

Some aspects of raspberry breeding with predominant fruiting on annual shoots

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Abstract. The purpose of the study was to identify the inheritance traits of economic and biological characteristics and properties in the hybrid progeny of primocane raspberry. The objects of study were 16 parental forms and progeny of 15 hybrid combinations of crosses with a total number of 1008 seedlings. It is established that in breeding of raspberry with a predominant fruiting on annual shoots, there are certain difficulties in obtaining forms with a high degree of remontancy, early, friendly crop ripening, multiple fruits and increased berry strength, as evidenced by the depression in the inheritance of these traits. Despite this, promising combinations of crosses were identified: Podarok Kashinu x Penguin, 44-154-2 x Poklon Kazakovu, 13-118-1 x 1-16-11, Podarok Kashinu x 1-16-11, 13-118-1 x Podarok Kashinu, Atlant x Bryanskoe Divo with the highest yield of transgressive seedlings. In the hybrid progeny, selections of 6-119-1, 3-170-1, 8-189-1, 11-165-10, 10-165-11, 9-163-2, 5-83-10 and others were revealed, combining the degree of remontancy, early fruiting with the components of productivity and fruit quality at a high level.

1 Introduction

Among berry plants, raspberry have long been particularly popular and in demand among the population due to their unique nutritional and medical properties. Purposeful breeding work with this crop has been carried out for about 200 years [1]. The period of the most active development of raspberry breeding occurred in the second half of the last century, when there were several dozen large breeding programs of the genus *Rubus* in the USSR, European countries, the USA and Canada. At this time, highly productive varieties were obtained, a number of which (Balsam, Gusar, Meteor, Glen Ample, Glen Fyne, Schönemann, Tulameen, Chilcotin, Cascade Delight, Meeker, etc.) are still included in the industrial assortment of many countries [2, 3, 4, 5].

Scientific breeding of primocane raspberry lasts less than a century. The interest in this group of varieties on the part of producers is caused by low labor intensity of cultivation, possibility of mechanization of most processes for plantings management, an increase in the period of receipt of fresh berries by 2-3 months. Their cultivation with the annual stem removal in late autumn after fruiting allows to completely solve the problem of winter hardiness of the aboveground plant system, significantly reduce the level of fungal

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infection. Varieties with predominant fruiting on annual shoots are suitable for growing in open ground, tunnels and greenhouses [6, 7, 8]. Due to their use, the area of successful raspberry cultivation has significantly expanded [9]. In this regard, in recent years, there has been an increase in the area occupied by primocane varieties, and the share of their research in breeding programs, reaching in some cases 60-70% [2, 10, 11].

The world assortment of primocane raspberry is represented by varieties created in the USA, Canada, Great Britain, Poland, Switzerland, the Netherlands, France, the Russian Federation, and Ukraine. In recent years, breeding has become more active in Chile, China, Brazil, Mexico, and Italy [12, 13, 14]. The main purposes and objectives of modern breeding programs have much in common. The ultimate aim of any such program is to create highly productive varieties adapted to adverse environmental factors, having high taste, commercial and technological qualities of berries, suitable for mechanized harvesting. This is achieved by combining necessary morphological characteristics of plants, high levels of adaptation components, productivity, biochemical substances, etc. in one genotype. Provided that the priority of directions within the breeding program is closely related to the natural and climatic conditions of the proposed variety cultivation area, the cultivation technologies used, the nature and traditions of the local market, the prevalence and harmfulness of individual pests and diseases.

Thus in North America, raspberry breeding is conducted according to five programs. Here, the main research areas are breeding for suitability for machine harvesting, resistance to pests (aphids, ticks, nematodes, etc.), fungal (gray fruit rot, powdery mildew, late blight) and viral (mosaic, RBDV) diseases. In the breeding process for improving the quality indicators of fruits, the selection criteria are light red color, sweet taste, low acid content, aroma, and the ability not to darken during storage [4, 15, 16]. As a result of these programs, the primocane varieties Anne, Caroline, Driscoll Maravilla, Jaclyn, Josephine and others were created.

In the UK, the priority is to create forms for growing in protected ground that are resistant to pests and diseases unusual for open ground (tick *Tetranychus urticae*, powdery mildew *Sphaerotheca macularis*). In addition, resistance to root rot, especially to *Phytophthora fragariae var. rubi*, as well as to the RBDV virus, does not lose its relevance. Among the qualitative indicators, more attention is paid to the taste of fruits and transportability [17, 18]. Such primocane varieties as Autumn Bliss, Autumn Treasure, Autumn Britten, Brice, Joan Squire, Joan J, etc. are created here.

Large-scale breeding work with raspberry is carried out in Poland. The main objectives of breeding in the Polish research program are high quality of fruits, ability to mechanized harvesting, adaptation to local conditions, increased resistance to pests and diseases, especially to the RBDV virus. Much attention is also paid to the accumulation of anthocyanins, phenols, ascorbic acid, and soluble solids in fruits [10, 19]. Primocane raspberry varieties of Polish breeding Polka and Polana have been widely used in production, and new varieties Delniwa, Polonez, and Poemat have been created in recent years.

Raspberry breeding in Mexico, Chile, and Brazil is focused on obtaining high-yielding varieties adapted to local growing conditions, with high transportability, and suitable for export to the United States and Europe [20, 21].

In Russia, for about fifty years, successful work has been carried out to create raspberry varieties with predominant fruiting on annual shoots. The most important task of this program breeding was and remains the production of highly productive primocane varieties with a short growing season. In addition, the priority tasks include improving the quality of fruits, increasing transportability and post-harvest storage, resistance to fungal and viral diseases, and suitability for machine harvesting [2, 22]. During this period, more than 20 primocane raspberry varieties were created, of which the varieties Atlant, Zhar-Ptitsa,

Eurasia, Medvezhonok, Penguin, Podarok Kashinu, and Poklon Kazakovu have the production value [23].

2 Material and methods

Breeding work was carried out on the experimental site of the Kokinsky control station of the FSBRI FRC for Horticulture in 2017-2020. The objects of research were 12 varieties and 4 selected forms of raspberry of the primocane type and the progeny of 15 hybrid combinations of crossing with a total number of 1008 seedlings. The parental forms have a complex origin, being distant descendants of interspecies hybrids that include in various combinations the genoplasm of *R. idaeus* L., *R. odoratus* L., *R. occidentalis* L., *R. spectabilis* Pursh., *R. crataegifolius* Bge. and *R. arcticus* L. The studies were carried out taking into account the main provisions of the raspberry and blackberry breeding methodology [24].

When assessing the degree of manifestation of the primocane character of parental forms and their progeny, the following scale was used:

- weakly primocane, form no more than 8 fruit branches on the shoot, the degree of buds awakening does not exceed 20%;
- medium-primocane, plants form from 9 to 14 fruit branches or the degree of bud awakening reaches 25-50%;
- highly primocane - form >14 laterals per shoot or the degree of bud awakening is >50% of the total number of nodes.

The degree of fruit maturation was determined by calculating the proportion of the ripened crop on the date of the first frost.

The fruit strength was determined during their optimal picking maturity. For this purpose, 10 berries of each sample were taken in three repetitions, expressing the squashing force of the fruit in Newtons (1 kgf = 9.8 N).

The soils of the breeding area are gray forest medium loamy slightly acidic (pH 6.1). They contain 2.6-3.2% humus, 25-35 mg P₂O₅ per 100 g of soil, 9.8-14.1 mg K₂O per 100 g of soil. The arable horizon thickness is 25 cm.

The weather conditions of the research period were generally favorable for the growth and development of raspberry plants of the primocane type. The average daily air temperature of the growing season for the years ranged from 14.8 °C to 15.6 °C, the sum of active temperatures from 2430 to 2882 °C, the sum of precipitation from 335 to 347 mm.

3 Research results

In the central part of Russia, it is recommended to grow primocane raspberry only for obtaining one crop on annual shoots, due to the natural and climatic conditions. For this technology, it is desirable to create varieties that form fruiting branches along the entire length of the shoot or on most of it. According to the primocane raspberry variety model developed by academician I.V. Kazakov, the zone of autumn fruiting should be more than 100 cm and have at least 20 pieces of fruiting branches [25]. There is another variant of this technology, when varieties with fruiting on the tops of shoots (20-30 cm) and thick, wide rows are used [26]. This technology is less widespread in the middle zone of horticulture in the Russian Federation.

The appearance of autumn fruiting is determined by plant genotype, but it significantly depends on the environmental impact [26, 27]. In conditions of heat deficiency and solar insolation, with a strong thickening of plantings, there is a sharp decrease in buds

awakening and, accordingly, a decrease in the number of fruiting branches and productivity.

In most modern domestic varieties, the length of autumn inflorescences is on average 60-75 cm or 48-60% of the shoot length, while 15-18 pieces of fruiting branches are formed (Table 1). According to these indicators, only the Podarov Kashinu variety approaches the model, which had 20 laterals and a length of 94 cm of autumn inflorescences on the shoot during the period of research. The lower fruiting branches of this variety reached 40-50 cm and had 2-3 branching orders.

Table 1. Major economic and biological characteristics of raspberry parental forms primocane type (2017-2020)

Variety, form	Autumn fruiting zone		Number of fruiting branches, pcs.	Number of generative organs per shoot, pcs.	Degree of crop maturation, %	Fruit strength N
	Length (l), cm	l/h, %*				
Oranzhevoye Chudo	63	47	15	104	90.0	4.0
Nizhegorodets	65	54.5	14	80	100	4.3
13-118-1	83	62.7	19	105	93.4	4.7
Snezhnet	55	69.3	14	87	100	5.1
Rubinovie Ozherelye	70	58.6	18	122	96.5	5.1
Penguin	50	45.6	16	87	100	5.8
1-16-11	65	50.8	17	152	100	6.1
Bryanskoe Divo	69	60.8	16	131	100	6.4
Zhar-Ptitsa	75	50.5	18	158	82.8	6.4
Podarok Kashinu	94	61.7	20	171	93.5	6.4
Poklon Kazakovu	64	41.0	17	106	95.2	6.6
Karamelka	59	47.2	15	86	78.3	6.8
Medvezhonok	77	47.8	17	147	100	6.9
37-143-3	65	50.0	17	113	92.3	7.6
Atlant	73	47.7	18	124	87.3	7.8
44-154-2	64	51.5	15	103	100	8.0
LSD ₀₅	24.7	-	1.82	37.6	-	1.4

Note: l/h is the ratio of the length of the autumn inflorescences to the height of the shoot

The creation of raspberry varieties with predominant fruiting on annual shoots at the Kokinsky CS is allocated to an independent program. Currently, parental forms are used in hybridization, as a rule, combining a high degree of remotancy and early fruiting periods in their genotype. This has led to the fact that there are practically no non-primocane seedlings among the hybrid progeny, and the share of weakly primocane seedlings has significantly decreased (Fig. 1). At the same time, hybrids in combinations of crosses differ significantly for the manifestation of autumn fruiting trait. In most families, seedlings of all three groups are segregated in different proportions: low-primocane, medium-primocane and high-primocane. In four combinations of crosses of Poklon Kazakovu x Podarok Kashinu, Rubinovie Izherelye x Penguin, Podarok Kashinun x 1-16-11, 13-118-1 x 1-16-11, seedlings with weak remotancy were absent. At the same time, in the family of high-primocane parents of 1-16-11 x Atlant, more than 25% of hybrids were low-primocane and less than 25% were high-primocane, which indicates the importance of pair matching when crossing. In the overwhelming number of crossbreeding combinations, a large yield of seedlings (53.8-88.6%) with a high manifestation of autumn fruiting trait was observed, but their level often did not go beyond the parental forms.

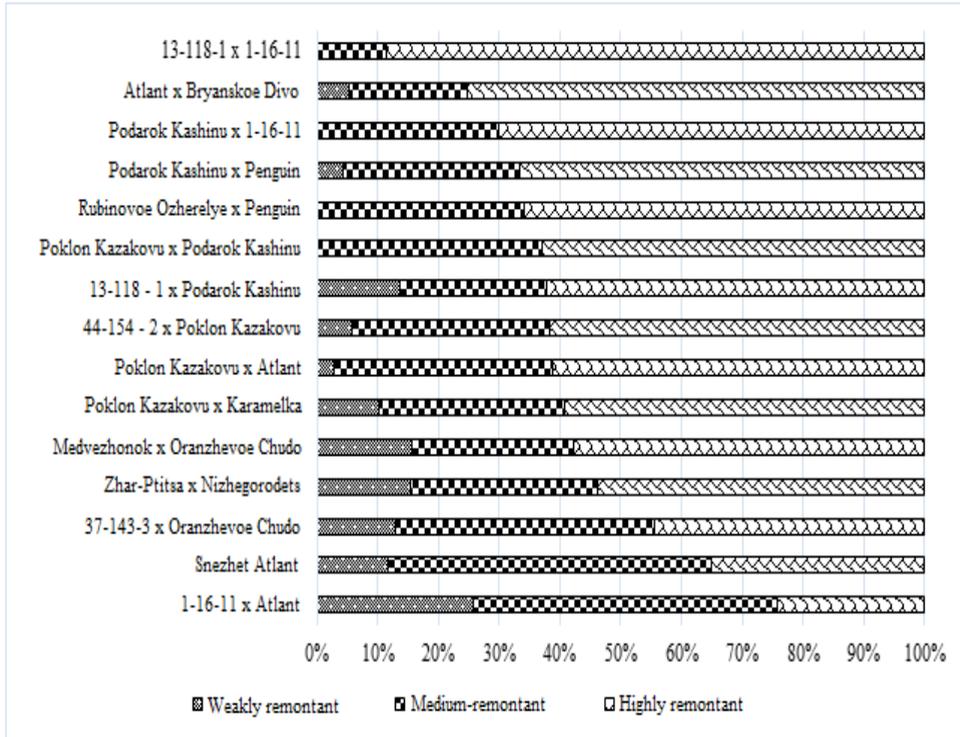


Fig. 1. Manifestation of autumn fruiting in the hybrid raspberry progeny

The calculation of the dominance coefficient (H_p) showed that the inheritance of the remontancy trait was multidirectional and depended on the combinational ability of the parent pairs: in five combinations of crosses, depression was observed, in three combinations – deviation towards the worst parent, in three more families – deviation towards the best parent, and in four combinations – heterosis (Table 2). Despite the negative value of the dominance coefficient in the families Snezhet x Atlant, Podarok Kashinu x 1-16-11, Poklon Kazakovu x Podarok Kashinu, Medvezhonok x Oranzhevoe, hybrids with a length of autumn inflorescences up to 110 cm were isolated, numbering up to 20-23 fruiting branches. Thus, the production of high-primocane forms of raspberry when used in the hybridization of modern source material is not very difficult.

Table 2. Inheritance of some economic and biological traits by the hybrid raspberry progeny

Crossing combinations	Dominance coefficient H_p			
	Degrees of remontancy	Early crop ripening	Number of fruits on the shoot	Fruit strength
37-143-3 x Oranzhevoe Chudo	-7.0	-1.2	-2.7	-4.7
1-16-11 x Atlant	-4.1	-1.5	-5.1	-5.5
Snezhet x Atlant	-3.6	-2.2	-1.3	-1.8
Podarok Kashinu x 1-16-11	-1.88	-2.35	-1.9	-1.3
Zhar-Ptitsa x Nizhegorodets	-1.4	-1.05	-3.6	-1.5
Poklon Kazakovu x Podarok Kashinu	-0.5	-2.8	-1.7	-1.2
Medvezhonok x Oranzhevoe	-0.45	-5.4	-7.1	-1.5

Chudo				
Poklon Kazakovu x Karamelka	-0.36	-1.5	0.8	-0.8
44-154-2 x Poklon Kazakovu	0.33	-3.4	0.3	-3.3
Atlant x Bryanskoe Divo	0.57	-1.6	-1.2	-5.2
Rubinovoe Ozherelye x Penguin	0.67	-2.7	-0.6	0.2
Poklon Kazakovu x Atlant	1.3	-1.4	-5.0	-2.9
13-118-1 x Podarok Kashinu	1.6	-3.5	-4.0	-2.7
Podarok Kashinu x Penguin	1.8	-3.1	-0.8	-2.4
13-118-1 x 1-16-11	2.2	-4.7	-4.2	-1.3

It is much more difficult to combine a high level of remontancy and early friendly fruiting in one genotype. As a rule, forms with a large number of long, branched fruiting branches are characterized by a long ripening of the crop (more than 2 months). Breeders have to find a compromise between plant morphology and timing of fruiting. Usually, when selecting, preference is given to early-ripening forms to the detriment of the remontancy level. During the research period, regardless of weather conditions, the varieties Bryanskoe Divo, Medvezhonok, Nizhegorodets, Penguin, Snezhet and selected forms 1-16-11, 44-154-2 managed to mature annually before the onset of autumn frosts. Moreover, in the varieties Bryanskoe Divo and Medvezhonok, it was possible to destroy the negative relation between the vast area of autumn fruiting and the early ripening period. These varieties have a total length of fruiting branches of more than 3 m and finish fruiting in late September - early October. A number of varieties (Rubinovoe Ozherelye, Poklon Kazakovu, Podarok Kashinu, Oranzhevoye Chudo) and forms (13-118-1, 37-143-3) in favorable seasons for primocane raspberry also manage to completely finish fruiting, but in the average weather conditions of the Bryansk region, up to 5-10% of their harvest remains unsold. The late ripening of the fruit is distinguished by the varieties Atlant, Zhar-Ptitsa and Karamelka. They regularly do not fit into the growing season and the sum of active temperatures of 2300-2700 °C is not enough for them to complete fruiting.

Obtaining early-ripening primocane forms of raspberries with short fruiting period is one of the most difficult tasks of breeding. Depression is observed in the inheritance of this trait ($H_p = -1.05 \dots -5.4$). Among the studied combinations of crosses, no families with a positive coefficient of dominance were identified. Despite this, in some families (Podarok Kashinu x Penguin, 44-154-2 x Poklon Kazakovu, 13-118-1 x 1-16-11, Podarok Kashinu x 1-16-11, 13-118-1 x Podarok Kashinu), up to 8-15% of seedlings were obtained that surpass the best parental form in terms of maturation. In addition, it is possible to obtain single transgressive hybrids when using late-ripening Atlant variety as a staminate parent in crosses with early-ripening forms (1-16-11 x Atlant, Snezhet x Atlant, Poklon Kazakovu x Atlant).

Varieties of primocane raspberry with a compact inflorescence (the length of fruiting branches is not >20 cm) are characterized by a low load of the stem with generative organs. They form from 40 to 100 pcs. of buds, flowers and fruits on the shoot. This group includes Nizhegorodets, Karamelka, Penguin, Snezhet varieties. More than half (56.2%) of the studied parental forms had a moderate level of the trait (103-147 pcs. on the stem). The varieties Zhar-Ptitsa, Podarok Kashinu, and form 1-16-11 were distinguished by multiplicity, which had an average of 152-171 berries during the observation period on an annual shoot, and in some years - more than 200 pcs. Their use in hybridization does not always guarantee the production of polycarpous hybrids, since the inheritance of this trait goes by the type of depression or deviation in the direction of the worst parent (Table 2). However, in families 13-118-1 x 1-16-11, 13-118-1 x Podarok Kashinu, Podarok Kashinu x 1-16-11, Podarok Kashinu x Penguin, Atlant x Bryanskoe Divo, from 2.5 to 17% of transgressive seedlings with a stem load of more than 160 pieces of fruit were segregated.

In the family of 13-118-1 x Podarok Kashinu, a unique selection of 11-165-10, consisting of 350 generative organs on the stem, was identified.

One of the limiting factors limiting the industrial cultivation of some primocane varieties of raspberry is the fruit strength. For manual harvesting and long-term transportation, varieties with a fruit strength of more than 6 N are suitable, and for mechanized harvesting - more than 7.0 N [28]. The varieties Bryanskoe Divo, Zhar-Ptitsa, Podarok Kashinu, Poklon Kazakovu, Karamelka, Medvezhonok had the effort to squish berries in the range of 6.1-6.9 N. Nevertheless, this level of trait does not always ensure the quality of berries during post-harvest transportation and storage. The Atlant variety and selected forms 37-143-3, 44-154-2 are suitable for mechanized harvesting. It is desirable to create varieties with a margin of strength (8-9 N), which will allow to maintain transportability even in rainy seasons. As experience shows, in the hybrid progeny of raspberry, transgressive seedlings are extremely rarely segregated, and even more so hybrids with an effort to squish the fruits of more than 7 N. Despite this, in the families of Atlant x Bryanskoe Divo, 44-154-2 x Poklon Kazakovu, 13-118-1 x Podarok Kashinu, 13-118-1 x 1-16-11, Podarok Kashinu x 1-16-11, 1-16-11 x Atlant, selections with berry strength of 7.1-8.4 N were allocated (Table 3).

Table 3. Combination of economic and biological traits in selected forms of raspberry primocane type

Selection	Origin		Length of autumn fruiting, cm	Average fruit weight, g	Biological productivity, g	Crop ripening time	Taste score	Fruit strength, N
	♀	♂						
6-119-1	3-8-1	Free pollination	90	6.0	3234	early	3.9	8.4
3-170-1	Atlant	Snezhet	80	5.6	3304	early	4.0	7.6
8-189-1	16-88-1	Medvezhonok	75	5.1	3754	Very early	4.1	7.7
11-165-10	13-118-1	Podarok Kashinu	115	5.5	3850	Very early	3.8	7.1
9-163-2	13-118-1	1-16-11	70	4.8	3917	early	4.2	7.6
6-154-1	44-154-2	Poklon Kazakovu	90	4.6	4232	Medium-early	3.9	7.2
10-165-11	13-118-1	Podarok Kashinu	100	5.8	4454	early	4.0	5.8
5-83-10	9-163-2	Free pollination	70	5.5	4752	Mid-late	4.0	8.0
2-159-1	Podarok Kashinu	Atlant	80	5.4	5605	Mid-late	3.9	6.5

During the research period, forms of primocane raspberry were created that combine a high level of remontancy, early fruiting with other economically valuable traits and properties. Thus, selection 11-165-10 combines in its genotype a large area of autumn fruiting, a large stem load with generative organs, large-fruiting, productivity, fruit strength and unusually early ripening of the crop (in the first decade of September). The selected form 9-163-2 is distinguished by the dessert taste of the fruits of increased strength, early ripening of the crop, straight-growing habitus of the shrub. In the forms 6-154-1, 5-83-10, 2-159-1, it was possible to combine the components of productivity and increased fruit strength at a high level.

4 Conclusions

1. In breeding of raspberry with a predominant fruiting on annual shoots, there are certain difficulties in obtaining forms with a high degree of remontancy, early, friendly crop ripening, multiple fruits and increased berry strength, as evidenced by the depression in the inheritance of these traits.

2. The best combinations of parental forms were identified, in the combinations of which the highest yield of transgressive seedlings was observed according to the studied traits.

3. Selected forms 6-119-1, 3-170-1, 8-189-1, 11-165-10, 10-165-11, 9-163-2, 5-83-10 and others are highlighted, combining a high level of remontancy, early fruiting with other economically valuable traits and properties.

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