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Modifications of taste-relevant compounds in strawberry fruit under NaCl salinity

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Abstract

Two strawberry (*Fragaria* × *ananassa* Duch.) cultivars differing in their sensitivity to NaCl stress, cv. Elsanta (sensitive) and cv. Korona (less sensitive), were cultivated under 0, 40 and 80 mmol NaCl/l for two months during flowering and fruiting until final fruit harvest. Modifications of sensory quality parameters and selected chemical properties of the non-climacteric fruit were evaluated. Generally, NaCl salinity decreased quality of strawberry fruit, especially in cv. Elsanta. Fruits of stressed plants contained lower amounts of sugars, organic acids and soluble solids, were less sweet and did not meet consumers' requirements. Overall appearance of fruits decreased significantly. The reduced acceptance to consumers was closely correlated with the decline of sugar contents, especially sucrose content, as well as with the increase of organic acids, such as acetic acid. Sensory changes were revised on the basis of a dose to threshold relationship. Decreasing contributions of sugars to taste and a rising importance of sodium, acetic and citric acids as the most taste-relevant compounds were the main causes of the limited acceptance of salt-stressed fruits.

Keywords: *Fragaria* × *ananassa*; Fruit quality; Sensory panel test; Carbohydrates; Organic acids; Salt stress

1. Introduction

In order to improve flavour and taste of fruit, moderate or even enhanced salinity has been applied in hydroponic systems. Also, cultivation on dry land soils, where plants are contemporaneously exposed to moderate salt and water stresses, has been considered. Salt-stressed fruits of tomato or melon had elevated sugar and acid contents and were generally more attractive for consumers (Botia, Navarro, Cerdá, & Martinez, 2005; Del Amor, Martinez, & Cerdá, 1999; Sato, Sakaguchi, Furukawa, & Ikeda, 2006; Serio, De Gara, Caretto, Leo, & Santamaria, 2004; Zushi, Matsuzoe, Yoshida, & Chikushi, 2005). However, the contents of Na^{+} and Cl^{-} ions in fruits rose as well and marketable yield was reduced. Also, for strawberry fruit cultivated under salt stress, Awang and Atherton (1995) and Awang, Atherton, and Taylor (1993) reported an increase of taste and taste-related components such as sugars and acids. Several authors (Awang et al., 1993; Petersen, Willumsen, & Kaack, 1998; Sato et al., 2006) reported a higher consumer preference for fruit produced under moderate salinity, which was explained by increased sweetness and flavour, and firmer fruits. However, salt stress can result in a poorer overall appearance of fruit, which influences the perception of flavour and taste (Saied, Keutgen, & Noga, 2005). In consequence, fruit quality represents a sum of different attributes. The contribution of selected sugars and acids to quality is investigated in the present study by taking advantage of the dose-over-threshold in order to estimate the contribution of single compounds to fruit quality (Scharbert & Hofmann, 2005) and to evaluate changes in their concentrations.

In the case of strawberry fruit, the relationship between fruit physiology, biochemistry, and consumer preference on the one hand and NaCl salinity on the other is not yet fully understood. Stress-specific responses determine

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fruit quality to a larger extent, which could even result in a more variable response due to different sensitivity levels and defence strategies of cultivars. Therefore, the present work was set out to examine the modifications of strawberry fruit quality induced by moderate and elevated NaCl stress on selected quality properties in two genotypes differing in their sensitivities to NaCl stress, with special attention to quantitative changes of taste-related compounds. In order to cover consumer acceptance, quality changes of fruit were evaluated by a sensory panel and the contributions of individual compounds to taste were estimated.

2. Materials and methods

Experiments were conducted during two successive vegetative periods in 2002 and 2003 in Göttingen, Germany, with strawberry (*Fragaria* × *ananassa* Duch.) cvs Elsanta (NaCl-sensitive) and Korona (less sensitive). Commercial strawberry frigo-plantlets (class A+) were purchased from Kraege Beerenobst Spezialkulturen, Telgte, Germany, and cultivated in 6 l metallic Mitscherlich containers filled with quartz sand (0.7–1.2 mm ∅). Twelve plants per m^2 were placed randomly, with 10 replications for each of the three treatment-combinations (control 0 mmol/l of $E_c = 0.0013$ dS/m, moderate 40 mmol/l of $E_c = 3.9$ dS/m, excessive 80 mmol/l NaCl of $E_c = 7.5$ dS/m) to ensure a statistical design and to exclude position effects. Plants were grown in a greenhouse in order to avoid a dilution of salt applied to the plants by rainfall under mean ambient temperature of 17 °C (max temp. = 22.7 °C; min temp. = 11.3 °C) and mean humidity regimes of 77%. Experiments were conducted from the end of April to mid August, 2002 and 2003. Each plant received 200 ml of modified Hoagland nutrient solution (pH 6.5) twice a week and 100 ml solutions, containing either 0, 40, or 80 mM NaCl, were supplied four times a week. Once a week, 200 ml of demineralized water were added to all treatments. All plants received extra water when needed to avoid an additional water stress. Surpluses of solutions were allowed to pass the containers to ensure salt stress in the root medium at given concentration, but to avoid anoxia by water logging. Runners were removed immediately. Fruits were harvested at the optimum of fruit maturity, when about 90% of the fruit surface had reached a fully red colour. Fruits were separated into sepals and fruit flesh and only fruit flesh was used for further analyses. They were either frozen in liquid nitrogen immediately after harvest, stored at −30 °C and freeze-dried (Epsilon 2-40, Christ, Germany) or further processed as fresh fruit. After determination of dry matter content, fruits were milled to a fine powder (Ultra-Centrifuge Retsch mill ZM 100, Retsch, Germany) and samples were stored in darkness in desiccators.

Four replicates per treatment (10 berries per sample) were homogenized (Ultra-Turrax) for 5 min. The weighed pulp was centrifuged at 10,000 rpm and 5 °C for 15 min. The obtained clear juice (supernatant) was used for the determination of total soluble solids (TSS), pH-value, and titratable acids (TA). TSS was evaluated with a hand-refractometer (Krüss, Germany) and the results were presented as % fresh mass. In the juice of strawberry fruit, the pH-value was determined with a pH meter (InoLab 1, WTW, Germany). For the determination of TA, 3 ml of fruit juice diluted with 20 ml of distilled water were titrated with 0.1 M NaOH to the titration end-point at a pH of 8.1. The results were calculated as equivalents of citric acid, which is the main organic acid in strawberry fruit, and expressed per fresh mass.

For carbohydrate analyses, 100 mg of dried fruit material were extracted with 10 ml of distilled water, heated for 60 min in a water bath at 60 °C, and centrifuged for 20 min at 10,000 rpm. Glucose, fructose and sucrose, as well as organic acids, were determined in the membrane-filtered supernatant (Ø 0.45 μm). These carbohydrates were analyzed by injection of a 20 μl sample volume into an HPLC system using a LiChrospher 100 NH_2 (5 μm) 4 × 4 mm pre-column (No. 1.50966.0001, Merck KGaA, Darmstadt, Germany), in combination with a LiChrospher 100 NH_2 (5 μm) 4 × 250 mm separation column (No. 1.50834.0001, Merck KGaA, Darmstadt, Germany). The column temperature of 20 °C was controlled by the column thermostat Jetstream 2 (Knauer, Berlin, Germany). An acetonitrile : pure water solution (80:20 v/v) was used as mobile phase (flow rate 1.0 ml min^{-1}). Carbohydrates were detected with a Knauer differential refractometer 198.00 (Knauer, Berlin, Germany) and their concentrations were calculated according to Keutgen and Keutgen (2003). The sum of glucose, fructose, and sucrose was considered as a measure of total soluble carbohydrates. The results were recalculated per fresh mass.

The supernatants of carbohydrate analyses were also used for the determination of organic acids according to a method modified after Szmigielska, van Rees, Cieslinski, and Huang (1997). The protonated organic acids (pH of eluent = 2.2) were separated by hydrophobic interactions with the apolar stationary phase of the reversed phase column. The HPLC consisted of a WellChrom Degasser K-5004 (Knauer, Berlin, Germany), a WellChrom HPLC-pump Maxi Star K-1000 (Knauer, Berlin, Germany), an autosampler WISP 712 (Waters, Milford, MA, USA), a Photodiode Array Detector 996 (Waters, Milford, MA, USA), a column thermostat Jetstream 2 (Knauer, Berlin, Germany) and a Millennium data acquisition system (Waters, Germany). Organic acids were separated with a pre-column LiChroCART 4-4, Purospher STAR RP-8e, 5 μm (Merck, Darmstadt, Germany) and a guard column LiChroCART 250-3, Purospher STAR RP-8e, 5 μm (Merck, Darmstadt, Germany) at a flow rate of 0.4 ml/min and a temperature of 22 °C. As isocratic solution 18 mM KH_2PO_4 water solution (pH 2.0) was used as eluent. The concentrations of organic acids were detected at 210 nm (injection volume 20 μl). The results were expressed in g per unit fresh mass.

The sweetness index of fruit, an estimate of total sweetness perception, was calculated based on the amount and sweetness properties of individual carbohydrates in strawberry (Qian, 2006). The contribution of each carbohydrate was calculated, based on the fact that fructose is 2.30 and sucrose 1.35 times sweeter than glucose and, hence, the sweetness index was calculated as (1.00 [glucose]) + (2.30 [fructose]) + (1.35 [sucrose]).

The importance of individual compounds to taste, the dose-over-threshold value (DOT), was calculated as the ratio of actual concentration and taste threshold for the given compound (Scharbert & Hofmann, 2005), where the taste threshold concentration in water was taken from literature (Scharbert & Hofmann, 2005; Weiß & Hofmann, 2007). By definition, values larger 1 indicate a significant influence on taste; the larger the values the higher are the contribution of the compounds to taste.

The sensory panel test was performed with 10 panellists, 6 female and 4 male, 26–45 years in age. All panellists worked at the Quality laboratory and were well experienced and trained in sensory evaluations. Randomly offered strawberry fruits were rated from 0 to 5 points for their appearance and taste, from 0 to 4 points for aroma, and from 0 to 2 points for colour and firmness. Overall fruit quality was calculated as a sum of all recorded sensory properties. This rating scale was selected in line with the recommendations of the German Food Association DLG (Herrmann, 1966).

The obtained data were analyzed with the SPSS 12.0 statistical programme (SPSS Inc, 1989–1999). All data sets were tested for normal distribution and variance homogeneity ($P = 0.05$). In case of homogeneous sample variance, calculated means were compared by Duncan's multiple range test, and, in case of non-homogeneous variance by Tamhane tests ($P = 0.05$). Correlation and multiple regression procedures between normally distributed quality parameters were performed using *Pearson*-correlation coefficients.

3. Results and discussion

A good and well-balanced flavour of strawberry fruit is based on a high sugar and a comparatively high acid content, i.e. the balance between sweetness and acidity (Wang, Li, & Ecker, 2002). Therefore, the ratio of soluble solids (TSS) to titratable acids (TA) is commonly used to evaluate taste and ripening stage of fruit. A ratio of TSS to TA of 8.5–14 is considered an appropriate balance of sweet-tart flavour notes in strawberry for human palatability (Oregon Strawberry Commission, 2006). In the present study, TSS values were slightly higher in controls of cv. Korona than in cv. Elsanta with values of 9.50% and 8.40%, respectively (Table 1). These values are within the range of 8–12%, as reported by the Oregon Strawberry Commission (2006), Ménager, Jost, and Aubert (2004), Cordenunsi, Nascimento, and Lajolo (2003), Schöpplein, Krüger, Rechner, and Hoberg (2002) Kallio, Hakala, Pelkkikangas, and Lapveteläinen (2000).

The studied genotypes, Korona and Elsanta, varied significantly in their response to salt stress. In fruit of cv. Korona, TSS did not change under NaCl salinity while, in cv. Elsanta, a considerable decrease of more than 40% was detected. Comparison of TSS data and carbohydrate contents revealed that, in control berries of cv. Korona, the TSS consisted of 66.6% total soluble carbohydrates. With increasing salt stress, the relative contents of soluble carbohydrates were reduced to 54.3% and 59.9% at 40 and 80 mM NaCl, respectively. In control fruit of cv. Elsanta, the percentage of soluble carbohydrates in TSS was smaller than in cv. Korona (56.7%) but, in contrast to this cultivar, stepwise increase of salinity raised the relative contents of soluble carbohydrates in Elsanta up to 64%.

Titratable acids were 0.98 and 1.12 g per 100 g fresh fruit in controls of cvs Korona and Elsanta, respectively, and decreased in both cultivars as a result of salt stress, with a higher decline in cv. Elsanta. Despite these decreases, pH values did not change (data not shown).

Table 1
Changes in fruit quality parameters of the strawberry cvs Korona and Elsanta differing in their sensitivity to NaCl salinity stress

Quality parameter	Salt concentration (mM NaCl)					
	Korona (less salt sensitive)			Elsanta (salt sensitive)		
	0	40	80	0	40	80
TSS (%)^{x}	9.50 ± 3.77ab	10.80 ± 1.57a	8.90 ± 1.31ab	8.40 ± 2.24ab	6.56 ± 1.01bc	4.85 ± 0.87c
TA (g citric aicid 100 g^{-1} FM)^{x}	0.98 ± 0.24ab	0.92 ± 0.16ab	0.82 ± 0.23bc	1.12 ± 0.12a	0.87 ± 0.16ab	0.60 ± 0.14c
Dry matter (g 100 g^{-1} FM)^{y}	10.48 ± 2.48a	11.29 ± 3.87a	10.83 ± 1.45a	9.15 ± 1.09b	9.10 ± 1.03b	8.72 ± 1.23b
TSS/TA ratio (relative units)^{x}	9.83 ± 3.44ab	11.96 ± 2.20a	11.48 ± 3.09a	7.46 ± 1.50b	7.60 ± 1.00b	8.18 ± 0.93b
Sensory panel test (score points)^{x}	15.00 ± 1.00a	13.40 ± 2.30ab	11.80 ± 2.30b	13.10 ± 1.50ab	11.40 ± 1.60bc	8.80 ± 3.30c
Na^{+} (mg 100 g^{-1} FM)^{y}	1.17 ± 0.41d	30.51 ± 4.36c	56.69 ± 10.87ab	0.57 ± 0.14e	46.13 ± 11.83b	66.52 ± 8.03a
Cl^{-} (mg 100 g^{-1} FM)^{y}	4.61 ± 0.70cd	15.63 ± 5.13ab	17.33 ± 3.61a	4.58 ± 0.78d	11.98 ± 2.59b	22.43 ± 8.45a
Total sol. carbohydrates (g 100 g^{-1} FM)^{y}	6.33 ± 0.39a	5.86 ± 0.33a	5.33 ± 0.44ab	4.76 ± 0.53b	3.86 ± 0.27c	3.10 ± 0.22d
Total sweetness index (relative units)^{y}	10.13 ± 0.63a	9.38 ± 0.51ab	8.57 ± 0.63bc	7.59 ± 0.78c	6.23 ± 0.36d	5.06 ± 0.36e
Total organic acids (g 100 g^{-1} FM)^{x}	1.21 ± 0.16ab	1.24 ± 0.11a	1.29 ± 0.19ab	1.02 ± 0.06b	1.03 ± 0.04b	1.22 ± 0.09a
Total sol. carbohydrate/acid ratio (relative units)^{x}	5.28 ± 0.46a	4.73 ± 0.23b	4.17 ± 0.49c	4.65 ± 0.44b	3.76 ± 0.22d	2.55 ± 0.20e

Different letters within a row indicate significances by Duncan (^{x}) or Tamhane (^{y}) tests at $P = 0.05$ (FM – fresh mass, TSS – total soluble solids, TA – titratable acids).

The present results are in contrast to Awang et al. (1993), who reported a significant increase of TA in fruit of cv. Rapella in response to salt treatments. The differences between the present results and those of Awang et al. (1993) are due to the differences in fruit dry matter content. In the present study, NaCl salinity did not alter dry mass of strawberry fruit in either cultivar (Table 1), while Awang et al. (1993) found a considerable increase of dry matter content. This represents a concentration effect by higher water losses or a limitation of water uptake, but not by an enhanced import of solutes into the fruit. During the present experiment, we did in fact vary the osmotic potential of the water supplied to the strawberry plants, in contrast to Awang et al. (1993). The application of 200 ml demineralized water, once a week, and also of 100 ml modified Hoagland nutrient solution, twice a week, to all treatment combinations was intended to compensate for water stress effects on strawberry fruit (Munns, 2002) and, hence, the modifications of strawberry fruit quality in the present study should be due to NaCl accumulation rather than due to water stress. In light of these considerations, the increase of TA reported by Awang et al. (1993) is regarded as typical of water, but not of NaCl stress.

Decreases of TA and also TSS due to salinity, as observed in cv. Elsanta, were also reported by Saied et al. (2005), Kaya, Ak, and Higgs (2003), Kepenek and Koyuncu (2002) and Kaya et al. (2001), but were in contrast to the accumulation of both mentioned by Awang et al. (1993) for reasons given above. The ratio TSS/TA of both cvs Korona and Elsanta remained unaffected by salt stress and was on average 11.1 in cv. Korona and 7.7 in Elsanta. These values are indicative of a better taste of cv. Korona, as reported by the Oregon Strawberry Commission (2006). Elsanta is seemingly less palatable and balanced, which was also noticed by the sensory panel (Table 1).

Although a positive consumer preference for berry fruit grown at elevated salinity has been reported before (D'Amico, Izzo, Navari-Izzo, Tognoni, & Pardossi, 2003; Del Amor et al., 1999; Gough & Hobson, 1990; Pluda, Rabinowitch, & Kafkafi, 1993), panellists of the present study judged the influence of NaCl stress negatively. Especially, fruit of cv. Elsanta, produced at the highest level of 80 mM NaCl, was completely rejected (Table 1). Judging from the evaluations of the panellists, fruit appearance was the most obvious difference among fruits; significant differences in further sensory parameters were not identified (Fig. 1). Worthy of note, is that the sensory panel also observed a slight decrease in fruit firmness in cv. Elsanta but not in cv. Korona. Some panellists described fruits grown at the highest salt stress level of both cultivars as slightly salty. Their perception can be explained by higher contents of Na^{+} and Cl^{-} in fruits, which increased irrespective of genotype (Table 1).

Except for fruit appearance, which was related to salinity, panellists responded more to differences in sweetness than to differences in acidity. Sweetness, however, was directly related to the contents of soluble carbohydrates. Higher contents of total as well as of individual carbohydrates were positively correlated with taste, colour, and firmness ($P < 0.05$) and a better perception of fruits was also related to their firmness and brighter colour.

Major soluble carbohydrates detected in strawberry fruit were fructose, glucose and sucrose (Fig. 2). The relationship between fructose and glucose content was about 1:1, which is typical for berry fruits (Whiting, 1970), and remained fairly constant under NaCl salinity. Irrespective of cultivar, sucrose concentrations were 60–70% those of glucose or fructose. Generally, cv. Korona was characterized by higher contents of total carbohydrates and monosaccharides, as well as sucrose (here referred to as

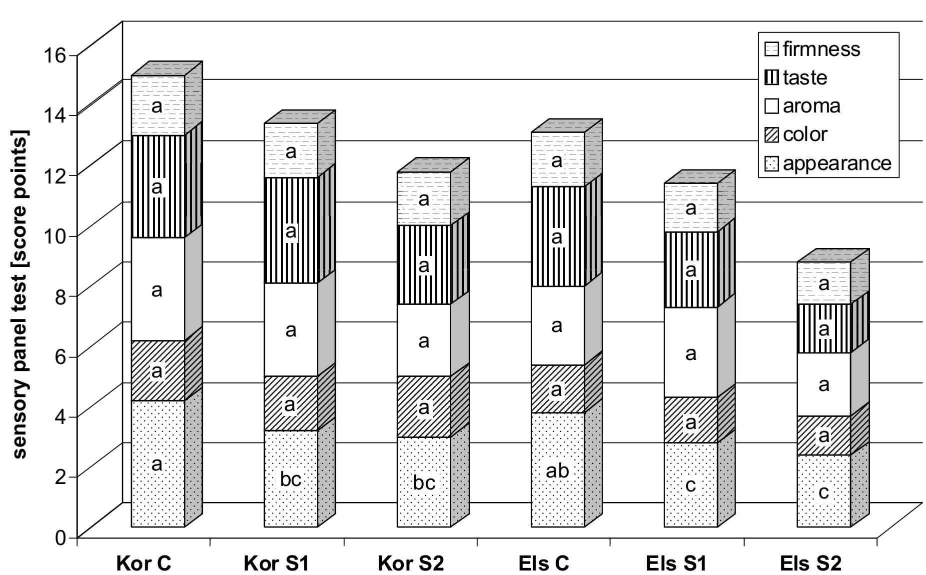

Fig. 1. Modifications of sensory fruit characteristics of the strawberry cvs Korona (Kor) and Elsanta (Els) in response to different levels of NaCl in the root medium. Different letters indicate significances at $P = 0.05$ after Duncan's test (C – control, S1 – 40 mM NaCl, S2 – 80 mM NaCl).

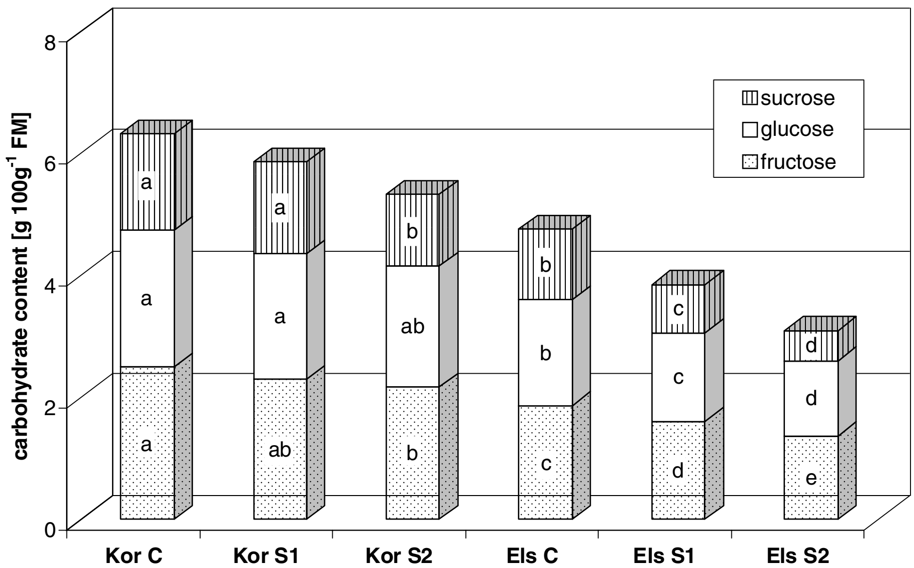

Fig. 2. Modifications of fruit carbohydrate contents of the strawberry cvs Korona (Kor) and Elsanta (Els) in response to different levels of NaCl in the root medium. Different letters indicate significances at $P = 0.05$ after test (C – control, S1 – 40 mM NaCl, S2 – 80 mM NaCl).

individual carbohydrates) than cv. Elsanta. Average values of fructose, glucose and sucrose content in control plants of cv. Korona were 2.50 g, 2.25 g, and 1.58 g per 100 g of fresh fruit, but these were only 1.87, 1.74 and 1.16 in cv. Elsanta. The carbohydrate profiles and concentrations resembled those given by Pelayo-Zaldivar, Ebeler, and Kader (2005), Ménager et al. (2004), Pelayo, Ebeler, and Kader (2003) or Wang, Zheng, and Galetta (2002), but were higher than those reported by Cordenunsi, Nascimento, Genovese, and Lajolo (2002). In fruits of cv. Elsanta concentrations of total (Table 1) and individual carbohydrates (Fig. 2) decreased progressively due to NaCl. Sucrose content was affected most, decreasing ca. 58% at the highest salt stress level. In cv. Korona, total soluble carbohydrates decreased significantly and fructose and sucrose contributed most to this decrease (Fig. 2). However, this decline was about 50% less than in cv. Elsanta. In both cultivars, the carbohydrate reduction was probably due to consumption of photoassimilates for osmotic adjustment (Awang et al., 1993), production of antioxidants and proteins related to stress defence (unpublished results) and reduced whole plant photosynthesis (Saied et al., 2005). Modifications of carbohydrate metabolism in fruit are also related to the responses of enzyme systems, which are sensitive to changes in Na^+ and Cl^- concentrations in the fruit tissue (Greenway & Munns, 1980). For instance, a more rapid degradation of sucrose levels implicates accelerated ripening processes in cv. Elsanta (Forney & Breen, 1986).

The taste of strawberry fruit depended less on total carbohydrate content, but more on type and quantity of individual carbohydrates, summarized in the total sweetness index (Table 1). The results indicated that cv. Korona was, independent of the salt stress level, significantly sweeter than was cv. Elsanta. Generally, salt stress caused a decrease of strawberry sweetness, which was higher in cv. Elsanta, being 18% and 33% at 40 and 80 mM NaCl in the nutrient solution, respectively (Table 1). In cv. Korona, the negative influence of salt stress became significant only at the highest stress level (80 mM NaCl) while, in the more sensitive cv. Elsanta, already the moderate NaCl level (40 mM) caused a significant decrease in sweetness.

Apart from sweetness, organic acids represent further compounds contributing to taste and flavour of strawberry fruit. In addition, organic acids are crucial for processing of fruit, due to their influence on gelling properties of pectins (Cordenunsi et al., 2002). Total acidity of ripened strawberry fruit is about 1% of fresh mass and ranges between 0.6% and 2.3% (Cordenunsi et al., 2002). Citric acid represents the main organic acid in strawberry, being 80% to over 90% of total organic acids (Pelayo-Zaldivar et al., 2005; Wang, Zheng, et al., 2002), followed by malic and acetic acids (Table 2). Further carboxylic acids were formic, gallic and fumaric acids. In control fruits of cv. Korona, the citric acid concentration was 0.85 g, while that of cv. Elsanta accounted for 0.74 g per 100 g of fruits, which corresponds well with the results of Holcroft and Kader (1999). The contributions of citric, malic and acetic acids to total organic acids were 70.6%, 23.5%, and 5.7% in cv. Korona, and 72.0%, 19.8%, and 7.8% in cv. Elsanta, respectively. These results were in line with Pelayo et al. (2003), but different from those of Wang, Zheng, et al. (2002), who reported a higher malic acid content at the expense of citric acid. NaCl stress increased the concentration of most of the organic acids in cv. Elsanta significantly, while concentrations of citric, malic and acetic acid remained fairly constant in cv. Korona (Table 2). In cv. Elsanta, the increase at the highest stress level (80 mM NaCl) was that of citric acid (Table 2). The studied

Table 2
Concentrations of organic acids in g 100 g^{-1} FM in fruit of strawberry cvs Korona and Elsanta as influenced by NaCl salinity in the root medium

Org. acids	Salt concentration (mM NaCl)					
	Korona (less salt sensitive)			Elsanta (salt sensitive)		
	0	40	80	0	40	80
Citric acid[y]	0.85 ± 0.13ab	0.95 ± 0.11a	0.99 ± 0.19ab	0.74 ± 0.04b	0.76 ± 0.03b	0.93 ± 0.08a
Malic acid[y]	0.28 ± 0.04a	0.19 ± 0.01b	0.19 ± 0.02b	0.20 ± 0.03b	0.16 ± 0.01c	0.16 ± 0.01c
Acetic acid[x]	0.07 ± 0.01c	0.10 ± 0.02b	0.11 ± 0.01ab	0.08 ± 0.02c	0.10 ± 0.01b	0.12 ± 0.01a
Formic acid[y]	0.0013 ± 0.0006f	0.0018 ± 0.0004ef	0.0037 ± 0.0014cde	0.0030 ± 0.0005d	0.0062 ± 0.0005b	0.0082 ± 0.0004a
Gallic acid[x]	0.0011 ± 0.0001d	0.0014 ± 0.0000b	0.0019 ± 0.0002a	0.0009 ± 0.0001e	0.0010 ± 0.0001e	0.0012 ± 0.0001c
Fumaric acid[y]	0.00017 ± 0.00001c	0.00022 ± 0.00002b	0.00035 ± 0.00003a	0.00013 ± 0.00001d	0.00021 ± 0.00002b	0.00032 ± 0.00002a

Different letters within a row indicate significant differences by Duncan ([x]) or Tamhane ([y]) tests at $P = 0.05$.

cultivars differed, especially in their contents of malic acid, and Korona was characterized by a higher concentration than Elsanta. Salinity resulted in a decline of malic acid with a larger response in cv. Korona. Generally, increasing salt stress resulted in increasing concentrations of minor organic acids, such as acetic, fumaric, gallic and formic acids.

Changes in the contributions of taste relevant compounds can be expressed by a dose-over-threshold value, where the concentration of a compound is related to a taste-threshold value (Scharbert & Hofmann, 2005). Salt stress reduced the contribution of sugar to taste, especially in cv. Elsanta (Table 3). Most affected was the contribution of sucrose. The reduction was up to 26% in cv. Korona and up to 96% in cv. Elsanta; for glucose it was up to 12% and 29%, and for fructose 13% and 27%, respectively. A limited acceptance by the sensory panel was also related to changes in organic acids. The contributions of acetic and citric acid rose, that of malic acid decreased and cv. Elsanta was more susceptible to NaCl salinity than was cv. Korona (Table 3). Gallic, fumaric and formic acids did not reach the taste threshold values and were less important for human taste perception of strawberry fruit. However, their additive effects should be considered. The obtained concentrations of formic acid were negatively correlated with taste ($r = -0.953$), firmness ($r = -0.959$) and appearance of strawberry fruit. A negative influence of acetic acid on appearance ($r = -0.965$) was also found. Also, higher accumulation of Na^+ contributed to the taste of salinity-affected fruits while, in control fruit, the Na^+ content did not influence taste (Table 3; values <0.1).

The ratio of total soluble carbohydrates/organic acids reflected differences between cultivars and effects of the salinity treatments on fruit quality much better than did the ratio TSS/TA (Table 1). Rising salinity levels decreased the ratio of soluble carbohydrates/organic acids, indicating a higher sourness or lower sweetness of fruit. The more salt-sensitive cv. Elsanta was characterized by a more distinct decline of this ratio. Fruits with higher carbohydrate contents or total sweetness index were generally preferred by consumers and this was confirmed in the present study by the sensory panel for colour, taste, firmness and overall impression. A similar trend was reported for tomatoes (Gough & Hobson, 1990; Sato et al., 2006).

A comparison of the Pearson correlation coefficients of the TSS/TA ratio and the ratio of soluble carbohydrates/organic acids with parameters of consumer acceptance showed that only the ratio of soluble carbohydrates/organic acids was closely correlated with taste ($r = 0.968$), firmness ($r = 0.968$), appearance ($r = 0.902$), and general rating ($r = 0.992$). Noteworthy is that, in the present study, the TSS/TA ratio did not correspond with any of the sensory parameters. This result was unexpected, because this ratio is generally recommended as a quick measure of consumer acceptance (Cordenunsi et al., 2003; Ménager et al.,

Table 3
Contribution of selected taste-relevant compounds expressed as dose-over-threshold (DOT) of strawberry fruits cvs Korona and Elsanta differing in their sensitivity to NaCl salinity stress

Compound	Threshold conc. (mM, water)	Korona (less salt sensitive) [mM NaCl]			Elsanta (salt sensitive) [mM NaCl]		
		0	40	80	0	40	80
Sucrose	24.0	1.92	1.83	1.42	1.41	0.10	0.06
Glucose	90.0	1.39	1.27	1.22	1.07	0.90	0.76
Fructose	52.0	2.67	2.46	2.32	1.99	1.72	1.46
Citric acid	2.60	17.08	18.96	19.82	14.64	14.76	18.54
Acetic acid	2.00	5.83	8.50	8.92	6.67	8.33	9.83
Malic acid	3.70	5.68	3.78	3.78	4.04	3.16	3.26
Na^+	7.50	0.07	1.77	3.29	0.03	2.67	3.86
Cl^-	7.50	0.17	0.59	0.65	0.17	0.45	0.84

DOT was calculated as the ratio of actual concentration and taste threshold for the given compound, where the taste threshold concentration in water was taken from the literature.

2004; Schöpplein et al., 2002). An explanation of the lack of correlation could be that TSS includes, not only sugars, but also organic acids, amino acids, pectins and other solutes. Salt stress increased the contents of some of these compounds, for instance proline content (unpublished data). Moreover, the composition of acids was modified (Table 2).

In this experiment the application of salt stress to strawberry did not improve sensory attributes. Different from tomato and melon, the application of NaCl in the nutrient solution is less appropriate in commercial strawberry production practice. The present results are contrary to those of Awang et al. (1993), who reported better taste and higher concentrations of taste-related compounds in strawberry fruit produced under moderate NaCl salinity stress, due to decreased water contents of fruits. However, by using an application technique that minimized water and maintained NaCl stress during strawberry cultivation, concentrations of sugars, organic acids and soluble solids were reduced, in line with the overall appearance of fruits.

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