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Evaluation of Advanced Selections Obtained in the Berries Breeding Program

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Abstract

The berry breeding program aims to improve the quality, yield, and disease resistance of berry crops through systematic selection and hybridization. This evaluation focuses on advanced selections developed in recent breeding cycles, assessing their performance in key traits such as fruit size, flavor, texture, and overall resilience to environmental stressors. By analyzing these traits, the program seeks to identify the most promising candidates for commercialization, ultimately contributing to the advancement of berry cultivation and providing growers with superior varieties that meet consumer demands. The analysis of the hybrid progeny from 'Azur' × 'Duke' revealed interesting trends in biometric characteristics. The parental variety 'Elsanta' demonstrated the highest yield at 789.33 g, indicating its potential for maximizing harvests. In contrast, hybrid 17-4-150 exhibited a significantly larger average fruit weight of 22.97 g, highlighting its promise for quality production.

The objective is to evaluate fruit quality and weight traits of various advanced selections of strawberries and blueberries, with the aim of identifying new genotypes for subsequent breeding stages. This assessment will focus on traits such as size, weight, flavor, texture, and biochemical compounds, ensuring that selected genotypes not only meet market preferences but also contribute to improved yield and disease resistance in future breeding programs. The evaluation of these strawberry hybrids indicates significant potential for improving both physical and chemical characteristics. Continuous selection and breeding efforts can yield cultivars that are not only high-yielding but also of superior quality and consumer appeal. The variability observed in traits such as sweetness, firmness, and color offers a strategic foundation for future breeding programs aimed at meeting market demands.

Keywords: Hybrids, Fruit Quality, Genetic Variatios

Introduction

The cultivated strawberry (*Fragaria* × *ananassa*) is an octoploid species that emerged from the hybridization of two wild octoploid relatives, *Fragaria chiloensis* and *Fragaria virginiana*, in the mid-1700s at a botanical garden in Versailles, France (Faedi *et al*., 2016) [6].

The strawberry (*Fragaria x ananassa* Duch.) is a fruit species highly valued by both growers and consumers, due to its early ripening, high yields, and exceptional nutritional qualities, including a rich content of minerals and vitamins. Strawberry fruits rank among the most consumed in the world, celebrated particularly for their delightful taste and aroma. Their popularity extends beyond mere consumption, as they are also utilized in various culinary applications, ranging from desserts to beverages. The combination of flavor, health benefits, and versatility contributes to the strawberry's enduring appeal in global markets (Azodanlou *et al*., 2003, Sehrish *et al*., 2021, Porter *et al*., 2023) [1, 14, 13]. Strawberry fruit quality is determined by several key characteristics, including color, shape, size, sweetness, acidity, and aroma. These qualities are influenced by a combination of genetic factors, climatic conditions, and cultivation techniques (Magnani *et al*., 2008) [9]. Genetic variations among different strawberry cultivars can lead to differences in flavor and appearance. Additionally, environmental factors such as temperature, sunlight, and soil composition play crucial roles in fruit development. Lastly, cultural practices, including irrigation, fertilization, and pest management, significantly impact the overall quality of strawberry fruits (Diamanti *et al*., 2012, Temocico *et al*., 2017) [5, 17]. Together, these elements contribute to the final characteristics that consumers appreciate.

In Romania, the strawberry breeding program has primarily been conducted at the Research Institute for Fruit Growing in Pitești. The goal has been to develop new cultivars that produce fruit only once a year in the spring. This program follows a classic selection scheme that includes several key steps: Selecting parental varieties based on important traits aligned with breeding objectives, making directed crosses, evaluating hybrids and new selections, registering new cultivars, and producing biological material for nurseries. This systematic approach aims to enhance fruit quality and yield while meeting the specific needs of growers and consumers. The cultivars chosen for new strawberry plantations must be well adapted to the specific climate and soil conditions of each cultivation area. Additionally, they should exhibit enhanced resistance to diseases and pests. This adaptability is crucial for ensuring successful cultivation and high-quality fruit production, as it minimizes the need for chemical treatments and contributes to sustainable farming practices (Barneche *et al*., 2012) [2]. Selecting resilient cultivars helps improve yield and fruit quality while also supporting the long-term viability of strawberry production in diverse environments (Sturzeanu *et al*., 2021) [15].

In strawberry breeding, yield evaluation is essential, as fruit quality is fundamental for consumer acceptance. Therefore, it is necessary to employ methodologies that enable selection based on a comprehensive set of variables, encompassing various economically important characteristics. This includes not only yield but also traits such as flavor, size, color, texture, and disease resistance (Cruz *et al*., 2014) [4]. By integrating these factors into the breeding process, growers can develop strawberry varieties that meet market demands and enhance overall consumer satisfaction.

The blueberry (*Vaccinium corymbosum*) is a member of the *Ericaceae* family and belongs to the *Vaccinium* genus, specifically the section *Cyanococcus* (Brevis *et al*., 2008) [3]. It is a berry species of significant economic and nutritional value for both growers and consumers. According to Hancock *et al*. (2008) [7], blueberry breeding programs in the United States primarily focus on enhancing two types of highbush blueberry cultivars: Northern highbush blueberry (NHB) and southern highbush blueberry (SHB), as well as rabbiteye (RY) cultivars (*Vaccinium virgatum*) and their interspecific hybrids. These efforts aim to improve traits such as yield, fruit quality, disease resistance, and adaptability to different growing conditions.

In Romania, the blueberry breeding program at the Research Institute for Growing, Pitești-Mărăcineni, was established in 1982 with the primary aim of enhancing yield, fruit quality, and adaptation to Romania's specific climatic conditions. The initial phase involved selecting new material through the use of F1 seedlings and open-pollinated crosses sourced from the USA, focusing on the unique attributes necessary for successful cultivation in Romania. Following 1990, the program achieved notable success with the release of several northern highbush cultivars. These included 'Safir', 'Azur', 'Lax', 'Pastel', 'Prod', 'Augusta', 'Simultan', 'Delicia', and 'Vital' (Mladin *et al*., 2007). Each of these cultivars was developed with specific traits in mind, such as improved fruit size, taste, and disease resistance, aimed at meeting both grower and consumer preferences.The development of blueberry cultivars is a direct outcome of systematic breeding activities, which prioritize not only high productivity but also the quality of the fruit produced. This quality is defined by various parameters, including size, flavor, and nutritional content, which are essential for market acceptance and consumer satisfaction. Public health analysis reveals a concerning rise in the number of individuals affected by or at risk for cardiovascular diseases, cancer (Hera *et al*., 2023) [8], disorders related to lipid metabolism (such as elevated cholesterol and blood sugar levels, as well as weight gain), allergic conditions, and various neurological disorders (Mazilu *et al*., 2022) [11].

Economic traits of interest in blueberry cultivation are highly influenced by the specific area of cultivation and the unique challenges posed by local environmental conditions. Factors such as soil type, climate, and pest pressures play a significant role in determining which characteristics are prioritized during breeding. Selecting appropriate parent cultivars for breeding is one of the most critical decisions faced by berry breeders. The choice of genitors directly impacts the potential success of the new blueberry cultivars developed. Breeders must consider traits like disease resistance, yield potential, and adaptability to ensure that the new varieties will thrive in their intended growing environments. Overall, the blueberry breeding program aims to produce high-quality cultivars that not only fulfill the economic demands of growers but also provide consumers with berries that are flavorful, nutritious, and visually appealing. This comprehensive approach ensures the long-term sustainability and success of blueberry cultivation in Romania.

The objective is to evaluate fruit quality and weight traits of various advanced selections of strawberries and blueberries.

Materials and Methods

The research was conducted from 2021 to 2023 at the Research Institute for Fruit Growing, Pitesti, utilizing an open experimental field. The study focused on several genotypes, including two strawberry cultivars, 'Elsanta' and 'Onebor', which served as control cultivars. Additionally, the research included selections derived from their cross combination: 'Elsanta' × 'Onebor', specifically the following genotypes bred in 2017: '17-4-150', '17-4-349', '17-4-381', '17-4-421', '17-4-450', '17-4-459', '17-4-467', and '17-4-486'. For blueberry, the study involved two cultivars, 'Azur' and 'Duke', also used as control cultivars. The research incorporated selections from their cross combination, 'Azur' × 'Duke', which included the following genotypes bred in 2016: '16-7-2', '16-7-3', '16-7-4', '16-7-5', '16-7-6', '16-7-10', '16-7-13', and '16-7-17'. At harvest, *the yield* per plant was recorded by weighing the total fruit and summing the weights to calculate cumulative production. *The average fruit weight* was determined by weighing a sample of 50 berries using an HL-400 digital balance. This method ensures accurate measurement of both individual fruit weight and overall yield per plant, providing valuable data for evaluating the performance of the selected genotypes. *The shape index* was calculated as the ratio of length to diameter, following methods described by Tudor *et al*. (2014) [19] and Jamieson (2017). Specifically, short-conic strawberries typically have a length-to-width ratio of approximately 0.9 to 1.1, while long-conic fruits range from 1.2 to 1.4. *Fruit firmness* was assessed using a Bareiss HPE

II Fff penetrometer, a non-destructive testing method.

Chemicals and Reagents: 2,2-Diphenyl-1-picrylhydrazyl (DPPH), 2,6-dichloroindophenol (DCPIP), sodium hydroxide, sodium carbonate, sodium bicarbonate, sodium nitrite, disodium phosphate, aluminum chloride, methanol, acetone, *n*-hexane, ethanol, citrate/acetate buffer, gallic acid, catechin, vitamin C, cyanidin-3-*O*-glucoside, metaphosphoric acid, acetic acid, hydrochloric acid, citric acid, and Folin−Ciocalteu reagent were obtained from Merck, Darmstadt, Germany.

Soluble solids content was measured using a Kruss DR201-95 refractometer, with results expressed as °Brix at 20 °C. *pH* values were measured in freshly extracted blueberry and strawberry juice at 20 °C using a Consort C-561 multimeter. *The total polyphenol content* (TPC) was determined following the methodology proposed by Matić *et al*. By reacting polyphenols with phosphotungstic acid in an alkaline medium, a blue-colored compound is formed, which has a maximum absorption at 760 nm. The results are expressed as mg of gallic acid equivalent (GAE) per 100 g of fresh weight (FW). *The total flavonoid content* (TFC) was determined following the methodology suggested by Tudor-Radu *et al*. Flavonoids react with aluminum chloride to form a yellow-orange compound, which exhibits maximum absorption at 510 nm. The results are expressed as mg of catechin equivalent (CE) per 100 g of fresh weight (FW). The determination of *vitamin C content* was performed using a colorimetric method based on the methodology suggested by Omaye *et al*. Vitamin C reduces 2,6-dichloroindophenol (DCPIP) at pH 3–4.5, resulting in a colorless solution and a corresponding decrease in absorption at 520 nm. The results are expressed as mg of vitamin C per 100 g of fresh weight (FW). *Total anthocyanin content* (TAC) was determined using the pH differential method as suggested by Di Stefano and Cravero. This method assesses total monomeric anthocyanin content by leveraging the reversible structural transformation of the anthocyanin chromophore at different pH levels. Absorbance was measured at 520 nm after 30 minutes of blueberry extract preparation in two buffers: pH 0.6 (2% hydrochloric acid) and pH 3.5 (a phosphate buffer containing 0.1 M citric acid and 0.2 M disodium phosphate). Results are expressed as cyanidin-3-O-glucoside equivalent (C3-GE) per 100 g of fresh weight (FW). *The lycopene and β-carotene content* was determined using the methodology proposed by Tudor-Radu *et al*. This involved extracting carotenoids using a mixture of hexane, ethanol, and acetone (Tudor *et al*.,). The results were expressed in mg of lycopene or β-carotene per 100 g of fresh weight (FW), utilizing the molar extinction coefficients for both compounds at wavelengths of 470 nm for β-carotene and 503 nm for lycopene (Rubio *et al*., 2011) [16]. The determination of *antioxidant activity* was conducted by evaluating the radical scavenging capacity against DPPH free radicals, following a modified methodology by Moon and Shibamoto. A DPPH solution in methanol (0.116 mM) was prepared, and 2.97 mL of this solution was mixed with 0.03 mL of the methanolic extract of blueberry. The mixture was gently homogenized and allowed to stand at room temperature for 30 minutes. The absorbance of the resulting mixture was then measured spectrophotometrically at a wavelength of 517 nm. *The total sugar content* of blueberries was assessed using a UV-Visible spectrophotometric method, recognized for its simplicity and reliability in measuring sugars in plant materials. The methodology, based on Dubois *et al*. (1956) with some modifications, capitalizes on the chemical reaction between sugars and phenol in the presence of concentrated sulfuric acid. *The skin color* of the strawberries was evaluated on both sides of the fruit using a colorimeter (Konica Minolta CR 400) based on the Huntel system (L*, a*, b*). In this system, L* indicates brightness, while a* and b* represent chromaticity coordinates, measuring the transition from green to red and from blue to yellow, respectively. Generally, lower values for L*, a*, and b* indicate darker fruit coloration (Zorrilla-Fontanesi *et al*., 2011) [20]. All analyses were conducted in triplicate, and results were expressed as mean ± standard deviation (SD). Statistical significance was assessed using one-way analysis of variance (ANOVA), allowing for the comparison of means across different genotypes. A significance level of $p \leq 0.05$ was used to determine statistical differences among treatments. This rigorous statistical approach ensures the reliability of the results and aids in the interpretation of the data related to fruit quality and characteristics.

Results and Discussion

Evaluation of fruits from the hybrid combination 'Elsanta' × 'Onebor'

The genotype 'Elsanta' showed the highest yield (789.33 g), making it a promising choice for growers aiming to maximize harvests. In contrast, the genotype '17-4-150' demonstrated a significantly higher fruit weight (22.97 g), suggesting its potential for quality fruit production.

The shape index varied among genotypes, with '17-4-381' exhibiting the highest index (1.36), indicating a more elongated form. This could positively influence consumer perception regarding the aesthetics of the fruit.

All genotypes displayed high firmness values, which is a positive indicator for transportability and post-harvest quality preservation. The genotype '17-4-467' had the highest firmness (45.28 N), suggesting good resistance to damage.

The total soluble solids (TSS) values indicate the sugar content and overall sweetness of the strawberries. The genotype '17-4-381' recorded the highest TSS at 9.5 °Brix, suggesting it has a pronounced sweetness that could enhance its appeal to consumers. In contrast, 'Elsanta' had a lower TSS of 6.91 °Brix, which might negatively impact consumer preferences as sweetness is a key factor in fruit selection. Higher TSS values often correlate with better flavor profiles, making '17-4-381' a potentially more desirable choice in the market.

pH values were similar across genotypes, indicating relatively constant acidity, which is important for taste balance. This aspect can also influence the stability of products derived from the fruits.

The selections from hybrid combinations show interesting variability, suggesting opportunities for improving desired characteristics through selection programs.

The results indicate significant potential in the studied selections for improving the physical and chemical characteristics of strawberry fruits. A systematic approach in continuing the selection of these genotypes could lead to the development of more productive and higher-quality cultivars.

Table 1: Physical and chemical characteristics of fruits in some strawberry selections from the hybrid combination 2017-4 (Elsanta × Onebor)

Genotype	Yield (g)	Berry weight (g)	Shape index	Firmness (N)	°Brix	pH
Elsanta	789,33±68,85^{a}	20,02±2,21^{bc}	0,97±0,03^{sb}	35,19±1,54^{a}	6,91±0,12^{c}	3,85±0,27^{a}
Onebor	555,67±139,59^{b}	15,79±2,10^{c}	0,99±0,10^{sb}	36,13±4,23^{a}	7,83±0,35^{abc}	3,81±0,30^{a}
17-4-150	162,48±22,46^{c}	22,97±5,19^{bc}	0,8±0,49^{b}	41,27±4,40^{a}	9,03±0,87^{ab}	3,83±0,09^{a}
17-4-349	230,91±90,54^{c}	36,65±8,25^{a}	0,82±0,49^{b}	41,44±4,15^{a}	8,4±0,36^{abc}	3,73±0,18^{a}
17-4-381	189,01±97,65^{c}	18,64±3,43^{bc}	1,36±0,05^{a}	33,42±1,81^{a}	9,5±1,73^{a}	3,72±0,08^{a}
17-4-421	189,47±84,59^{c}	36,42±8,81^{a}	1,09±0,17^{sb}	43,75±5,70^{a}	8,1±0,80^{abc}	4,07±0,17^{a}
17-4-450	261,22±50,41^{c}	37,65±4,80^{a}	0,7±0,20^{b}	44,75±6,47^{a}	8,27±0,25^{abc}	3,96±0,27^{a}
17-4-459	136,73±34,66^{c}	34,29±3,50^{a}	0,8±0,21^{b}	39,72±11,35^{a}	7,8±0,70^{abc}	3,68±0,07^{a}
17-4-467	124,91±82,45^{c}	29,43±10,39^{ab}	0,77±0,27^{b}	45,28±2,91^{a}	7,8±1,57^{abc}	3,96±0,29^{a}
17-4-486	176,88±48,01^{c}	20,89±1,45^{bc}	0,71±0,18^{b}	39,72±11,350^{a}	7,7±0,61^{bc}	3,92±0,26^{a}

*Duncan's test: Means with the same letter do not differ significantly (P≤0.05).

The lightness values (L*) indicate the brightness of the fruit. The genotype 'Onebor' had the highest L* value (37.32), suggesting it appears brighter than the others. This brightness could enhance visual appeal to consumers.

The a* values reflect the red color intensity. '17-4-150' exhibited the highest a* value (29.75), indicating a more intense red hue, which is typically desirable in strawberries. In contrast, 'Onebor' had a lower a* value (25.92), suggesting a slightly less vibrant color.

The b* values measure the yellow-blue component. All genotypes displayed similar b* values, indicating that the yellow component is consistent across the selections. The values ranged from 13.05 to 15.14, showing minimal variation.

The differences in a* values highlight the variability among the genotypes regarding red color intensity. This variability presents an opportunity for breeders to select for color preferences that align with market demands.

The statistical analysis indicates significant differences among some genotypes. For instance, 'Onebor' is notably different in its L* value, while '17-4-150' stands out in a* value. These differences could guide future breeding decisions focused on enhancing specific color traits.

The colorimetric traits of the strawberry genotypes provide valuable insights into their visual characteristics, which play a crucial role in consumer acceptance. The variability observed in the a* values, particularly, suggests potential for developing more attractive cultivars through targeted breeding strategies. Further research may focus on correlating these color traits with consumer preferences to inform breeding objectives.

Table 2: Colorimetric traits of strawberry genotypes

Genotype	L*	a*	b*
Elsanta	32,07±0,35	28,77±3,17^{a}	13,31±0,42^{a}
Onebor	37,32±1,62^{a}	25,92±0,60^{a}	15,1±0,56^{a}
17-4-150	30,98±0,38^{b}	29,75±0,96^{a}	13,26±0,49^{a}
17-4-349	32,2±1,90^{b}	29,61±1,34^{a}	15,14±0,67^{a}
17-4-381	31,42±4,42^{b}	26,41±1,67^{a}	13,05±2,22^{a}
17-4-421	32,54±2,70^{b}	28,05±2,46^{a}	14,01±1,30^{a}
17-4-450	31,56±1,89^{b}	29,44±1,09^{a}	14,65±1,39^{a}
17-4-459	32,69±2,62^{b}	27,95±2,43^{a}	13,98±1,33^{a}
17-4-467	32,21±2,99^{b}	28,02±2,55^{a}	14,48±1,18^{a}
17-4-486	33,31±2,53^{ab}	28,37±2,63^{a}	15,03±1,10^{a}

*Duncan's test: Means with the same letter do not differ significantly (P≤0.05).

Evaluation of Fruits from the Hybrid Combination 'Azur × Duke'

In the hybrid progeny 'Azur × Duke', the fruit weight of the parental varieties was superior to that of the 8 evaluated hybrids. The 'Azur' cv. recorded an average weight of 2.32 g, while 'Duke' cv. had an average of 2.14 g. The weight of the hybrids varied from 1.4 g (hybrid 16-7-6) to 2 g (hybrid 16-7-17).

The shape index reached its maximum at hybrid 16-7-2, with a value of 0.81, surpassing both genitors ('Azur' cv. at 0.76 and 'Duke' cv. at 0.74). Firmness was highest in hybrid 16-7-2, reaching a value of 25.76 N, exceeding the parental values (17.48 N for 'Azur' cv. and 20.02 N for 'Duke' cv.).

Table 3: The genotype influence on biometric indicators (fruits weight, size index and firmness) for 'Azur × Duke' progenies

Genotype	Berry weight (g)	Shape index	Firmness (N)
Azur	2,32±0,23^{a}	0,76±0,04^{ab}	17,48±5,24^{bc}
Duke	2,14±0,31^{ab}	0,74±0,05^{ab}	20,02±3,98^{abc}
16-7-2	1,86±0,44^{abcd}	0,81±0,17^{a}	25,76,88^{a}
16-7-3	1,84±0,35^{abcd}	0,72±0,03^{ab}	15,12±3,71^{c}
16-7-4	1,47±0,42^{cd}	0,76±0,07^{ab}	20,72±3,28^{abc}
16-7-5	1,7±0,56^{bcd}	0,790,05^{ab}	17,55±6,07^{bc}
16-7-6	1,4±0,59^{d}	0,71±0,05^{b}	19,12±6,36^{abc}
16-7-10	1,82±0,38^{abcd}	0,73±0,08	19,35±4,23^{abc}
16-7-13	1,92±0,12^{abc}	0,74±0,04^{ab}	23,3±5,63^{ab}
16-7-17	2±0,15^{ab}	0,71±0,06^{b}	22,87±8,32^{ab}

*Duncan's test: Means with the same letter do not differ significantly (P≤0.05).

Biochemical Characteristics

The soluble solids content reached a maximum of 17.33 °Brix in hybrid 16-7-5, while the minimum was recorded at 11.92 °Brix in hybrid 16-7-6. Both parents surpassed the minimum values of the hybrids, with 'Azur' cv. at 14.23 °Brix and 'Duke'cv. at 13.02 °Brix.

Regarding sugar content, no significant differences were observed among the genotypes. The parents, 'Azur' (8.32%) and 'Duke' (5.79%), exceeded all descendants, whose values ranged from 3.69% for hybrid 16-7-5 to 5.47% for hybrid 16-7-3. Similarly, there were no significant differences in acidity among the genotypes, with the maximum determined in 'Azur' (0.89%) and the minimum in hybrid 16-7-10 (0.37%).

Significant differences were highlighted in the pH of the cell sap, with 'Duke' having the highest value of 3.94, while the hybrids ranged from 3.1 to 3.82.

In terms of vitamin C content, hybrid 16-7-13 achieved a maximum of 12.39 mg/100 g, equal to that of the parent 'Azur'. The minimum was 3.50 mg/100 g, recorded in hybrid 16-7-17 (Table 5).

Carotenoid compounds reached their maximum levels in the parents. The lycopene level was 0.24 mg/100 g in 'Azur' and 0.18 mg/100 g in 'Duke'. The maximum among hybrids was 0.14 mg/100 g for hybrid 16-7-3, while the minimum was 0.03 mg/100 g for hybrids 16-7-2 and 16-7-4. The level of β-carotene also peaked in the parents (0.39 mg/100 g in 'Duke' and 0.6 mg/100 g in 'Azur'), with hybrids ranging from 0.03 mg/100 g in hybrid 16-7-4 to 0.35 mg/100 g in hybrid 16-7-5.

Antioxidant activity varied from 0.17 mmol/g Trolox in hybrid 16-7-3 to a maximum of 0.21 mmol/g Trolox achieved by both parents and hybrid 16-7-17.

The polyphenolic compounds in the hybrid descendants exceeded the maximum levels of the genitors: 'Azur' cv. (359.27 mg EAG/100 g) and 'Duke' cv. (396.51 mg EAG/100 g). The hybrids with the highest polyphenol content were 16-7-2 (642.18 mg EAG/100 g), 16-7-3 (659.87 mg EAG/100 g), 16-7-4 (638.82 mg EAG/100 g), and 16-7-5 (635.21 mg EAG/100 g). The lowest content was recorded in hybrid 16-7-3 (334.44 mg EAG/100 g).

Table 4: The genotype influence on biochemical indicators (total soluble solids, total sugar content, titratable acidity and pH) for 'Azur × Duke' progenies

Genotype	Total soluble solids (°Brix)	Totasl sugar content (%)	Acidity (%)	pH
Azur	14,23±5,4^{ab}	8,32±0,34^{a}	0,89±0,69^{a}	3,47±0,22^{bcd}
Duke	13,02±2,66^{b}	5,79±3,19^{a}	0,4±10,19^{a}	3,94±0,36^{a}
16-7-2	11,94±1,53^{b}	4,5±2,7^{a}	0,51±0,5^{a}	3,68±0,1^{abc}
16-7-3	12,52±2,07^{b}	5,47±4,3^{a}	0,47±0,46^{a}	3,39±0,36^{cd}
16-7-4	13,38±2,03^{b}	5,01±3,51^{a}	0,5±0,54^{a}	3,44±0,36^{bcd}
16-7-5	17,33±4,9^{a}	3,69±3,05^{a}	0,53±0,5^{a}	3,53±0,45^{abc}
16-7-6	11,92±2,53^{b}	4,6±3,89^{a}	0,54±0,49^{a}	3,4±0,28^{cd}
16-7-10	13,83±0,93^{b}	5,41±4,19^{a}	0,37±0,36^{a}	3,71±0,4^{abc}
16-7-13	12,42±1,13^{b}	5,16±4,65^{a}	0,59±0,63^{a}	3,1±0,26^{d}
16-7-17	12,73±1,04^{b}	4,05±2,97^{a}	0,41±0,44^{a}	3,82±0,26^{ab}

*Duncan's test: Means with the same letter do not differ significantly (P≤0.05).

Table 5: The genotype influence on biochemical indicators (vitamin C, lycopene, β-carotene and antioxidant activity) for 'Azur × Duke' progenies

Genotype	Vitamin C (mg/100 g)	Lycopene (mg/100 g)	β-carotene (mg/100 g)	Antioxidant activity (mmol/g Trolox)
Azur	12,39±0,45^{a}	0,24±0,21^{a}	0,6±0,43^{a}	0,21±0,01^{abc}
Duke	3,55±0,01^{d}	0,18±0,13^{ab}	0,39±0,2^{ab}	0,21±0,01^{a}
16-7-2	8,84±0,24^{b}	0,03±0,03^{b}	0,07±0,05^{c}	0,2±0,01^{c}
16-7-3	6,76±0,01^{c}	0,14±0,08^{ab}	0,1±0,08^{c}	0,17±0,01^{f}
16-7-4	4,48±0,01^{d}	0,03±0,03^{b}	0,03±0,01^{c}	0,2±0,01^{c}
16-7-5	9,96±0,32^{ab}	0,13±0,12^{ab}	0,25±0,25^{bc}	0,2±0,01^{bc}
16-7-6	7,41±0,01^{b}	0,11±0,11^{ab}	0,2±0,21^{bc}	0,19±0,01^{d}
16-7-10	9,61±0,01^{ab}	0,11±0,11^{ab}	0,1±0,08^{c}	0,2±0,01^{bc}
16-7-13	12,39±0,45^{a}	0,08±0,06^{b}	0,13±0,12^{c}	0,18±0,01^{e}
16-7-17	3,50±0,01^{d}	0,11±0,09^{ab}	0,16±0,17^{bc}	0,21±0,01^{ab}

*Duncan's test: Means with the same letter do not differ significantly (P≤0.05).

An opposite situation was observed in the case of tannins, as the parent cultivars exhibited higher levels compared to their hybrid descendants. Specifically, 'Azur' cv. recorded a tannin content of 200.96 mg GAE/100 g, while 'Duke' cv. had 125.89 mg GAE/100 g. The tannin content in the hybrids ranged from 67.48 mg GAE/100 g in hybrid 16-7-17 to a maximum of 125.79 mg GAE/100 g in hybrid 16-7-4.

Table 6: The genotype influence on biochemical indicators (total content polyphenols, tanins, flavonoids and anthocyanins) for 'Azur × Duke' progenies

Genotip	Total content polyphenols (mg EAG/100 g)	Total content tanins (mg EAG/100 g)	Total content flavonoids (mg EC/100 g)	Total content anthocyanins (mg C3G/100 g)
Azur	359,27±96,33^{b}	200,96±109,64^{b}	130,49±14,28^{ab}	296,23±24,89^{a}
Duke	396,51±69,40^{b}	125,89±21^{ab}	399,1±160,67^{ab}	127,59±33,71^{ef}
16-7-2	642,18±181,81^{a}	125,28±58,56^{ab}	504,32±89,88^{a}	139,41±0,21^{de}
16-7-3	659,87±35,16^{a}	124,9827,32^{ab}	325±319,28^{bc}	130,4±3,33^{ef}
16-7-4	638,82±218,2^{a}	125,79±59,23^{ab}	396,21±86,25^{ab}	117,76±0,31^{f}
16-7-5	635,21±277,85^{a}	137,72±58,78^{a}	194,9±50,66^{b}	124,290,05^{ef}
16-7-6	509,65±305,05^{ab}	101,77±57,63^{abc}	251,49±47,04^{bc}	190,14±0,13^{b}
16-7-10	543,77±6,62^{ab}	101±24,97^{abc}	416,78±81,15^{ab}	138,81±0,01^{de}
16-7-13	334,44±75,72^{b}	81,11±11,98^{bc}	278,2998,12^{bc}	150,4±0,1^{cd}
16-7-17	377,09±171,47^{b}	67,48±7,2^{c}	243,33±19,31^{bc}	162,42±0,2^{c}

*Duncan's test: Means with the same letter do not differ significantly (P≤0.05).

In the case of flavonoids, all eight hybrids exhibited higher content compared to the genitors, which recorded 130.49 mg CE/100 g for 'Azur' cv. and 399.1 mg CE/100 g for 'Duke' cv. For the hybrids, the values ranged from 194.9 mg CE/100 g in hybrid 16-7-5 to 504.32 mg CE/100 g in hybrid 16-7-2. The anthocyanin content of the hybrid descendants was only surpassed by the genitors. 'Azur' cv., which recorded a value of 296.23 mg C3G/100 g. The minimum anthocyanin content among the hybrids was 117.76 mg C3G/100 g in hybrid 16-7-4, while the maximum was 190.14 mg C3G/100 g in hybrid 16-7-6.

Conclusions

Among the studied genotypes, 'Elsanta' cv. consistently demonstrated the highest yield, averaging 789.33 g per plant. This trait makes 'Elsanta' particularly attractive for commercial growers looking to maximize their harvests, suggesting it could serve as a reliable variety in high-production scenarios.

The hybrid '17-4-150' distinguished itself by achieving the highest average fruit weight of 22.97 g. This characteristic indicates its strong potential for producing premium-quality fruit, which is a crucial factor for marketability. Higher fruit weight often correlates with consumer preferences for larger berries.

The shape index revealed significant variability among the genotypes, with '17-4-381' exhibiting the highest index value of 1.36. This suggests a more elongated form that could enhance the fruit's visual appeal, potentially influencing consumer purchasing decisions based on aesthetics. A well-shaped fruit is often associated with quality and can command a better price in the market.

All genotypes exhibited high firmness values, which is a critical attribute for transportability and the preservation of post-harvest quality. Notably, '17-4-467' achieved the highest firmness value of 45.28 N, indicating strong resistance to damage during handling and transportation. This trait is essential for reducing losses in the supply chain and ensuring that consumers receive fresh, intact fruit.

The total soluble solids (TSS) measurements indicated that '17-4-381' had the highest TSS at 9.5 °Brix, signifying a pronounced sweetness that enhances its appeal to consumers. In contrast, 'Elsanta' recorded a lower TSS of 6.91 °Brix, which could negatively impact consumer preference, as sweetness is a critical factor in fruit selection. Higher TSS values are generally associated with improved flavor profiles, reinforcing '17-4-381' as a potentially more desirable choice in the market.

Color have a significant role in consumer acceptance, and the study revealed notable differences in colorimetric traits among the genotypes. 'Onebor' had the highest lightness value ($L^* = 37.32$), suggesting a brighter appearance that could attract consumers. Conversely, '17-4-150' exhibited the highest red color intensity ($a^* = 29.75$), which is often perceived as a sign of ripeness and flavor. Such color variability provides breeders with opportunities to select for specific color traits that align with market preferences.

The data suggests that while 'Azur' and 'Duke' maintain advantageous traits in berry weight and firmness, the hybrid '16-7-2' stands out for its superior firmness and shape index. This information can inform breeding strategies focused on enhancing desirable characteristics in future blueberry cultivars.

The hybrid progeny from the 'Azur × Duke' combination showcased significant potential in terms of polyphenol and flavonoid content.Hybrids such as '16-7-2' and '16-7-3' exceeded the parental varieties in total polyphenols, indicating that these hybrids may offer enhanced health benefits. This increase in beneficial compounds aligns with consumer trends favoring nutritious and functional foods.

The findings underscore the necessity for ongoing research and systematic selection programs targeting these genotypes. Such efforts could lead to the development of new cultivars that are not only more productive but also exhibit improved sensory qualities and nutritional profiles. Addressing consumer preferences through breeding can enhance market competitiveness and ensure the sustainability of strawberry production.

In conclusion, the results of this study indicate a promising outlook for the selected strawberry genotypes. By leveraging the identified traits, breeders and growers can make informed decisions to enhance both the quality and quantity of strawberry production, ultimately meeting market demands and consumer expectations.

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