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ADAPTIVE POTENTIAL AND PHENOTYPIC VARIABILITY OF RIBES SPECIES IN THE LOWER VOLGA REGION

A.S. Solomentseva

Background. *The climate, soil, and hydrology of the Volgograd Region complicate agricultural work. The ever-greater intensification of agriculture has brought substantial anthropogenic change upon the natural terrain in the agricultural areas of the country. Protective afforestation seeking to address soil erosion and drought, as well as the artificial selection of economically valuable species, have been the source of the most prominent change.*

Purpose. *To evaluate the biological potential of Ribes L. species, the authors compared the development and reproductive traits, assessed the ecological flexibility of the species (an effective metric for introduction in arid regions that can be used in practice to muster biological resources and nursery work).*

Materials and methods. *Currant populations were mainly studied by sampling population statistics and biometry, to which end the authors applied analysis of variance.*

Quantitative varying traits included fruiting, qualitative traits included leaf, fruit, and shoot color, and ordinal traits included bark smoothness. To evaluate the biological potential of the species Ribes aureum Pursh., the authors compared the development and reproductive traits, assessed the ecological flexibility of the species (an effective metric for introduction in arid regions that can be used in practice to muster biological resources and nursery work). Annual maturation rates of Ribes aureum Pursh. Shoots determine whether they will survive at winter. The following visual cues of maturation were used: lignification, coloring, and development of outer covers, budding, shoot growth completion, and leaf fall completion timings.

Results. *Currant grows in any soil, including alkaline light-chestnut soils, outcrops of bedrock ravines (Kamyshin), washed-away, eroded soils of steep slopes and ravines (Volgograd); winter hardiness depends on the natural range. Currant tends to live longer in soils most suitable for afforestation. Young shoots also differed in color. In Volgograd and its vicinity, such shoots were green (or brown), rugged. In*

Kamyshin, they were reddish or grayish, finely pubescent. Lamina morphometry revealed pronounced differences in lamina size and color from area to area.

Conclusions. *Currant species are promising shrubs that are important for forest reclamation and for nurseries. Currant plantations enrich flora and fauna as they form an ecological niche where beneficial insects, birds, mammals, and other animals can disperse, feed, or find a habitat. Currant polymorphism has an important role to play in plant evolution. It is caused by the variability of various traits in individuals of a population, which creates subspecies that are valuable for the purposes of selection and introduction. The genotype of a species determines its lamina parameters. Air temperature, precipitation, and soil moisture affect the modifiability of leaf parameters, as well as the location of leaves in the bush and on the shoots. A stable difference between lamina parameters indicates a species difference. The results hereof could be of use in the context of bioindicators of the ecological status and adaptability of currant.*

Keywords: *currant; Ribes L.; growth; development; resilience; phenotypic variability; arid region*

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АДАПТИВНЫЙ ПОТЕНЦИАЛ И ФЕНОТИПИЧЕСКАЯ ИЗМЕНЧИВОСТЬ ВИДОВ РОДА RIBES В УСЛОВИЯХ НИЖНЕГО ПОВОЛЖЬЯ

А.С. Соломенцева

Обоснование. *Сельскохозяйственное производство в условиях Волгоградской области ведется в сложных климатических и почвенно-гидрологических условиях. В результате возрастающей интенсификации сельскохозяйственного производства природные ландшафты земледельческих районов страны подвергались значительной антропогенной модификации. Наиболее существенные изменения в них внесло защитное лесоразведение, направленное на борьбу с эрозией почв и засухой, а также селекционный подбор хозяйственно ценных видов.*

Цель. *Чтобы оценить биологический потенциал вида Ribes L., автор сравнила развитие и репродуктивные признаки, оценила экологическую пла-*

стичность вида (показатель эффективности для интродукции в засушливых регионах, который может быть использован на практике для восполнения биологических ресурсов и работы питомников).

Материалы и методы. *Основой изучения популяций смородины являлся популяционно-статистический и биометрический метод. Для этой цели использовался дисперсионный анализ. Количественными варьирующими признаками было плодоношение, качественными – окраска листьев и плодов, побегов, порядковым – гладкость коры. Для оценки биологического потенциала вида Ribes aureum Pursh. проводилось сопоставление развития и репродуктивных способностей, выявление экологической пластичности вида, которая служит мерой успешности интродукции в засушливом регионе и дает возможность его практического использования для целей мобилизации биоресурсов и питомниководства. Степень ежегодного вызревания побегов смородины определяет их более или менее успешную перезимовку, визуально вызревание побегов определялось по одревеснению, окраске и развитию наружных покровов, по заложению степени сформированности и защищенности почек, по времени окончания ростов побегов и окончанию листопада.*

Результаты. *Смородина растет на любых почвах, в том числе и на сильно солонцеватых комплексных светло-каштановых, на обнажениях оврагов коренной породы (Камышин), на смытых эродированных почвах крутых склонов и оврагов (Волгоград), зимостойкость видов зависит от их природного ареала. Кора и ветви побегов в южной части региона – красно-бурые, серо-бурые. Чуть севернее кора приобретает бурый оттенок и слегка растрескивается. Цвет молодых побегов также заметно различается. У Волгоградских видов они зеленые (или коричневые), шероховатые. У видов Камышина – красноватые, или сероватые, мелкоопушенные. Морфометрический анализ листовых пластин смородины показал явно выраженные отличия между их размерами и цветом в разных пунктах произрастания.*

Выводы. *В насаждениях различного назначения используется разнообразный ассортимент деревьев и кустарников, их биологические свойства отражают их отношение к факторам внешней среды. Виды смородины, как перспективные кустарники, имеют огромное значение для лесомелиорации и питомниководства. Полиморфизм смородины играет большую роль в процессе эволюции растений. Он обусловлен изменчивостью различных признаков у особей, которые входят в состав популяции, это влечет за собой образование внутривидовых форм, которые представляют собой ценный материал для целей селекции и интродукции. Генотипические особенности*

вида растения определяют параметры его листовой пластинки. Температура воздуха, количество осадков, влажность почвы влияют на модификационную изменчивость листовых параметров, расположение листьев на кусте и побеге. Если разница в параметре листовых пластинок устойчива, то данный факт говорит о видовых различиях растений. Результаты работы могут быть использованы в биоиндикации экологического состояния и адаптивной способности смородины.

Ключевые слова: *смородина, Ribes L., рост, развитие, устойчивость, фенотипическая изменчивость, аридный регион*

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Purpose

The Lower Volga Region’s steppes, dry steppes, and semi-deserts are nearly void of forestation, not only due to lack of moisture, but also due to the terrain, edaphic factors, agriculture, and climate. The regional climate is the dominant factor of the actual distribution of plants and their ability to withstand climate; it also affects how the habitat range of each species changes. The Volgograd Region has a dry continental climate [1].

The total effective temperature >10 °C equals 3000–3300; the coldest month temperature is –5–11 °C, the warmest month temperature is +20.5–23 °C. The total annual precipitation is 300–400 mm, winter precipitation is 40 mm, and spring soil moisture equals 28 mm. The total heavy rainfall is 40 mm, the total runoff is 25 mm, and the runoff coefficient is 0.07. February to July, October and December are the windiest months [2].

Vega (a satellite-based vegetation analysis service) reports vegetation-less land in the Volgograd Region to increase, and the total area of forests and shrubs to decrease every year, see fig. 1.

These conditions are harsh on trees and shrubs, which is why soil and climate conditions have caused a phenotypic change in many species without affecting their genotype. *Ribes aureum* Pursh. of the family *Grossulariaceae* is one attention-worthy shrub. This species is of North American origin but is prevalent in the Lower Volga Region.

Over the last reporting decade, the total area of currant plantations only rose by 31.4 ha; the area of perennial plantings did not increase either, see fig. 2 and fig. 3 [4, 5, 6].

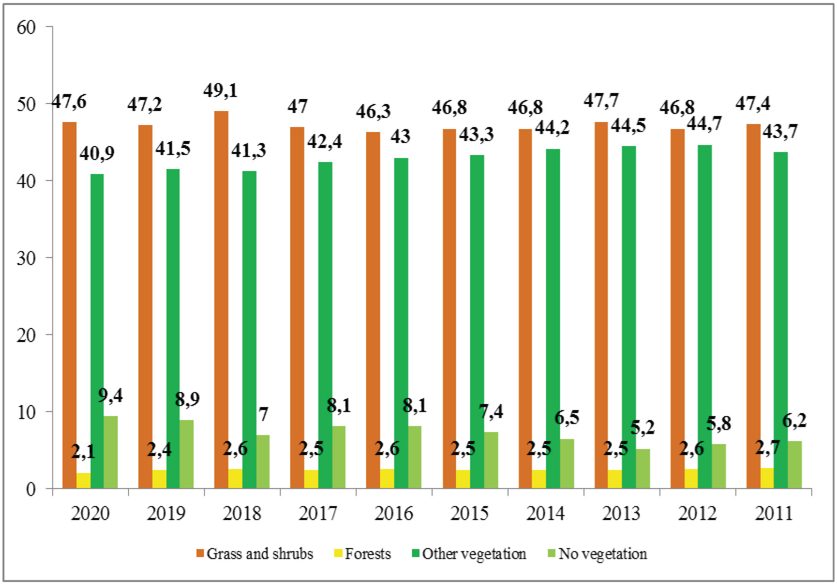

Fig. 1. Distribution of vegetation area across the south of Russia (Volgograd Region) [3]

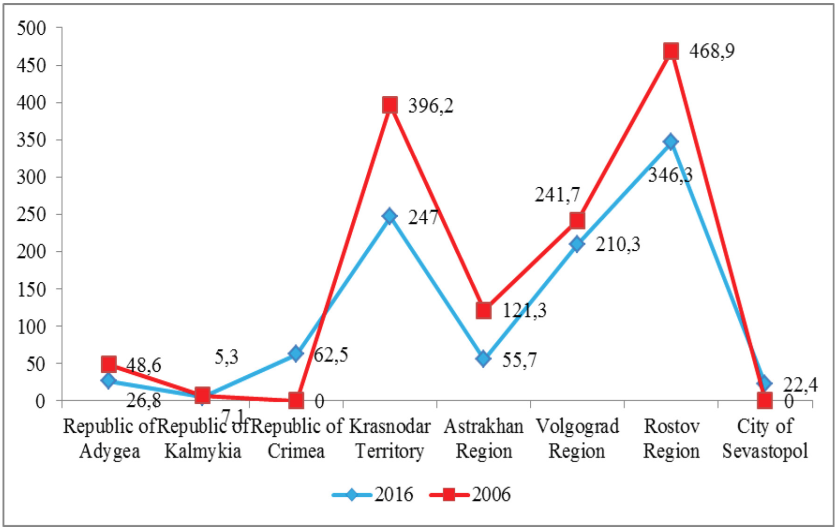

Fig. 2. Area of currant plantations (for berry production), ha, 2006–2016

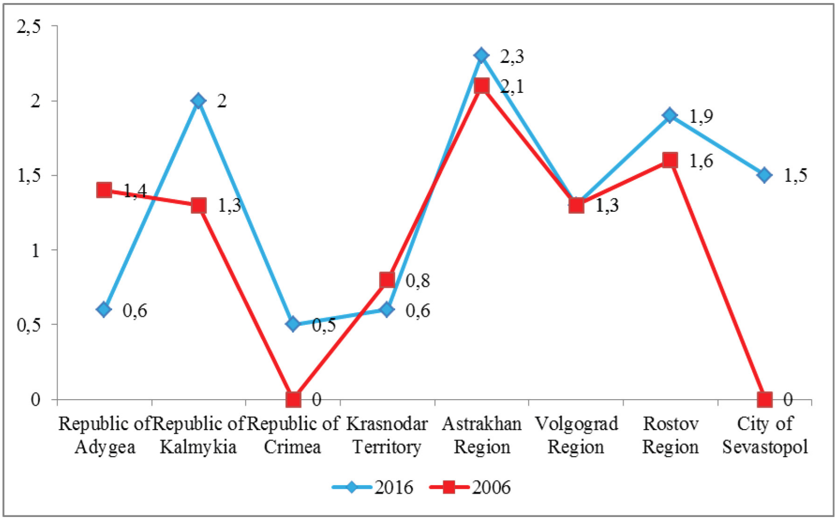

Fig. 3. Area of perennial currant plantings, ha, 2006–2016

Currant could be a valuable source of material for plant selection [7]. Thus, phylogenetic testing revealed a group of BRV isolates from red currant, which had unique nucleotide substitutions. Five putative recombinants were first identified among BRV isolates from Latvia, Finland, Scotland, and the Czech Republic [8]. Currant species are capable of active seed replenishment without irrigation [9]. Consumption of various berries, including those of *Ribes*, has been associated with a variety of health benefits. Some studies have shown that *Ribes aureum* Pursh. berries are rich in nutrients [10]. Currant species have been shown to renew and grow well on saline soils [11].

*R. aureum Pur*sh. is a promising crop for landscaping. For hedge design, the hedge width and the desired color scheme limit the selection. Compared to other shrubs, *R. aureum* Pursh. as a hedge shrub can also provide nearby kindergartens and schools with berries, making it an indispensable hedge crop [12]. Currant berries contain a complex of biologically active substances, making them a valuable source of vitamins for Russian regions [13, 14].

Siberian and Scandinavian subspecies of black currant and *Ribes dikuscha* are where the winter hardiness of black currant comes from. Statistical evaluation of the heritability of this trait in a large group of seedlings returned a total heritability coefficient H2 of 0.84. That means the initial forms are selectable by phenotype [15-22].

Plants of the genus grow and shoot well, are winter-hardy and drought-resistant, making them a promising solution for protective afforestation and for use in pure crops.

Scientific novelty

For the first time in the arid conditions of the Lower Volga region, intrapopulation phenotypic variability of currants in terms of crown, shoot, leaf, flowering dates, and fruiting parameters was established. The optimal temperatures for the formation of cold resistance in various conditions, as well as the life expectancy and the age of the rejuvenating pruning were revealed. It has been established that the productivity of the cambium of the shrub is affected by repeated droughts. Experiments have been conducted to determine the content of heavy metals, which can be used in bioindication.

Materials and methods

Currant populations were mainly studied by sampling population statistics and biometry, to which end the authors applied analysis of variance. When using ANOVA to detect variability, the condition is written as σ2ph = σ2q + σ2e, i.e., the total phenotypic variance σ2ph is a bi-component measure of the total variability of traits: hereditary (genotypic) variance σ2q, which describes the genetic variability of the mean presence of a trait in a population; and non-hereditary (paratypic) variance σ2e, which describes the variability of the mean presence of a trait that is attributable to the environmental diversity. Quantitative varying traits included fruiting, qualitative traits included leaf, fruit, and shoot color, and ordinal traits included bark smoothness.

To evaluate the biological potential of the species *Ribes aureum* Pursh., the authors compared the development and reproductive traits, assessed the ecological flexibility of the species (an effectiveness metric for introduction in arid regions that can be used in practice to muster biological resources and nursery work). Annual maturation rates of *Ribes aureum* Pursh. shoots determine whether they will survive winter. The following visual cues of maturation were used: lignification, coloring, and development of outer covers, budding, shoot growth completion, and leaf fall completion timings.

To avoid errors, the evaluation only involved shrubs of the same age such that most traits would manifest stably; all the tested shrubs grew in the same natural region and had identical habitats. Age-wise, they were one or two age classes apart at max. Forest growth conditions were monitored using a VEGA-Science unit (BS IKI-Monitoring), which is designed for remote sensing-based environmental monitoring. Currant plantings were made at experimental sites: Nizhnevolzhskaya Tree Species Selection Station (Kamyshin), Dubovka Experimental Nursery, Volgograd Arboretum, and plantations in Kalachevsky Municipality.

Results

Decade-long monthly average temperature and precipitation monitoring showed winters to had become warmer in recent years. January and February 2019–2020 are highlights of this statistic. Precipitation of 123.1 mm and 128.6 mm was observed in May 2020 and July 2018, respectively. Over the decade, only in 2013, 2016, and 2018, the normal annual precipitation rate was reached sufficiently, see fig. 4.

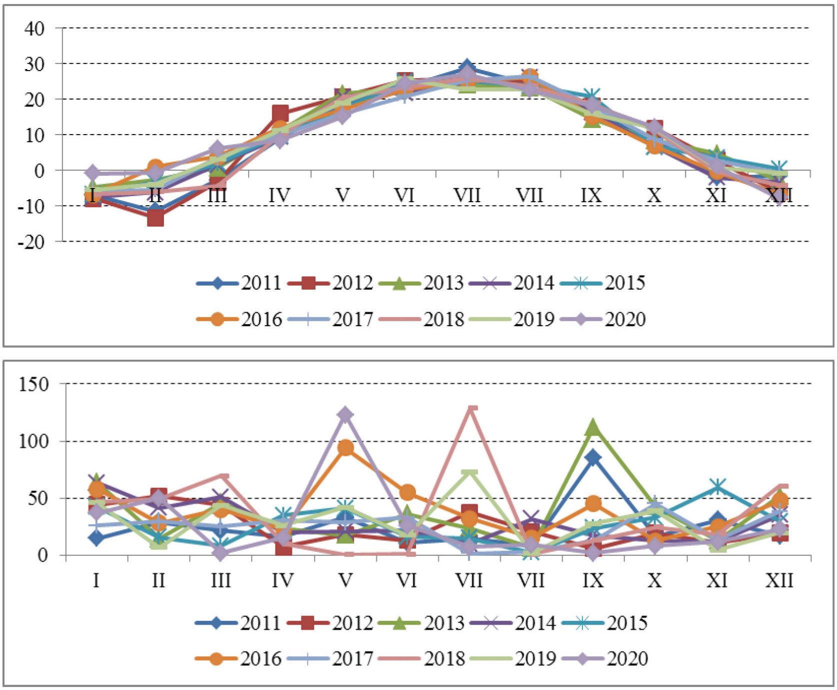

Fig. 4. Temperature and precipitation in the studied region, breakdown by years

In natural plant populations, currant species are of great interest as economically valuable plants that beavers, hazel grouse, coniferous forest birds, cattle and small ruminants, pigs, and horses feed on. They are also valuable as honey-bearing and ornamental species. Analysis of phenotypic variability of currant species revealed their biometry to differ significantly in arid environments, see fig. 5.

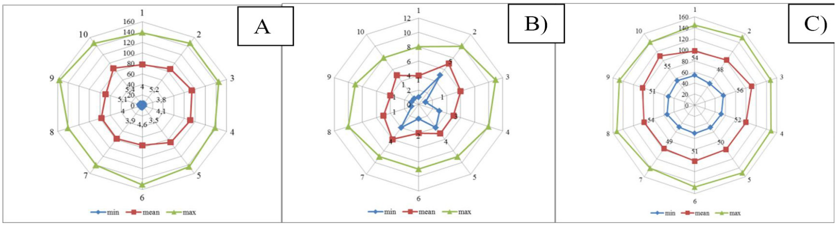

Fig. 5. Intrapopulation phenotypic variability of some traits in *Ribes aureum* Pursh.: (a) shoot length; (b) number of shoots; (c) crown circumference

Bark and shoot branches were red-russet or gray-russet in the south of the region. Further north, bark was russet and cracked slightly. Young shoots also differed in color. In Volgograd and its vicinity, such shoots were green (or brown), rugged. In Kamyshin, they were reddish or grayish, finely pubescent. Lamina morphometry revealed pronounced differences in lamina size and color from area to area, see Figure 6. A smaller lamina due to a shorter cell division window and faster cell differentiation is an indicative response to the arid environment.

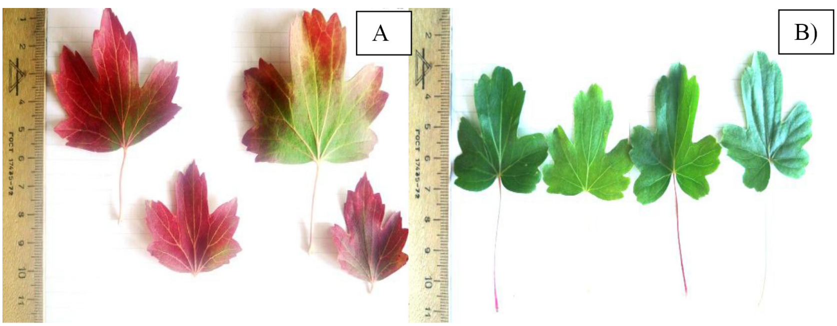

Fig. 6. Differences in leaf morphometry between Ribes aureum Pursh. in Volgograd (a) and Kamyshin (b)

Currant grows on any soil, including alkaline light-chestnut soils, outcrops of bedrock ravines (Kamyshin), washed-away eroded soils of steep slopes and ravines (Volgograd); winter hardiness depends on the natural range, see tab. 1.

Table 1.

Winter adaptation conditions of *Ribes* species in various environments

Species	Natural area indices*	Long-term minimum average annual t, ºC		
		natural introduced	range where introduced	
		t min	areas of introduction	t min
Ribes triste Pall.	1, 2, 9	-60	Moderately arid	-38
Ribes spicatum Robson	2–6, 8, 9, 11	-58		
Ribes nigrum L.	2–6, 8, 9, 11	-56	Extremely arid	-37
Ribes mandshuricum (Maxim.) Kom.	9	-40		
Ribes komarovii Pojark.	9	-32	Arid	-38
Ribes alpinum L.	6, 8, 13	-28		
Ribes aureum Pursh.	1	-60		

*Note: 1 for North America, 2 for Northeast Asia, 3 for Western Siberia, 4 for Mongolia, 5 for Boreal Kazakhstan, 6 for Eastern Europe, 8 for Western Europe, 9 for East Asia, 11 for Turan, Kazakhstan, 13 for Crimea and Caucasus

Currant tends to live longer on soils more suitable for afforestation. Thus, plants of the genus live longer on ordinary and southern chernozem, dark chestnut soils, chernozem-like non-alkaline or weakly alkaline meadow soils, dark chestnut non-alkaline meadow soils, where water-soluble salts are absent from the 1.5 m upper layer. Species growing on dark chestnut soils, strongly alkaline chestnut meadow soils, sabulous to medium-clayey medium-alkaline soils; any soils with the toxic presence of water-soluble content at less than 1.5 m off the surface; complex soils where alkaline and strongly alkaline soils account for 25 to 50 percent, see tab. 2.

Table 2.

Ribes life expectancy in a degrading, desertified environment

Afforestation suitability class of soil	large, broad planting		6–9 rows of protective planting		3–5 rows of protective planting	
	age, years	height, cm	age, years	height, cm	age, years	height, cm
1	25	250–300	25	250–300	25	250–300
2	25	250	25	200–300	25	200–300
3	15	150	15	150	15–18	200
4	5–7	70–100	5–7	70–100	0.7–10	100–120

Currant life expectancy can be improved by regenerative pruning that should begin when the plant is 4 to 8 years of age. Pruning affects the development and growth of new shoots, as well as the ability to produce new seeds, see tab. 3. In poor forest environments, currants are shorter-lived due to qualitative inner change. Repeated droughts cause cambium productivity to drop so low the plant is no longer able to respond to an improvement in its environment, i.e., it becomes physiologically senile.

Table 3.

Regenerative pruning age in dry steppes and semi-deserts

Afforestation suitability class of soil	Plantings		
	Large and broad	6–7 rows of field–protecting plantings	3–5 rows of field–protecting plantings
1	6–8	6–8	6–8
2	5–7	5–7	5–7
3–4	5–7	5–4	5–4

In natural plant populations, currant species are of great interest as economically valuable plants that beavers, hazel grouse, coniferous forest birds, cattle and small ruminants, pigs, and horses feed on. They are also valuable as honey-bearing and ornamental species.

Early vegetation is typical of growth and development in arid environments. Comparative analysis of phenological dates showed *Ribes aureum* Pursh. to blossom early in Novocherkassk, Volgograd and Mariupol. Specimens in Minsk, Belarus, bloomed later. Manchurian currant's blossom came last, perhaps due to a different climate and habitat, see tab. 4.

Table 4.

Average dates and duration of currant's blossom at various monitoring stations

Species	Average blossom date	Blossom duration, days
Ribes sanguineum	7.05 27.04–18.05* 22.05 15.04–30.04**	12 8–18
Ribes aureum	8.05 29.04–16.05 * 1.04 24.04–15.05 ** 2.04 29.04–15.05 *** 4.05 27.04–13.05****	17 12–27

End of table

Ribes nigrum	9.05 29.04–21.05* 6.05 27.04–15.05****	12 8–15
Ribes mandshuricum	10.05 30.04–22.05*	8 6–11
Ribes alpinum	6.05 26.04–18.05* 1.04 29.04–16.05***	11 7–16

*Note: comparative metrics: *Minsk, **Novocherkassk, ***Mariupol, ****Volgograd

Table 5.

Economically valuable traits and methods for stratification of currant seeds

Species	Height, m	Leaves		Fruits*		Flowers	Crown	Possible applications	Stratification and storage
		L	D	diameter	coloring				
Ribes alpinum	1.5–2 m	1.5 cm	4 cm	0.7–0.9 mm	pinkish or red	greenish-yellow	150 cm	ornamental, nutritional	store in dry ventilated room in tightly sealed bottles at t = 0–5 °C for 1-2 years. No pre-treatment for planting in fall. 90-day stratification at 3–5 °C for planting in spring.
Ribes cereum	Up to 1 m	1 cm	4 cm	5–12 mm	vivid red, orange,	greenish-white, pinkish-white	150 cm	ornamental	
Ribes cucullatum	Up to 1 m	1 cm	3 cm	5–7 mm	black	red	150 cm	nutritional	
Ribes spicatum	Up to 1.5 m			6–10 mm	red	pinkish	170 cm	nutritional	
Ribes komarovii	2.5 m	2 cm	4.5 cm	7–8 mm	red	greenish	100 cm	ornamental, nutritional	
Ribes sanguineum	Up to 4 cm	2 cm	8 cm	1 cm	very dark blue and glaucous	red	140 cm	ornamental, nutritional	
Ribes mandshuricum	1–2 m	9 cm	11 cm	7–9 mm	red	greenish	180 cm	nutritional	
Ribes triste	up to 75 cm	6.5 cm	9 cm	6–10 mm	vivid red	dirty purple	120 cm	nutritional, breeding	
Ribes punctatum	1.5–2 m	1 cm	3 cm	0.6–0.9	red, purple	purple, brownish	140 cm	ornamental, nutritional	
Ribes nigrum	1–1.25 m	10 cm	12 cm	10 mm	black, russet or greenish	mauve or pinkish-gray	150 cm	ornamental, nutritional	
Ribes aureum	2.0–2.2 m	5 cm	6 cm	6–8 mm	yellow, russet-red, black	yellow	180 cm	ornamental, nutritional	

Note*: fruiting onset at 3 years, mass fruiting onset at 5, average yield 48 kg/ha. Seeds harvested in July. Seed yield of 4–5%. Seeding rate of 12 kg/ha, planting 1–2 cm deep.

Protective afforestation and plant selection for growth in arid environments come down to creating special artificial stool beds using species selected for their economically valuable traits; other measures include storing the oversupply of seeds for use in lean years, appropriate utilization of species in terms of habitat range and ecological zoning, and guaranteed replication of selected gene pool of woody species, see Table 5.

The seeds came from a source designed for cultivating biologically resilient planting material capable of withstanding adverse conditions. Fruiting onset at 3 years, mass fruiting onset at 5, average yield 48 kg/ha. Harvesting in July, seed yield from fruits at 4–5%, see tab. 6.

Table 6.

Ribes aureum Pursh. fruiting in the experimental network of the Agroecological Federal Research Center (AFRC), Russian Academy of Sciences

Fruiting indicators	Kalach-na-Donu	Dubovka	AFRC Arboretum, RAS
Fruit weight, g	0.58	0.59	0.52
Fruit width, mm	0.80	0.65	0.71
Fruit length, mm	1.04	0.86	0.68
Seeds per fruit, pcs	24.0	22.0	22.0
Weight, 10 seeds	0.15	0.09	0.07

Green spaces are important for Volgograd, a city with a severe anthropogenic load, as they protect the natural environment; therefore, it is critical to transform and preserve them with their functional role in mind. Heavy metals can end up in a plant in a variety of pathways; this diversity implies the existence of two core factors behind the elemental chemistry of plants: genetics and ecology. The contribution of each factor may vary depending on environmental change. During phytogenesis and ontogenesis, shrubs develop mechanisms capable of controlling the intake and removal of certain elements by means of physiological response. Heavy-metal presence in *Ribes aureum* Pursh. fruits can serve as a bioindicator of the ecological status; they are fundamental to assessing the consequences of anthropogenic pollution of natural and agricultural ecosystems, see tab. 7.

Table 7.

Heavy metal presence

Harvesting site	Element			
	Cadmium (Cd)	Zinc (Zn)	Lead (Pb)	Copper (Cu)
Volgograd	0.04	12.07	0.84	8.19
Dubovka	0.05	5.20	0.10	2.10
MPC*	0.03	10.0	0.40	5.0

*Note: value for an air-dry sample, mg/kg

Conclusion

Investigation of the phenotypic variability and adaptability have shown currant species to be fit in a variety of harsh forest environments. Nevertheless, plants growing in the most arid of places have smaller fruits that accounted for a greater percentage of the total biomass; vegetation and blossom start earlier in such plants. Lamina differs in color and size, and so does the crown diameter. Analysis and generalization of the experimental data helped reveal patterns and mechanisms of adaptation in the genus Ribes to arid environments; the investigation consisted in comprehensive research relying on the criteria descriptive of the biological potential and economic viability of plants for selecting adapted gene pool of economically valuable species in order to create environmentally balanced plantations serving a multitude of purposes, including without limitation aesthetics, recreation, soil protection, soil improvement, sheltering, enhancement of the natural environment, and production of raw materials for drug, honey, food industries, etc.

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DATA ABOUT THE AUTHOR

Alexandra S. Solomentseva, Cand. Sc. (Agriculture), Senior Researcher of the Laboratory of Breeding, Seed and Nursery Production
Federal Scientific Center of Agroecology, Complex Melioration, and Protective Afforestation RAS
97, Universitetsky pr., 400062, Volgograd, Russian Federation
Alexis2425@mail.ru
SPIN-code: 6832-7471
ORCID: https://orcid.org/0000-0002-5857-1004
ResearcherID: W-4142-2018
Scopus Author ID: 57220036834

ДАННЫЕ ОБ АВТОРЕ

Соломенцева Александра Сергеевна, к. с.-х. наук, старший научный сотрудник лаборатории селекции, семеноводства и питомниководства
Федеральное государственное бюджетное научное учреждение «Федеральный научный центр агроэкологии, комплексных мелиораций и защитного лесоразведения Российской академии наук»
пр-т Университетский, 97, г. Волгоград, 400062, Российская Федерация
alexis2425@mail.ru

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