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DETERMINING CONSUMER APPEAL OF SELECTED GARDEN STRAWBERRY VARIETIES (*FRAGARIA* × *ANANASSA* DUCH.)

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Improving the biochemical strawberry fruit composition and aroma is an important goal to develop the assortment of strawberry plants because only a few present-day varieties combine the high quality and aroma in strawberry fruits with increased accumulation of the biochemical composition components. The paper aims to assess hybrid strawberry seedlings based on a range of properties in strawberry fruits to select the most promising genotypes. Strawberry aroma and its consumer appeal were evaluated organoleptically. The biochemical component was tested in the laboratory according to standard methods, and the strawberry aroma was evaluated using DNA markers.

The research identified promising genotypes showing a high level of different characteristics: 75-30 (Tokado × Elianny) – consumer appeal (5.0 points), flavor (4.5 points), polychlorinated biphenyl levels [PCB] (9.2% Brix), and vitamin C (72.1 mg/100 g); 34-2 (922-67 × Privlekatelnaya) – consumer appeal (5.0 points), strawberry aroma (FaOMT gene), flavor (4.5 points), PCB levels (14.7% Brix), and sugars (10.8%); 153-41 (Senga Sengana × Redcoat) –consumer appeal (5.0 points), strawberry aroma (FaOMT gene), PCB levels (12.8% Brix), sugars (10.2%), and vitamin C (76.1 mg/100 g); 153-60 (Senga Sengana × Redcoat) – consumer appeal (5.0 points), strawberry aroma (FaOMT gene), flavor (4.6 points), PCB levels (11.7% Brix), and sugars (10.5%); 35-16 (922-67 × Maryshka) – flavor (4.6 points) and anthocyanins levels (90.7 mg/100 g); 72-25 (Privlekatelnaya × Bylinnaya) – combination of FaOMT and FaFAD1 strawberry aroma genes.

Keywords: *strawberry; genotype; consumer appeal; flavor; biochemical composition; aroma*

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ОЦЕНКА ПОТРЕБИТЕЛЬСКИХ КАЧЕСТВ ПЛОДОВ ОТБОРНЫХ ФОРМ ЗЕМЛЯНИКИ САДОВОЙ (*FRAGARIA* × *ANANASSA* DUCH.)

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Улучшение биохимического состава и аромата плодов является актуальной задачей совершенствования сортимента земляники, так как немногие из современных сортов сочетают высокий уровень качества и аромата плодов с повышенным накоплением компонентов биохимического состава. Цель исследования – анализ гибридных сеянцев земляники по комплексу потребительских качеств плодов для выделения перспективных генотипов. Оценку привлекательности и вкусовых качеств плодов проводили органолептически, содержание биохимических компонентов – в лабораторных условиях по стандартным методикам, аромата плодов – с использованием ДНК-маркеров.

В результате проведённых исследований идентифицированы перспективные генотипы, характеризующиеся высоким уровнем проявления комплекса признаков: 75-30 (Tokado × Elianny) – привлекательность (5,0 балла), вкус плодов (4,5 балла), содержание растворимых сухих веществ (РСВ) (9,2% Brix) и витамина С (72,1 мг/100 г); 34-2 (922-67 × Привлекательная) – привлекательность (5,0 балла), аромат плодов (ген FaOMT), вкус (4,5 балла), содержание РСВ (14,7% Brix) и сахаров (10,8%); 153-41 (Senga Sengana × Redcoat) – привлекательность (5,0 балла), аромат плодов (ген FaOMT), содержание РСВ (12,8% Brix), сахаров (10,2%) и витамина С (76,1 мг/100 г); 153-60 (Senga Sengana × Redcoat) – привлекательность (5,0 балла), аромат плодов (ген FaOMT), вкус (4,6 балла), содержание РСВ (11,7% Brix) и сахаров (10,5%); 35-16 (922-67 × Maryshka) – вкус плодов (4,6 балла) и содержание антоцианов (90,7 мг/100 г); 72-25 (Привлекательная × Былинная) – комбинация генов аромата плодов FaOMT и FaFAD1.

Ключевые слова: *земляника; генотип; потребительские качества; вкус; биохимический состав; аромат*

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Introduction

Garden strawberries are among the most widely cultivated berry crops in the world. Its fruits contain a large number of phytochemical compounds: catechins, flavonols, anthocyanins, vitamin C, folic acid, etc. [6; 14]. Strawberry consumption helps to prevent inflammatory processes, hypertension, and atherosclerosis [9; 15]. However, only a few of the cultivated genotypes are associated with a high quality of fruits and increased accumulation of biochemical composition components [11].

Furthermore, what attracts consumers to high-quality strawberries is their distinctive pleasant aroma attributed to a number of volatile aroma-forming organic compounds [17; 19]. The most significant contribution to the strawberry aroma is made by about 20 organic compounds, which include γ-decalactone (peach-like, fruity, sweet aroma) and mesifuran (fruity and caramel aroma) [10; 21]. According to [20] and [10], many present-day high-yielding garden strawberry varieties possess weak aroma characteristics due to the domestication effect, and plant breeders who neglected the "strawberry aroma" component as important for breeding purposes over a long time. In this regard, improving the biochemical composition and preservation of aroma is an urgent and important task concerning strawberry varieties' genetic and breeding improvement.

The scientific novelty is as follows:

- Polymorphic selected hybrid forms of strawberries of interspecific and intervarietal origin (created at the I. V. Michurin Federal Research Center) were characterized for the first time based on a complex of new methods of DNA technology, genetic selection, and biochemical analysis;
- Qualitatively new genotypes with fragrant dessert-flavored fruits with a high accumulation of biologically active substances (anthocyanins, vitamin C) were identified).

Materials and methods

The paper aims to assess hybrid strawberry seedlings based on a range of properties in strawberry fruits to select the most promising genotypes and the origins of their high quality.

Research objectives:

- To evaluate the strawberry fruit appeal and palatability in selected varieties;
- To examine the selected strawberry fruits' biochemical composition;
- To analyze the selected varieties for genetic determinants of the strawberry's aromatic properties;

- To select promising strawberry genotypes with a high number of qualities enjoyed by consumers.

The research was conducted in 2019–2020. It targeted promising selected seedlings of garden strawberries obtained at the I.V. Michurin Federal Research Center.

Garden strawberry appeal and palatability were evaluated organoleptically following the Program and Methods of Variety Research on Fruit, Berry, and Nut Crops [8].

Strawberry fruit biochemical analyses were performed according to standard methods [1; 7]. The obtained data were statistically processed using the Microsoft Excel 2016 software.

Strawberry aroma evaluation was based on identifying genes of volatile aroma-forming substances through molecular genetic analysis. The FaOMT-SI/NO marker [22] was used to detect the *FaOMT* gene (mesifuran levels in strawberry fruits). The FaFAD1 marker [12] was chosen to identify the *FaFAD1* gene (γ-decalactone levels in strawberry fruits). The 15 μl polymerase chain reaction [PCR] mixture contained 1.5 mM of a buffer solution for PCR, 2.0 mM of a deoxyribonucleotide triphosphate solution, 2.5 mM of magnesium chloride, 0.2 U of Taq polymerase, 0.2 μM of forward and reverse primers, and 20 ng of genomic DNA. Amplification was performed with the help of a BIO-RAD T100 thermocycler and in the modes described earlier [5]. The amplification products were separated by agarose gel electrophoresis. The Gene Ruler 100 bp DNA Ladder was used to determine the size of amplicons.

Results

In the studied hybrid varieties of garden strawberry, we estimated how attractive their fruits can be to consumers (4.0 to 5.0 points); identified strawberry fruits flavor (4.0 to 4.6 points); polychlorinated biphenyl [PCB] levels (8.3 to 10.6% Brix), total sugars (5.1 to 8.4%); vitamin C (37.0 to 88.5 mg/100 g); and anthocyanins (30.3 to 114.0 mg/100 g) (Table 1).

Among the studied biochemical components of strawberry fruits, the greatest variability was noted in the anthocyanins levels (3.8-fold difference between the maximum and minimum values) and vitamin C levels (2.4-fold difference between the maximum and minimum values).

Hybrid varieties possess a number of qualities desirable to consumers:

- 75-30 (Tokado × Elianny) – consumer appeal (5.0 points), flavor (4.5 points), PCB levels (9.2% Brix), and vitamin C (72.1 mg/100 g);
- 34-2 (922-67 × Privlekatelnaya) – consumer appeal (5.0 points), flavor (4.5 points), PCB levels (14.7% Brix), and sugars (10.8%);

- 153-41 (Senga Sengana × Redcoat) – consumer appeal (5.0 points), PCB levels (12.8% Brix), sugars (10.2%), and vitamin C (76.1 mg/100 g);
- 153-60 (Senga Sengana × Redcoat) – consumer appeal (5.0 points), flavor (4.6 points), PCB levels (11.7% Brix), and sugars (10.5%);
- 35-16 (922-67 × Maryshka) – flavor (4.6 points) and anthocyanins levels (90.7 mg/100 g).

Table 1.

Consumer appeal to the selected hybrid varieties of strawberries

Indicator	Average (x)	Standard error $S_{(x)}$	Variation intervals			Selected varieties with the best indicators
			min	max	difference, (Δ)	
Consumer appeal, score	4.9	0.10	4.0	5.0	1.0	920-76, 75-30, 914-13, 914-27, 20-8, 35-1, 34-2, 153-41, 153-60, 35-10, 26-10, 56-19
Flavor, score	4.2	0.16	4.0	4.6	0.6	920-62, 914-67, 75-30, 928-25, 927-14, 914-13, 26-5, 26-10, 25-2, 21-14, 35-10, 35-16, 56-19, 34-2, 153-60
PCB, % Brix	9.4	0.17	8.3	10.6	2.3	153-41, 153-60, 34-2, 4/1-126, 4/1-110, 75-30
Sugar (levels), %	6.6	0.14	5.1	8.4	3.3	153-41, 153-60, 34-2, 4/1-126, 4/1-110
Vitamin C, mg/100 g	57.5	2.39	37.0	88.5	51.5	72-12, 153-41, 75-30
Anthocyanins, mg/100 g	55.1	4.23	30.3	114.0	83.7	25-1, 30-1, 35-1, 35-16

Using the FaOMT-SI/NO marker, a functional allele of the *FaOMT* gene (248 bp amplicon) was detected in 64.3% of the strawberry varieties studied, among which 55.6% of hybrids show a combination of functional and nonfunctional alleles, and 44.4% of genotypes show a functional allele in the homozygous state. The *FaFAD1* gene (500 bp amplicon) was identified in 35.7% of the strawberry varieties under study (Table 2).

The combination of functional alleles in *FaOMT* and *FaFAD1* genes was revealed in one genotype: seedling 72-25 taken from the Privlekatelnaya × Bylinnaya plant breeding combination. The selected seedling 65-26 (Olimpiyskaya

Nadezhda × Bylinnaya) inherited no functional alleles of the target genes (amplicons of 248 bp (*FaOMT* gene) and 500 bp (*FaFAD1* gene) were not present).

Table 2.

Allelic diversity of aroma genes in selected strawberry seedlings

Genotype	Plant breeding combination	*FaOMT*		*FaFAD1*
		217 bp	248 bp	500 bp
928-12	298-19-9-43 × Privlekatelnaya	+	+	
72-25	Privlekatelnaya × Bylinnaya	+	+	+
72-71		+	+	
26-5	Rubinovy Kulon × 298-19-9-43	+	+	
65-26	Olimpiyskaya Nadezhda × Bylinnaya	+		
65-34		+		+
69-29	Feyerverk × Bylinnaya	+	+	
56-5	Gigantella Maxim × Privlekatelnaya		+	
56-8		+		+
61-3	Bylinnaya × Olimpiyskaya Nadezhda	+		+
61-12		+		+
34-2	922-67 × Privlekatelnaya		+	
153-41	Senga Sengana × Redcoat		+	
153-60			+	

Discussion

Significant variability was observed for the studied selected strawberry varieties with regard to the qualities consumers find desirable in strawberry fruits. This is due to the polymorphism of the original parental forms and polygenic control and independent pattern in the inheritance of strawberry fruit quality properties and biochemical composition [2; 3; 18].

In addition, various present-day strawberry varieties (generally used as the original parental forms) show a low concentration of biochemical components in their fruits, which makes it challenging to obtain genotypes with high-quality properties.

However, if we consider particular plant breeding combinations, then it is possible to isolate hybrid seedlings with high-quality properties of individual components within the strawberry fruit biochemical composition originated from genetic determinants recombination and transgressive variability [3; 4].

High-quality properties desirable to consumers were found in the following strawberry varieties: 920-76 (Rubinovy Kulon × Dedanka), 75-30 (Tokado × Elianny), 914-13, 914-27 (Festivalnaya × Privlekatelnaya), 20-8 (Festivalnaya

× Dedanka), 35-10 (922-67 × Maryshka), 26-10 (Rubinovy Kulon × 298-19-9-43), 153-41 (Senga Sengana × Redcoat), 34-2 (922-67 × Privlekatelnaya), 56-19 (Gigantella Maxim × Privlekatelnaya), etc. (consumer appeal – 5.0 points); 21-14 (Urozhaynaya TSGL × Rubinovy Kulon), 920-62 (Rubinovy Kulon × Dedanka), 914-13, 914-67 (Festivalnaya × Privlekatelnaya), 26-5, 26-10 (Rubinovy Kulon × 298-19-9-43), 75-30 (Tokado × Elianny), 928-25 (298-19-943 × Privlekatelnaya), 927-14 (298-19-9-43 × Rubinovy Kulon), 35-10, 35-16 (922-67 × Maryshka), 153-60 (Senga Sengana × Redcoat), 25-2 (Rubinovy Kulon × Maryshka), 34-2 (922-67 × Privlekatelnaya), 56-19 (Gigantella Maxim × Privlekatelnaya) (flavor – 4.5 points or more); 153-41, 153-60 (Senga Sengana × Redcoat), 34-2 (922-67 × Privlekatelnaya), 4/1-110, 4/1-126 (Polka × Vima Zanta), 75-30 (Tokado × Elianny) (PCB levels – 9% or more); 153-41, 153-60 (Senga Sengana × Redcoat), 34-2 (922-67 × Privlekatelnaya),4/1-110, 4/1-126 (Polka × Vima Zanta) (sugar levels – 7% or more); 72-12 (Privlekatelnaya × Bylinnaya), 75-30 (Tokado × Elianny), 153-41 (Senga Sengana × Redcoat) (vitamin C – 70 mg/100 g or more); 25-1 (Rubinovy Kulon × Maryshka), 30-1 (Feyerverk × Privlekatelnaya), 35-1, 35-16 (922-67 × Maryshka) (anthocyanin levels – 80 mg/ 100 g or more).

According to the studies of Zorrilla-Fontanesi et al. [22], Cruz-Rus et al. [13], the high levels of mesifuran in strawberry fruits occur in their selected varieties that carry a functional allele of the *FaOMT* gene in the genome in a homozygous or heterozygous state. These include the following seedlings: 56-5 (Gigantella Maxim × Privlekatelnaya), 34-2 (922-67 × Privlekatelnaya), 153-41, 153-60 (Senga Sengana × Redcoat) (homozygous genotype by functional allele); 72-25, 72-71 (Privlekatelnaya × Bylinnaya), 928-12 (298-19-9-43 × Privlekatelnaya), 26-5 (Rubinovy Kulon × 298-19-9-43), 69-29 (Feyerverk × Bylinnaya) (heterozygous genotype). Molecular genetic testing data are also confirmed by analyzing the origin of the varieties studied. The seedlings possessing the homozygous state of the *FaOMT* gene functional allele were isolated in plant breeding combinations where, according to the data obtained earlier [5; 16], both parental forms contain the *FaOMT* functional allele in their genome and, therefore, it is possible to have homozygous forms in the hybrid progeny. Heterozygous genotypes affected by the *FaOMT* gene have been isolated in hybrid combinations, where one or both parental forms show the *FaOMT* gene functional allele, while homozygous seedlings with the inactive allele have the original parental forms without the functional *FaOMT* allele in their genome.

The γ-decalactone levels in strawberry fruits are controlled by the expression of the *FaFAD1* dominant gene [12]. According to molecular genetic anal-

ysis, high γ-decalactone levels are found in fruits of 72-25 (Privlekatelnaya × Bylinnaya), 61-3, 61-12 (Bylinnaya × Olimpiyskaya Nadezhda), 65-34 (Olimpiyskaya Nadezhda × Bylinnaya), and 56-8 (Gigantella Maxim × Privlekatelnaya) obtained using previously identified [5] donors with the target allele of the *FaFAD1* gene, the Bylinnaya and Gigantella Maxim cultivars. A combination of the *FaOMT* and *FaFAD1* functional alleles was identified in seedlings 72-25 (Privlekatelnaya × Bylinnaya). It should be noted that the seedling 72-71 from the same breeding combination did not inherit the functional allele of the *FaFAD1* gene. In addition, seedlings 56-5, 56-8 (Gigantella Maxim × Privlekatelnaya), and 69-29 (Feyerverk × Bylinnaya) also inherited only one locus of the two possible.

Conclusion

Based on the evaluation of selected strawberry varieties in terms of a number properties desirable by consumers, we identified promising genotypes that possess one prominent strawberry property or a number of properties. The most valuable varieties for breeding purposes are:

- 75-30 (Tokado × Elianny) – consumer appeal (5.0 points), flavorful (4.5 points) strawberry fruits with high PCB levels (9.2% Brix), and vitamin C (72.1 mg/100 g);
- 34-2 (922-67 × Privlekatelnaya) – consumer appeal (5.0 points), flavorful (4.5 points) and aromatic (*FaOMT* gene) strawberry fruits with high PCB levels (14.7% Brix), and sugars (10.8%);
- 153-41 (Senga Sengana × Redcoat) – consumer appeal (5.0 points), aromatic (*FaOMT* gene) strawberry fruits with high PCB levels (12.8% Brix), sugars (10.2%), and vitamin C (76.1 mg/100 g);
- 153-60 (Senga Sengana × Redcoat) – consumer appeal (5.0 points), flavorful (4.6 points) and aromatic (*FaOMT* gene) strawberry fruits with high PCB levels (11.7% Brix), and sugars (10.5%);
- 35-16 (922-67 × Maryshka) – flavorful (4.6 points) strawberry fruits with high anthocyanins levels (90.7 mg/100 g);
- 72-25 (Privlekatelnaya × Bylinnaya) is a combination of functional alleles in the *FaOMT* and *FaFAD1* strawberry aroma genes.

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