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The composition of fruit of different strawberry varieties depending on maturity stage

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Abstract

The fruits of the cultivars 'Eros', 'Selena', 'Northaester', 'Fern', 'Simphony', 'Mohawk', 'Elsanta', 'Miss', 'Evita', 'Marmolada', 'Pegasus', 'Kent' and 'Cortina' were chemicaly analysed. With the high-performance liquid chromatography (HPLC) method the individual sugars (sucrose, glucose, fructose and xylose) and organic acids (citric, fumaric and shikimic) were estimated in two different stages of ripeness: the stage of technological ripeness and the stage of complete ripeness. Statistical differences among the fruits of the same cultivar and of different maturity stages were established in the contents of glucose, fructose, xylose, fumaric and shikimic acids, but there were no statistical differences in the contents of sucrose and citric acid. Among the fruits in the stage of complete ripeness the cvs. 'Mohawk' and 'Evita' were outranking with regard to the content of sucrose, while the fruits of the cvs. 'Fern' and 'Northaester' attained the highest contents of glucose, fructose and citric acid. During the same time of ripeness the highest content of total soluble solids (TSS) was measured in the cv. 'Mohawk', and the lowest content of TSS was exhibited by the cv. 'Miss'. The results of the analyses conducted during the research confirm that the chemical composition of strawberry fruits significantly varied among the genotype of the plant and on the stage of maturity of fruits. Therefore harvesting in optimal fruit bearing time is essential for achieving good quality of strawberries, since important changes in the content of individual sugars and acids occur in the last period of maturity as well.

Keywords: *Fragaria×ananasa*; Maturity; Fruit quality; HPLC method

1. Introduction

Strawberries (*Fragaria×ananassa* Duch.) have unique, highly desirable taste and flavour and are one of the most popular summer fruits. Consumers mainly purchase strawberries for an enjoyable eating experience. Media reports have indicated increasing consumer dissatisfaction with the flavour and inconsistent quality of strawberries (Ford et al., 1997). The components of quality can be sensory and nutritional. Implicit in the use of single and multiple physical or chemical characteristics to determine optimum maturity is that changes in the selected parameter correlate with the attainment of the general composite of quality characterises of the product (Kays, 1991). Pérez, Olías, Espada, Olías, and Sanz (1997) have found a very poor correlation value for total soluble solids (TSS) and total sugars, titratable acids (TA) and total organic acids, therefore those parameters are not good enough for the evaluation of strawberry quality. The use of TSS and TA should be limited to comparative studies in which variations by genotype and environment are low. Of the many factors that can affect the taste quality of a product, ripeness, maturity, cultivar, irrigation, and fertilisation are especially important (Kays, 1991). The cultivation of strawberries in plastic tunnels decreased the dependency of the yield quality and quantity on the climatic and soil conditions. Furthermore, it increasingly equalised the conditions during the ripening time due to better control of water regime, sunlight, and temperature. Harvesting at the proper stage of maturity

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is essential for optimum quality and often for the maintenance of this quality after harvest.

The aim of the research was to establish the differences in quality between the technologically and completely ripe fruits of 13 strawberry varieties. To achieve the goal several chemical analyses were carried out. We aimed to identify those chemical components in the fruits, which in the last stage of maturity alter most significantly. An additional objective was to establish a simple and rapid analytical procedure for quantification of individual and total sugars and organic acids in strawberries, since important evaluation of some quality parameters of apricots (Dolenc-Sturm, Stampar, & Usenik, 1999) was already done.

2. Materials and methods

2.1. Plant materials

The strawberry samples intended for the analysis of the fruit quality were harvested in the plantation located in the central area of Slovenia. At the same time the introduction of new strawberry varieties was conducted in the plantation. The comparison was between the standard cultivars 'Elsanta' and 'Marmolada' on one side and the once bearing cultivars 'Cortina', 'Eros', 'Kent', 'Miss', 'Mohawk', 'Northaester', 'Pegasus', 'Selena' and 'Simphony' and monthly bearing cultivars 'Evita' and 'Fern'. Ten plants of each cultivar were planted in July 1997, applying the standard technology. The plants were planted on the slopes, covered with a black foil, in a two-row planting system, and the density of 0.25×0.25 m. In March, the plantation was covered with a plastic tunnel. The samples for the analysis were gathered in the last week of May 1999 when most varieties were highly ripe. From every strawberry plant of each variety 4–6 technologically ripe fruits and 4–6 completely ripe fruits were gathered. Technologically ripe fruits were light green or white at the top, while completely ripe ones exhibited an intense red colour all over the fruits.

2.2. Chemical analysis

High-performance liquid chromatography (HPLC) method was used for separation, identification and quantification of individual compounds in strawberry puree. The HPLC system consisted of Thermo Separation Products (TSP) equipment with a model P2000 pump, autosampler model AS1000, Mistral column heater and OS/2 Warp IBM Operating system (1994)-work station. Solute elution was monitored using a variable wavelength UV detector set at 210 nm and differential refractive index RI (model Shodex-71RI).

For sugar determination (glucose, fructose, sucrose and xylose) and organic acids (citric, fumaric and shikimic) we used the modified HPLC method according to Dolenc and Štampar (1997). Samples were prepared from 4 to 6 fruits of fresh strawberries of individual plants and converted into pulp by a mixer and homogenised with Ultra-Turrax T-25 (Ika-Labortechnik). The fruit puree (10 g) was diluted to 50 ml with bidistilled water and clarified by centrifugation at 6000*g* for 15 min. The extract was filtered through 0.45-μm Millipore filters and a 20-μl sample was used for current HPLC analysis of sugars and organic acids.

Sugar analyses were performed isocratically on Aminex HPX-87C cartridge at a flow rate of 0.6 ml/min at temperature 85 °C with bidistilled and on-line degassed water used as eluent. Sugars present in each sample were identified and quantified by external standard method. The reproducibility of the chromatographic separation of the components was determined by making five injections of the standard solutions and strawberry sample. The results expressed as relative standard deviation (RSD%) are as follows: 0.26 for sucrose, 0.23 for glucose, 0.20 for fructose and 0.16 for xylose.

Organic acids were determined by HPLC analysis using an Aminex HPX-87H column, thermostated at 65 °C, with diluted 4 mmol sulphuric acid used as eluent. Organic acids were identified and quantified by using a UV detector with wavelength set at 210 nm and by comparison of retention times and peak areas with standard solutions of known organic acids. Results of reproducibility study of chromatographic separation for organic acids expressed as RSD% are as follows: 0.27 for citric acid, 0.18 for shikimic acid and 0.16 for fumaric acid.

The TSS, expressed as%, were determined in the juice of each sample using Atago digital refractometer at 21 °C.

2.3. Standard materials

Standards for sucrose, glucose, fructose and xylose, as well as citric, shikimic and fumaric acids were obtained from Fluka Chemical (New York, NY, USA). Linearity of the response to UV and RI detection was tested for each compound with five different concentrations prepared in bidistilled water and all correlation coefficient were in required range.

2.4. Statistical analysis

Samples of fruits from individual plants were considered as a source of variation. The results were statistically evaluated by one way analysis of variance (ANOVA). Statistically differences with *P*-values under 0.05 were considered significant and means were compared by 95% Tukey's HSD multiple range test, using STATGRAPH program, version 7.

3. Results

The content of sucrose (Table 1) was the highest in the fruits of the cv. 'Mohawk' during both stages (21.7 and 18.5 g/kg). In the fruits during the stage of technological ripeness (column 1) the content of sucrose was the lowest in the cv. 'Pegasus' (1.9 g/kg), but in the stage of complete ripeness (column 2) the fruits of the cv. 'Marmolada' were the ones which exhibited the lowest amount of sucrose (1.1 g/kg). The content of sucrose decreased with maturity except in the cultivars 'Kent' and 'Pegasus' where it showed a slight increase. The mean sucrose content in the fruits during both stages was 6.0 g/kg with the highest variability among different genotypes.

The content of glucose increased in completely ripe strawberry fruits. The increase was the highest in the cvs. 'Fern' and 'Kent'. The cvs. 'Elsanta' and 'Pegasus' were exceptions. Their fruits exhibited lower amounts of glucose in completely mature fruits. The highest contents of glucose measured in this stage were in the cvs. 'Fern' (28.2 g/kg) and 'Northaester' (27.1 g/kg), while the fruits of cvs. 'Marmolada' (16.3 g/kg) and 'Elsanta' (16.9 g/kg) contained the lowest amounts of glucose.

The content of fructose increased at the transition between the stage of early ripeness and the stage of complete ripeness of strawberries. During this time the highest increase in the fructose content was measured in the cv. 'Fern' (by 9.5 g/kg), which also contained the most fructose of all (33.0 g/kg). A slightly lower increase was measured in the cvs. 'Kent' (by 5.8 g/kg) and 'Evita' (by 5.6 g/kg). During the two stages of maturity the smallest differences in the contents of fructose were calculated in the cvs. 'Elsanta' and 'Pegasus', namely 0.4 g/kg. On average, less ripe fruit contained 22.3 g/kg of fructose, while more ripe ones had 26.2 g of fructose per kg of fresh fruits.

The highest content of xylose, which however, presents a small share among the sugars even in highly ripe fruits, was measured in the fruits of the cvs. 'Northeaster' and 'Simphony' (1.4 and 1.2 g/kg, respectively). The lowest amounts were in the cvs. 'Miss' (0.5 g/kg) and 'Selena' (0.6 g/kg). The results point to the fact that there are very small differences in the xylose contents among the technologically and completely ripe fruits of the treated cultivars. The mean xylose content is the same in all the varieties (0.9 g/kg).

The highest share of total acids (approximately 90%) was exhibited by citric acid (Table 2). Its content decreased with the maturity of fruits in the majority of cultivars. But in the cvs. 'Kent' and 'Northaester' the content of citric acid increased. The mean content of citric acid in the fruits during the stage of technological maturity (column 1) extended from 4.4 g/kg in the cv. 'Miss' to 10.4 and 10.5 g/kg in the cvs. 'Evita' and 'Fern', respectively. During the stage of complete ripeness (column 2) the strawberry fruits of the cv. 'Fern' contained the highest amount of citric acid, namely 10.3 g/kg, while the cv. 'Miss' fruits exhibited only 4.5 g/kg. On average, the content of citric acid in the strawberry fruits reached 8.4 and 8.2 g/kg, and it did not differ statistically significantly among the cultivars with regard to the stage of ripeness.

The presence of tartaric acid in the strawberries during both stages of maturity was detected only in the following cultivars: 'Marmolada', 'Miss', 'Elsanta', 'Pegasus', and 'Northaester'. The highest content of tartaric acid irrespective of the maturity stage was measured in the fruits of the cv. 'Elsanta' (1.6 and 1.8 g/kg).

Table 1
The mean±SE content of individual sugars in strawberry fruits of different cultivars and maturity stage

Cultivar	Sucrose (g/kg)		Glucose (g/kg)		Fructose (g/kg)		Xylose (g/kg)	
	1	2	1	2	1	2	1	2
Marmolada	2.8±0.3	1.1±0.1	14.9±2.0	16.3±1.8	18.6±2.4	20.5±1.5	0.8±0.1	0.8±0.0
Miss	2.2±0.6	2.1±0.8	14.2±2.3*	18.6±2.2*	16.0±2.4*	20.7±2.2*	0.4±0.0	0.5±0.0
Elsanta	4.9±1.9	4.4±1.9	17.5±3.3	16.9±2.3	20.8±3.2	20.4±4.3	0.8±0.1	1.0±0.3
Pegasus	1.9±1.1	2.1±1.8	20.6±3.5	19.8±1.9	24.4±3.8	24.8±1.6	0.9±0.1	1.0±0.2
Simphony	3.3±1.1	2.6±0.7	17.1±3.8	20.6±2.4	20.0±3.8	24.2±2.7	1.0±0.1	1.2±0.4
Cortina	4.9±0.6	4.8±1.8	18.8±1.9	21.3±3.1	22.3±2.0	24.8±2.9	0.9±0.1	0.8±0.0
Selena	5.3±0.7	4.8±0.3	18.8±1.9*	22.9±1.6*	21.8±2.0*	26.5±1.6*	0.6±0.0	0.6±0.0
Eros	2.1±0.6	1.9±1.1	21.3±3.4	25.2±2.3	25.1±2.6	29.4±2.3	1.1±0.2	1.1±0.1
Kent	4.3±1.5	6.8±1.2	18.1±1.1*	23.2±2.5*	21.2±0.9*	27.0±3.8*	1.0±0.1	0.9±0.1
Northaester	3.5±1.4	2.8±0.2	25.5±1.6	27.1±2.7	28.6±3.7	31.5±2.6	1.0±0.3	1.4±0.2
Evita	12.5±2.9	10.3±2.6	19.5±1.6	24.6±1.9	22.8±1.7*	28.4±4.3*	0.8±0.1*	0.9±0.1*
Fern	8.5±3.3	6.3±2.0	20.6±1.2*	28.2±2.2*	23.5±1.8*	33.0±2.9*	0.9±0.3	1.1±0.3
Mohawk	21.7±3.4	18.5±1.4	21.6±1.9	25.1±2.5	24.8±2.5	29.6±4.2	1.0±0.2	0.8±0.2
Average	6.0±5.4	6.0±4.7	19.1±3.0	22.3±3.8	22.3±3.2	26.2±4.1	0.9±0.2	0.9±0.2

* Mean values, which according to the HSD (Tukey's) test differ statistically significantly, are marked with an asterisk ($P < 0.05$).

Table 2
The mean ± SE content of individual organic acids in strawberry fruits of different cultivars and maturity stage

Cultivar	Citric acid (g/kg)		Tartaric acid (g/kg)		Shikimic acid (mg/kg)		Fumaric acid (mg/kg)	
	1	2	1	2	1	2	1	2
Marmolada	6.7±0.5	6.6±0.9	0.7±0.1	0.7±0.2	5.8±1.1	6.4±0.8	6.7±0.9	7.7±1.8
Miss	4.4±0.6	4.5±0.3	0.6±0.1	0.5±0.1	7.5±0.9	8.9±0.9	12.9±0.8*	17.5±1.7*
Elsanta	9.3±1.8	9.4±2.1	1.6±0.3	1.8±0.4	6.5±0.5	6.7±0.5	4.4±0.8*	6.1±0.1*
Pegasus	8.6±1.1	7.3±1.0	1.0±0.2	1.1±0.2	4.1±0.6	4.8±1.8	7.5±1.2	8.6±2.4
Simphony	8.7±2.0	8.7±1.8	0.8±0.1	–	4.2±0.9	4.2±0.5	7.0±1.4	7.9±1.2
Cortina	9.3±2.2	8.4±1.1	–	–	8.8±1.6	8.6±2.5	8.5±2.5	9.8±1.6
Selena	10.0±0.3	9.9±0.9	–	–	10.3±0.7	11.2±0.9	4.9±1.1	6.4±1.3
Eros	7.0±0.7	6.8±0.8	–	–	15.3±2.7	17.5±0.8	11.5±2.3	13.2±1.3
Kent	7.2±0.8	7.7±0.3	1.1±0.3	–	11.3±3.3	15.3±4.7	10.2±2.0	11.2±1.4
Northaester	7.2±1.7	9.2±0.7	0.7±0.1	1.1±0.2	11.1±3.3	15.3±2.0	9.1±3.1*	14.1±1.2*
Evita	10.4±1.9	9.0±1.3	–	1.0±0.2	11.5±2.1	17.0±2.1	12.0±3.1	16.4±5.4
Fern	10.5±0.1	10.3±0.3	0.7±0.1	–	8.9±1.8*	13.8±3.4*	7.1±0.9*	12.3±3.1*
Mohawk	9.8±1.1	8.5±1.1	0.9±0.2	–	8.0±2.6	10.3±1.9	11.0±3.0*	16.7±0.6*
Average	8.4±1.8	8.2±1.6	0.9±0.3	1.0±0.4	8.7±3.2	10.8±4.6	8.7±2.7	11.4±4.0

* Mean values, which according to the HSD (Tukey's) test differ statistically significantly, are marked with an asterisk ($P<0.05$).

Shikimic and fumaric acids were presented in the strawberry fruits in very small amounts; therefore they did not significantly influence the flavour of the fruits. In the chemical analysis they were distinguished by a very high extinction. The content of fumaric and shikimic acids was statistically significantly higher during the stage of complete ripeness in some cultivars (Table 2).

The content of TSS is the function of several factors of which total sugars and organic acids constitute the major part. The lowest contents of total soluble solids in the fruits of complete ripeness were detected in the cvs. 'Miss' (5.2%) and Marmolada (5.4%). The cv. 'Mohawk' fruits developed as much as 8.7% of total soluble solids. We should stress the fact that the highest increase in the content of total soluble solids happened in the cvs. 'Kent' (by 1.3%), 'Fern' (by 1.2%) and 'Selena' (by 1.0%). The cultivars 'Miss', 'Eros' and 'Simphony' also exhibited a strong increase in the content of soluble solids during the last stage of ripening (Table 3).

The total sugars content (comprising sucrose, glucose, fructose, and xylose) was the highest in the cv. 'Mohawk', namely 74.1 g/kg during the time of complete ripeness. The fruits of the cvs. 'Northeaster', 'Evita' and 'Fern' developed high contents of total sugars as well (from 62.8 to 68.6 g/kg), while the fruits of the cvs. 'Marmolada', 'Miss' and 'Elsa' attained very small amounts of total sugars (from 38.8 to 42.7 g/kg).

The content of total acids, comprising the sum of individual acids, decreased with the maturity. This can

Table 3
The mean ± SE content of total soluble solids and the mean content of total sugars, total organic acids and sugar/acid ratio in strawberry fruits of different cultivars and maturity stage

Cultivar	Total soluble solids (%)		Total sugars (g/kg)		Total acids (g/kg)		Sugar/acid ratio	
	1	2	1	2	1	2	1	2
Marmolada	5.0±0.4	5.4±0.2	37.2	38.8	7.4	7.3	5.0	5.3
Miss	4.3±0.4	5.2±0.2	32.8	41.8	5.0	5.0	6.6	8.4
Elsanta	5.8±0.6	5.7±0.4	44.0	42.7	10.9	11.2	4.0	3.8
Pegasus	6.3±0.6	6.3±0.6	47.7	47.6	9.6	8.4	5.0	5.7
Simphony	5.3±0.3	6.1±0.4	41.4	48.5	9.5	8.7	4.4	5.6
Cortina	6.3±0.2	7.0±0.6	46.8	51.6	9.3	8.4	5.0	6.1
Selena	5.8±0.2	6.8±0.7	46.5	54.7	10.0	9.9	4.7	5.5
Eros	6.1±0.4	6.9±0.4	49.4	57.6	7.0	6.8	7.1	8.5
Kent	5.7±0.3	7.0±0.3	44.6	57.9	8.3	7.7	5.4	7.5
Northaester	6.8±0.5	7.4±0.4	58.6	62.8	7.9	10.3	7.4	6.1
Evita	6.9±0.4	7.5±0.5	55.6	64.2	10.4	10.0	5.3	6.4
Fern	6.5±0.5	7.7±0.4	53.4	68.6	11.2	10.3	4.8	6.7
Mohawk	8.2±0.6	8.7±0.8	69.2	74.1	10.7	8.5	6.5	8.7
Average	6.1±1.0	6.7±1.0	48.2±9.5	54.7±9.8	9.0±1.8	8.7±1.7	5.5±1.1	6.5±1.4

be due to the negative trend of the citric acid content. The lowest content of total acids was measured in the cv. 'Miss', which exhibited also low amounts of sugars. The cv. 'Elsanta' had a high content of total acids but a low content of total sugars. Therefore the sugars: acids ratio was low in the cv. 'Elsanta' (3.8), and high in the cv. 'Miss'. In the time of complete ripeness the ratio was the highest in the cv. 'Mohawk' due to the high content of sugars.

4. Discussion

Quality is usually estimated from the relative values of several characteristics considered together (Kader, 2000). Quality control starts in the field with the selection of the proper time to harvest for maximum quality. When then is the optimum point in the period of maturity for harvest? Optimum harvest maturity for the grower is a function of both product and marketing conditions. It is not a fixed point in the developmental cycle of a plant, determined by specific physical and/or chemical characteristics of the fruit to be harvested.

Our hypothesis that in the last stage of ripening the fruits not only alter in colour, shape, weight, but also in inner quality proved to be correct. During the time of transition from the stage of technological to the stage of complete ripeness an increase in the contents of sugars and a decrease in the contents of acids mainly determined the alterations. With the exception of the two cultivars 'Kent' and 'Pegasus', the content of sucrose decreased, and the contents of glucose, fructose, and xylose increased. On average, the total sugars content increased by 6.6 g/kg and in the cvs. 'Fern' and 'Kent' it increased even by 15.2 and 13.3 g/kg, respectively. The content of total acids was decreased in most of the cultivars due to citric acid reductions. The contents of fumaric and shikimic acids raised; however, an increase was not significant in the content of total acids.

The strawberry cultivars of various genetically and geographical sources which grew in equalised cultivation conditions developed fruits which differed in their chemical compositions. The mean values calculated during the research correspond to those measured by Wrolstad and Shallenberger (1981). The contents of fructose and glucose in the fruits which Wrolstad and Shallenberger chemically analysed reached the values of 22.3 and 23.3 g/kg, respectively. In our research the fruits of the 13 cultivars exhibited the following amounts: 22.3 and 26.2 g/kg of fructose, and 19.1 and 22.3 g/kg of glucose. The mean value of sucrose (6.0 g/kg) measured in the sample fruits in our research was lower than the value measured in the research by Wrolstad in Shallenberger (9.0 g/kg), but the interval was larger in our case, what points to typical characteristics of various strawberry genotypes as they were cultivated in equalised growth conditions. The contents of fructose and glucose are similar also to those measured by Richmond, Brandao, Gray, Markakis, and Stine (1981) in their research, but they reported an even higher value of sucrose (16.4 g/kg). The deviations in the values arrived at in the experiments by various authors can be due to a slight variability of the analysed genotypes or due to a low number of the cultivars analysed during the experiments. In the Slovene research the contents of sucrose in the fruits of the cv. 'Mohawk' were 21.7 and 18.5 g/kg, and in the fruits of the cv. 'Marmolada' the contents were only 2.8 and 1.1 g/kg. The correlation between sucrose and hexose (glucose and fructose) content in strawberries indicates that the accumulation of glucose and fructose in the fruit is dependent on the hydrolysis of translocated sucrose (Shaw, 1988).

The determination of the malic acid content in the strawberry fruits was not reliable due to the co-elution with fructose. However, Pérez et al. (1997) succeeded in separating the components and thus analysing the content of malic acid that in their research exhibited the value of 1.1 g/kg, and citric acid that reached the value of 3.1 g/kg. The values for citric acid in the fruits in our study extended from 4.4 to 10.5 g/kg. Perkins-Veazie (1995) also report similar contents of citric acid (4.2–12.4 g/kg) which in there research presented 88% of total acids. They detected from 0.9 to 6.8 g/kg of malic acid in the fruits.

The content of TSS is quite stable characteristic of different strawberry cultivars. The results of the organoleptic evaluation of strawberries performed by Wozniak, Radajewska, Reszelska-Sieciechowicz, and Dejwor (1997) displayed that in the fruits with flavour defined as sweet, the sugar:acid ratio was 7:1 and in the fruits defined as acid, this ratio was approximately 6:1. We concluded that the average ratio between total sugars and total acids during last maturation stage had increased from 5.5 to 6.5. Individual values deviated from the mentioned ones and in the time of complete ripeness they were 3.8 in the cv. 'Elsanta', and 8.7 in the cv. 'Mohawk'. This can undoubtedly have effects also on the flavour of fruits.

5. Conclusions

The knowledge of the exact qualitative and quantitative distribution of the sugars and organic acids, characteristic for strawberry fruits, is of capital importance for the evaluation of quality of fruits. The accurate analysis of those components enables us to observe the changes in the production of strawberries and during the storage time. To establish the differences among cultivars it is also necessary to eliminate variability due to growing conditions and the degree of ripeness. We propose that the objective analytical determinations of critical components, in future investigations, should be coupled with subjective evaluations by a taste panel to yield useful and meaningful information about edible quality of fresh fruits.

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