Original article
УДК 634.739
DOI: 10.37482/0536-1036-2025-3-121-131

Adaptation Features of Kamchatka Bilberry (*Vaccinium praestans* Lamb.) Plants Grown *in vitro*

Natal'ya R. Sungurova[1]✉***, Doctor of Agriculture, Assoc. Prof.;***
ResearcherID: H-1847-2019, ORCID: https://orcid.org/0000-0002-8464-4596
Sergey S. Makarov[2]***, Doctor of Agriculture;*** *ResearcherID: AAK-9829-2021, ORCID: https://orcid.org/0000-0003-0564-8888*
Anton I. Chudetsky[2]***, Candidate of Agriculture;*** *ResearcherID: H-1210-2019, ORCID: https://orcid.org/0000-0003-4804-7759*
Yuliya S. Cheryatova[2]***, Candidate of Biology, Assoc. Prof.;***
ORCID: https://orcid.org/0000-0001-5614-2225
[1]Northern (Arctic) Federal University named after M.V. Lomonosov, Naberezhnaya Severnoy Dviny, 17, Arkhangelsk, 163002, Russian Federation; n.sungurova@narfu.ru✉
[2]Russian State Agrarian University – Moscow Timiryazev Agricultural Academy, ul. Timiryazevskaya, 49, Moscow, 127550, Russian Federation; s.makarov@rgau-msha.ru, chudetski@rgau-msha.ru, u.cheryatova@rgau-msha.ru

Received on November 23, 2023 / Approved after reviewing on February 18, 2024 / Accepted on February 20, 2024

Abstract. Currently, the demand for berry products with high nutritional and medicinal value is increasing. To preserve biodiversity and industrial propagation, it is necessary to grow plants *in vitro* and create a gene bank. Kamchatka bilberry (*Vaccinium praestans* Lamb.) is one of the valuable and rare forest berry plants, which requires the improvement of accelerated propagation technologies for further cultivation. The aim of the study has been to investigate the adaptation features of *in vitro* propagated *V. praestans* plants under *ex vitro* conditions and in open ground. The objects of the study have been *V. praestans* plants (2 hybrid forms and 3 selected forms from natural populations) obtained by the *in vitro* method. Morphometric parameters of the regenerated plants have been taken into account under *ex vitro* conditions when grown on various substrates (high-moor peat; peat + river sand 3:1; peat + vermiculite 3:1; peat + perlite 3:1; peat + zeolite 3:1) treated with aqueous solutions of growth stimulants (Zircon 0.5 ml/l; Epin-extra 0.5 ml/l). When adapting *ex vitro*, the highest survival rates (90 %), number of shoots (3.8 pcs. on average) and number of leaves (5.1 pcs. on average) of the *V. praestans* regenerated plants on the 28th day after transplantation have been revealed on a substrate made of a mixture of peat and zeolite (3:1) when treated with Epin-extra 0.5 ml/l. For the first time, the morphometric parameters and yield dynamics of *V. praestans* plants obtained by clonal propagation have been studied in open ground conditions in the natural and climatic conditions of Moscow, the Kostroma Region and the Khabarovsk Territory. The maximum shoot length in 2022–2023 was recorded in hybrid form 235261 (7.0–7.4 cm on average). The highest yield of 2–5-year-old *V. praestans* plants in open ground conditions has been noted in hybrid forms (362.75–383.0 g/m^2 on average) and has varied depending on the growing area.

Keywords: Kamchatka bilberry, *Vaccinium praestans*, adaptation, *ex vitro,* survival rate, introduction, morphometric parameters, yield
Acknowledgements: The work was carried out with the support of the Ministry of Science and Higher Education of the Russian Federation within the framework of the agreement on

the provision of a grant in the form of subsidies from the Federal budget for state support for the creation and development of a world-class scientific centre "Agrotechnologies of the Future".

For citation: Sungurova N.R., Makarov S.S., Chudetsky A.I., Cheryatova Yu.S. Adaptation Features of Kamchatka Bilberry (*Vaccinium praestans* Lamb.) Plants Grown *in vitro*. *Lesnoy Zhurnal* = Russian Forestry Journal, 2025, no. 3, pp. 121–131.
https://doi.org/10.37482/0536-1036-2025-3-121-131

Научная статья

Особенности адаптации растений красники (*Vaccinium praestans* Lamb.), выращенных *in vitro*

Н.Р. Сунгурова[1]✉***,*** *д-р с.-х. наук, доц.; ResearcherID: H-1847-2019,*
ORCID: https://orcid.org/0000-0002-8464-4596
С.С. Макаров[2]***,*** *д-р с.-х. наук; ResearcherID: AAK-9829-2021,*
ORCID: https://orcid.org/0000-0003-0564-8888
А.И. Чудецкий[2]***,*** *канд. с.-х. наук; ResearcherID: H-1210-2019,*
ORCID: https://orcid.org/0000-0003-4804-7759
Ю.С. Черятова[2]***,*** *канд. биол. наук, доц.; ORCID: https://orcid.org/0000-0001-5614-2225*
[1]Северный (Арктический) федеральный университет им. М.В. Ломоносова, наб. Северной Двины, д. 17, г. Архангельск, Россия, 163002; n.sungurova@narfu.ru✉
[2]Российский государственный аграрный университет – Московская сельскохозяйственная академия им. К.А. Тимирязева, ул. Тимирязевская, д. 49, Москва, Россия, 127550; s.makarov@rgau-msha.ru, chudetski@rgau-msha.ru, u.cheryatova@rgau-msha.ru

Поступила в редакцию 23.11.23 / Одобрена после рецензирования 18.02.24 / Принята к печати 20.02.24

Аннотация. В настоящее время возрастает спрос на ягодную продукцию с высокой пищевой и лекарственной ценностью. Для сохранения биоразнообразия и промышленного размножения необходимо выращивание растений в культуре *in vitro* и создание генетического банка. Красника (*Vaccinium praestans* Lamb.) – одно из ценных и редких лесных ягодных растений, для его дальнейшего культивирования требуется совершенствование технологий ускоренного размножения. Цель исследования – изучение особенностей адаптации полученных *in vitro* растений *V. praestans* в условиях *ex vitro* и в открытом грунте. Объекты исследования – растения *V. praestans* (2 гибридные формы и 3 отборные формы из природных популяций), выращенные методом *in vitro*. Учитывали морфометрические показатели растений-регенерантов в условиях *ex vitro* при культивировании на различных субстратах (торф верхового типа; торф + речной песок 3:1; торф + вермикулит 3:1; торф + перлит 3:1; торф + цеолит 3:1) с обработкой водными растворами стимуляторов роста (Циркон 0,5 мл/л; Эпин-экстра 0,5 мл/л). При адаптации *V. praestans ex vitro* наибольшие приживаемость (90 %), число побегов (в среднем 3,8 шт.) и листьев (в среднем 5,1 шт.) на 28-е сутки после пересадки выявлены у растений-регенерантов на субстрате из смеси торфа с цеолитом (3:1) при обработке препаратом Эпин-экстра 0,5 мл/л. Впервые в условиях открытого грунта в природно-климатических условиях г. Москвы, Костромской области и Хабаровского края изучали морфометрические показатели и динамику урожайности растений *V. praestans*, полученных методом клонального размножения. Максимальная длина побега в 2022–2023 гг. отмечена у гибридной формы 235261 (в среднем 7,0–7,4 см). Наибольшая урожайность 2–5-летних растений *V. praestans* в открытом грунте зафиксирована у гибридных форм (в среднем 362,75–383,0 г/м²) и различается в зависимости от района выращивания.

Ключевые слова: красника, *Vaccinium praestans*, адаптация, *ex vitro*, приживаемость, интродукция, морфометрические показатели, урожайность

Благодарности: Работа выполнена при содействии Минобрнауки России в рамках соглашения о предоставлении гранта в форме субсидий из федерального бюджета на осуществление государственной поддержки создания и развития научного центра мирового уровня «Агротехнологии будущего».

Для цитирования: Sungurova N.R., Makarov S.S., Chudetsky A.I., Cheryatova Yu.S. Adaptation Features of Kamchatka Bilberry (*Vaccinium praestans* Lamb.) Plants Grown *in vitro* // Изв. вузов. Лесн. журн. 2025. № 3. С. 121–131. https://doi.org/10.37482/0536-1036-2025-3-121-131

Introduction

The genus *Vaccinium* L. (family Ericaceae) contains more than 4 thousand species, of which the most valuable are representatives of the subfamily *Vaccinioidae*, widespread in Europe, Southeast and Central Africa, Asia, North and Central America. Berry crops of the Ericaceae family are among the best dietary sources of biologically active compounds, which are of great interest to nutritionists and food technologists [7, 9]. The main biologically active substances identified in *Vaccinium spp.* include anthocyanins (cyanidin, malvidin, and delphinidin), flavonoids (quercetin, isoquercetin, and astragalin), phenolic acids (gallic, P-coumaric, cinnamic, syringic, ferulic and caffeic acids), and iridoids [2, 17]. Numerous scientific studies of *Vaccinium spp.* fruits confirm their high content of biologically active substances with pronounced antioxidant, antimicrobial, and anti-inflammatory properties, helping in the fight against diabetes, obesity, cancer, atherosclerosis, rheumatoid arthritis, neurodegenerative and cardiovascular diseases, etc. In addition, *Vaccinium spp.* plants, especially those with a high content of polyphenols such as anthocyanins, are believed to be able to inhibit and initiate apoptosis in cancer cells. Scientists have described the inhibition of tumor growth, angiogenesis and metastasis when using extracts of *Vaccinium spp.* fruits [1, 3, 8, 10, 19].

Currently, there is a growing demand throughout the world for products of wild berry plants with high nutritional and medicinal value, including Kamchatka bilberry (*Vaccinium praestans* Lamb.), which has become widespread mainly only in the regions of its natural growth [11, 24]. The nutritional and functional properties of Kamchatka bilberry described in literature justify the growing interest in this berry crop. *V. praestans* fruits are a rich source of micronutrients and phytochemical compounds beneficial to health, such as organic acids, sugars, vitamins, fiber, and phenolic compounds [12, 18, 20–22].

Taking into account the limited range and reduction of natural populations of *V. praestans* due to the increasing anthropogenic load and unregulated exploitation of berry lands, as well as the unavailability of plant material outside the Russian Far East, the most optimal and effective method of reproduction of this species today is clonal micropropagation [5, 15, 16]. The creation of an *in vitro* gene bank will contribute to the preservation of the gene pool of economically valuable forms of Kamchatka bilberry and the possibility of their further breeding and industrial cultivation. At the same time, additional research is needed on the adaptation of regenerated plants in non-sterile *ex vitro* conditions – one of the most difficult stages of micro-plant development.

The aim of this study has been to investigate the adaptation features of *in vitro* propagated *V. praestans* plants under *ex vitro* conditions and in open ground.

Research Objects and Methods

The objects of the study have been the most productive forms of *V. praestans* selected in places of their natural growth – Sakhalin (the Korsakovsky District of the Sakhalin Region), Iturup (the Kurilsky District of the Sakhalin Region), Khabarovsk (the Khabarovsky District of the Khabarovsk Territory), as well as the promising hybrid forms created on their basis – 129634 and 235261 – candidates for varieties (see Figure).

a *b*

The hybrid forms of *V. praestans* in the variety testing sites:
a – 129634; *b* – 235261

Studies on clonal plant micropropagation have been carried out according to generally accepted methods [13]. At the stage of adaptation to non-sterile *ex vitro* conditions, regenerated plants have been transplanted from the first 10 days of March to the third 10 days of May into substrates made of high-moor peat (pH_{KCl} – 2.8…3.5), which has been pre-steamed (sterilized) at a temperature of +90 °C, including a mixture with river sand (in a ratio of 3:1), vermiculite (3:1), perlite (3:1) and fine-grained zeolite (3:1). At that, the river sand has been pre-washed and calcined at a temperature of +180 °C for 2 hours. The plants have been adapted under illumination of 8,000 lux, air temperature of +25 °C and a relative air humidity of 80–90 %. In addition, the plants have been sprayed with aqueous solutions of growth stimulants Zircon (Nest-M, Russia) at a concentration of 0.5 ml/l and Epin-extra (Nest-M, Russia) at a concentration of 0.5 ml/l; spraying with water has been used as control. After 14 and 28 days after transplantation, plant survival rate has been considered, as well as the number of shoots and the number of leaves per plant.

After 90 days of adaptation, the planting material has been transplanted to variety testing sites in various natural and climatic conditions: in the central part of the European part of Russia – the Kostroma District of the Kostroma Region (LLC "Krem"), Moscow (the Arboretum named after R.I. Schroeder of the Russian State Agrarian University – Moscow Timiryazev Agricultural Academy); in the Far East of Russia – the Lazo District of the Khabarovsk Territory (Agricultural Consumer Processing Supply and Marketing Cooperative "Berry Symphony"). The plants have been planted according to a 1.5×0.3 m pattern in prepared trenches 1.5 m wide and 0.5 m deep, filled with high-moor peat. The morphometric parameters of plants have been taken into account, such as shoot length (cm), lamina dimensions (cm), inflorescence length (mm), flower diameter (mm), fruit diameter (mm) and weight (g). The yield has been determined by the weight of berries per unit area (g/m^2) [23].

Statistical processing of experimental data has been carried out using generally accepted methods [6] and Microsoft Office Excel 2019 software.

Results and Discussion

As a result of the conducted experimental studies, it has been established that when adapting to non-sterile *ex vitro* conditions, the regenerated *V. praestans* r plants obtained by the method of clonal micropropagation have had the highest survival rate (90 %) when grown on a substrate made of a mixture of peat and zeolite (3:1) with simultaneous treatment with Epin-extra growth stimulant 0.5 ml/l. The survival rate has been lower on peat substrates, peat-sand mixtures 3:1, peat-vermiculite mixtures 3:1, also with Epin-extra treatment 0.5 ml/l (75, 70 and 68 %, respectively). The lowest plant survival rate has been observed on a substrate made of a mixture of peat and perlite 3:1 (45–60 %). At the same time, no statistically significant differences have been found in the number of plant shoots depending on the substrate and preparation treatment, although the values have been maximal when treated with Epin-extra. There have also been no significant differences in the number of leaves, however, on the 28th day of adaptation, the highest values have been observed in the substrate variant made of a mixture of peat and zeolite 3:1, and the highest values have been observed when treated with Epin-extra 0.5 ml/l and Zircon 0.5 ml/l (5.1 and 4.7 pcs. on average, respectively) (Table 1).

Table 1

The survival rate and morphometric parameters of *V. praestans* plants during adaptation to non-sterile *ex vitro* conditions depending on the adaptation timing and treatment with growth-stimulating preparations

Substrate	Treatment option	Survival rate, %	Number of shoots, pcs.	Number of leaves, pcs.
On the 14th day				
High-moor peat	Control (water)	60	2.6±0.36	3.2±0.35
	Zircon 0.5 ml/l	69	2.4±0.28	3.0±0.26
	Epin-extra 0.5 ml/l	75	3.0±0.11	3.1±0.19
Peat + river sand 3:1	Control (water)	52	2.5±0.40	3.6±0.27
	Zircon 0.5 ml/l	66	2.6±0.32	2.9±0.31
	Epin-extra 0.5 ml/l	70	2.8±0.19	3.0±0.25
Peat + vermiculite 3:1	Control (water)	57	3.0±0.12	3.3±0.32
	Zircon 0.5 ml/l	48	2.6±0.36	3.5±0.19
	Epin-extra 0.5 ml/l	68	2.2±0.30	3.8±0.11
Peat + perlite 3:1	Control (water)	45	2.3±0.29	3.1±0.06
	Zircon 0.5 ml/l	50	2.2±0.21	3.3±0.11
	Epin-extra 0.5 ml/l	60	2.1±0.23	3.4±0.18
Peat + zeolite 3:1	Control (water)	50	2.0±0.25	3.2±0.11
	Zircon 0.5 ml/l	61	2.6±0.31	3.7±0.13
	Epin-extra 0.5 ml/l	90	2.8±0.17	3.0±0.18

End of Table 1

Substrate	Treatment option	Survival rate, %	Number of shoots, pcs.	Number of leaves, pcs.
On the 28th day				
High-moor peat	Control (water)	60	2.9±0.31	3.8±0.38
	Zircon 0.5 ml/l	69	3.0±0.33	4.0±0.21
	Epin-extra 0.5 ml/l	75	3.1±0.18	3.8±0.26
Peat + river sand 3:1	Control (water)	52	2.7±0.41	3.9±0.25
	Zircon 0.5 ml/l	66	2.9±0.32	3.3±0.34
	Epin-extra 0.5 ml/l	70	3.2±0.17	3.5±0.26
Peat + vermiculite 3:1	Control (water)	57	3.0±0.10	3.5±0.34
	Zircon 0.5 ml/l	48	2.6±0.36	4.0±0.15
	Epin-extra 0.5 ml/l	68	2.0±0.16	3.9±0.10
Peat + perlite 3:1	Control (water)	45	2.5±0.27	3.4±0.10
	Zircon 0.5 ml/l	50	2.9±0.30	3.7±0.17
	Epin-extra 0.5 ml/l	60	2.8±0.28	3.8±0.16
Peat + zeolite 3:1	Control (water)	50	2.2±0.23	3.4±0.10
	Zircon 0.5 ml/l	61	2.9±0.34	4.7±0.26
	Epin-extra 0.5 ml/l	90	3.8±0.44	5.1±0.53

V. praestans plants adapted to non-sterile *ex vitro* conditions and fully ready for transplantation have been planted in experimental open ground plots with high-moor peat in various growing areas. The morphometric parameters of the plants of the studied Kamchatka bilberry forms are presented in Table 2.

Table 2

The average morphometric parameters of introduced *V. praestans* plants in various growing areas

Parameter	Testing site					
	Moscow		The Kostroma Region		The Khabarovsk Territory	
	2022	2023	2022	2023	2022	2023
Hybrid form 129634						
Shoot length, cm	6.6±0.47	6.9±0.42	6.5±0.42	6.4±0.44	6.6±0.42	6.8±0.48
Lamina length, cm	6.2±0.44	6.2±0.49	5.9±0.41	6.0±0.43	6.4±0.50	6.5±0.52
Lamina width, cm	3.5±0.31	3.2±0.29	2.9±0.30	3.0±0.32	3.4±0.36	3.4±0.36
Inflorescence length, mm	14.9±1.23	15.2±1.23	14.6±1.14	14.8±1.19	15.5±1.15	16.0±1.23
Flower diameter, mm	6.4±0.59	6.5±0.56	6.5±0.44	6.2±0.49	6.7±0.61	7.0±0.64
Fruit diameter, mm	11.1±1.08	11.2±1.04	11.8±1.06	12.1±1.11	11.5±0.89	11.8±0.98
Fruit weight, g	1.6±0.16	1.7±0.14	1.6±0.13	1.6±0.15	1.8±0.15	1.9±0.18
Hybrid form 235261						
Shoot length, cm	7.1±0.58	7.2±0.62	7.0±0.62	7.1±0.65	7.2±0.74	7.4±0.71
Lamina length, cm	3.8±0.31	4.1±0.38	3.8±0.32	4.0±0.32	4.3±0.38	4.5±0.41
Lamina width, cm	2.5±0.26	2.6±0.29	2.4±0.25	2.5±0.28	2.7±0.35	2.8±0.30
Inflorescence length, mm	18.4±0.85	18.2±0.89	17.7±0.82	17.6±0.79	19.0±0.92	19.5±0.98
Flower diameter, mm	9.0±0.40	9.2±0.43	9.0±0.25	8.9±0.22	9.4±0.22	9.7±0.27

End of Table 2

Parameter	Testing site					
	Moscow		The Kostroma Region		The Khabarovsk Territory	
	2022	2023	2022	2023	2022	2023
Fruit diameter, mm	13.2±1.06	13.5±1.09	14.0±1.03	14.1±1.06	14.2±1.10	14.5±1.12
Fruit weight, g	1.7±0.18	1.6±0.16	1.6±0.19	1.6±0.17	1.7±0.22	1.8±0.20
The Sakhalin form						
Shoot length, cm	6.4±0.44	6.5±0.40	6.1±0.32	6.0±0.36	6.5±0.50	6.9±0.52
Lamina length, cm	5.7±0.35	6.0±0.39	5.5±0.30	5.7±0.35	5.9±0.44	6.0±0.48
Lamina width, cm	3.3±0.24	3.4±0.26	2.5±0.23	2.6±0.25	3.2±0.31	3.0±0.32
Inflorescence length, mm	14.2±1.07	14.4±1.10	14.5±0.99	14.8±1.03	15.4±1.16	15.6±1.12
Flower diameter, mm	6.3±0.50	6.4±0.54	5.9±0.40	6.0±0.43	6.8±0.60	6.6±0.58
Fruit diameter, mm	9.6±0.90	10.0±0.96	11.2±0.95	11.6±0.98	10.4±0.94	10.5±0.98
Fruit weight, g	1.5±0.10	1.6±0.12	1.6±0.14	1.5±0.11	1.6±0.18	1.7±0.12
The Iturup form						
Shoot length, cm	5.8±0.54	6.0±0.58	6.1±0.65	6.5±0.60	6.7±0.62	7.0±0.68
Lamina length, cm	3.7±0.32	3.8±0.34	3.7±0.34	3.8±0.36	4.1±0.45	4.2±0.40
Lamina width, cm	2.4±0.25	2.5±0.27	2.6±0.27	2.4±0.26	2.4±0.37	2.6±0.34
Inflorescence length, mm	14.5±1.04	14.8±1.09	16.2±0.60	16.5±0.62	17.5±0.84	18.1±0.80
Flower diameter, mm	7.3±0.52	7.5±0.59	8.2±0.40	8.4±0.42	9.1±0.26	9.4±0.29
Fruit diameter, mm	11.2±0.98	10.9±0.92	12.8±1.06	13.0±1.02	13.8±1.00	14.1±1.05
Fruit weight, g	1.6±0.13	1.5±0.15	1.7±0.15	1.7±0.18	1.7±0.15	1.7±0.14
The Khabarovsk form						
Shoot length, cm	5.7±0.34	5.8±0.37	6.0±0.35	6.0±0.39	6.3±0.47	6.6±0.45
Lamina length, cm	6.1±0.42	6.0±0.45	5.0±0.44	5.2±0.45	6.0±0.48	6.3±0.50
Lamina width, cm	2.8±0.24	3.0±0.25	2.8±0.32	2.7±0.29	3.0±0.30	3.2±0.32
Inflorescence length, mm	14.4±1.07	14.8±1.13	13.8±1.02	13.6±1.06	14.6±1.11	15.0±1.15
Flower diameter, mm	6.2±0.50	6.4±0.54	6.2±0.45	6.4±0.41	6.2±0.55	6.3±0.69
Fruit diameter, mm	10.9±1.06	10.6±1.06	11.2±1.14	11.4±1.17	11.2±0.92	11.1±0.94
Fruit weight, g	1.6±0.17	1.6±0.15	1.6±0.22	1.6±0.18	1.7±0.19	1.7±0.16

Unfortunately, to date only a few published results of studies on the cultivation of *V. preastans in vitro* and their adaptation *ex vitro* are known. According to the study by G. Stanienė et al. [26], the survival rate of regenerated *V. preastans* plants under *ex vitro* conditions on a sandy substrate has been 33.3–100 % depending on the form, whereas in our study the maximum survival rates (88–91 %) have been noted when plants have been transplanted in May onto high-moor peat, peat + river sand 3:1 and peat + zeolite 3:1. The positive experience of using the growth-regulating preparation Zircon at the stage of adaptation of *V. preastans* regenerants in terms of increasing plant survival and morphometric parameters is consistent with the results of our other studies on its use in the adaptation of *in vitro*-obtained *V. praestans* plants of natural forms from the Sakhalin Region and lingonberry (*V. vitis-idaea*) to *ex vitro* conditions on peat substrates [4]. The results obtained can be used to improve the elements of the technological cycle of accelerated cultivation of *V. praestans* using the clonal micropropagation method.

For all propagated *V. praestans* hybrid plants, an assessment has been carried out for distinctiveness, homogeneity and stability in comparison with the parent forms based on morphological characteristics [14].

The Kamchatka bilberry plants of all the studied forms at the variety testing sites have been completely preserved during the observation period. In the 3rd and 4th year of cultivation in the open ground, *V. praestans* plants had the following average morphometric indicators: shoot length – 5.7–7.4 cm; lamina dimensions – 3.7–6.5×2.5–3.5 cm; inflorescence length – 14.2–19.5 mm; flower diameter – 6.2–9.7 mm; fruit diameter – 9.6–14.5 mm; fruit weight – 1.5–1.9 g. No statistically significant differences in the studied morphometric parameters have been found depending on the growing area, although the maximum values have been observed mainly in hybrid forms. Meanwhile, the plants of the studied forms are characterized by a pronounced anthocyanin coloration of the shoots of the current year, weak or moderately pronounced anthocyanin coloration of the leaves, pink or slightly pink coloration of the flowers, and red or dark red coloration of the fruits.

The yield accounting over the course of 4 years has shown that, on average, the highest yields have been achieved by hybrid forms of Kamchatka bilberry in all areas of the study: form 129634 – 364.25–383.0 g/m^2, form 235261 – 362.75–379.25 g/m^2 (Table 3). The Khabarovsk form growing in the Khabarovsk Territory has had a yield close to that of hybrid forms on average over 4 years (354.25 g/m^2). Otherwise, the yield indicators of natural forms have been lower.

Table 3

The average yield of *in vitro* grown *V. praestans* plants in various growing areas

Form	Yield, g/m^2				
	by year				Average for 4 year
	2020	2021	2022	2023	
The Kostroma Region					
Hybrid 129634	182±16.5	380±36.2	402±38.0	550±53.2	378.50
Hybrid 235261	202±19.2	382±35.5	362±35.6	505±49.2	362.75
Sakhalin	165±15.1	352±33.2	350±33.1	452±43.8	329.75
Iturup	134±12.6	341±32.8	325±30.1	438±41.5	309.50
Khabarovsk	141±13.8	332±32.1	316±29.7	426±40.6	303.75
Moscow					
Hybrid 129634	185±17.2	370±36.0	382±36.8	520±50.6	364.25
Hybrid 235261	180±16.2	390±37.8	373±35.9	512±50.1	363.75
Sakhalin	152±14.6	330±30.4	321±30.8	454±43.0	314.25
Iturup	145±14.2	320±29.8	309±29.0	445±42.6	304.75
Khabarovsk	150±14.8	310±29.4	302±28.4	433±41.8	298.75
The Khabarovsk Territory					
Hybrid 129634	192±15.9	388±36.4	411±39.0	541±51.8	383.00
Hybrid 235261	210±20.1	405±38.6	380±35.8	522±49.6	379.25
Sakhalin	142±13.9	355±33.4	364±35.9	452±43.5	328.25
Iturup	144±14.1	346±32.4	352±33.5	464±43.4	326.50
Khabarovsk	183±16.6	372±36.7	370±35.2	492±48.0	354.25

In general, there has been an increase in yield with increasing plant age. Thus, on variety testing sites in the open ground, this indicator has been: for hybrid form

129634 in the 1st year of cultivation – on average 182–192 g/m^2, in the 2nd year – 2.1 times higher, in the 3rd year – 2.1–2.2 times higher, in the 4th year – 2.8–3.1 times higher, compared to the 1st year; for hybrid form 235261 in the 1st year of cultivation – on average 180–210 g/m^2, in the 2nd year – 1.9–2.2 times higher, in the 3rd year – 1.8–2.1 times higher, in the 4th year – 2.5–2.8 times higher; for the Sakhalin form in the 1st year of cultivation – 142–165 g/m^2, in the 2nd year – 2.2–2.5 times higher, in the 3rd year – 2.1–2.6 times higher, in the 4th year – 2.8–3.2 times higher; for the Iturup form in the 1st year of cultivation – 134–145 g/m^2, in the 2nd year – 2.3–2.6 times higher; in the 3rd year – 2.1–2.5 times higher, in the 4th year – 3.1–3.3 times higher; for the Khabarovsk form in the 1st year of cultivation – 141–183 g/m^2, in the 2nd year – 2.1–2.4 times higher, in the 3rd year – 2.0–2.1 times higher, in the 4th year – 2.7–3.0 times higher. At this, hybrid form 235261 has shown a slight decrease in yield (on average by 17–25 g/m^2) in the 3rd year of cultivation, compared to the 2nd year. A similar trend has been observed in the Iturup and Khabarovsk forms in the conditions of the Kostroma Region and Moscow, as well as in the Sakhalin form in the conditions of Moscow. Most likely, this is due to the influence of early spring frosts in 2022, which have contributed to the freezing of flower buds. In other years of observation, no damage has been noted.

The data obtained on the yield of natural forms of *V. praestans* in crop conditions in the studied regions are quite consistent with the data obtained in the early 2000s by scientists from the All-Russian Horticultural Center for Breeding, Agrotechnology and Nursery (Moscow, Russia), where the yield of plants in crop conditions in the Moscow Region in different years has been equal to: for the Kunashir form (the Kurilsky District, the Sakhalin Region, Russia) from 297.0 to 355.9 g/m^2, for the Sakhalin form (the Yuzhno-Sakhalinsky District, the Sakhalin Region, Russia) – from 362.5 to 502.8 g/m^2 [25]. At this, the yield in crop conditions has turned out to be approximately 2–4 times higher than in natural conditions in years with high yields, where it averages up to 90 g/m^2 [12]. This indicates the prospects of crop cultivation of this species, especially high-yielding hybrid forms, as a valuable food, medicinal and also ornamental plant, in the conditions of the European part of Russia and the Far East.

Conclusions

Thus, the highest survival rate of regenerated *V. praestans* during adaptation to non-sterile *ex vitro* conditions has been revealed when using a substrate made of a mixture of peat and zeolite (3:1) and simultaneous treatment with Epin-extra growth stimulant 0.5 ml/l (90 %). The yield of Kamchatka bilberry plants obtained by clonal micropropagation has depended on the origin of the form and the growing area, and has generally increased with increasing plant age from 2 to 5 years. The results obtained allow us to recommend the use of a mixture of peat and zeolite 3:1 and Epin-extra growth stimulant as an element of improving the technology of adaptation of *in vitro* propagated *V. praestans* plants when grown in the conditions of the European part and the Far East of Russia.

REFERENCES

1. Albert N.W., Iorizzo M., Mengist M.F., Montanari S., Zalapa J., Maule A., Edger P.P., Yocca A.E., Platts A.E., Pucker B., Espley R.V. *Vaccinium* as a Comparative System for

Understanding of Complex Flavonoid Accumulation Profiles and Regulation in Fruit. *Plant Physiology*, 2023, vol. 192, iss. 3, pp. 1696–1710. https://doi.org/10.1093/plphys/kiad250

2. Alsharairi N.A. Experimental Studies on the Therapeutic Potential of *Vaccinium* Berries in Breast Cancer – A Review. *Plants*, 2024, vol. 13, no. 2, art. no. 153. https://doi.org/10.3390/plants13020153

3. Chehri A., Yarani R., Yousefi Z., Shakouri S.K., Ostadrahimi A., Mobasseri M., Araj-Khodaei M. Phytochemical and Pharmacological Anti-Diabetic Properties of Bilberries (*Vaccinium myrtillus*), Recommendations for Future Studies. *Primary Care Diabetes,* 2022, vol. 16, iss. 1, p. 27–33. https://doi.org/10.1016/j.pcd.2021.12.017

4. Chudetsky A.I., Rodin S.A., Zarubina L.V., Kuznetsova I.B. Adaptation of Varietal Planting Material of Lingonberry to Non-Sterile Conditions *ex vitro* for Growing on Non-Forest Lands. *Lesokhozyajstvennaya informatsiya* = Forestry Information, 2021, no. 4, pp. 106–113. (In Russ.). https://doi.org/10.24419/LHI.2304-3083.2021.4.08

5. Chudetsky A.I., Rodin S.A., Zarubina L.V., Kuznetsova I.B., Tyak G.V. Clonal Micropropagation and Peculiarities of Adaptation to *ex vitro* Conditions of Forest Berry Plants of the Genus *Vaccinium*. *Tekhnika i tekhnologiya pishchevykh proizvodstv* = Food Processing: Techniques and Technology, 2022, vol. 52, iss. 3, pp. 570–581. (In Russ.). https://doi.org/10.21603/2074-9414-2022-3-2386

6. Dospekhov B.A. *Field Experiment Methodology* (*with the Basics of Statistical Processing of Research Results*): Textbook. Moscow, Al'yans, 2011. 350 p. (In Russ.).

7. Dunford N.T. Blueberries and Health. *Functional Food Science,* 2022, vol. 2(1), pp. 1–15. https://doi.org/10.31989/ffs.v2i1.875

Golovinskaia O., Wang C.K. Review of Functional and Pharmacological Activities of Berries. *Molecules,* 2021, vol. 26, no. 13, art. no. 3904. https://doi.org/10.3390/molecules26133904

8. Kopystecka A., Kozioł I., Radomska D., Bielawski K., Bielawska A., Wujec M. *Vaccinium uliginosum* and *Vaccinium myrtillus* – Two Species – One Used as a Functional Food. *Nutrients,* 2023, vol. 15, no. 19, art. no. 4119. https://doi.org/10.3390/nu15194119

9. Kowalska K. Lingonberry (*Vaccinium vitis-idaea* L.) Fruit as a Source of Bioactive Compounds with Health-Promoting Effects – A Review. *International Journal of Molecular Sciences*, 2021, vol. 22, no. 10, art. no. 5126. https://doi.org/10.3390/ijms22105126

10. Krasikova V.I. *Biology and Rational Use of Kamchatka Bilberry* (*Vaccinium praestans* Lamb.) *on Sakhalin.* Vladivostok, Far East Scientific Centre of the USSR Academy of Sciences Publ., 1987. 108 p. (In Russ.).

11. Kryshnyaya S.V., Krasikova V.I. Chemical Composition of Fruits and Leaves of *Vaccinium praestans*. *Terrestrial Ecosystems of Sakhalin Island: Current State, Natural and Anthropogenic Changes, Protection and Rational Use of Natural Resources*. Yuzhno-Sakhalinsk, 1999, pp. 121–128. (In Russ.).

12. Makarov S.S., Antonov A.M., Kulikova E.I., Chudetsky A.I., Solovyov A.V. *Biotechnology in Horticulture. Growing Fruit and Rare Berry Plants in in vitro Culture. Laboratory Practical Training*: Manual. St. Petersburg, Lan' Publ., 2023. 128 p. (In Russ.).

13. Makarov S.S., Chudeckiy A.I., Cheryatova Yu.S., Kuznetsova I.B. Kamchatka Bilberry (*Vaccinium praestans* Lamb.): Testing Methodology Development for Distinctiveness, Homogeneity and Stability. *Vestnik KrasGAU* = Bulletin of Krasnoyarsk State Agrarian University, 2024, no. 5, pp. 42–51. (In Russ.). https://doi.org/10.36718/1819-4036-2024-5-42-51

14. Makarov S.S., Rodin S.A., Kuznetsova I.B., Chudetsky A.I., Tsaregradskaya S.Yu. Effect of Light on Rhizogenesis of Forest Berry Plants during Clonal Micropropagation. *Tekhnika i tekhnologiya pishchevykh proizvodstv* = Food Processing: Techniques and Technology, 2021, vol. 51, iss. 3, pp. 520–528. (In Russ.). https://doi.org/10.21603/2074-9414-2021-3-520-528

15. Makarov S.S., Upadyshev M.T., Kuznetsova I.B., Zaushintsena A.V., Kulikova E.I., Surina E.A. The Use of Lighting of Various Spectral Ranges for Clonal Micropropa-

gation of Forest Berry Plants. *Lesnoy Zhurnal* = Russian Forestry Journal, 2022, no. 6, pp. 82–93. (In Russ.). https://doi.org/10.37482/0536-1036-2022-6-82-93

16. Mirghani M.E.S., Daoud J.I., Elnour A.A.M. Wild Species of *Vaccinium* Composition, Nutritional Value and Utilization. *Wild Fruits: Composition, Nutritional Value and Products.* Springer, Cham, 2019, pp. 523–537. https://doi.org/10.1007/978-3-030-31885-7_39

17. Plaksen N.V., Stepanov S.V., Ustinova L.V. Hepatoprotective Effect of *Vaccinium praestans* Syrup. *Tikhookeanskij meditsinskij zhurnal* = Pacific Medical Journal, 2014, no. 2, pp. 59–61. (In Russ.).

18. Prieto Martínez A., Coutiño Diaz M., Anaya Romero L., Ali Redha A., Zare R., Ventura Hernandez S., Prokopidis K., Clifford T. Effects of *Vaccinium* Berries (Blueberries, Cranberries and Bilberries) on Oxidative Stress, Inflammation, Exercise Performance, and Recovery – a Systematic Review. *Food & Function*, 2024, iss. 15, pp. 444–459. https://doi.org/10.1039/d3fo04435a

19. Salikova A.A., Ponomarchuk S.G., Plaksen N.V., Ustinova L.V., Stepanov S.V., Zheludkova N.N. Amino Acid Composition of Fruits Representing the Far Eastern Flora. *Dal'nevostochnyj meditsinskij zhurnal* = Far Eastern Medical Journal, 2023, no. 2, pp. 69–73. (In Russ.). https://doi.org/10.35177/1994-5191-2023-2-12

20. Salikova A.A., Ponomarchuk S.G., Plaksen N.V. Study of the Chemical Composition of Fruits of Far Eastern Plant Species of the Heather Family (*Ericaceae*). *Tikhookeanskij meditsinskij zhurnal* = Pacific Medical Journal, 2021, no. 3, pp. 40–44. (In Russ.). https://doi.org/10.34215/1609-1175-2021-3-40-44

21. Salikova A.A., Ustinova L.V., Plaksen N.V., Stepanov S.V. Influence of Weather Conditions on the Accumulation of Antioxidants in the Fruits of *Vaccinium praestans*. *Problemy regional'noj ekologii* = Regional Environmental Issues, 2019, no. 5, pp. 6–10. (In Russ.). https://doi.org/10.24411/1728-323X-2019-17006

22. Sedov E.N., Ogoltsova T.P. (eds.). *Program and Methodology for Studying Varieties of Fruit, Berry and Nut Crops.* Oryol, All-Russian Research Institute of Fruit Crops Breeding Publ., 1999. 606 p. (In Russ.).

23. Smirnov I.Yu. Kamchatka Bilberry. *Nauka i zhizn'*, 1999, no. 10, pp. 49–52. (In Russ.).

24. Smirnov I.Yu. Productivity of Lingonberry under Cultivation Conditions. *Plodovodstvo i yagodovodstvo Rossii* = Pomiculture and Small Fruits Culture in Russia, 2003, vol. 10, pp. 352–357. (In Russ.).

25. Stanienė G., Stanys V., Kawecki Z. Peculiarities of Propagation *in vitro* of *Vaccinium vitis-idaea* L. and *V. praestans* Lamb. *Biologija,* 2002, vol. 48, no. 1, pp. 84–86.

Конфликт интересов: Авторы заявляют об отсутствии конфликта интересов
Conflict of interest: The authors declare that there is no conflict of interest

Вклад авторов: Все авторы в равной доле участвовали в написании статьи
Authors' Contribution: All authors contributed equally to the writing of the article