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Productivity of Modern Raspberry Varieties and Prospects for Their Selection

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Abstract: Industrial raspberry plantations do not provide the domestic Russian market with products in full. Open-ground raspberries are only available in July, August, and September. These time intervals can be extended by using tunnel shelters and remontant varieties. The aim of this study was to evaluate foreign remontant raspberry varieties for industrial cultivation in the Central Russia region and their potential use in breeding programs to improve domestic varieties. The data was collected from four-year-old plants over three years. The studied varieties—including 'Amira', 'Enrosadira', 'Maravilla', 'Mapema', 'Kwanza', and 'Eros'—were grown in film greenhouses. The vegetative and generative parts of the plant were assessed, as well as the characteristics of the fruits. The plants were grown in film tunnels (10 m × 100 m × 4.7 m). Thirty fruits were randomly selected for the study, in which quantitative and qualitative parameters were evaluated. The parameters of the vegetative and generative organs were also measured. According to the study results, based on raspberry fruit quality indicators, four raspberry variety groups were distinguished. The content of soluble solids was highest in the Maravilla variety, amounting to 14.14 ± 0.71 Brix. Based on a set of characteristics, it was established that if agronomic activities including irrigation and basic fertilizer application are observed, the varieties 'Maravilla', 'Enrosadira', and 'Mapema' are promising for use in the central zone of Russia.

Keywords: remontant raspberries; tunnel shelters; breeding programs; industrial production of raspberries

1. Introduction

In 2022, global raspberry production was approximately 950 thousand tons [1], and from 2012 to 2019, the global import and export volumes increased by 50% and 56%, respectively [2]. This indicates a raspberry demand increase. The majority of commercial berry production is concentrated in the Russian Federation (174,000 t.), Mexico (128,848 tons), and Serbia (120,058 tons) [3–6].

Rubus breeding programs have been developed in worldwide practice. Modern breeding concerns such areas as the improvement of fruit quality and yield, extension of the growing season, preservation of organoleptic properties during storage, resistance to diseases and pests, and adaptation to growing conditions [7]. Despite recent advancements, there remains a need for varieties with improved environmental tolerance, extended ripening periods, compatibility with modern agricultural technologies, and enhanced consumer appeal [8].

Raspberries are very popular due to their excellent taste and unique aroma [9]. Due to their high content of anthocyanins, flavonoids, phenolic acids, vitamins C and E, and carotenoids, raspberries are considered a good source of natural antioxidants that can provide protection against various human diseases caused by oxidative stress [10–14]. Raspberries have certain advantages in cultivation compared to other crops, namely:

- the possibility of cultivation on different soil types;
- the remontant nature of many varieties allows berries to be obtained in the same year as the plantation was laid;
- high productivity and rather simple ripe fruit collection (if agrotechnical measures are observed);
- demand for berries is high not only in the fresh market but also for processing [15,16].

Currently, there are about 600 raspberry varieties in the world, but only about 30–40 varieties have great industrial importance [17]. Significant progress in the creation of genotypes with a high level of economically valuable characteristics has been achieved through the implementation of raspberry breeding programs. The yield potential of modern domestic and foreign varieties can reach 40–60 t/ha [18]. However, the actual crop yield is much lower; usually, it does not even exceed 40 t/ha [19].

Industrial raspberry plantations in Russia make up just over 10% of all plantings and do not fully satisfy the needs of the population or the processing industry for berry products [14]. As such, for the period of 2022, the area used for raspberry planting in the Russian Federation was 27,331 hectares, with a yield of 212,300 tons [5].

In the central zone of Russia, raspberry cultivation on open ground is possible in July, August, and September. The use of tunnel shelters in June, September, and October allows for the period when local raspberries are available on the market to be extended. In other months, additional lighting and heating are required to obtain commercial-quality berry products, but this method is quite expensive. From November to April, berries enter the Russian market from Mexico, Poland, Serbia, and other countries [20–22].

The purpose of the study was to evaluate foreign remontant raspberry varieties for industrial cultivation and potential use in breeding programs.

2. Materials and Methods

2.1. Plant Material

The study was conducted in the village Chebyshovka, Odoevsky district, Tula region, Russia, over three years (2021–2023). The objects of the study were the following varieties of remontant raspberries: 'Amira', 'Enrosadira', 'Maravilla', 'Mapema', 'Kwanza', and 'Eros'. The studied varieties were selected based on the climatic zone required and their growing season. The plants were grown in film tunnels (10 m × 100 m × 4.7 m), and the film density was 150 microns. The soil on the territory of the farm was leached chernozem. The plants were arranged according to the 3.0m × 0.5 m scheme. Two drip tapes with a water supply of 1.6 l per hour were installed in a row (0.5 m). NPK (18-18-18), (3-11-38), and (13-40-13) fertilizers were applied annually by fertigation at different stages of plant development.

The age of the studied plants was 4 years. The experimental samples are presented in triplicate, with five plants in each. For the study, 30 fruits were randomly selected. Their quantitative characteristics (fruit length (mm), fruit diameter (mm), fruit weight (g), number of drupes (pcs)), soluble dry substance content (°Bx), fruit density (g), storage time (at a temperature of +4 °C, days), and qualitative characteristics (fruit shape, separability from the receptacle at the full ripening stage, glossiness, color, aroma) were assessed. The parameters of the vegetative and generative organs (number of shoots (pcs), shoot height (mm), number of laterals (pcs), length of laterals (pcs), number of fruits on a lateral (pcs)) were also measured.

Fruit length and diameter were measured with an Ada Mechanic 150 electronic caliper with an accuracy of 0.01 mm. The fruits were weighed on electronic scales with an accuracy of 0.1 g. An AQ-REF-BRIX4 refractometer with an accuracy of 1°Bx was used to determine sugar amounts. Fruit density was measured with a Megeon 03004 penetrometer.

The accounting and observations were carried out according to the standard methodology for setting up experiments with fruit crops, as outlined by E.N. Sedov [23].

2.2. Statistical Analysis

Statistical analysis of the data was performed in the SPSS Statistics 25 program. Descriptive statistics are given in the form of box plot figures. The arithmetic average values of the characteristics are given, along with the standard deviation. Analysis of variance with Duncan's post hoc test (ANOVA) was used to compare average values ($p = 0.05$). To establish the presence of dependencies between characteristics, Pearson's correlation analysis was used, along with a two-sided assessment of the reliability of the coefficient according to Student's *t*-test ($p = 0.05$).

3. Results

Analysis of quantitative characteristics using the comparison of averages method showed that among the six raspberry varieties, Enrosadira and Maravilla stand out with regard to a complex of characteristics and have the maximum values in the sample for many parameters (Table 1). Despite the fact that these varieties fell into the group of samples with the lowest shoot quantity (on average 4.4–4.8 shoots per plant), while Mapema has almost twice as many shoots (8.4 ± 0.5 shoots), they are not inferior in fruit quantity per plant due to their longer shoots and greater lateral quantity per shoot.

Table 1. ANOVA results comparing mean characteristic values in six raspberry varieties (average arithmetic mean is given with standard deviation; letters indicate groups of varieties according to the ANOVA results and Duncan's posterior criterion ($p = 0.05$)).

	Enrosadira	Mapema	Kwanza	Amira	Eros	Maravilla
Shoot quantity, pcs	4.4 ± 0.5 a	8.4 ± 0.5 d	5.6 ± 0.5 c	5.0 ± 0 a, b, c	5.2 ± 0.4 b, c	4.8 ± 0.4 a, b
Shoot height, cm	217.8 ± 8.4 d	122.2 ± 7.9 a	138.5 ± 5.6 b	137.4 ± 5.0 b	164.0 ± 6.0 c	224.0 ± 6.7 e
Lateral quantity per plant, pcs	52.8 ± 9.9 a	76.6 ± 5.9 c	66.6 ± 6.0 b	46.8 ± 2.3 a	55.0 ± 5.3 a	64.4 ± 6.4 b
Lateral quantity per shoot, pcs	12.0 ± 2.1 c	9.1 ± 0.9 a	11.9 ± 1.5 c	9.4 ± 1.1 a	10.6 ± 1.2 b	13.4 ± 1.1 d
Fruit quantity per plant, pcs	537.4 ± 108.6 b	578.0 ± 56.3 b	396.8 ± 49.7 a	349.2 ± 16.0 a	419.6 ± 31.0 a	563.2 ± 159.5 b
Fruit quantity per shoot, pcs	122.1 ± 23.3 c	68.8 ± 7.7 a	70.9 ± 10.1 a	69.8 ± 8.1 a	80.7 ± 10.4 b	117.3 ± 32.2 c
Fruit quantity per lateral, pcs	10.1 ± 0.5 d	7.6 ± 0.5 b	6.0 ± 0.4 a	7.5 ± 0.4 b	7.6 ± 0.6 b	8.7 ± 1.9 c
Total lateral length on shoot per plant, cm	311.6 ± 58.4 d	96.1 ± 14.1 a	102.7 ± 15.0 a, b	117.6 ± 16.1 b, c	129.0 ± 13.8 c	336.9 ± 34.4 e
Lateral length per shoot, cm	25.8 ± 0.7 e	10.5 ± 1.1 b	8.6 ± 0.4 a	12.5 ± 0.5 c	12.2 ± 0.5 c	25.1 ± 1.3 d

The varieties Kwanza, Amira, and Eros were grouped together as the varieties with the lowest fruit quantity per plant (349–419 pcs) (Table 1). The lateral quantity per shoot of Kwanza (11.9 ± 1.5 pcs) was statistically the same as Enrosadira (12.0 ± 2.1 pcs), but Enrosadira was significantly inferior to Kwanza in shoot quantity, while it instead superior in fruit quantity per plant.

Enrosadira and Maravilla laterals are about 25 cm. They are two times longer than the other varieties.

Pearson's correlation analysis revealed strong relationships between fruit quantity per shoot and fruit quantity per lateral (r = 0.8) and also between fruit quantity per shoot and total lateral length per shoot (r = 0.9) for all studied varieties (Table 2).

Table 2. Pearson's correlation coefficients for raspberry characteristics (** shows coefficient reliability at *p* = 0.01).

	Shoot Quantity	Shoot Height	Lateral Quantity per Shoot	Fruit Quantity per Shoot	Fruit Quantity per Lateral	Total Length of Laterals on the Shoot	Lateral Length per Shoot	Correlation Strength and Direction
Shoot quantity								strong straight
Shoot height	−0.663 **							medium straight
Lateral quantity per shoot	−0.488 **	0.622 **						weak straight
Fruit quantity per shoot	−0.443 **	0.776 **	0.751 **					unreliable
Fruit quantity per lateral	−0.242	0.624 **	0.219 **	0.800 **				weak reverse
Total lateral length on shoot per plant	−0.542 **	0.923 **	0.721 **	0.888 **	0.673 **			medium reverse
Lateral length per shoot	−0.530 **	0.930 **	0.514 **	0.793 **	0.737 **	0.956 **		Strong reverse

Shoot height was closely related to both lateral length on the shoot (r = 0.9) and the total lateral length per plant (r = 0.9). An in-depth examination of the relationships between the characteristics for each variety revealed that the fruit quantity per lateral and lateral quantity per shoot of Enrosadira was r = 0.96, Amira r = 0.92, Kwanza r = 0.84, Eros r = 0.82, Mapema r = 0.79, and Maravilla r = 0.69. Also, fruit quantity per lateral showed significant strong relationships with total lateral length, with coefficients of r = 0.96 for Enrosadira, r = 0.89 for Amira, r = 0.82 for Kwanza and Maravilla, r = 0.71 for Eros, and r = 0.49 for Mapema. Consequently, Enrosadira and Amira can be used as breeding trait donors when developing a breeding program whose objective is to increase fruit quantity per lateral.

Traits alignment checking in the raspberry varieties showed that shoot height is very homogeneous—only 3–6% of shoots within a variety differ from the average (Figure 1). The most variable trait is fruit quantity per lateral (varying from 11 to 27%). Thus, Mapema, Eros, and Amira could be donors for ensuring stable lateral quantity, while Mapema and Amira could be donors for attaining predictable fruit quantity per shoot.

The ANOVA demonstrated that all the studied fruit parameters differed among the varieties (Figure 2). Thus, Enrosadira has the largest fruits—with a fruit length of 26.2 ± 2.2 mm—while its fruit diameter of 23.5 ± 1.4 mm), and weight of 5.8 ± 0.6 g are statistically similar to Maravilla (22.9 ± 1.8 mm, 5.5 ± 1.0 g).

Under the studied region conditions, Kwanza was shown to be the variety with the lowest trait values (Figure 3). For this variety, fruit length was only 21.8 ± 1.3 mm, diameter 20.6 ± 1.4 mm, weight 3.9 ± 0.5 g, and drupe quantity 76.0 ± 8.6 pcs. Amira had the biggest drupe quantity per fruit at 142.1 ± 12.6 pcs, while varieties with large fruits had many fewer (Enrosadira, 90.4 ± 9.3 pieces; Maravilla, 90.2 ± 11.8 pieces; Eros, 93.9 ± 8.8 pieces).
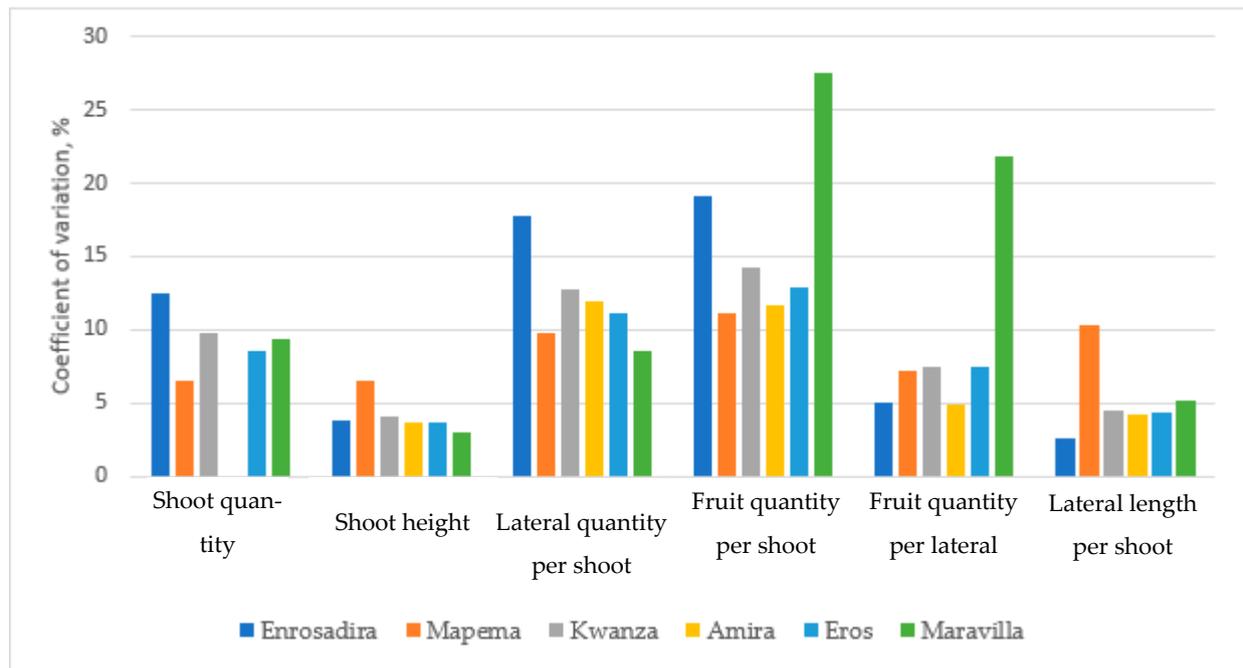
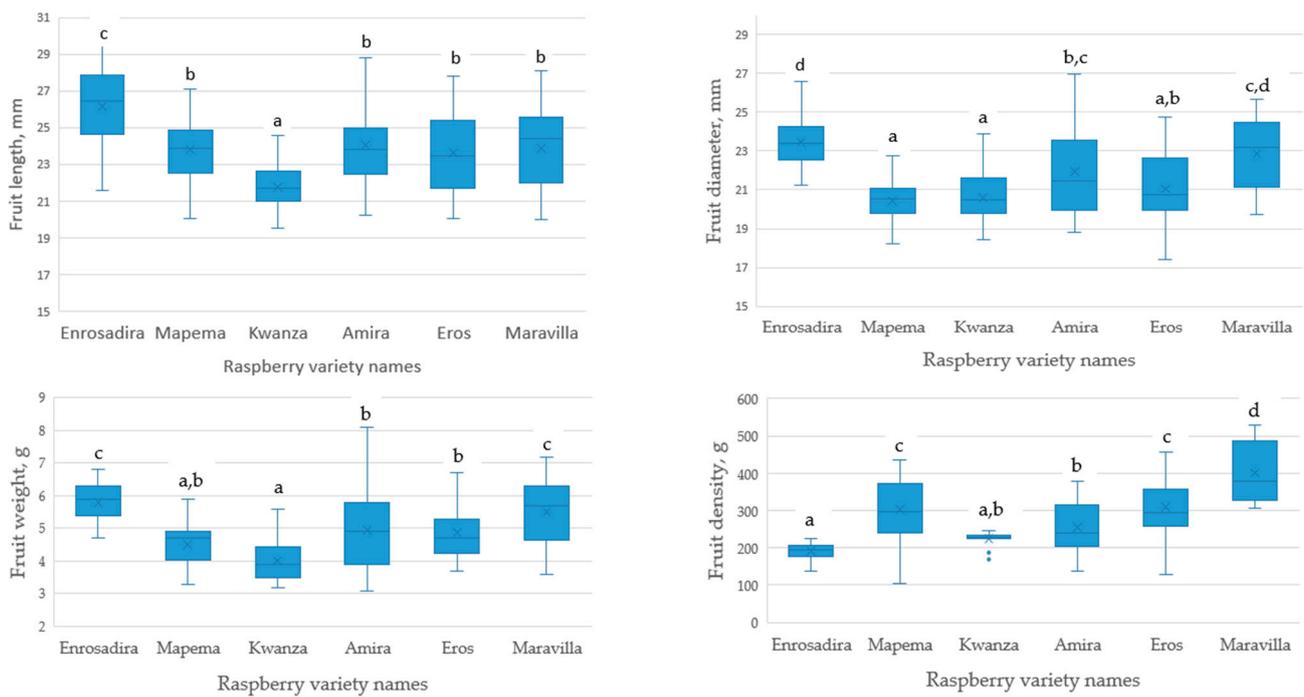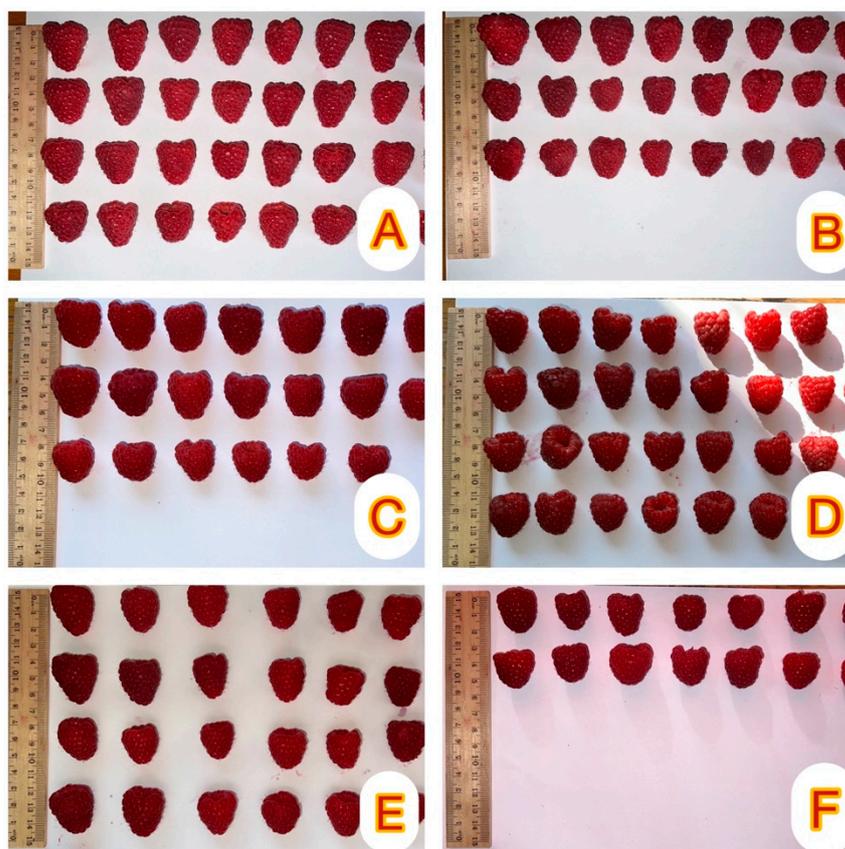**Figure 1.** Variation coefficients of raspberry traits.

Figure 2. Descriptive statistics of the main raspberry fruit characteristics (Duncan's posterior criterion was used for comparison of averages, *p* = 0.05), letters show the variants grouping by attributes.

Figure 3. Experimental raspberry fruit varieties: (**A**) Enrosadira; (**B**) Amira; (**C**) Maravilla; (**D**) Mapema; (**E**) Eros; (**F**) Kwanza.

Spearman correlation analysis revealed an inverse relationship between fruit density and aroma (r = −0.6), i.e., less aromatic fruits are stored for significantly longer. Among the samples, only Enrosadira has a strong aroma, while the others have a faint aroma. No relationship with fruit shape or color was found, as all varieties in the study produced conical red fruits. Glossiness has a medium-strength correlation with fruit density (r = −0.53) and with storage duration at +4 °C (r = 0.55). The samples with faint glossiness are Amira, Maravilla, and Kwanza. The rest of the varieties have medium glossiness. Almost all samples had good fruit detachability from the peduncle at the fully ripe stage; only Kwanza's fruit detachability is average. The longest shelf life at +4 °C temperature was observed for Mapema (8 days); a medium shelf life for Enrosadira (6 days), Kwanza (5 days), and Maravilla (5 days); and a short shelf life for Eros (4 days) and Amira (3 days).

Indicators determining raspberry fruit quality are the soluble solids content, titratable acidity, and sugar content. Therefore, four groups were formed, distinguished according to the soluble solids content of the representatives of the studied varieties. The diametrical groups were Maravilla at 14.14 ± 0.71 Brix and Mapema at 9.66 ± 0.48 Brix. Kwanza (10.36 ± 0.63 Brix) and Eros (10.43 ± 0.50 Brix) do not differ among themselves and have the lowest dry matter content. Enrosadira (10.88 ± 0.42 Brix) and Amira (11.13 ± 0.54 Brix) are in a separate group.

4. Discussion

In our experiment, raspberry varieties that show high productivity and fruit quality in their home regions were chosen for assessment. These are the reasons for their wide use in industrial production in many countries. The Tula region is characterized by heavy soil. The sum of active temperatures in the Tula region is 2100–2300 degrees Celsius,

which is much inferior to the sum of active temperatures in the varieties' origin countries (for example, Enrosadira is bred in Italy, where the sum of active temperatures is more than 4000 degrees). Our results show that the fruit quantity per plant of Enrosadira and Maravilla are not inferior to Mapema, despite the fact that they have half the shoot quantity. It is worth considering the varieties' shoot-forming ability and the growing conditions. For raspberries growing in an industrial plantation, the optimal shoot quantity for Enrosadira and Maravilla is 5–6 per linear meter. This quantity is justified by the large number of leaves on the shoot, which can lead to thickening and the appearance of fungal diseases. At the same time, Mapema has a smaller leaf plate, which allows you to leave a greater number of shoots on the plant. The main task in berry production is to have high productivity, which will reduce production costs and significantly increase the producer's profit [24]. Consequently, the number of shoots is a significant characteristic, because if their number is low, labor input for shoot normalization can be reduced [25].

To date, the raspberry breeding program in Russia has had the goal of creating remontant varieties with early and late ripening dates, high fruit quality, and resistance to major fungal diseases [26]. According to studies by S. N. Evdokimenko, the Maravilla and Kwanza varieties are worth special attention as a source of large fruit size and increased contents of soluble solids [27]. Similar results have been given by Lawrence for the Enrosadira variety [28].

Also, these varieties have shown high fruit density, which partially corresponds with our study. For example, the fruit density of Maravilla is about 400 g, while that of Enrosadira is only 190 g. This can be explained by the high nutritional requirements of Enrosadira. At the same time, for the Russian market, Enrosadira is of interest as a variety that is suitable for quick sale in chain markets due to its color, shape, and fruit quality, while Maravilla is excellent for long-term sale to fresh markets and chain stores due to its high density and taste quality. However, in our assessment of fruit storage period at +4 °C, it was found that Kwanza and Maravilla can be stored for 5 days and Enrosadira for 6 days, and in this regard, it is worth noting the variety Mapema, which has a storage period of 8 days. In Russia, varieties with dense, tasty berries have been bred, but their shelf life does not exceed 5–7 days [29]. In our studies, the storage life of the varieties under study could be affected by the harvesting conditions, because after harvesting, the fruits were not immediately placed in the cold room.
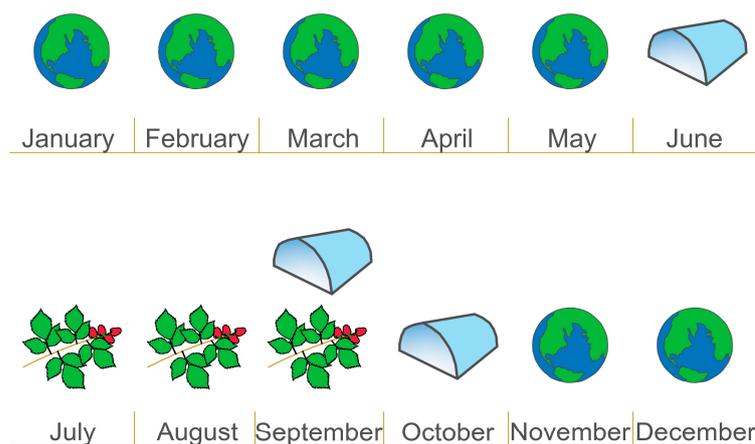
In the conditions of the studied region, the Kwanza variety showed the lowest values with regard to fruit length, diameter, and weight, as well as the number of drupes. In the meantime, in G. S. Gabrielyan's studies, this variety showed high yield and fruit quality through industrial cultivation in Armenia. This is presumably due to the agronomic measures carried out at the plantation and the sum of the active temperatures [30]. Therefore, we assume that the shoot quantity should be changed, and plant nutrition should be improved in our cultivation methodology.

In the central region of Russia, to improve the yield potential of the available varieties, one of the priority tasks is to increase fruit weight [31], since it is of critical importance at harvest and directly affects economic efficiency [32]. Progress in obtaining large-fruited remontant varieties is associated with the use of interspecific hybridization. Active inclusion of varieties and forms cultivated from *Rubus idaeus* L. and descendants of wild Rubus species (*R. occidentalis* L., *R. grataegifolius* Bge., *R. odoratus* L., *R. spectabilis* Pursh., *R. arcticus* L.) in the breeding process has led to the creation of a modern variety of remontant raspberry. Large-fruited varieties such as 'Himbo-Top', 'Joan J', 'Autumn Britten', 'Poranna Rosa', 'Kweli', 'Kwanza', 'Enrosadira', 'Atlant', 'Bryanskoye Divo', 'Podarok Kashin', 'Heracle', 'Golden Autumn', and other varieties with fruit weights of more than 4.5 g were obtained on the above genetic basis [33,34]. As a result of long-term breeding

work, Russian scientist S. N. Evdokimenko recommends using combinations of Podarok Kashinu × Atlant, 9-113-1 × Poklon Kazakov, 9-113-1 × Podarok Kashinu, and Poklon Kazakovu × Karamelka as domestic donors of large-fruited characteristics [34]. The varieties Maravilla and Enrosadira are grown in the ground in tunnel shelters to obtain a double harvest—in the fall, on shoots of the current year, and in the summer, on shoots of the previous year. Consequently, they can be considered as donors of a set of traits for quality double yield.

We also see prospects for directed breeding to create hybrids resistant to fungal diseases and pests, whose degree of spread varies annually due to the influence of agroclimatic conditions [35,36]. We believe that this is one of the important factors restraining the realization of the yield potential of biological raspberry varieties and limiting wide cultivation [37]. In this regard, we recommend growing remontant raspberry varieties—their fruited shoots are removed in the fall, thereby reducing the pesticide load and the spread of diseases and pests. For the consumer market, it will be significant to establish a balance in breeding work between fruit density and aroma. Our study confirmed an inverse correlation between the traits, which confirms the results of Arifova's study, i.e., less aromatic fruits can be stored for significantly longer [38].

At present, supplies of raspberry products to Russia in the cold season are mainly from Mexico, Morocco, and other countries. At the same time, from June to October, the domestic market can be provided with its own berry production (Figure 4).

| January | February | March | April | May | June |

| July | August | September | October | November | December |

Figure 4. Delivery periods and raspberry cultivation methods in the Central Russia region (November–May—imported products; June, September, October—tunnel cultivation of own products; July–September—raspberry cultivation on the open ground).

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