Europe in the summer season. It is expected that precipitation totals will increase by 1–4% in winter and by 2% in summer in the North, and decrease by 5% in the South; winds will be stronger, and storms will occur more frequently. A 1% temperature rise in the period of snow thawing would result in the shortened duration of snow cover at altitudes of 600–1400 m.

The expected consequences of the climate change would include an increased frequency of droughts and fires, larger extent of wind and pest damage, greater damage to the regeneration during tree felling (due to the shorter duration of snow cover, and the waterlogging of soils), increased drought threat in the South of Europe, impaired quality of forest sites (due to the warmer and drier climate), changes in natural ecosystems, appearance of thermophilous tree and shrub species in the northern tundra, increased productivity of stands in the North, and reduced productivity in the southern and continental parts of Europe.

Such forecasts indicate that selection programmes should be accompanied by programmes aimed at preserving the gene resources of Norway spruce in Poland.

Variability and value of the Polish provenances of Norway spruce in provenance tests

Provenance experiments are a basic method for assessing the genetic and breeding value of partial populations of spruce, i.e. stands within the distribution range of the species and their generative progeny. Therefore, the IUFRO 1938, IUFRO 1964/68, and IUFRO 1972 provenance trials, and the family archives established in the Silesian Beskid Mts. play an important role in the current genetic evaluation of the Polish populations of Norway spruce.

The most recent genetic evaluation of the Polish Norway spruce was made by Giertych (1998) in the monograph *Biology of Norway Spruce*. According to the seed regionalisation worked out on the basis of the results of provenance studies, there are 13 maternal regions of spruce in Poland: four Beskid regions in the Western Carpathians (801, 802, 805, 808), three Sudeten regions (701, 702, 703), one region (807) in the Eastern and Southern Carpathians, and five regions of lowland spruce from the northeastern range of the species (Załęski et al. 2000).

The genetic and breeding value of the Polish populations of spruce is discussed below.

Lowland spruce

The results of provenance tests for the Norway spruce population from lowland Poland (mostly from the northeastern range of the species) showed a good value of the Masuria-Podlasie provenances from the Knyszyńska and Augustowska Primeval Forests, and the Baltic provenance from the Romincka Primeval Forest. It is noteworthy that the lowland spruce populations tested in the IUFRO 1964/68 and IUFRO 1972 experiments include both autochthonous stands from the natural range of spruce and stands of artificial origin (Sabor 1999). The Białowieża populations were found by Giertych (1999) to have a poor quality, and thus to be unsuitable for transfer. However, some provenance tests (e.g. IUFRO 1972) show that single populations from the managed part of the Białowieża Primeval Forest (Zwierzyniec Forest District) exhibit good plasticity and growth. The plasticity indices for spruce from the Knyszyńska, Augustowska, Romincka, Borecka, and Piska Primeval Forests suggest that these spruce sources may be used rather abroad (locally) than in Poland. Norway spruce from the latter areas achieved good scores in Scandinavia and western Canada, which may be attributed to its later spring flushing (Giertych 1977, 1999). Comparative studies conducted at the Forest Research Institute, Warszawa, mostly on the basis of the IUFRO 1972 experimental results (Matras 2006a, b), confirm that spruce stands from the lowland northeastern range of distribution have generally a lower quality than the Carpathian spruce. At provenance level, the spruce from Zwierzyniec stands out from the others.

Mountain spruce

Spruce as a forest-forming species covers 196 658 ha in the Sudetes and Carpathians, which accounts for 32.6% of this area, much more than the country's average (Sabor 1995). Mature spruce stands in the Carpathians exhibit significant variation in quality classes under the uniform site conditions of these mountains, with the mean quality class of the stands being higher by 0.4 classes than the country's average. Mature spruce stands in the Sudetes are much poorer, by one quality class, than the Carpathian stands. In view of their similar age and site conditions, this variation can be considered as genetic.

Istebna race

Most of the stands of Istebna spruce originating from the Silesian and Żywiecki Beskid Mts. have shown a good genetic quality in all the main Polish provenance tests, especially IUFRO 1964/68, but also IUFRO 1972. On the test site in Krynica, the Ujsoły and Rycerka-Kiczora provenances perform best in height growth terms and are resistant to spring frosts, forming a true selection elite (Sabor 1996).

The question about autochthony of the Istebna spruce is still open. Recent studies have demonstrated that it might be a foreign population of exceptional plasticity. As indicated by historical records, the present spruce-covered area had earlier been grown with fir-spruce-beech-sycamore stands. Therefore, the present occurrence of pure spruce stands can be attributed to the high demand for beech timber in the 19th century, and the preference given to spruce for reforestation purposes. Knowing the rules of management applied in Austrian forests, it is likely that the Istebna spruce may have had an artificial origin (the seeds came from a seed-extracting facility in Wiener-Neustadt), and that artificial selection has produced a positive effect (Sabor 1996). The evidence to support such a hypothesis can be found in the results of the phenol polymorphism studies made on seedlings of the Istebna spruce from Zapowiedź (comp. 121a, plus-tree DD 82) and on seedlings representing the progeny of two trees from the sites located near the Italian-Austrian border (Bormio and St. Catherine). Chromatographic analysis of chosen phenols in *Picea abies* of Polish and Alpine provenances revealed similarity in the two populations (Z. Janeczko, J. Sabor, personal communication 2007).

The current assessment of the survival and height of the progenies of 45 seed stands included in the archive of the Regional Gene Bank of the Katowice Regional Directorate of State Forests, carried out *in situ* in Wisła and *ex situ* under the lowland conditions of Kórnik (Zwierzyniec; Institute of Dendrology, Polish Academy of Sciences) and Sękocin (Forest Research Institute) and the mountain conditions of Beskid Sądecki (Krynica) has shown the usability of the Istebna spruce in lowland cultivation. The progeny of stands from the Dziechcianka and Głębce Forest Ranges (from comp. 22k, 25f, and 44d, among others) exhibit a significant effect of the interaction genotype × location of plantation. As indicated by an assessment of adaptation traits, the intra-population selection of the Istebna race has resulted in the high adaptability of the progeny of spruce stand 91h from Malinka. Owing to good height, survival, and plasticity, this population can be recommended for use in various site conditions. The 30-year-old parent stand (3.82 ha) has a mean d.b.h. of 48.2 cm, and a mean height of 37.6 m. This is a well-cropping stand (e.g., 1600 kg of cones were collected in 1993). The provenance from compartment 149 ha in Bukowiec, which used to perform best in provenance tests, is currently considered average (according to a study for the Katowice Regional Directorate of State Forests from 1998). In practically all family archives in Wisła, Krynica, and Strubin (Jabłonna Forest District, Forest Research Institute), the progeny of plus-trees have exhibited good adaptation (high survival rate). The best progenies are the generative progenies of Istebna spruce plus-trees numbered 5204, 5207, and 5219 from the Zapowiedź Forest Range in the Wisła Forest District (according to a study for the Katowice Regional Directorate of State Forests from 1997).

The important role of the Istebna spruce has been recognised in the current programme of the selection and preservation of forest genetic resources. The seeds of this race are recommended for use in 34 forest districts in the country, and the reproduction material (seed, grafts) have long been exported and studied internationally. The research on the Istebna spruce is presently focused on the intra-population variability of this race and the autochthony level of its populations. Other issues of interest comprise an assessment of the progeny of plus-trees and the protection of the gene resources of the race *in/ex situ* in the family archives of the Regional Gene Bank (Sabor 1996).

Orawa spruce

According to the current rules of seed regionalisation, the Orawa spruce makes the principal base of reproduction material in the central part of the Carpathians and the whole Carpathian Foothills. From the scientific viewpoint, however, its widespread use in the Carpathian conditions is not entirely justified, even though this population gradually improves the dynamics of growth and exhibits high plasticity in provenance tests (Sabor and Kulej 1997).

Tarnawa spruce

The general opinion of spruce from the Bieszczady Mts. is rather ambiguous. The Tarnawa spruce, for example, has shown poor height growth in the IUFRO 1964/64 test over the whole 25-year period. This population exhibits slow spring flushing and average resistance to *Chermes viridis*. By contrast, the Dolina provenance from the same region counts among the best provenances tested in the IUFRO 1938 experiment. In the IUFRO 1972 trial, the Tarnawa spruce is considered as rather good (Matras 2006b). Despite the divergence of opinions, this population should be treated as valuable. There is an urgent need to give it protection since its area of distribution steadily decreases. The results of provenance tests suggest that in plantations the eastern spruce may be supplemented with Ukrainian populations from Jasina and Dolina, and with Romanian provenances (Sabor 1998a).

Sudeten spruce

The Sudeten spruce has shown a very poor genetic value in provenance tests (Matras and Kowalczyk 1998; Sabor 1998b). According to the valuation made by Giertych (1998), spruce from the Kłodzko Valley area has a low genetic value, while provenances of the Western Sudetes (Izerskie Mts., Karkonosze Mts., Kaczawskie Mts.) and the Eastern Sudetes (Jesioniki Mts.) exhibit high plasticity. The latter populations can be recommended for lowlands in western Poland, and those from the Karkonosze Mts., for mountain plantations. The Szczytna Śląska provenance, tested in the IUFRO 1964/68 experiment, has proved valuable.

Conclusions

The provenance experiments testing the Polish populations of Norway spruce have demonstrated a good genetic and breeding value of the Istebna race. The high quality of the Silesian and Żywiecki Beskid Mts. provenances has been confirmed in most progeny tests, among them the IUFRO 1972 and 1964/68 trials. Since the progeny of Istebna spruce tested so far represents only single stands, it is necessary to determine the range of distribution for this race.

There is a significant correlation between the altitude of the location of mother stands and the genetic and breeding value exhibited by their progeny on comparative plantations established at different altitudes. This suggests that altitudinal zoning is necessary, and that altitude and exposure should be specified for individual provenances to be used in plantations established in mountain forest belts.

It is essential to launch new inventory provenance tests. Those should be established under varied site conditions in such a way that both the genetic value and plasticity range of the provenances could be assessed.

Due to the biotic and abiotic threats facing spruce, there is a need to work out detailed programmes aimed at preserving its gene resources in gene banks and *in vivo* archives.

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