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Możliwości poprawy jakości owoców truskawki metodą hybrydyzacji wewnątrz- i międzygatunkowej w obrębie rodzaju Fragaria

Possibilities of improvement the quality of strawberry fruit by intra- and interspecific hybridization within the *Fragaria* genus

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Prace badawcze nad poszerzaniem zmienności genetycznej u truskawki na świecie ukierunkowane są głównie na poprawę zewnętrznej i wewnętrznej jakości owoców. Celem podjętych w Instytucie Ogrodnictwa badań było określenie możliwości zwiększenia zawartości substancji bioaktywnych (przede wszystkim polifenoli, antocyjanów oraz kwasów organicznych) w owocach truskawki metodą hodowli konwencjonalnej. Na podstawie dwuletniej oceny fenotypowej spośród 6097 siewek, otrzymanych w wyniku krzyżowań wewnątrz- i międzygatunkowych w obrębie rodzaju *Fragaria*, wyselekcjonowano 90 wartościowych genotypów. W roku 2019 genotypy te oceniono pod względem plonu, masy, atrakcyjności i jędrności owoców, a także zawartości w owocach ekstraktu, związków fenolowych, antocyjanów i kwasu askorbinowego.
Stwierdzono, że największe, najbardziej atrakcyjne i jędrne owoce wytworzyły klony T-201536-16 i T-201536-08 (‘Clery’ × ‘Grandarosa’), T-201514-04 i T-201514-05 (‘Candiss’ × ‘Panvik’) oraz T-201560-07 (‘Onda’ × ‘Panvik’). Największą zawartością ekstraktu odznaczały się owoce genotypów T-201536-16 i T-201536-09 (‘Clery’ × ‘Grandarosa’). Najwięcej związków fenolowych zawierały owoce klonów T-201501-02 (‘Alba’ × ‘Grandarosa’), T-201512-04 (‘Camarosa’ × ‘Panvik’) oraz T-201567-01 (‘Patty’ × ‘Panvik’), zaś antocyjanów - owoce klonów T-201514-08 (‘Candiss’ × ‘Panvik’), T-201508-01 (‘Alice’ × ‘Matis’), T-201517-05 (‘Chandler’ × ‘Matis’) oraz T-201580-01 (*Fragaria chiloensis* Del Norte × ‘Elsanta’). Najbardziej bogate w kwas askorbinowy były owoce klonów T-201526-05 (‘Cigaline’ × ‘Grandarosa’), T-201501-03 (‘Alba’ × ‘Grandarosa’), T-201536-15 (‘Clery’ × ‘Grandarosa’) oraz T-201567-01 (‘Patty’ × ‘Panvik’). Najwyższą łączną zawartością wszystkich analizowanych związków bioaktywnych w owocach odznaczały się klony T-201514-08 (‘Candiss’ × ‘Panvik’), T-201517-05 (‘Chandler’ × ‘Matis’) oraz T-201567-04 (‘Patty’ × ‘Panvik’).

Słowa kluczowe: antocyjany, jakość owoców, kwas L-askorbinowy, polifenole, truskawka

Research on widening genetic variation in strawberry around the world is focused mainly on improving external and internal fruit quality. The aim of the research undertaken at the Research Institute of Horticulture was to determine the possibility of increasing the content of bioactive compounds (polyphenols, anthocyanins and organic acids) in strawberry by conventional breeding. Based on a two-year phenotypic evaluation, 90 valuable genotypes were selected from 6097 hybrids obtained as a result of intra- and interspecific hybridization within the *Fragaria* genus. In 2019, these genotypes were assessed in terms of fruit yield, weight, attractiveness and firmness, as well as the content of the extract, phenolic compounds, anthocyanins and ascorbic acid in the fruit.
We found that the largest, most attractive and firmest fruits were produced by clones T-201536-16 and T-201536-08 (‘Clery’ × ‘Grandarosa’), T-201514-04 and T-201514-05 (‘Candiss’ × ‘Panvik’) and T-201560-07 (‘Onda’ × ‘Panvik’). The highest extract content was noted in the fruits of genotypes T-201536-16 and T-201536-09 (‘Clery’ × ‘Grandarosa’). The greatest number of phenolic compounds were encountered in the fruits of clones T-201501-02 (‘Alba’ × ‘Grandarosa’), T-201512-04 (‘Camarosa’ × ‘Panvik’) and T-201567-01 (‘Patty’ × ‘Panvik’), while the highest anthocyanin levels were evident in the fruit of clones T-201514-08 (‘Candiss’ × ‘Panvik’), T-201508-01 (‘Alice’ × ‘Matis’), T-201517-05 (‘Chandler’ × ‘Matis’) and T-201580-01 (*Fragaria chiloensis* Del Norte × ‘Elsanta’). Moreover, the richest levels of ascorbic acid were in the fruits of clones T-201526-05 (‘Cigaline’ × ‘Grandarosa’), T-201501-03 (‘Alba’ × ‘Grandarosa’), T-201536-15 (‘Clery’ × ‘Grandarosa’) and T-201567-01 (‘Patty’ × ‘Panvik’). Finally, the highest total content of all analyzed bioactive compounds in fruits was noted for clones T-201514-08 (‘Candiss’ × ‘Panvik’), T-201517-05 (‘Chandler’ × ‘Matis’) and T-201567-04 (‘Patty’ × ‘Panvik’).

Key words: anthocyanins, fruit quality, L-ascorbic acid, polyphenols, strawberry

Introduction

Poland is one of the leading producers and exporters of strawberries in the world. In recent years it produced about 180-200,000 tonnes of strawberries (data for 2013-2018). According to FAOSTAT (data for 2017),

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this volume ranks Poland second in Europe and seventh in the world. In order to maintain such a high position in the market, research work on improving the quality of strawberries should take into account European trends, the most important of which is now focused on improving the quality of life and health of European citizens. In fruit production, strong emphasis is put on improving the nutritional and health-promoting properties of fruit by increasing the content of bioactive compounds (Capocasa et al., 2008 a, b). These compounds, known for their antioxidant and anti-carcinogenic properties, play an essential role in the human diet, especially in the prevention of cancer, atherosclerosis and diabetes, as well as arterial hypertension (Battino et al., 2009; 2017; Mirończuk-Chodakowska et al., 2011; Giampieri et al., 2012; Bialasiewicz et al., 2014; Zasowska et al., 2016). A particular role in the prevention of these diseases is attributed to polyphenols, flavonoids and anthocyanins, ascorbic acid, as well as ellagic acid oligomers – ellagotanins (da Silva-Pinto et al., 2008; Kazimierczak et al., 2009; Marques et al., 2010; Prymont-Przymińska et al., 2016).

Strawberries, like other berries, are known as a very important source of bioactive compounds. However, the content of these compounds largely depends on the genotype/cultivar (Wang and Lewers, 2007). High levels of bioactive compounds are found in fruit from 'Clery', 'Diana', 'Selvik' (Michalska et al., 2017), 'Manille', 'Matis', 'Asia', 'Camarosa', 'Alice', 'Roxana', 'Madeleine', 'Cifrance', 'Patty' and 'Dora' cultivars (Capocasa et al., 2008 b), but also 'Alba', 'Sveva', 'Marina', 'Darselect', 'Elsanta', 'Honeoye' and 'Panvik' (EUBerry germplasm database, 2014). Much higher levels of bioactive compounds, compared to the listed cultivars of *Fragaria* × *ananassa*, are found in wild forms of strawberry, *F. chiloensis* and *F. virginiana* (Wang and Lewers, 2007; Diamanti et al., 2012). Some studies revealed that the use of the gene pool of these species may result in an increase in the content of nutrients and phytochemicals in strawberry fruit (Capocasa et al., 2008 a).

The aim of the study was to determine the possibility of increasing the content of bioactive compounds (polyphenols, anthocyanins and organic acids) in strawberry fruit by conventional breeding and based on a phenotypic evaluation of plants obtained as a result of intra- and interspecific hybridization of selected parental forms of the *Fragaria* genus.

Material and Methods

The study was carried out at the Research Institute of Horticulture (INHORT)) in Skierniewice in 2019. We analysed fruits from 90 hybrids (clones) of strawberry, selected and propagated in 2017 after a two-year evaluation of 6097 seedlings from F_1 generation obtained as a result of intra- and interspecific hybridization of *Fragaria* parental forms characterised by a high content of bioactive compounds, mainly ascorbic acid, anthocyanins and polyphenols.

A comparative experiment was established in the autumn of 2017 in the Pomological Orchard of INHORT in Skierniewice on lessive soil, quality class IV, moderately rich in nutrients. A detailed list of genotypes with their pedigrees is presented in Table 1. Each of the selected genotypes was represented by 15 plants, planted in one replicate spaced 1.1 × 0.3 m, in an order consistent with the numbering of the selected plants. All cultivation and maintenance works were carried out in accordance with the recommendations for commercial plantations. Ripe fruits of each clone were harvested successively (a total of 5 fruit harvests), and then sorted into healthy fruits and those infested with grey mould. On each of the harvest dates, the total yield and average fruit weight were assessed, and the attractiveness and firmness of fruit were evaluated using a 1 to 5 ranking scale, where 1 is the lowest value, and 5 the highest value of the analysed trait. The evaluation of fruit attractiveness was focused in particular on the shape of the fruit and its uniformity (no deformities), the colour of the skin and its gloss. After the assessment of yield and external quality, all fruit harvested on each date were washed, calyx removed, packed in separate zipper bags and placed in a freezer at -25°C for further analysis. After the end of harvest, mixed samples of fruit from each genotype were prepared and submitted to the Laboratory of Processing and Quality Evaluation of Fruit and Vegetables at the Department of Fruit and Vegetables Storage and Processing in order to perform basic analysis of the chemical composition of the fruit. Immediately before analysis the fruit was disintegrated in a Blixer 3 blender. Solid CO_2 or liquid N_2 was used, depending on the sample size.

The mean sample prepared in this way divided into two technical replicates and analysed for chemical composition. Samples were analysed for the content of the following components: extract (total extract): total content of non-volatile compounds up to 100°C, soluble in water, determined with a refractometer (RE 50, Mettler Toledo, Switzerland) according to the PN-90 A-75101/02 standard; content of anthocyanins pigments (ANT) – by means of differential pH methods and a UV/Vis CARY 300E spectrophotometer (Varian) and a procedure proposed by Giusti and Wrolstad (2001). Absorbance was measured at 520 nm. The anthocyanin content was calculated based on the molar absorbance of glucoside-3-pelargonidine (22400) and the molar mass - 433.2 g/mol, and the results were expressed in mg/100 g of fresh fruit; total phenolic content (TPC) was measured using a modified spectrophotometric method (Tsao and Yang, 2003) using the Folin-Ciocalteau reagent. The total phenolic content measured at the wavelength of 765 nm was expressed in mg of gallic acid/100 g of fresh fruit. The content of L-ascorbic acid was measured by high-performance liquid chromatography (Agilent 1200, DAD detector) after extraction in 6% metaphosphoric acid. Separation was carried out on a Supelco LC-18 column with a pre-column. Elution parameters: 0.8 ml/min, temperature 30°C, wavelength 244 nm and 210 nm, mobile phase – 1% phosphate buffer (K2HPO4) at pH=2.5 in isocratic flow. Results were expressed in mg/100 g of fresh fruit.

Results and Discussion

The yield of the analysed genotypes differed significantly and was in the range from 104 to 2802 g/plot (Tab. 1). These differences were mainly associated with damage to flower buds and flowers by spring frosts in early flowering genotypes. In spring 2019 the temperature measured 2 m above ground level dropped to -1.2°C (10-11 April), to -3.6°C (15-16 April) and -1.7°C on 8 May. The best yield (more than 2 kg of fruit/plot) was obtained from the following genotypes: T-201506-01 and T-201506-02 ('Alice' × 'Pink Rosa'), T-201510-02 and T-201510-04 ('Asia' × 'Matis'), T-201511-01 ('Asia' × 'Panvik'), T-201526-01, T-201526-02 and T-201526-05 ('Cigaline' × 'Grandarosa') and T-201536-06 ('Clery' × 'Grandarosa'). Two of the paternal cultivars, 'Grandarosa' and 'Pink Rosa', were also characterised by high yield in previous studies carried out at the Research Institute of Horticulture in Skierniewice (Masny and Żurawicz, 2015; Masny et al., 2015). Earlier studies demonstrated that these cultivars are highly suitable for commercial cultivation, but they are also good donors of the high yield trait which is inherited by progeny.

Phenotypic evaluation of fruit quality traits in the analysed clones (fruit size, attractiveness and firmness) allowed for the identification of the most valuable genotypes. Clones with the largest fruit included: T-201536-07 ('Clery' × 'Grandarosa'; mean weight of one fruit 21.0 g), T-201525-01 ('Cifrance' × 'Panvik'; 18.0 g) and T-201536-16 ('Clery' × 'Grandarosa'; 16.2 g). The most attractive fruit (score higher than 4.5 in 1 to 5 grading system) were obtained from T-201511-01 ('Asia' × 'Panvik'), T-201536-04 and T-201536-16 ('Clery' × 'Grandarosa'), and the firmest fruit (score 5 in 1 to 5 grading system) were produced by the following clones: T-201501-03 ('Alba' × 'Grandarosa'), T-201512-06 ('Camarosa' × 'Panvik'), T-201536-10 ('Clery' × × 'Grandarosa'), T-201555-02 ('Marmolada' × × 'Grandarosa') and T-201560-02 ('Onda' × × 'Panvik'). Considering the whole set of listed quality traits of fruit, the most valuable clones were selected: T-201501-03 ('Alba' × 'Grandarosa'), T-201511-01 ('Asia' × 'Panvik'), T-201512-05 and T-201512-06 ('Camarosa' × 'Panvik'), T-201514-04 ('Candiss' × 'Panvik'), T-201526-06 ('Cigaline' × 'Grandarosa'), T-201536-01, T-201536-02, T-201536-05, T-201536-06, T-201536-07 and T-201536-09 ('Clery' × 'Grandarosa') and T-201560-07 ('Onda' × 'Panvik').

The listed genotypes produced very attractive fruits: large or very large, conical or cordiform, with orange-red or bright red skin, very glossy and very firm. Fruits with such traits are particularly preferred by consumers, which is why focus on the high visual quality of the fruit is one of the main trends in breeding work carried out worldwide (Roudeillac and Trajkovski, 2004), including at the Research Institute of Horticulture.

The content of refractometric extract (soluble solids) in the fruit of 90 tested genotypes ranged from 5.3% to 12.7% (Tab. 2). The highest content of extract (more than 11%) was found in fruit produced by the following clones: T-201508-03 ('Alice' × 'Matis'), T-201517-05 ('Chandler' × 'Matis'), T-201536-09

Tabela 1
Table 1

Plon i wizualna jakość owoców 90 genotypów truskawki (Skierniewice, 2019)

Fruit yield and external fruit quality of 90 strawberry genotypes (Skierniewice, 2019)

Genotyp Genotype	Rodowód Parentage	Plon owoców Fruit yield (g)	Masa 1 owocu Weight of 1 fruit (g)	Atrakcyjność owoców[1] Fruit attractiveness[1]	Jędrność owoców[1] Fruit firmness[1]
T-201501-01	Alba × Grandarosa	1414	10,63	4,4	4,3
T-201501-02	Alba × Grandarosa	819	9,53	3,7	4,8
T-201501-03	Alba × Grandarosa	1494	8,81	4,2	5,0
T-201506-01	Alice × Pink Rosa	2094	11,44	3,6	4,3
T-201506-02	Alice × Pink Rosa	2334	10,14	3,5	4,5
T-201508-01	Alice × Matis	827	6,70	3,0	3,8
T-201508-02	Alice × Matis	832	7,46	2,8	4,8
T-201508-03	Alice × Matis	530	8,25	2,8	4,7
T-201508-04	Alice × Matis	1608	10,51	4,0	4,1
T-201510-01	Asia × Matis	771	7,02	3,9	4,9
T-201510-02	Asia × Matis	2737	11,49	3,9	4,9
T-201510-03	Asia × Matis	1860	8,01	4,3	4,4
T-201510-04	Asia × Matis	2744	8,18	4,1	4,8
T-201511-01	Asia × Panvik	2802	10,96	4,6	4,8
T-201512-01	Camarosa × Panvik	617	7,90	3,6	4,3
T-201512-02	Camarosa × Panvik	1934	9,06	4,1	4,6
T-201512-03	Camarosa × Panvik	1934	10,61	3,5	4,8
T-201512-04	Camarosa × Panvik	1057	8,20	3,7	4,8
T-201512-05	Camarosa × Panvik	333	8,74	4,5	4,8
T-201512-06	Camarosa × Panvik	1016	8,23	4,0	5,0
T-201513-01	Candiss × Matis	626	8,89	4,0	4,1
T-201513-02	Candiss × Matis	680	6,09	4,0	4,7
T-201513-03	Candiss × Matis	373	6,80	3,9	4,5
T-201513-04	Candiss × Matis	1060	7,59	3,9	4,8
T-201513-05	Candiss × Matis	1067	9,92	3,7	4,3
T-201513-06	Candiss × Matis	1145	9,89	4,0	4,4
T-201514-01	Candiss × Panvik	2000	10,74	4,2	4,6
T-201514-02	Candiss × Panvik	1987	9,27	3,3	4,3
T-201514-03	Candiss × Panvik	1569	7,00	4,1	4,4
T-201514-04	Candiss × Panvik	1784	11,62	4,3	4,7
T-201514-05	Candiss × Panvik	628	11,80	4,5	4,6
T-201514-06	Candiss × Panvik	692	9,73	4,3	4,8
T-201514-07	Candiss × Panvik	472	8,73	4,0	4,8
T-201514-08	Candiss × Panvik	536	7,70	3,6	4,1
T-201514-09	Candiss × Panvik	561	10,95	3,8	4,5
T-201517-01	Chandler × Matis	734	10,65	3,9	4,5
T-201517-02	Chandler × Matis	672	8,71	4,1	4,6
T-201517-03	Chandler × Matis	1251	10,32	4,4	4,6
T-201517-05	Chandler × Matis	1282	5,39	3,3	4,8
T-201524-01	Cifrance × Matis	1333	8,05	4,1	4,7

Objaśnienie: [1]Ocena według skali bonitacyjnej 1-5, gdzie 1 oznacza najniższą wartość, zaś 5 – najwyższą wartość badanej cechy.
Explanation: [1]Assessment according to the rating scale 1-5, where 1 is the lowest value and 5 - the highest value of the examined trait

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Genotyp Genotype	Rodowód Parentage	Plon owoców Fruit yield (g)	Masa 1 owocu Weight of 1 fruit (g)	Atrakcyjność owoców[1] Fruit attractiveness[1]	Jędrność owoców[1] Fruit firmness[1]
T-201524-02	Cifrance × Matis	916	9,59	4,0	4,6
T-201525-01	Cifrance × Panvik	821	17,97	3,3	4,5
T-201526-01	Cigaline × Grandarosa	2294	8,10	4,1	4,9
T-201526-02	Cigaline × Grandarosa	2618	10,97	3,7	4,7
T-201526-03	Cigaline × Grandarosa	1010	7,59	3,6	4,6
T-201526-04	Cigaline × Grandarosa	1374	8,07	3,9	4,6
T-201526-05	Cigaline × Grandarosa	2143	7,70	4,0	4,5
T-201526-06	Cigaline × Grandarosa	840	9,96	4,5	4,7
T-201529-01	Cigaline × Matis	476	10,08	4,0	4,0
T-201536-01	Clery × Grandarosa	1103	9,08	4,2	4,8
T-201536-02	Clery × Grandarosa	1033	9,03	4,5	4,9
T-201536-03	Clery × Grandarosa	1208	7,13	4,3	4,8
T-201536-04	Clery × Grandarosa	671	10,81	4,6	4,6
T-201536-05	Clery × Grandarosa	997	9,44	4,3	4,7
T-201536-06	Clery × Grandarosa	2791	10,44	4,4	4,7
T-201536-07	Clery × Grandarosa	218	20,96	4,5	4,9
T-201536-08	Clery × Grandarosa	362	11,37	4,5	4,5
T-201536-09	Clery × Grandarosa	633	9,22	4,0	4,9
T-201536-10	Clery × Grandarosa	489	11,76	4,0	5,0
T-201536-14	Clery × Grandarosa	187	6,74	3,8	4,8
T-201536-15	Clery × Grandarosa	202	7,35	3,8	4,5
T-201536-16	Clery × Grandarosa	744	16,12	4,9	4,6
T-201536-17	Clery × Grandarosa	241	14,92	3,8	4,0
T-201537-01	Clery × Matis	226	10,23	3,5	4,2
T-201537-02	Clery × Matis	1031	9,16	4,0	4,3
T-201539-01	Darselect × Grandarosa	920	6,27	3,3	3,5
T-201555-01	Marmolada × Grandarosa	1170	8,18	3,0	4,3
T-201555-02	Marmolada × Grandarosa	996	8,79	3,3	5,0
T-201555-04	Marmolada × Grandarosa	952	7,83	4,3	4,4
T-201555-06	Marmolada × Grandarosa	1241	7,43	3,8	4,8
T-201555-07	Marmolada × Grandarosa	104	11,00	4,0	4,8
T-201555-08	Marmolada × Grandarosa	833	7,92	3,6	4,9
T-201555-09	Marmolada × Grandarosa	675	10,33	3,7	4,7
T-201560-01	Onda × Panvik	629	6,29	3,8	4,5
T-201560-02	Onda × Panvik	397	5,79	4,0	5,0
T-201560-04	Onda × Panvik	519	7,37	3,8	4,3
T-201560-05	Onda × Panvik	244	5,71	3,3	4,7
T-201560-07	Onda × Panvik	1563	11,44	4,2	4,8
T-201560-08	Onda × Panvik	1167	11,61	3,8	4,9
T-201567-01	Patty × Panvik	876	6,86	3,9	4,9

Objaśnienie: [1]Ocena według skali bonitacyjnej 1-5, gdzie 1 oznacza najniższą wartość, zaś 5 – najwyższą wartość badanej cechy.
Explanation: [1]Assessment according to the rating scale 1-5, where 1 is the lowest value and 5 - the highest value of the examined trait

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Fruit yield and external fruit quality of 90 strawberry genotypes (Skierniewice, 2019)

Genotyp Genotype	Rodowód Parentage	Plon owoców Fruit yield (g)	Masa 1 owocu Weight of 1 fruit (g)	Atrakcyjność owoców[1] Fruit attractiveness[1]	Jędrność owoców[1] Fruit firmness[1]
T-201567-02	Patty × Panvik	307	11,80	3,9	4,6
T-201567-03	Patty × Panvik	1070	8,27	4,1	4,8
T-201567-04	Patty × Panvik	1173	7,98	4,1	4,3
T-201571-01	Sophie × Pink Rosa	509	8,70	4,0	4,5
T-201571-02	Sophie × Pink Rosa	210	4,62	3,3	4,3
T-201571-03	Sophie × Pink Rosa	725	8,78	3,4	4,6
T-201580-01	*F. chil.* Del Norte × Elsanta	1046	3,56	3,2	4,3
T-201580-02	*F. chil.* Del Norte × Elsanta	649	3,61	2,8	4,3
T-201585-01	*F. chil.* Yaquina A × Matis	335	4,53	3,7	4,5
T-201590-01	*F. chil.* Yaquina B × Panvik	1408	4,49	2,7	4,3
Średnia dla wszystkich genotypów Average for all genotypes		1051	9,05	3,87	4,58

Objaśnienie: [1]Ocena według skali bonitacyjnej 1-5, gdzie 1 oznacza najniższą wartość, zaś 5 – najwyższą wartość badanej cechy.
Explanation: [1]Assessment according to the rating scale 1-5, where 1 is the lowest value and 5 - the highest value of the examined trait

and T-201536-16 (‘Clery’ × ‘Grandarosa’), T-201567-01 and T-201567-04 (‘Patty’ × ‘Panvik’) and T-201580-01 (*F. chiloensis* Del Norte × ‘Elsanta’). Of note is the fact that the content of soluble sugars in fruits from these clones was higher compared to fruits from hybrids obtained by Hasing et al. (2013) as a result of a factorial hybridization (5 × 4), where the extract content was 5.1% to 9.9% and 6.5% to 10.6%, depending on the season. Voća et al. (2008) also analysed the chemical composition of fruit from 7 strawberry cultivars (‘Clery’, ‘Maya’, ‘Alba’, ‘Miss’, ‘Camarosa’, ‘Queen Elisa’ and ‘Elsanta’) and reported the content of soluble solids from 6% for ‘Maya’ to 10.1% for ‘Elsanta’. The content of soluble sugars in strawberry fruit, especially sucrose, glucose and fructose, is an important quality trait determining their taste (Cordenunsi et al., 2002; Perkins-Veazie, 1995).

The content of ascorbic acid in the fruit of the analysed clones ranged from 24 to 106 mg/100 g. Such a large variation of this trait is typical for the cultivars of strawberries (da Silva-Pinto et al., 2008; van De Velde et al., 2013). However, from the point of view of human health, fruits with a high content of ascorbic acid are the most valuable (Cruz-Rus et al., 2011). In our study, the highest levels of ascorbic acid (more than 90 mg/100 g) were found in fruit from the following clones: T-201501-03 (‘Alba’ × ‘Grandarosa’), T-201526-02 and T-201526-05 (‘Cigaline’ × ‘Grandarosa’), T-201536-08andT-201536-15(‘Clery’ × ‘Grandarosa’), T-201537-02 (‘Clery’ × ‘Matis’), T-201539-01 (‘Darselect’ × ‘Grandarosa’), T-201555-02, T-201555-08 and T-201555-09 (‘Marmolada’ × ‘Grandarosa’), T-201567-01 and T-201567-03 (‘Patty’ × ‘Panvik’). The content of ascorbic acid in the fruits of the above-mentioned clones is therefore much higher than the reported average, i.e. about 60 mg/100 g of fresh fruit (Miller et al., 2019). According to Cruz-Rus et al. (2011), lower content of ascorbic acid (50 mg/100 g) was found in fruit from the ‘Camarosa’ cultivar, which was the maternal form of six out of 90 genotypes described in our study.

The content of anthocyanins in the fruit of all analysed clones ranged from 8 to 70 mg/100 g. It should be pointed out that a very high content of anthocyanins in consumed fruits is desirable due to the strong antioxidant properties of these compounds. In our research, anthocyanin content higher than 50 mg/100 g of fruit was found for the following clones: T-201508-01 (‘Alice’ × ‘Matis’), T-201512-03 (‘Camarosa’ × ‘Panvik’), T-201514-02 and T-201514-08 (‘Candiss’ × ‘Panvik’), T-201517-05 (‘Chandler’ × ‘Matis’), T-201567-04 (‘Patty’ × ‘Panvik’) and T-201580-01 (*Fragaria chiloensis* Del Norte × ‘Elsanta’). This shows the high health promoting value of fruits from the listed clones. According to Voća et al. (2008), the content of anthocyanins (for seven strawberry cultivars analysed) was lowest in the fruit of the 'Elsanta' cultivar (114.76 mg/kg), and highest in the 'Camarosa' cultivar (327.39 mg/kg), which was the maternal form of one above-listed hybrid genotype. The very high content of anthocyanins in the fruit of the 'Camarosa' cultivar (840.2 mg/kg) was also noted by Garcia-Viguera et al. (1998).

The content of phenolic compounds in the fruit of the analysed genotypes ranged from 257 to 478 mg/100 g of fresh fruit. The highest levels of phenolic compounds in fruits (more than 430 mg/100 g) were found for the following genotypes: T-201501-02 and T-201501-03 ('Alba' × 'Grandarosa'), T-201512-04 and T-201512-05 ('Camarosa' × 'Panvik'), T-201567-01, T-201567-02 and T-201567-04 ('Patty' × 'Panvik') and T-201585-01 (*Fragaria chiloensis* Yaquina A × 'Matis'). Such a high level of phenolic compounds is especially desired in strawberries produced for the fresh fruit market, due to their high health-promoting value. However, despite the great importance of polyphenols in the human diet, excessive levels of these compounds may cause a slightly tart taste in strawberries and thus lower their sensory value. On the other hand, a high level of phenolic compounds in fruit for processing may be associated with a number of technological problems, so the best for this purpose are strawberries with a moderate content of phenolics, which in the case of the analysed clones was 360 mg/100 g of fresh fruit. A study conducted by Palmieri et al. (2017) revealed that the content of phenolics in ripe strawberries also depended on the cultivar and ranged from 33.2 mg/100 g of fresh fruit for 'Marmolada' to 127.3 mg/100 g for 'Eva', which is much lower compared with clones grown at the Research Institute of Horticulture.

Considering all analysed bioactive compounds, T-201510-02 ('Asia' × 'Matis'), T-201514-02 and T-201514-08 ('Candiss' × × 'Panvik'), T-201517-05 ('Chandler' × × 'Matis'), T-201526-01 and T-201526-04 ('Cigaline' × 'Grandarosa'), T-201567-03 and T-201567-04 ('Patty' × 'Panvik') and T-201571-02 ('Sophie' × 'Pink Rosa') clones were regarded as particularly valuable because of the high content of total phenolic compounds, anthocyanins and ascorbic acid in the fruit. Moreover, due to the fact that phenolic compounds produce a synergistic effect on the human body along with L-ascorbic acid (Kazimierczak et al., 2009), clones designated T-201501-02 and T-201501-03 ('Alba' × 'Grandarosa'), T-201526-05 and T-201526-06 ('Cigaline' × 'Grandarosa'), T-201536-04, T-201536-05, T-201536-06, T-201536-14, T-201536-15 and T-201536-16 ('Clery' × 'Grandarosa') and T-201571-02 ('Sophie' × 'Pink Rosa') were also classified as valuable because they produced fruit with a high content of both these compounds. It should also be emphasized that four of the above-listed clones (T-201501-03, T-201526-06, T-201536-05, T-201536-06) were also characterised by high external quality of fruits. Therefore, it can be expected that the fruits of these clones will be particularly appreciated by consumers due to their high quality and health benefits. These clones may give rise to new, valuable cultivars in the future, if their other positive productivity traits are confirmed, including resistance or low susceptibility of plants

Tabela 2
Table 2

Skład chemiczny owoców 90 genotypów truskawki (Skierniewice, 2019)

Chemical composition of fruit of 90 strawberry genotypes (Skierniewice, 2019)

Genotyp Genotype	Ekstrakt Extract [%]	Zawartość związków fenolowych Content of phenolic compounds [mg /100 g]	Zawartość antocyjanów Content of anthocyanins [mg/100 g]	Zawartość kwasu L-askorbinowego Content of L-ascorbic acid [mg/100 g]
T-201501-01	9,0	306	20	73
T-201501-02	9,3	478	20	89
T-201501-03	8,8	434	18	103
T-201506-01	7,9	265	42	52
T-201506-02	7,2	369	48	26
T-201508-01	9,0	322	54	39
T-201508-02	8,6	337	48	32

Tabela 2 cd.
Table 2 cd.

Skład chemiczny owoców 90 genotypów truskawki (Skierniewice, 2019)

Chemical composition of fruit of 90 strawberry genotypes (Skierniewice, 2019)

Genotyp Genotype	Ekstrakt Extract [%]	Zawartość związków fenolowych Content of phenolic compounds [mg /100 g]	Zawartość antocyjanów Content of anthocyanins [mg/100 g]	Zawartość kwasu L-askorbinowego Content of L-ascorbic acid [mg/100 g]
T-201508-03	11,1	366	34	61
T-201508-04	8,9	291	39	60
T-201510-01	8,8	303	26	74
T-201510-02	8,7	372	50	71
T-201510-03	9,3	360	37	66
T-201510-04	7,2	298	31	41
T-201511-01	9,3	325	20	69
T-201512-01	9,0	383	35	44
T-201512-02	9,0	362	33	50
T-201512-03	7,5	391	55	58
T-201512-04	9,9	452	36	52
T-201512-05	10,2	433	46	45
T-201512-06	10,0	388	43	56
T-201513-01	9,8	348	24	39
T-201513-02	10,1	421	50	59
T-201513-03	9,6	358	38	54
T-201513-04	9,1	390	26	53
T-201513-05	8,6	392	41	46
T-201513-06	9,6	422	40	59
T-201514-01	8,0	304	27	61
T-201514-02	9,3	394	65	75
T-201514-03	9,1	322	33	71
T-201514-04	9,1	367	34	52
T-201514-05	11,0	356	41	75
T-201514-06	10,0	301	36	67
T-201514-07	9,2	321	23	61
T-201514-08	10,5	403	70	70
T-201514-09	10,1	397	40	65
T-201517-01	8,0	381	36	54
T-201517-02	8,6	328	32	55
T-201517-03	9,4	359	44	59
T-201517-05	11,2	390	54	81
T-201524-01	5,3	318	21	25
T-201524-02	10,5	344	37	84
T-201525-01	9,6	326	34	61
T-201526-01	7,8	407	33	83
T-201526-02	9,0	351	26	98
T-201526-03	10,0	319	23	83
T-201526-04	9,7	392	34	88
T-201526-05	9,9	422	28	106
T-201526-06	9,1	377	25	80
T-201529-01	9,3	344	24	88
T-201536-01	9,4	306	31	85
T-201536-02	9,4	347	20	87
T-201536-03	9,1	313	25	75
T-201536-04	8,6	385	21	73
T-201536-05	10,5	368	19	78
T-201536-06	9,4	385	23	74
T-201536-07	8,3	320	39	65
T-201536-08	8,8	340	22	98
T-201536-09	11,6	280	12	86
T-201536-10	10,5	325	20	76
T-201536-14	10,2	427	24	60

Tabela 2 cd.
Table 2 cd.

Skład chemiczny owoców 90 genotypów truskawki (Skierniewice, 2019)

Chemical composition of fruit of 90 strawberry genotypes (Skierniewice, 2019)

Genotyp Genotype	Ekstrakt Extract [%]	Zawartość związków fenolowych Content of phenolic compounds [mg /100 g]	Zawartość antocyjanów Content of anthocyanins [mg/100 g]	Zawartość kwasu L-askorbinowego Content of L-ascorbic acid [mg/100 g]
T-201536-15	11,0	373	30	102
T-201536-16	11,8	418	22	83
T-201536-17	7,0	341	27	33
T-201537-01	6,0	295	22	24
T-201537-02	10,9	354	27	98
T-201539-01	10,3	354	27	91
T-201555-01	10,0	258	35	73
T-201555-02	9,7	257	32	98
T-201555-04	9,5	318	27	57
T-201555-06	9,0	367	24	54
T-201555-07	6,6	333	25	27
T-201555-08	8,5	335	25	94
T-201555-09	8,1	340	16	97
T-201560-01	6,3	309	9	47
T-201560-02	8,2	367	29	46
T-201560-04	10,1	366	27	73
T-201560-05	7,1	281	35	46
T-201560-07	9,5	327	18	49
T-201560-08	8,7	345	27	62
T-201567-01	11,2	454	8	102
T-201567-02	10,7	442	33	64
T-201567-03	10,1	386	34	98
T-201567-04	12,7	442	52	80
T-201571-01	8,2	419	24	76
T-201571-02	11,0	419	33	74
T-201571-03	10,0	332	28	65
T-201580-01	11,1	367	54	57
T-201580-02	10,0	314	43	59
T-201585-01	8,8	435	34	44
T-201590-01	10,9	416	18	45
Średnia dla wszystkich genotypów Average for all genotypes	9,31	359,5	31,9	66,5

to biotic and abiotic stressors.

Conclusions

1. It is possible to improve the external quality of strawberry fruit and increase the content of bioactive compounds in fruits by conventional breeding based on intra- and interspecific hybridization within the genus *Fragaria*.
2. Fruit from clones T-201510-02 ('Asia' × 'Matis'), T-201514-02 and T-201514-08 ('Candiss' × 'Panvik'), T-201517-05 ('Chandler' × 'Matis'), T-201526-01 and T-201526-04 ('Cigaline' × 'Grandarosa'), T-201567-03 and T-201567-04 ('Patty' × 'Panvik') and T-201571-02 ('Sophie' × 'Pink Rosa') have particular value for the human diet because of the high content of bioactive compounds such as polyphenols, anthocyanins, and ascorbic acid.
3. Genotypes producing fruit with high external and internal quality traits may become valuable cultivars or be used in further breeding research as a source of genes determining these traits.

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