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Evaluation of some Selections Obtained in the Strawberry Breeding Program

Oana HERA, Amelia PETRESCU, Monica STURZEANU*

Research Institute for Fruit Growing, Pitesti, Marului Street, No. 402, Maracineni, Arges, 117450, Romania
** Corresponding author: M. Sturzeanu, E-mail: sturzeanu1980monica@yahoo.it*

RESEARCH ARTICLE

Abstract

The strawberry (*Fragaria x ananassa* Duch.) is a fruit species of interest to growers and consumers due to the early ripening of the fruits, high yields and special nutritional qualities (high content of minerals and vitamins). The paper evaluates the performance of 14 selections from Romanian strawberry breeding and a Romanian cultivar ('Premial') of strawberry under field conditions during 2021-2023. The characteristics evaluated are: phenological data, yield (g/plant), average fruit weight (g), firmness (N), shape, color, soluble solid content and pH. Based on the data obtained, from the 14 selections, it was proposed to introduce into next stages for evaluation those that recorded over 500 g/plant and over 20 g/fruit, namely: '16-3-188', '16-2-12', '16-3-170', '16-3-123'.

Keywords: *Fragaria x ananassa* Duch., selection, productivity, quality characteristics

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INTRODUCTION

The strawberry (*Fragaria x ananassa* Duch.) is a fruit species of interest to growers and consumers due to the early ripening of the fruits, high yields and special nutritional qualities (high content of minerals and vitamins). Strawberry fruits are some of the most consumed fruits in the world, being appreciated especially for their taste and aroma (Azodanlou et al., 2003, Sehrish et al., 2021, Porter et al., 2023). Strawberry fruit quality is defined by several characteristics (colour, shape, size, sweetness, acidity, aroma) and it is influenced by genetic, climatic factors and culture technology (Maltoni et al., 2009, Diamanti et al., 2012, Temocico et al., 2017). For centuries, quality fruits have been selected, and the varietal assortment is constantly enriched with new varieties obtained through the breeding program. There are numerous breeding programs around the world that produce specific cultivars for the annual production system that produce profitable quantities of high-quality fruit. In Romania, the strawberry breeding program was carried out mainly at Research Institute for Fruit Growing Pitesti, in order to released new cultivars, which fruit only once per year, in the spring, following the classic selection scheme: parental selection based on the important traits according the breeding goals, directed crosses, assessment of hybrids and new selections, registered a new cultivar and the production of biological material for nurseries (Sturzeanu et al., 2018). The cultivars used in the new strawberry plantations must be well adapted to the climate and soil conditions specific to each cultivation area and show increased resistance to diseases and pests (Barneche and Bonow, 2012, Sturzeanu et al., 2021). In strawberry breeding, yield evaluation is essential, and for fruit, quality is fundamental for consumer acceptance of the product. Therefore, it is necessary to use methodologies that allow selection based on a set of variables that include different characteristics of economic interest (Cruz et al., 2014). Utilizing simultaneous cues for fruit quality (size, shape, taste, aroma, color) alongside production attributes is essential (Vilarinho et al., 2003; Piston et al., 2021).

Strawberry yield and average fruit weight are two of the representative quality parameters for the commercial strawberry market, since the cultivars with good production and larger-sized fruits positively influence buyers' decisions. In Romania, the most widely grown Romanian strawberry cultivar is 'Premial'. More recently, the cultivars 'Mira', 'Alba' 'Clery' and 'Albion' have been introduced into production. Commercially available strawberry cultivars are changing rapidly and information on important compounds for taste and associated health benefits should be updated for fruit from recently launched breeding programmes (Sturzeanu et al., 2015; Temocico et al., 2019; Tomić et al., 2019). To create genotypes/cultivars with a high size and quality of the berries, visually attractive for traders and consumers, and productive in the edapho-climatic conditions from Romania, one has to select the appropriate parental forms. If we are aware of the correlations between the fruit quality, larger fruit and produces individual-plant yields ones, this will allow us to select the parent pairs within the enhancement process aiming to obtain new varieties with the relevant attributes of fruit quality and production, which will be more beneficial for consumers. In cross combination 'Nora' × 'Benicia', ' Nora' maternal genitor has fruits, regular and alongated, are homogeneous, attractive, bright red also when completely ripe. Flesh and skin are very resistant to manipulations and to the transport. Cultivar characterized by excellent trading and gastronomic qualities. The paternal genitor 'Benicia' has larger fruit and produces individual-plant yields, the fruit shape is typically medium to long conic, which can be flattened or slightly obovate. In cross combination 'Mira' × 'Argentera', the maternal genitor is typical of short-day varieties and produces fruit over a four-week period in temperate climates. 'Mira' cv. ripens in the mid-late season, and production is a yield substantially greater than the 'Premial' cv. The fruit color of 'Mira' cv. does not darken excessively when over-ripe or after storage. The paternal genitor 'Argentera' cv. has late ripening, suitable for continental climate. The plant is vigorous and very productive. The fruit is conic shape, perfectly regular, large and uniform. The color is bright orange- red and it remains the same also after the harvest.

The objective of this study was to evaluate relevant fruit quality and production attributes for 14 strawberry selections and a control cultivar ('Premial') in order to select new genotypes for future breeding stages.

MATERIALS AND METHODS

The research was carried out during 2021-2023, at Research Institute for Fruit Growing, Pitesti in open experimental field. The following genotypes were studied: Romanian cultivar 'Premial' used as control and the selections obtained from cross combination: 'Nora' × 'Benicia' ('16-2-10', '16-2-12', '16-2-15', '16-2-55', '16-2-127`, '16-2-216`, '16-2-233`, '16-2-237') and 'Mira' × 'Argentera' ('16-3-48`, '16-3-86', '16-3 -123', '16-3-170', '16-3-188') in 2016 year. A WatchDog 900 ET weather station, located nearly the experimental lot, was used to record the evolution of climatic factors. The Pitesti-Arges area has a continental humid climate, Cfbx category (Păltineanu et al., 2020). In the last 54 years, the multiannual average temperature is 10 °C, and the annual amount of precipitation averages 678.1 mm. Taking into account the fact that strawberry bud-breaking occurred starting from the second half of March and the last harvest was made in the last week of June. The Table 1 presents the meteorological parameters from January to June in the years 2021 - 2023, along with the average values of the 1969–2022 period.

During the study period, 2021–2023, the mean annual temperature, as well as the mean maximum and minimum temperatures were higher than normal areas in January, February and June.

The intensity and quality of light, as well as solar radiation, clearly influence both the differentiation of the flower's generative organs and vegetative growth. During the period 2021 – 2023, the insolation had values close to the normal of the area.

The relative humidity of the air has, also, an influence on fertilization, especially by maintaining the receptivity of the stigma. Thus, the relative humidity of the air had an average value lower in period 2021-2022 than the normal of the area.

Analyzing the amount of precipitation that fell during the study years, the inconstancy of this vital factor was observed. Phenological phases were recorded when 50% of the plants showed signs of early flowering, mass flowering and harvest maturity. The evaluated indicators were recorded at the optimal fruit harvesting time on a sample of 20 fruits. Fruit production (g/plant) was determined by weighing the fruits on each plant at each harvest and cumulating yield. The average fruit weight was determined by weighing each fruit using the HL-400 digital balance.

The length and diameter of the fruit were determined by measuring the fruit using a digital caliper. The shape index of the fruit was calculated as the ratio of these two dimensions (Tudor et al. 2014, Jamieson, 2017). The short-conic strawberries have length/width of about 0.9-1.1 and long-conic fruits 1.2-1.4. For each sample, strawberry fruit firmness was determined with a Bareiss HPE II Fff penetrometer, non-destructive test, soluble solid content with the digital refractometer Hanna Instruments 96801 and pH values were measured in strawberry fresh juice using a pH meter (ISFET pH Meter, IQ 125, Japan).

The skin color was determined in on both sides of the fruit using the colorimeter (Konica Minolta CR 400), based on system Huntel L*, a*, b*. L* corresponds to brightness, a* and b* chromaticity coordinates from green to red and from blue to yellow. Low values of color indicators L*, a*, b* generally indicate darker fruit color (Zorrilla-Fontanesi et al., 2011).

All analyses were performed in triplicate and data were reported as mean ± standard deviation (SD). One-way analysis of variance.

The statistical analysis of the data was performed using SPSS 14.0 software and the Duncan test comparison for determining the significance of differences with an error probability of (P) ≤0.05.

Table 1. Meteorological Parameters during January-June, 2021-2023 and their multiannual values (1969-2022)

Meteorological parameters		**Interval**	**January**	**February**	**March**	**April**	**May**	**June**
Air temperature (°C)	Monthly average	2021	0.5	3.0	4.1	8.6	15.6	19,3
		2022	0.8	3.1	3.6	10.1	16.4	21.1
		2023	4.0	2.6	7.1	9.7	15.1	19.4
		1969-’22	-1.1	0.6	5.0	10.4	15.4	19.0
	Maximum temperature average	2021	5.3	9.1	10.5	15.0	22.3	26.6
		2022	7.1	10.5	10.3	17.4	24.4	29.2
		2023	8.2	9.2	14.0	15.9	21.7	26.0
		1969-’22	4.4	6.2	11.2	17.0	22.2	25.9
	Minimum temperature average	2021	-3.3	-2.0	-1.3	2.6	9.0	13.4
		2022	-12.0	-7.6	-9.3	-3.8	2.9	11.0
		2023	0.8	-3.0	1.1	4.1	9.3	13.8
		1969-’22	-5.1	-3.7	-0.1	4.5	9.3	12.8
Sunshine hours (monthly sum, hours)		2021	91.0	145.6	160.3	176.8	266.2	259.9
		2022	161.1	161.4	185.4	215.3	286.0	286.3
		2023	66.7	137.4	191.1	135.8	160.4	191.7
		1969-’22	103.5	118.9	160.1	194.8	247.9	276.0
Air relative humidity (%)		2021	76.8	65.3	64.6	64.8	65.1	73.3
		2022	76.3	70.7	65.9	74.7	72.9	75.2
		2023	94.5	75.4	70.4	80.1	78.2	83.0
		1969-’22	79.6	76.7	71.0	68.5	71.6	72.7
Rainfall (monthly sum, mm)		2021	73.6	12.4	66.8	38.4	65.4	104.0
		2022	6.4	10.8	19.4	88.0	72.6	25.6
		2023	101.7	7.9	18.8	80.4	77.4	78.7
		1969-’22	33.2	31.4	37.1	55.6	79.9	98.4

RESULTS AND DISCUSSIONS

The time of flowering, ripening and the rate of development of strawberry fruits are characters controlled quantitatively by heredity. The analysis of the growth and fruiting phenophases can be an indication of the intensity of the physiological processes that determine plant growth, showing particular interest, especially in the context in which it influences the fruiting process and the production of fruits per plant. It is certain that constant, large and quality harvests can only be achieved if a perfect balance is achieved between growth and fruiting.

Table 2. Phenological stages of some strawberry selections

Genotype	Beginning of flowering			Full bloom			Fruit ripening		
	2021	2022	2023	2021	2022	2023	2021	2022	2023
Premial	28.04	26.04	01.05	03.05	01.05	06.05	27.05	25.05	01.06
16 - 2 - 10	29.04	27.04	02.05	04.05	02.05	07.05	28.05	26.05	03.06
16 - 2 - 12	28.04	26.04	01.05	03.05	01.05	06.05	27.05	25.05	02.06
16 - 2 - 15	01.05	29.04	03.05	06.05	04.05	08.05	27.05	28.05	04.06
16 - 2 - 55	27.04	25.04	02.05	04.05	30.04	07.05	25.05	24.05	03.06
16 - 2 - 127	01.05	29.04	03.05	06.05	04.05	08.05	30.05	28.05	05.06
16 - 2 - 216	28.04	26.04	01.05	03.05	02.05	06.05	27.05	25.05	02.06
16 - 2 - 218	29.04	27.04	01.05	04.05	03.05	06.05	28.05	26.05	02.06
16 - 2 - 233	28.04	26.04	02.05	03.05	01.05	07.05	27.05	25.05	02.06
16 - 2 - 237	27.04	25.04	01.05	04.05	30.04	06.05	25.05	24.05	03.06
16 - 3 - 48	28.04	26.04	02.05	03.05	01.05	07.05	27.05	25.05	02.06
16 - 3 - 86	30.04	28.04	02.05	05.05	03.05	08.05	29.05	27.05	03.06
16 - 3 - 123	01.05	29.04	03.05	06.05	06.05	08.05	30.05	28.05	04.06
16 - 3 - 170	29.04	27.04	01.05	04.05	04.05	07.05	28.05	26.05	02.06
16 - 3 - 188	02.05	30.04	04.05	06.05	07.05	10.05	30.05	29.05	03.06

For the agricultural year 2021, the period of the beginning of flowering started from April, 27th for the selections '16-2-55', '16-2-237', until May, 2nd for '16-3-188'. Full bloom took place from May, 3rd for the control cultivar and selections '16-2-12', '16-2-216', '16-2-233' and '16-2-48', and the harvest maturity started from May 25th for '16-2-55' to May 30 th for '16-3-123' and '16-3-188' (Table 2).

In 2022, for 15 genotypes the beginning of flowering was started from April, 25th (for the selections: '16-2-55', '16-2-237') until the end of April (for the selection '16-3-188'). The full bloom period was noted from April, 30th for selections: '16-2-55' and '16-2-237', until the end of the first week of May for '16-3-188'. Regarding fruit ripening, the following selections stood out for early fruit: '16-2-55' and '16-2-237', and for lateness '16-2-15', '16-2-127', '16-2-123' and '16-3-188' (Table 2).

In the year 2023, the beginning of flowering started on May, 1st for the control and the selections '16-2-12', '16-2-216', '16-2-218', '16-2-237' and '16 -2-170'. Full bloom started from May 6 for the 'Premial' and three selections to May, 10th for the '16-3-188'. Fruit harvesting maturity started from June, 1st for the control variety until June,5th for the '16-3-127' selection (Table 2).

In our study, production over 500 g /plant was recorded by four of the 15 studied genotypes: '16-3-188' (801.23 g), '16-2-12' (715.53 g), '16-3-170' (544.53 g) and '16-3-123' (541.60 g). The 'Premial' cv. recorded a total production value of 414.67 g, being exceeded by five selections. The lowest yield was 134.67 g in selection '16-2-233'.

Significant differences for average fruit weight were found between some genotypes, in our study four selections with a weight over 30 g are noted, respectively '16-3-188' (40.71 g), '16-3-86' (39.81 g), '16 -2-237' (31.78 g) and '16-2-12' (31.11 g). The 'Premial' cv. and the other five selections had an average weight/fruit below 20 g. The pH of strawberries increased from 3.43 ('16-3-123') to 4.24 ('16-2-237') exceeding 'Premial' cv. that recorded the value of 3.58 (Table 3).

Table 3. Productivity and fruit size of some strawberry selections

Genotype	Yield (g/plant)	Fruit weight (g/fruit)
Premial	414.67 ± 31.39^{cde*}	19.90 ± 1.68^{cde}
16 - 2 - 10	364.80 ± 87.99^{cdef}	28.68 ± 1.48^{abcde}
16 - 2 - 12	715.53 ± 82.34^{ab}	31.11 ± 0.18^{abcd}
16 - 2 - 15	166.03 ± 27.19^{f}	17.79 ± 6.99^{e}
16 - 2 - 55	255.03 ± 102.76^{def}	18.66 ± 0.94^{cde}
16 - 2 - 127	162.17 ± 85.47^{f}	19.58 ± 1.82^{cde}
16 - 2 - 216	318.00 ± 28.90^{cdef}	27.76 ± 1.01^{bcde}
16 - 2 - 218	320.30 ± 108.29^{cdef}	18.48 ± 0.95^{de}
16 - 2 - 233	134.67 ± 60.68^{f}	16.83 ± 1.87^{e}
16 - 2 - 237	175.70 ± 35.10^{f}	31.78 ± 23.35^{abc}
16 - 3 - 48	212.53 ± 92.64^{ef}	21.25 ± 3.13^{cde}
16 - 3 - 86	451.07 ± 139.77^{cd}	39.81 ± 5.49^{ab}
16 - 3 - 123	541.60 ± 62.50^{bc}	20.47 ± 0.62^{cde}
16 - 3 - 170	544.53 ± 154.56^{bc}	24.73 ± 1.03^{cde}
16 - 3 - 188	801.23 ± 351.26^{a}	40.71 ± 6.39^{a}

Note: Different letters between cultivars denote significant differences (Duncan test, $p < 0.05$). Different letters between susceptible and resistant cultivars denote significant differences (LSD test, $P < 0.05$).

During this study, significant differences were found for fruit shape index between genotypes and ranged from 0.91 ('Premial') to 1.49 ('16-2-218'). 'Premial' cv. has the short-conic fruits and long-conic fruits the other genotypes (Table 4). The data obtained for fruit firmness showed higher resistance value for the selections '16-2-237' (55.57 N) and the lowest on for '16-2-237' (13.80 N) Table 4.

Table 4. Physical characteristics of some strawberry selections

Genotype	Fruit firmness (N)	Fruit shape index
Premial	17.90 ± 1.97^{de}	0.91 ± 0.05^{g*}
16 - 2 - 10	39.03 ± 7.05^{abc}	1.26 ± 0.10^{bcde}
16 - 2 - 12	33.90 ± 2.88^{bcd}	1.28 ± 0.15^{bcd}
16 - 2 - 15	49.90 ± 11.38^{ab}	1.22 ± 0.12^{cde}
16 - 2 - 55	38.93 ± 12.10^{abc}	1.35 ± 0.12^{abc}
16 - 2 - 127	13.80 ± 3.94^{e}	1.28 ± 0.15^{bcd}
16 - 2 - 216	48.40 ± 8.07^{ab}	1.43 ± 0.07^{ab}
16 - 2 - 218	55.57 ± 4.40^{a}	1.49 ± 0.1^{a}
16 - 2 - 233	45.47 ± 14.52^{abc}	1.30 ± 0.05^{bcd}
16 - 2 - 237	47.87 ± 17.99^{abc}	1.09 ± 0.04^{ef}
16 - 3 - 48	35.13 ± 2.39^{abcd}	1.28 ± 0.07^{bcd}
16 - 3 - 86	45.37 ± 6.25^{abc}	1.15 ± 0.14^{def}
16 - 3 - 123	49.43 ± 18.13^{ab}	1.34 ± 0.07^{abcd}
16 - 3 - 170	29.70 ± 8.66^{bcde}	1.24 ± 0.08^{cde}
16 - 3 - 188	27.87 ± 15.58^{cde}	1.00 ± 0.05^{fg}

Note: Different letters between cultivars denote significant differences (Duncan test, $p < 0.05$). Different letters between susceptible and resistant cultivars denote significant differences (LSD test, $P < 0.05$).

In our study, a significant influence of the genotype on the soluble solids content was recorded:'16-3-48' (10.27 °Brix) and '16-2-127' (10.03 °Brix) Table 5. Sehrish et al (2021) found for fruit similar value soluble solids content to our study and ranged from 7.21 ^{0}Brix in 'Everly' cv. to 12.63 ^{0}Brix in 'Brighton' variety.
Color is an important attribute for strawberries because it determines the ideal conditions for harvesting and the commercial value of the fruit.

Table 5. Chemical characteristics and fruit color of some strawberry selections

Genotype	Soluble solids content (°Brix)	pH	Brightness (L*)	Red - green color (a*)	Yellow - blue color (b*)
Premial	9.17 ± 0.50^{abc*}	3.58 ± 0.13^{cd}	25.79 ± 5.58^{a}	26.61 ± 2.06^{a}	12.93 ± 3.08^{a}
16-2-10	6.37 ± 1.31^{d}	3.82 ± 0.14^{abcd}	13.85 ± 0.43^{bc}	9.41 ± 0.58^{bc}	4.58 ± 0.12^{b}
16-2-12	5.87 ± 0.70^{d}	3.82 ± 0.36^{abcd}	10.86 ± 1.44^{c}	7.69 ± 0.82^{c}	4.51 ± 0.23^{b}
16-2-15	8.03 ± 1.17^{abcd}	3.54 ± 0.17^{cd}	16.14 ± 1.01^{b}	10.89 ± 1.17^{b}	5.16 ± 0.97^{b}
16-2-55	9.50 ± 1.13^{ab}	3.81 ± 0.12^{abcd}	15.81 ± 0.28^{b}	10.46 ± 0.27^{bc}	5.17 ± 0.13^{b}
16-2-127	10.03 ± 0.68^{a}	4.15 ± 0.33^{ab}	12.99 ± 2.36^{bc}	8.77 ± 1.30^{bc}	5.39 ± 0.62^{b}
16-2-216	9.30 ± 2.87^{abc}	3.88 ± 0.71^{abcd}	14.16 ± 2.53^{bc}	9.74 ± 1.18^{bc}	5.37 ± 0.30^{b}
16-2-218	6.97 ± 1.16^{cd}	3.54 ± 0.1^{cd}	14.37 ± 2.19^{bc}	9.98 ± 2.00^{bc}	4.99 ± 0.96^{b}
16-2-233	7.23 ± 1.27^{bcd}	3.90 ± 0.380^{abcd}	11.51 ± 0.46^{bc}	7.96 ± 0.68^{bc}	5.37 ± 0.77^{b}
16-2-237	8.80 ± 0.75^{abc}	4.24 ± 0.24^{a}	12.27 ± 1.56^{bc}	8.12 ± 0.87^{bc}	4.93 ± 0.29^{b}
16-3-48	10.27 ± 0.85^{a}	3.82 ± 0.10^{abcd}	11.57 ± 2.00^{bc}	7.91 ± 1.28^{bc}	4.41 ± 0.53^{b}
16-3-86	8.73 ± 1.25^{abc}	4.17 ± 0.38^{ab}	14.35 ± 2.80^{bc}	9.92 ± 2.23^{bc}	5.21 ± 0.51^{b}
16-3-123	7.03 ± 1.10^{cd}	3.43 ± 0.09^{d}	13.39 ± 4.07^{bc}	9.29 ± 3.34^{bc}	3.88 ± 1.11
16-3-170	9.57 ± 0.87^{ab}	4.06 ± 0.17^{abc}	14.76 ± 1.70^{bc}	10.05 ± 1.34^{bc}	5.12 ± 1.45^{b}
16-3-188	7.23 ± 1.01^{bcd}	3.66 ± 0.04^{bcd}	14.93 ± 2.52^{bc}	10.23 ± 1.91^{bc}	4.30±0.10^{b}

Note: Different letters between cultivars denote significant differences (Duncan test, $p < 0.05$). Different letters between susceptible and resistant cultivars denote significant differences (LSD test, $P < 0.05$).

The genotype influences the fruit external color, nonsignificant differences were observed between the genotypes analyzed. L* values ranged from 10.86 to 25.79, a* values from 7.91 to 26.61, b* values from 3.88 to 12.93. In this area of the color sphere, the higher values L*, a*, b* represent the lighter sample color being recorded by 'Premial' (Table 5).

CONCLUSIONS

Selection '16-3-188' recorded the highest values in terms of yield and average fruit weight, while selection '16-2-218' recorded the highest value of fruit firmness. From the point of view of the biochemical quality of the fruits, we can see that the '16-2-127' selection has the highest soluble solids content. Our results will strengthen the breeding process at the Research Institute for Fruit Growing Pitesti-Arges, based on the data obtained, from the 14 selections, it was proposed to introduce into next stages for evaluation those that recorded over 500 g/plant, over 20 g/fruit, better fruit firmness and soluble solids content than 'Premial', namely: '16-3-188', '16-2-12', '16-3-170', '16-3-123', '16-2-127'.

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Conflicts of Interest

The authors declare that they do not have any conflict of interest.

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