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Genotype-environment interaction and F_2 seed progeny productivity in the genus Betula L

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Abstract. Creation and study of the potential of bioresource collections (BC) of living organisms, including woody plants, is one of the priority areas of the state policy of the Russian Federation. The Voronezh Region is unique for studying the genus Betula, since two species of this genus naturally grow here: diploid - silver birch and tetraploid - downy birch. These and introduced species, complex hybrids, as well as their reciprocal hybrids are the basis of BC F_1 and F_2; provide selection for somatic and adaptive heterosis. The seed progeny (families) of F_2 growing in conditions of leached chernozem were tested - C-4, C-20, C-27, C-31 and C-51 (silver birch); B-3, B-11, B-12, B-20 (downy birch); hybrids C-2 x b. The article presents data on the growth of birch hybrids from different subsections: Albae (*Betula mandshurica* Nakai, *B. papyrifera* Marsh., *B. pendula* Roth and *B. pubescens* Ehrh.) and Costatae (*Betula lenta* L.). The age of the test crops is 32 years. The possibility of obtaining intersectional birch hybrids and the prospects of crossing for obtaining genotypes with a large habitus, in which the paternal component exceeds the maternal one in terms of ploidy level, are shown.

1 Introduction

During ontogenesis, a woody plant grows and develops in certain external conditions, absorbing and releasing certain substances, CO_2, O_2, etc. Thus, the genotype-environment interaction is an important quantitative and qualitative characteristic of its condition, metabolism, growth dynamics and biomass accumulation. All these characteristics are studied at the individual and family level in specially created cultures, where trees are planted in a certain order and at a certain distance from each other.

The purpose of the work is to study the selection quantitative and qualitative seed progeny F_2 on the created object of the bioresource collection ex situ species and selection forms of birch.

Research objectives:

- to conduct hybridization and self-pollination of local and introduced birch species in F_1 test cultures, to obtain F_2 seed progeny;
- to determine the variability of quantitative traits in selection forms and F_2 hybrids of birches through phenotypic variability of height growth of silver birch, downy birch, and hybrids between them, Manchurian birch, paper birch and cherry birch;

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- to characterize the height growth of local birch species, silver birch and downy birch, with different pollination methods (self- and open pollination).

2 Materials and methods

The original trees (36 downy birch and 61 silver birch) were selected in 1981 in the Voronezh State Nature Biosphere Reserve. At the same time, self-pollination and hybridization according to generally accepted methods [1] were carried out on them. The F_1 seed progeny was planted in sandy loam soil conditions. The age of the F_1 crops is 41 years. In 1993, self-pollination and hybridization were also carried out on the F_1 object. F seedlings were planted in two soil conditions - in the Semiluki nursery (leached chernozem) and in the vicinity of the village of Knyazevo - gray forest soils. This article presents data on the growth of birch of the designated origin on the first type of soil. The data were processed by a one-way analysis of variance (ANOVA test).

Plant material. This article presents data on the growth of birch families obtained using different pollination methods: silver birch, open pollination – C-31, C-4, C-27, C-20, self-pollination, C-51; downy birch, open pollination – B-12, B-20, B-3, self-pollination – B-11. Hybrids: C-2 x B. paper, B-5 x silver birch pollen mixture (pm in the text), B-4 x B. cherry, B-5 x B. Manchurian. Productivity traits and some of their statistical parameters were determined using the Statistica v. 12 program.

3 Result and discussion

The development of the Global System for Plant Genetic Resources (GR) began in 1983. The first report on the state of world plant production GR was presented at the Fourth International Technical Conference (Leipzig, Germany, 1996). The Global Plan of Action, adopted on the basis of the Leipzig Declaration, includes a set of measures covering capacity building and in situ and ex situ conservation of plant genetic resources for food and agriculture [2]. In addition, biodiversity makes a significant contribution to national economies, and from the point of view of biodiversity conservation, reintroduction of commercially valuable species would be the best and most cost-effective solution [3].

Sustainable management of genetic resources and conservation of genetic diversity in exploited forests is an often overlooked aspect of forest biodiversity conservation [4]. In high-latitude forests, where tree species diversity is low and many species are wind-pollinated, timber harvesting may have little impact on genetic diversity. Trees reproduce primarily by seed, and our knowledge of seed production in tree species is fundamental to understanding their evolution and ability to recover from drought, fire, and logging [5-8].

There are several methods for obtaining improved reproductive material from open pollination. The most common of these are seed productin area (SPA) or seed stands (SS), parts of the forest isolated from natural forests or mature plantations. The next level of forest selection is seed orchard (SO), or trees without pedigree, and, finally, clonal plantations of the next generations from tested genotypes [9]. The obtained seeds from open pollination from stands and plantations can be used for general combining capacity [10]. In addition, forests and their fragments in agricultural landscapes provide a valuable ecosystem service by supporting pollination of agricultural crops [11]. Moreover, forest diversity promotes pollinator diversity, which improves pollination quality [12, 13]. Forests are both an important part of the solution to climate change and vulnerable to it [14- 16]. By increasing the uptake of atmospheric CO2 and binding it to living biomass and soils, regrowing forests have enormous potential to mitigate climate change [17]. Conversely, deforestation and forest degradation can cause forests to transform from carbon sinks to sources [18]. Forests and forest biodiversity are also vulnerable to the impacts of climate change, including increased frequency and severity of extreme climate events, especially droughts [19, 20, 14, 15].

Current conventional breeding programs are limited for woody plants by their longer reproductive cycles, long juvenile periods (up to 20 years), low fertility, high levels of heterozygosity, variable ploidy levels, polyembryony, intra- and interspecific incompatibility, inbreeding depression, and precise delineation of the boundary between phenotypic expression and environmental influences. Effective breeding depends on understanding the factors that determine the response to selection in both the short and long term [21]. Ultimately, the genetic information contained in the genotype is realized through the individual development program in the phenotype of the tree. And it is the phenotype that is the final product for consumers. In addition, the integral phenotype is now considered the main substrate of natural selection, and the epigenetic theory of evolution postulates the primacy of phenotypic changes [22], in contrast to the synthetic theory of evolution, in which the material for evolution is the hereditary variability of organisms, i.e. mutations and combinations of genes [23, 24]. It is believed that rapid speciation is characteristic of polyploid plants over short periods of time [25].

Hybridization is a possible way to achieve a rapid evolutionary leap; in addition, hybridization usually causes an explosion of variability in the second generation; it may contain new and valuable types that could not arise within the species due to slow types of evolution [26]. Polyploids in the genus Betula make up almost 60% of the described taxa, with the ploidy level reaching dodecaploid [27]. Two species of birch grow in the Voronezh region - silver birch (diploid) and downy birch (polyploid - namely tetraploid). This has been established at the morphological [28], cytological [29] and molecular genetic [30] levels. According to the classification [31], the genus Betula consists of two sections: Eubetula and Betulaster. These sections are subdivided into subsections: Eubetula - into Costatae, Albae and Nanae; Betulaster - Acuminatae. We have obtained and grown hybrids that belong to different subsections – Albae (Betula mandshurica Nakai, B. papyrifera Marsh., B. pendula Roth and B. pubescens Ehrh.) and Costatae (Betula lenta L.). Figure 1 shows the family variability of 5 selection forms of silver birch, 4 forms of downy birch and 6 hybrid families.

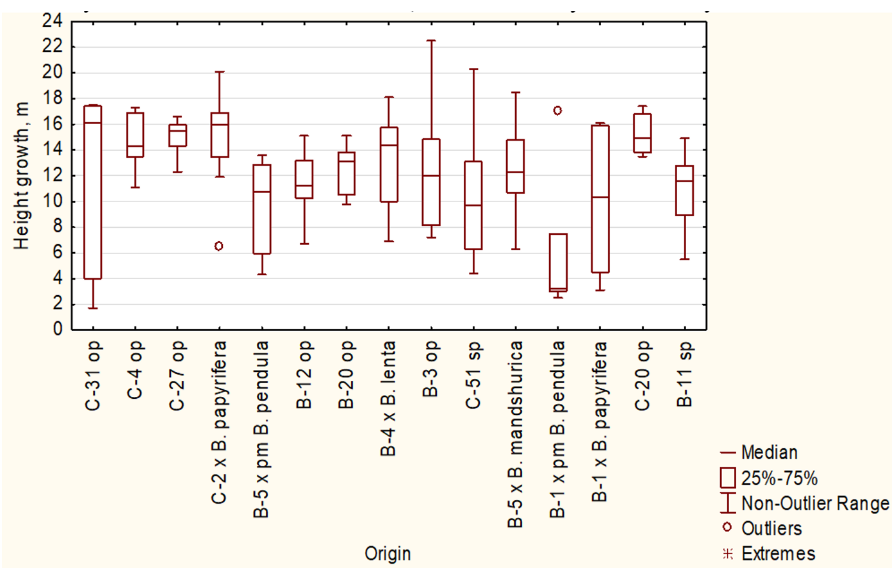

Fig. 1. Family variability of height growth of selected forms and hybrids of birch on chernozem.

Table 1. Average statistical characteristics of families by height growth of selected forms and hybrids of birch on chernozem.

Origin	Height growth, m Means ± Std.Err.	Number of trees N	Std.Dev.
C-31 op*	12.6 ± 2.5	7	6.78
C-4 op	14.8 ± 0.7	9	2.14
C-27 op	15.0 ± 0.6	8	1.44
C-2 x B. papyrifera	14.9 ± 1.4	8	4.10
B-5 x pm B. pendula	9.7 ± 1.0	12	3.65
B-12 op	11.6 ± 0.7	12	2.40
B-20 op	12.5 ± 0.5	11	1.77
B-4 x B. lenta	13.0 ± 1.0	12	3.58
B-3 op	12.5 ± 1.8	8	5.17
C-51 sp	10.9 ± 1.9	9	5.65
B-5 x B. mandshurica	12.5 ± 0.8	17	3.25
C-20 op	15.2 ± 0.6	7	1.48
B-11 sp	10.9 ± 0.9	10	2.82

*Abbreviations in the Figure 1 and Table 1: op – open pollination, sp – self-pollination, pm – pollen mixture.

Height growth indicators. Open pollination. The maximum average family height indicator on chernozem soil was shown by family S-20 – 15.2 meters, for downy birch – family B-20, 12.55 meters (open pollination). With this pollination method, one tree of downy birch B-3 had the highest indicator of this trait among all trees – 22.3 meters.

Self-pollination. In the experiment, with this pollination method, two families were obtained – downy birch B-11 and downy birch S-51. The average sample values were 10.92 and 10.97, respectively.

Hybrid growth. The growth of the following hybrids with local and introduced species was monitored: downy birch 2 x downy paper, downy birch 5 x pollen mixture of downy birch. drooping, downy birch 4 x b. cherry, downy birch 5 x b. Manchurian. Maximum and minimum average family values are C-2 x b. paper - 14.9 meters and B-5 x rm b. drooping - 9.7 meters.

4 Conclusion

- The possibility of intersectional hybridization in the genus Birch was demonstrated. The intersectional hybrid B-4 x cherry birch in terms of the average family growth rate in height (13.0 m) exceeded those of the hybrids B-5 x rm birch drooping (9.7 m) and B-5 x b. Manchurian (12.5 m), but was inferior in height to the hybrids C-2 x b. paper (14.9 m). Since b. paper is an octaploid (2n=8x=112) [32], crossing with pollen donor trees with increased ploidy compared to the maternal trees (drooping birch, 2n=2x=28) is promising for obtaining highly productive hybrids; - two local species of birch, drooping and downy, obtained with different pollination methods (self-pollination and open pollination), grow quite well on chernozem soils. The leader in height growth is the drooping birch with average family indicators of 12.6 m, 14.8 m, 15.1 m, 11.0 m and 15.2 m. Single inbreeding affected the growth of family C-51, and its indicator was the lowest among them;

- downy birch occupies a subordinate position to the first species, consisting in a more depressive growth - average family indicators of 11.6 m, 12.5 m, 12.5 m and 10.9 m. Also, the offspring of the self-pollinated family B-11 had a minimum value of this trait (B-11, 10.9 m). - statistically significant differences revealed using the ANOVA program ($p < 0.05$) were obtained between the families B-1 x rm b. drooping and C-27 or (0.41), C-2 x b. paper (0.049) and C-20 or.

Thus, in terms of overall productivity, it is possible to recommend growing silver birch for chernozem soils. In addition, individual trees of b. downy can also be used for growing on these types of soils.

References

1. S.S. Pyatnitskiy, Workshop on forest selection (Sel'hozizdat, M., 1961)
2. Earth Negotiations Bulletin. A Reporting Service for Environment and Development Negotiations **9**, 650-665 (2015)
3. R.D. Harrison, K. Shono, V. Gitz, A. Meybeck, T. Hofer, S. Wertz-Kanounnikoff, Mainstreaming biodiversity in forestry. FAO Forestry Paper 188 **(**Rome, FAO and Bogor, Indonesia, CIFOR, 2022) https://doi.org/10.4060/cc2229en
4. R. Jalonen, M. Valette, D. Boshier, J. Duminil, E. Thomas. Conservation Letters **11**, e12424 (2018) https://10.1111/conl.12424
5. T. Qiu, R. Andrus, MC. Aravena et al, Nat Commun **13**, 2381 (2022) https://doi.org/10.1038/s41467-022-30037-9
6. I.Yu. Isakov, IOP Conference Series: Earth and Environmental Science. International Forestry Forum "Forest Ecosystems as Global Resource of the Biosphere: Calls, Threats, Solutions", 12014 (2021)
7. S.A. Semerikova, V.L. Semerikov, I.Yu. Isakov, Russian Journal of Genetics **57**, 47-60 (2021)
8. S.A. Semerikova, V.L. Semerikov, I.Yu. Isakov, Russian Journal of Genetics **56**, 192-203 (2020)
9. V. Ivetić, J. Devetaković, M. Nonić, D. Stanković, M. Šijačić-Nikolić, iForest **9**, 801-812 (2016) https://doi.org/10.3832/ifor1577-009
10. T.J.B. Boyle, C. Cossalter, A.R. Griffin, Management of soil, nutrients and water in tropical plantation forests (ACIAR, Canberra, Australia, 1997)
11. S. Krishnan, G. Wiederkehr Guerra, D. Bertrand, S. Wertz-Kanounnikoff, C.J. Kettle, Forestry Working Paper 15 Rome (FAO & Bioversity International, 2020) https://doi.org/10.4060/ca9493en
12. J. Fründ, C.F. Dormann, A. Holzschuh, T. Tscharntke Ecology **94**, 2042–2054 (2013)
13. R. Winfree, J.R. Reilly, I. Bartomeus, D.P. Cariveau, N.M. Williams, J. Gibb Science **359**, 791–793 (2018) https://doi.org/10.1126/science.aao.2117
14. N. Seddon, E. Daniels, R. Davis et al, Global Sustainability (2020) https://10.1017/sus.2020.8
15. M. Edwards, P. Hélaouët, E. Goberville et al, Commun. Biol. **4**, 644 (2021) https://doi.org/10.1038/s42003-021-02159-1
16. G. Forzieri, V. Dakos, N.G. McDowell, A. Ramdane, A. Cescatti, Nature **608**, 534–539 (2022) https://doi.org/10.1038/s41586-022-04959-9
17. C.A.J. Girardin, S. Jenkins, N. Seddon et al, Nature **593**, 191-194 (2021)
18. L. Gatti, M. Pizzetti, P. Seele, Journal of Business Research **127**, 228–240 (2021)
19. M.D. Potts, J. Ecol. **91**, 467–474 (2003)
20. S. Greenwood, P. Ruiz-Benito, J. Martínez-Vilalta et al, Ecol Lett **20**, 539-553 (2017) https://doi.org/10.1111/ele.12748

21. R.D. Burdon, Encyclopedia of Forest Sciences (Elsevier, 2004)
22. E.B. Popov, V.A. Dragavtsev, S.I. Maletskiy, Tri kita ekoniki: Istoki i perspektivy novogo napravleniya v obschey biologii (Izdatelsko-poligraficheskaya assotsiatsiya vysshyh uchebnyh zavedeniy, SPb, 2020)
23. Ch. Darvinm, The effect of cross-pollination and self-pollination in the plant world (OGIZ Sel'hozgiz, M.-L., 1939)
24. J. Huxley, Evolution: The Modern synthesis (Georg Allen & Unvin Ltd., London, 1942)
25. W. Klug, M. Cummings, Ch. Spencer, M. Palladino, D. Killian, Concepts of Genetics (Pearson, 2018)
26. J.B.S. Haldane, Factors of evolution (State Publishing House of Biological and Medical literature, M.-L., 1935)
27. N. Wang, H.A. McAllister, P.R. Bartlett, R.J.A. Buggs Ann. Bot. **117**, 1023–1035 (2016) https://doi.org/10.1093/aob/mcw048
28. I. Isakov, Yu. Isakov, Inbreeding and hybridization in Birch genus (Saarbrukken, 2015)
29. I.Yu. Isakov, T.M. Tabatskaya, N.I. Vnukova, O.S. Mashkina, V.I. Mikhin, Z. Govedar, Forestry Engineering journal **13-2(50)**, 25-42 (2023) DOI: https://doi.org/10.34220/issn.2222-7962/2023.2/2
30. T. Grodetskaya, P. Evlakov, I. Isakov, V. Padutov, IOP Conference Series: Earth and Environmental Science. International Forestry Forum "Forest Ecosystems as Global Resource of the Biosphere: Calls, Threats, Solutions", 012039 (2020)
31. J. Raulo, Birch book (1981)
32. D. Right, Introduction in forest genetics (Forest industry, M., 1978)