IRSTI 34.31.31 https://doi.org/10.26577/IJBCh2023v16i2a8

T.V. Vostrikova[1,2], A.Yu. Potapov[2], N.V. Stolpovskaya[2], A.A. Kruzhilin[2], K.S. Shikhaliev[2], A.M. Abekova[2*]

[1]Voronezh State University, Voronezh, Russia
[2]A.L. Mazlumov All-Russian Research Institute of Sugar Beet and Sugar, Voronezh, Russia
*e-mail: aabekova@mail.ru

(*Received June 9 2023; received in revised form July 6 2023; accepted July 14 2023*)

Seeds diversity of different species in the genus *Rhododendron* after pre-sowing treatment

Abstract. The purpose of the study is the evaluation seeds diversity of different species in the genus *Rhododendron* after pre-sowing treatment with organic compounds. As the signs of the seeds diversity is understood the seed germination and the seedling height. The research was conducted at the B.M. Kozo-Polyansky Botanical Garden of Voronezh State University (geographic coordinates: E 39°12', N 51°42'; 168.2 meters above sea level), Central Chernozem region (chernozem soil) in 2019-2020. It has been used ornamental shrubs. The study was made about the pyrimidinecarboxylic acids effect on the seed germination and the seedling height of *Rhododendron* species. The diversity of seeds is manifested in their heterogeneity according to morphological characteristics (the seedling height) and sowing qualities (seed germination) of *Rhododendron* species. The sowing properties (germinating capacity, seedling growth) were improved after treating the seeds with the organic compounds. There is the trend of increasing the seed germination and the seedling height of *Rhododendron* depended on the concentration of applied compounds. The seed germination for *Rh. ledebourii*, *Rh. luteum*, *Rh. molle* was increased from 5 to 7%, for *Rh. schlippenbachii* – from 5 to 10%. The seed treatment with pyrimidinecarboxylic acids at concentrations 0.01%, 0.05% and 0.1% allows to increase the seedling height for *Rh. ledebourii* from 37.5 to 75%, for *Rh. luteum, Rh. molle* – from 18.2 to 45.5%, for *Rh. schlippenbachii* from 20 to 40% concerning the control. To increase the seedling height, 2-benzylamino-4-methylpyrimidine-5-carboxylic acid at concentrations 0.05% and 0.1% is most effective. Morphologically close *Rhododendron* species (*Rh. luteum, Rh. molle*) indicated similar reactions to the seed treatment with compounds of the pyrimidinecarboxylic acid series.

Key words: seeds diversity, seed germination, seedling height, ornamental shrubs.

Introduction

Seeds diversity often means seed quality or sowing qualities, depending on the genotype and growing conditions. Breeding and testing are carried out and aimed at increasing the yield, resistance of agricultural plants to adverse environmental conditions [1]. Productivity is increased with breeding techniques and modes for obtaining highly productive cultivars, various agricultural practices, and the use of new technologies for growing plant material. It was noted that the productivity of the fruiting plant and its resistance to adverse factors are antipodal in nature since the same metabolites are involved in their creation but in different quantities [2]. Thus, productivity and stability are formed from the same photosynthesis products but redistributed in different directions following genetic regulation [3]. Therefore, it is necessary to increase the plant resistance to adverse factors. The use of some biological growth regulators, organic and chemical fertilizers makes it possible to obtain more tolerant plants and their progeny with better qualities [3-5]. The example of species-specific reactions to external environmental factors (and internal factors of the organism) is the different quality of seeds. Sowing properties (germination capacity) of seeds as well as the growth processes can be improved by different growth stimulators [4, 5].

Sowing qualities of seeds and morphological characteristics of seedlings depend on the genotype and growing conditions. The leading indicators of the different plant quality is the germination energy and the germination capacity, which depend on the genotype [6]. For instance, the diversity of seeds manifests in their heterogeneity according to morphological characteristics and sowing qualities [7]. The influence of agricultural practices at the seeds diversity exceeds genetic factors [6]. An increase in yield and sugar content of mother roots after the seed treatment with organic compounds were revealed [8]. Further, the seeds yield and sowing properties (germination capacity) were improved, when planted roots were used for the hybrids reproduction [8].

Maintenance of seed quality is mandatory for final yields, so seed lots are assessed, based on their germination capabilities and vigor [9, 10]. A lot of tests are used to evaluate seed physiological characteristics require time and skilled labor, making it costly [9, 10, 11, 12]. For instance, cytogenetic and molecular studies of the growth process and the seeds diversity [13] are modern, but complex and cost. It was reported about revealing of gamma-rays and microwave irradiation influence using I – markers assisted selection for responding to mutagenic agents [14]. Plant screening with the optical chlorophyll counter made it possible to determine the responses of genotypes to the heat and water stress conditions [12]. However, there are simple characteristics, for example, biometric indicators, including plant height, seedling length and others.

As provocative backgrounds for the study of the seedling reaction to external influences, meteorological conditions, mutagenic agents, and agricultural practices, chemical compounds are often used. But a promising area of the study, related to the growing need for the development of effective and safe drugs, is the synthesis of new heterocyclic systems, containing a pyrimidine fragment [15-18]. For instance, a phosphomide contains two ethyleneimine groups and a pyrimidine base. Ethyleneimine causes mutations, the pyrimidine base is included in the DNA chromosome. The mutagenic effect of phosphomide was previously studied for the model object Crepis capillaris L. [19] and later – for Triticum aestivum L. [20]. Agrobiological characteristics were defined: field germination of seeds, morphological characteristics of the ear, stem, leaves and others [20]. The variability of quantitative traits under the environmental conditions influence is a traditional investigation. Laboratory seed germination and morphometric parameters of woody plants and agricultural crop were studied after seed treatment with heterocyclic compounds [21, 22]. So organic compounds with the pyrimidine fragment have the biological activity. In addition, it was reported about the antioxidant and antimicrobial activity of some selected derivatives with the pyrimidine fragments [23, 24]. The antioxidant [25] and antimicrobial [26] activity was found in *Rhododendron* leaves, flowers. That's why the representatives of the *Rhododendron* genus are valuable resource plant.

The purpose of the study is evaluation the seeds diversity, namely seed germination and the seedling height, of different species in the genus *Rhododendron* after the pre-sowing treatment with compounds of the pyrimidinecarboxylic acid series.

Materials and methods

The research was conducted at the B.M. Kozo-Polyansky Botanical Garden of Voronezh State University (geographic coordinates: E 39°12', N 51°42'; 168.2 meters above the sea level), Central Chernozem region (chernozem soil) in 2019-2020. The map of area is presented on Figure 1.

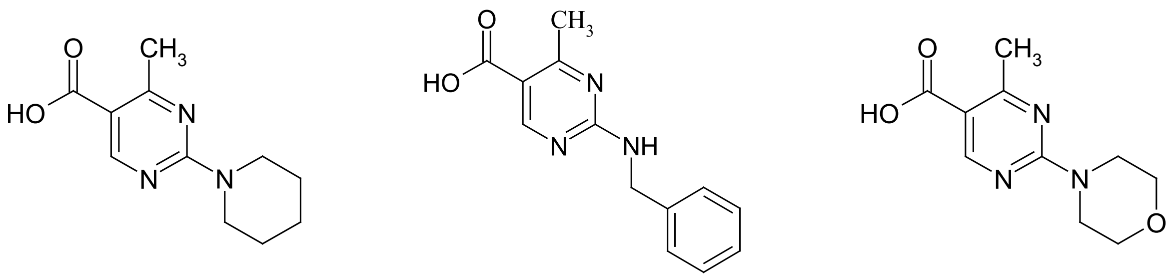
As research objects were used seeds and seedlings of ornamental woody plants. *Rhododendron ledebourii* Pojark. is a semi-evergreen shrub, and *Rhododendron luteum* Sweet*, Rhododendron molle* (Blume) G. Don, *Rhododendron schlippenbachii* Maxim. are deciduous shrubs. In controlled environment these species grow up to 2-meter in height and are highly decorative [26]. The long history of studying these species at Russian Federation has demonstrated, that *Rhododendron* species are winter-hardy, drought-resistant, and fruit-bearing shrubs [7, 26].

It was focused at the pyrimidinecarboxylic acids effect on the height of *Rhododendron* species seedlings. The following compounds were used: 4-methyl-2-piperidin-1-ylpyrimidine-5-carboxylic acid (1), 2-benzylamino-4-methylpyrimidine-5-carboxylic acid (2), and 4-methyl-2-morpholin-4-pyrimidine-5-carboxylic acid (3) synthesized at the Department of Organic Chemistry of Voronezh State University (presented on Figure 2).

Prior to the sprouting process, the seeds of *Rhododendron* species (*Rh. ledebourii, Rh. luteum, Rh. molle* and *Rh. schlippenbachii*) were soaked in a water suspension of the above listed compounds with concentrations of 0.01 %, 0.05 %, and 0.1 % for 18 hours.

The control group consisted of the same type of seeds soaked in tap water solution of a commonly used growth stimulator, Epibrassinolide (commercial fraction Epin Extra produced by NNPP NEST M, Russia), with the concentration of 0.05 % (according to the instruction [21, 22]). In case of each studied acid concentration (0.01%, 0.05%, 0.1%), as well as the control group, the experiment was conducted three times using a set of 100 seeds. After soaking, the rhododendron seeds were placed in Petri dishes containing blotting paper, and germinated in the laboratory conditions at a constant temperature 22 ºC. The laboratory seed germination was determined as the ratio of the number of germinated seeds to the total number of seeds and was expressed in %. *Rhododendron* seedlings were counted to study the laboratory germination and planted in crates in closed ground on 21 day after the start of the experiment. The seedling height was measured using a ruler. An increase in the seedling height was determined as the ratio of the difference between the average seedling height in the experimental group and in the control group to the average seedling height in the control group and was expressed in %.

Figure 1 – The map of the B.M. Kozo-Polyansky Botanical Garden of Voronezh State University [27].
Note: Place for an introductory conversation, Memorial, Historical part of the botanical garden, Tuetum, Dry forest, Pinetum, Larch forest, Forest belts, Arboretum, Michurinsky garden, Fallow plots, Protected oak forest, Grassy slopes, Bayrachnaya oak forest, Collection of wild fruit and stone fruit crops, Geographical arboretum [27].



(1) (2) (3)

Figure 2 – Synthesized organic compounds of the pyrimidinecarboxylic acid series.
Note: 4-methyl-2-piperidin-1-ylpyrimidine-5-carboxylic acid (1), 2-benzylamino-4-methylpyrimidine-5-carboxylic acid (2), and 4-methyl-2-morpholin-4-pyrimidine-5-carboxylic acid (3)

Computer statistical processing was performed using the Stadia software package. The procedures for grouping data and their processing were described in A. P. Kulaichev work [28]. The seed germination in the control and experimental variants was compared according to the criterion of frequency agreement using Z-test for equality of frequencies. Average values of seedling lengths were compared using Student's *t*-test. The influence of the treatment factor at different concentrations on growth rates was determined using two-way analysis of variance. Coefficient of variation (Cv) was counted according to G.F. Lakin [28]. If Cv was below 10%, it means that the degree of variation was low, with Cv between 10 and 25 % it was medium, and when Cv was over 25 % – the degree of variation was high [29].

Results and discussion

The results of the seeds treatment with pyrimidinecarboxylic acids on the germination and the height of *Rhododendron* seedlings are presented in tables 1-4. The laboratory germination of seeds was determined in the control group, Epin group, experimental groups for each species. An average height of seedling was estimated respectively. It wasn't revealed the significant difference between control group and Epin group in the seed germination, as well as in the seedling height for *Rhododendron* species. The seed germination wasn't strongly increased for *Rhododendron ledebourii* (Table 1). But there were significant differences between control and experimental groups for all acids in the 0.1% concentration, for 4-methyl-2-piperidin-1-ylpyrimidine-5-carboxylic and 2-benzylamino-4-methylpyrimidine-5-carboxylic acids in the 0.5% concentration.

It was indicated the most increase in the seedling height for 2-benzylamino-4-methylpyrimidine-5-carboxylic acid at the 0.1% concentration – 75% (the seedling height in the control group was 0.8±0.2 cm). The increase in the seedling height was smaller for 4-methyl-2-piperidin-1-ylpyrimidine-5-carboxylic acid (62%) and the smallest for 4-methyl-2-morpholin-4-pyrimidine-5-carboxylic acid (50%). The similar trend was saved for other acid concentrations. So 2-benzylamino-4-methylpyrimidine-5-carboxylic acid was the most effective for *Rhododendron ledebourii* at all tested concentrations (Table 1).The seed germination of *Rhododendron luteum* was increased by 2-benzylamino-4-methylpyrimidine-5-carboxylic, 4-methyl-2-piperidin-1-ylpyrimidine-5-carboxylic acids at the 0.1% concentration and by the last at the 0.05% concentration. This reaction is differ from responses of other *Rhododendron* species, where the 0.1% concentration was effective in all compounds (Table 2). That means the special stimulating impact for sowing qualities in *Rhododendron luteum* seeds or specific seeds reaction for the treatment.

Table 1 – The seeds diversity signs of *Rhododendron ledebourii* after treating the seeds with the synthesized organic compounds

Concentration, %	The average seedling height, cm	The seed germination, %	Cv, %	The increase in the seedling height, %
Control group	0.8±0.2	32.3	10.4	–
Epin group	0.9±0.2	35.7	11.8	–
4-methyl-2-piperidin-1-ylpyrimidine-5-carboxylic acid				
0.01%	1.1±0.2*[1]	35.4	11.6	37.5
0.05%	1.2±0.1**[2]	37.6*	9.2	50.0
0.1%	1.3±0.2***[3]	38.6*	10.3	62.5
2-benzylamino-4-methylpyrimidine-5-carboxylic acid				
0.01%	1.2±0.2**[2]	37.1	10.5	50.0
0.05%	1.3±0.2***[3]	39.4*	11.5	62.5
0.1%	1.4±0.3***[3]	40.8*[1]	10.9	75.0
4-methyl-2-morpholin-4-pyrimidine-5-carboxylic acid				
0.01%	1.1±0.2*[1]	35.2	10.4	37.5
0.05%	1.1±0.2**[2]	37.1	10.7	37.5
0.1%	1.2±0.2**[2]	39.6*	11.3	50.0

Note: Cv – variation coefficient; * – differences with the control group are reliable ($p<0.05$); ** – differences with the control group are reliable ($p<0.01$); *** – differences with the control group are reliable ($p<0.001$); [1] – differences with the Epin group are reliable ($p<0.05$); [2] – differences with the Epin group are reliable ($p<0.01$); [3] – differences with the Epin group are reliable ($p<0.01$)

Table 2 – The seeds diversity signs of *Rhododendron luteum* after treating the seeds with the synthesized organic compounds

Concentration, %	The average seedling height, cm	The seed germination, %	Cv, %	The increase in the seedling height, %
Control group Epin group	1.1±0.2 1.2±0.2	37.2 40.5	9.5 10.1	– –
4-methyl-2-piperidin-1-ylpyrimidine-5-carboxylic acid				
0.01% 0.05% 0.1%	1.3 ±0.3* 1.4±0.1**[1] 1.5±0.2***[2]	37.4 40.6* 42.4*	11.8 8.2 9.3	18.2 27.3 36.4
2-benzylamino-4-methylpyrimidine-5-carboxylic acid				
0.01% 0.05% 0.1%	1.4 ±0.2*[1] 1.5±0.2**[2] 1.6±0.3***[3]	37.1 40.4 42.5*	9.7 10.5 12.3	27.3 36.4 45.5
4-methyl-2-morpholin-4-pyrimidine-5-carboxylic acid				
0.01% 0.05% 0.1%	1.3±0.2* 1.4±0.2*[1] 1.4±0.2**[1]	37.2 38.1 39.7	9.7 9.8 10.3	18.2 27.3 27.3

Note: Cv – variation coefficient; * – differences with the control group are reliable ($p<0.05$); ** – differences with the control group are reliable ($p<0.01$); *** – differences with the control group are reliable ($p<0.001$);
[1] – differences with the Epin group are reliable ($p<0.05$); [2] – differences with the Epin group are reliable ($p<0.01$); [3] – differences with the Epin group are reliable ($p<0.01$)

But there were significant differences between control and experimental groups at all acids in each concentration for *Rhododendron luteum* (the seedling height in the control group was 1.1±0.2 cm, Table 2), as well as for other *Rhododendron* species into the seedling height (Table 1, 3, 4). The increase in the seedling height for *Rhododendron luteum* was smaller (Table 2), than for *Rhododendron ledebourii* (Table 1). However, the similar trend of the increase in the seedling height from low (0.01%) to high (0.1%) concentration was observed for each *Rhododendron* species.

Table 3 – The seeds diversity signs of *Rhododendron molle* after treating the seeds with the synthesized organic compounds

Concentration, %	The average seedling height, cm	The seed germination, %	Cv, %	The increase in the seedling height, %
Control group Epin group	1.1±0.2 1.2±0.2	40.8 42.5	10.5 11.6	– –
4-methyl-2-piperidin-1-ylpyrimidine-5-carboxylic acid				
0.01% 0.05% 0.1%	1.3 ±0.3* 1.4±0.2**[1] 1.5±0.2***[2]	43.4 44.6 46.4*	14.8 12.3 12.5	18.2 27.3 36.4
2-benzylamino-4-methylpyrimidine-5-carboxylic acid				
0.01% 0.05% 0.1%	1.4 ±0.2*[1] 1.5±0.2**[2] 1.6±0.3***[3]	43.8 45.8 47.7*[1]	11.7 12.5 12.3	27.3 36.4 45.5
4-methyl-2-morpholin-4-pyrimidine-5-carboxylic acid				
0.01% 0.05% 0.1%	1.3±0.2* 1.4±0.2*[1] 1.5 ±0.2**[1]	41.8 45.6 46.8*	10.7 10.8 13.3	18.2 27.3 36.4

Note: Cv – variation coefficient; * – differences with the control group are reliable ($p<0.05$); ** – differences with the control group are reliable ($p<0.01$); *** – differences with the control group are reliable ($p<0.001$); [1] – differences with the Epin group are reliable ($p<0.05$); [2] – differences with the Epin group are reliable ($p<0.01$); [3] – differences with the Epin group are reliable ($p<0.01$)

The seed germination of *Rhododendron ledebourii* and *Rhododendron molle* was increased by all tested chemical compounds at the concentration of 0.1% concerning the control (Table 3). But the plant height was significantly higher in each experimental group (the seedling height in the control group was 1.1±0.2 cm). The similar dynamic of the parameter increase was revealed for all acid concentrations in the height of *Rhododendron molle* seedlings.

The seed germination of *Rhododendron schlippenbachii* was differ from other species. This trait was significantly higher in each experimental group, than in control, as well as the plant height (Table 4). The same trend was observed for all acid concentrations in the height of *Rhododendron schlippenbachii* seedlings.

The seed germination for *Rh. ledebourii*, *Rh. luteum*, *Rh. molle* under the influence of pyrimidinecarboxylic acids in the tested concentrations was increased from 5 to 7%, for *Rh. schlippenbachii* – from 5 to 10%.

Morphologically close species (*Rh. luteum, Rh. molle*) reacted in a similar way to the seed treatment with pyrimidinecarboxylic acid series. Moreover, this species of Rhododendron genus are similar according to ITS1-ITS2 nucleotide sequence [30]. This species (*Rh. luteum, Rh. molle*) are characterized the similar form and size of seeds. The differences in the change in their germination and the size of seedlings were insignificant. The range of variation in the seedling height of these species was practically the same, although the seed progeny of *Rh. luteum* is more uniform, characterized by the low and medium coefficient of variation (Cv). This trait in *Rh. molle* is characterized by medium Cv, indicating greater heterogeneity of the offspring (Tables 2-3). The low coefficient of variation can mean that the population of *Rh. luteum* is more stable, than the one of *Rh. molle.*

Table 4 – The seeds diversity signs of *Rhododendron schlippenbachii* after treating the seeds with the synthesized organic compounds

Concentration, %	The average seedling height, cm	The seed germination, %	Cv, %	The increase in the seedling height, %
Control group	1.0±0.3	30.2	14.5	–
Epin group	1.1±0.3	33.8	14.6	–
4-methyl-2-piperidin-1-ylpyrimidine-5-carboxylic acid				
0.01%	1.2 ±0.3*	35.4*	15.6	20.0
0.05%	1.3±0.2*¹	37.6*	12.2	30.0
0.1%	1.4±0.3**¹	38.6*	14.3	40.0
2-benzylamino-4-methylpyrimidine-5-carboxylic acid				
0.01%	1.2 ±0.3*	37.1*	14.5	20.0
0.05%	1.3±0.3*¹	39.4*	15.6	30.0
0.1%	1.4±0.3**¹	40.8*¹	14.9	40.0
4-methyl-2-morpholin-4-pyrimidine-5-carboxylic acid				
0.01%	1.2 ±0.2*	35.2*	13.4	20.0
0.05%	1.3±0.2*¹	37.1*	12.7	30.0
0.1%	1.4±0.3**¹	39.6*	14.3	40.0

Note: Cv – variation coefficient; * – differences with the control group are reliable ($p<0.05$); ** – differences with the control group are reliable ($p<0.01$); *** – differences with the control group are reliable ($p<0.001$);
¹ – differences with the Epin group are reliable ($p<0.05$); ² – differences with the Epin group are reliable ($p<0.01$); ³ – differences with the Epin group are reliable ($p<0.01$)

The first statement is also true for *Rh. ledebourii* (low and medium Cv) and the second statement is also true for *Rh. schlippenbachii* (medium Cv) (Tables 1, 4). The lower coefficients of variation and smaller increases in the seedling height were illustrated in cases of 4-methyl-2-piperidin-1-ylpyrimidine-5-carboxylic and 4-methyl-2-morpholin-4-pyrimidine-5-carboxylic acids.

The germination capacity increase of *Rhododendron* species under the influence of 2-benzylamino-4-methylpyrimidine-5-carboxylic acid was observed mainly in concentrations of

0.05% and 0.1%. This compound had the strongest effect at the plant height for all *Rhododendron* species. The increase in the seedling height in comparison with the control was revealed in all experimental variants. But 2-benzylamino-4-methylpyrimidine-5-carboxylic acid indicated the highest stimulating activity at concentrations of 0.01%, 0.05% and 0.1% for the tested species of the genus *Rhododendron* (Tables 1-4). It was illustrated by the largest increases in the seedling height, especially for *Rh. ledebourii* (Table 1). Although cytogenetic and molecular studies can reveal the seed difference [13] more exactly, morphometric investigations adequately reflect parameters of the seeds diversity.

Apparently 2-benzylamino-4-methylpyrimidine-5-carboxylic acid retains its stimulating effect longer than other compounds and is more active, while Rh. ledebourii is most responsive to seed treatment with compounds. So in experiments with pyrimidine-carboxylic acids, as tested heterocycles, the "benzylamino" fragment increases the activity of the compounds. This is consistent with the results of O.N. Kulaeva and her colleagues, who have showed that the "benzylamino" substituent increases the activity of synthetic cytokinin: 6-benzylaminopurine is superior in activity to kinetin [31]. Two-way analysis of variance has showed a significant effect of "chemical treatment" and "concentration" factors on the seedling height Rh. ledebourii ($P<0.05$), Rh. luteum ($P<0.05$), Rh. molle ($P<0.05$), Rh. schlippenbachii ($P<0.05$).

The germination rate at Rh. ledebourii, Rh. luteum, Rh. molle increases from 5 to 7% under the influence of synthesized organic substances of pyrimidinecarboxylic acids, at Rh. schlippenbachii – from 5 to 10% in concentrations of 0.01%, 0.05% and 0.1%. The seeds treatment with compounds of pyrimidinecarboxylic acids in concentrations of 0.01%, 0.05% and 0.1% allows to increase the seedling height at Rh. ledebourii from 37.5 to 75%, at Rh. luteum, Rh. molle – from 18.2 to 45.5%, at Rh. schlippenbachii from 20 to 40% relatively to the control. To increase the seedling height, 2-benzylamino-4-methylpyrimidine-5-carboxylic acid in concentrations 0.05% and 0.1% is most effective.

Thus, parameters of the seed germination can be improved by the pre-sowing treatment with compounds of the pyrimidinecarboxylic acid series. The similar trends of the seed germination were revealed in this investigation. The strongest stimulating effect was demonstrated by all the studied compounds with a concentration of 0.1% for all Rhododendron species. The same dynamic of the increase in the seedling height from low (0.01%) to high (0.1%) concentration was observed for each Rhododendron species. On the other hand, there are some facts prove to be seeds diversity. The seed germination of Rhododendron luteum is differ from responses of other Rhododendron species. That means special stimulant impact for sowing qualities in Rhododendron luteum seeds or specific seeds reaction for the treatment. Rhododendron ledebourii had the largest increases in the seedling height. Morphologically close species (Rh. luteum, Rh. molle) reacted in a similar way to the seed treatment. But there is the difference between their parameters. The low coefficient of variation can mean that the population of Rh. luteum is more stable, than the one of Rh. molle.

Conclusion

There is the trend of increasing the seed germination and the height of Rhododendron seedlings depended on the concentration of applied organic compounds. A direct correlation can be noted: the higher concentration of 2-benzylamino-4-methylpyrimidine-5-carboxylic acid (within the range between 0.01 and 0.1%) leads the increase in the seed germination and the seedling height of Rhododendron species. The same correlation was demonstrated for the seeds germination and the seedlings height, when 4-methyl-2-piperidin-1-ylpyrimidine-5-carboxylic and 4-methyl-2-morpholin-4-pyrimidine-5-carboxylic acid was applied. But the last acid is weaker, than other. Morphologically close Rhododendron species (Rh. luteum, Rh. molle) indicated similar reactions to the seed treatment with compounds of the pyrimidinecarboxylic acid series. However, the diversity of seeds is manifested in their heterogeneity according to morphological characteristics (the seedling height) and sowing qualities (seed germination) of Rhododendron species including Rh. luteum, Rh. molle. The sowing properties (germinating capacity, the seedling growth) were improved after treating the seeds with the synthesized organic compounds in all studied species. The organic compounds of pyrimidinecarboxylic acids are characterized by high biological activity. These substances stimulate the growth of ornamental shrubs Rhododendron when their concentrations are low.

Acknowledgments

The study received financial support from the Ministry of Science and Higher Education of the Russian Federation within the framework of State Contract with universities regarding scientific research in 2023–2025, project No. FZGU-2023-0009.

References

1. Dyakov A.B., Trunova M.V., Vasiliev T.A. (2009) Evaluation of the potentials of productivity and drought tolerance of soybean varieties [Ocenka potencialov urozhajnosti i zasuhoustojchivosti sortov soi]. Oilseeds. Scientific and Technical Bulletin of the All-Russian Research Institute of Oilseeds [Maslichnye kul'tury. Nauchno-tehnicheskij bjulleten' Vserossijskogo nauchno-issledovatel'skogo instituta maslichnyh kul'tur], no. 2(141), pp. 78-86.

2. Doroshenko T.N. (2000) Physiological and environmental aspects of southern fruit growing [Fiziologo-jekologicheskie aspekty juzhnogo plodovodstva]. Krasnodar: KubSAU, 235 p.

3. Doroshenko T.N., Zakharchuk N.V., Ryazanova L.G. (2010) Adaptive potential of fruit plants in the south of Russia [Adaptivnyj potencial plodovyh rastenij juga Rossii: Monografija]. Krasnodar: Publishing House LLC "Enlightenment-South", 192 p.

4. Khodaei-Joghan A., Gholamhoseini M., Agha-Alikhani M., et al. (2018) Response of sunflower to organic and chemical fertilizers in different drought stress conditions. Acta agriculturae Slovenica, no. 111(2), pp. 271–284. https://doi:10.14720/aas.2018.111.2.03.

5. Nesterkina I.S., Musalov M.V., Gurina V.V., et al. (2019) The effect of a new non-toxic water-soluble selenorganic substance on antioxidant protection and development of seedlings of oilseed radish (Raphanus sativus L. var. oleiferus Metzg.). Acta agriculturae Slovenica, no. 114/1, pp. 61–67. https://doi:10.14720/aas.2019.114.1.7

6. Balagura O.V., Levshakov LV. (2013) Diversity of sugar beet seeds and its significance [Raznokachestvennost' semjan saharnoj svekly i ee znachenie]. Bulletin of the Kursk State Agricultural Academy [Vestnik Kurskoj gosudarstvennoj sel'skohozjajstvennoj akademii], no. 9, pp. 52-54.

7. Vostrikova T.V. (2011) Ecological and biological features of rhododendrons during introduction in the conditions of the Central Chernozem region [Jekologo-biologicheskie osobennosti rododendronov pri introdukcii v uslovijah Central'nogo Chernozem'ja]. Bulletin of Krasnoyarsk State Agrarian University [Vestnik Krasnojarskogo gosudarstvennogo agrarnogo universiteta], no. 4, pp. 27–30.

8. Tsareva L.E. (2013) Technique of improving yielding features of seeds in reproduction of sugar beet hybrids [Careva L.E. Sposob povyshenija urozhajnyh svojstv semjan pri vosproizvodstve gibridov saharnoj svekly]. Bulletin of Altai State Agrarian University [Vestnik Altajskogo gosudarstvennogo agrarnogo universiteta], no. 1(99), pp. 17–19 (in Russian).

9. Sudhakar P., Latha P., Reddy P.V. (2016) Seed physiological and biochemical traits. In Phenotyping Crop Plants for Physiological and Biochemical Traits, pp. 17-24. https://doi:10.1016/B978-0-12-804073-7.00002-8.

10. Fachi L.R., Krause W., Duarte H., et al. (2019) Digital image analysis to quantify genetic divergence in passion fruit (Passiflora edulis) seeds. Genetics and Molecular Research, no. 18(3). https://doi:10.4238 / gmr18331.

11. Baranova T.V. (2013) Accelerated production of plants resistant to urban conditions [Uskorennoe poluchenie ustojchivyh k gorodskim uslovijam rastenij]. Ecology and Industry of Russia [Jekologija i promyshlennost' Rossii], no. 4, pp. 65–67 (in Russian).

12. Bome N.A., Salekh S., Korolev K.P., et al. (2022) Biological potential of winter cereals in the Northern Trans-Urals, Russia. SABRAO J. Breed. Genet., no. 54(4), pp. 789-802. http://doi.org/10.54910/sabrao2022.54.4.10

13. Hassanien A.M., Mohammed A.H., Allah H.A. A.B.D., et al. (2020) Cytogenetic and molecular studies on two faba bean cultivars revealed their difference in their aluminum tolerance Acta agriculturae Slovenica, no. 116(2), pp. 273-285. http://dx.doi.org/10.14720/aas.2020.116.2.1346

14. Khaled K.A.M., Sultan F.M., Azzam C.R. (2022) Gamma-rays and microwave irradiation influence on guar (Cyamopsis tetragonoloba): I – markers assisted selection for responding to mutagenic agents. SABRAO J. Breed. Genet., no. 54(2), pp. 331-349. http://doi.org/10.54910/sabrao2022.54.2.10

15. Azizian J., Delbari A. S., One-Pot K.Y. (2014) Three-Component Synthesis of Pyrimido[4,5-b] quinoline-tetraone Derivatives in Water. Synthetic Commun., no. 44 (22), pp. 3277–3286.

16. Ghoneim A.A., Assy M.G. (2015) Synthesis of Some New Hydroquinoline and Pyrimido[4,5-b]

Quinoline Derivatives. Current Research in Chemistry, no. 7(1), pp. 14–20. doi: 10.3923/crc.2015.14.20

17. Tkachenko E. V., Gubar S. N., Zhuravel I. A., et al. (2018) Synthesis and antimicrobial activity of amides 2,4-dioxo-1,4-dihydro-2H-thieno [3,2-d] pyrimidin-3yl) carboxylic acids [Sintez i protivomikrobnaja aktivnost' amidov 2,4-diokso-1,4-digidro-2N-tieno[3,2-d]pirimidin-3il)karbonovyh kislot]. Bulletin of the Kazakh National Medical University [Vestnik Kazahskogo Nacional'nogo medicinskogo universiteta], no. 1, pp. 347–350.

18. Vostrikova T.V., Kalaev V.N., Potapov A.Yu., et al. (2020) Using synthesized organic compounds as environmentally friendly retardants for ornamental plants. Southern Brazilian Journal of Chemistry, no. 28 (28), pp. 40-44.

19. Weisfeld L.I. (2015) About cytogenetic mechanism of chemical mutagenesis. In Ecological consequences of increasing crop productivity. Plant breeding and biotic diversity. Toronto-New Jersey: Apple Academic Press Inc., pp. 259-269.

20. Bome, N.A., Weisfeld, L.I., Babaev, E.V., et al. (2017) Influence of phosphomide, a chemical mutagen, on agrobiologial signs of soft spring wheat Triticum aestivun L. [Agrobiologicheskie priznaki jarovoj mjagkoj pshenicy (Triticum aestivum L.) pri obrabotke semjan himicheskim mutagenom fosfemidom] Agricultural Biology [Sel'skohozjajstvennaja biologija], no. 52 (3), pp. 570-579 (Ru). doi: 10.15389/agrobiology.2017.3.570rus

21. Vostrikova T.V., Kalaev V.N., Potapov A.Yu., et al. (2021) Use of new compounds of the quinoline series as growth and yield stimulants of agricultural crop. Periódico Tchê Química, no. 18 (38), pp. 123-136.

22. Vostrikova T.V., Kalaev V.N., Potapov A.Yu., et al. (2020) Use of new compounds of the quinoline series as effective stimulants of growth processes. Periódico Tchê Química, no. 17 (35), pp. 781-790.

23. El-Gazzar A.B.A., Hafez H.N., Nawwar G.A.M. (2009) New acyclic nucleosides analogues as potential analgesic, anti-inflammatory, anti-oxidant and anti-microbial derived from pyrimido[4,5-b] quinolines. European Journal of Medicinal Chemistry, no. 44(4), pp. 1427–1436.

24. Elkholy Y.M., Morsy M.A. (2006) Facile Synthesis of 5, 6, 7, 8-Tetrahydropyrimido[4, 5-b]-quinoline Derivatives. Molecules, no. 11, pp. 890–903.

25. Vostrikova, T.V., Burmenko, J.V., Kalaev, V.N., et al. ***(2022)*** Anthropogenic Pollution Influence on the Antioxidant Activity in Leaves and on the Cytogenic Structures in the Seedlings of the Representatives of the Rhododendron Genus. In Biological Assessment of Natural and Anthropogenic Ecosystems: Trends in Diagnosis of Environmental Stress. Burlington: Apple Academic Press Inc., pp. 121-136.

26. Alexandrova M.S. (2003) Rhododendrons [Rododendrony]. Moscow: ZAO Fiton+, 192 p. (in Russian).

27.The map of the B.M. Kozo-Polyansky Botanical Garden of Voronezh State University. https://hb.karelia.ru/files/img/01b31d63629c5eea37dda39f6a9c3fd2.jpg

287. Kulaichev A.P. (2006) Methods and tools for integrated data analysis [Metody i sredstva kompleksnogo analiza dannyh]. Moscow: FORUM: INFA-M, 512 p.

29. Lakin G.F. (1990) Biometry [Biometrija]. Moscow: Higher School, 352 p.

30. Baranova T.V., **K**alendar R.N., Kalayev V.N. (2014) To the Question of Rhododendron L. Genus Phylogeny Based on ITS1-ITS2 Spacers Sequence Studies [K voprosu filogenii vidov roda Rhododendron L. na osnovanii issledovanij posledovatel'nosti spejserov ITS1-ITS2]. Siberian Forestry Journal [Sibirskij lesnoj zhurnal], no. 6, pp. 30–46.

31. Muromtsev G.S, Chkanikov D.I., Kulaeva O.N., Hamburg K.Z. (1987) Fundamentals of chemical regulation of plant growth and productivity [Osnovy himicheskoj reguljacii rosta i produktivnosti rastenij]. Moscow: Agropromizdat, 383 p.