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# Effects of NaCl application to hydroponic nutrient solution on fruit characteristics of tomato (*Lycopersicon esculentum* Mill.)

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**Abstract**

NaCl was applied to nutrient solution (5 dS $m^{-1}$ versus 1.4 dS $m^{-1}$ in the control) of hydroponically-grown tomato and its effects on taste grading and chemical composition of fruit were investigated. Taste panels indicated NaCl treatment increased sweetness, acidity, umami (i.e. the taste of deliciousness) and overall preference. Hexose concentration of the fruit grown on NaCl treated plants significantly increased; and at the same time, chloric ion, organic and amino acids in general had higher concentrations in NaCl treated plants than the control. Our results showed that (1) consumer grading of the tomato fruit was influenced not only by sugar content but also by the organic and amino acids; (2) increased concentration of soluble solids in the fruit of NaCl treated plants was not the result of simple overall condensation due to the reduction of water transport. The relation of diversified consumer preference, fruit chemical composition, and appropriate evaluation of tomato fruit are also discussed.


*Keywords:* *Lycopersicon esculentum* Mill.; Umami; Sweetness; Consumer preference; Salinity; Nutrient solution; Firmness; Soilless culture

## 1. Introduction

Consumer preference and demand for vegetables are increasingly diversified. Some consumers may weigh priority on how vegetables are produced, i.e. if vegetables are produced environmentally sound and/or organically (Magkos et al., 2003), or on vegetable quality (i.e. lower nitrate content, Escobar-Gutierrez et al., 2002). Consequently, it is essential for growers to understand which segment of the market they are producing for (Carruthers, 2003). Among that diverse preference, there is an increasing consumption and demand for sweeter tomatoes (Aoki, 2003). Some tomatoes are even labeled as 'dessert tomato'; growers claim these tomatoes are sweet enough to be served as a dessert. For such a specific demand of tomato, growers often apply salt and/or drought stress before the harvest to enhance sweetness of fruit (Ehret and Ho, 1986; Adams and Ho, 1992). Petersen et al. (1998) reported that hydroponically produced tomato with NaCl enriched nutrient solution had higher consumer preference, increased sweetness and flavor, but also made the fruit harder. Salt enrichment in nutrient solution is known to increase ascorbic acid as well, which adds acidic taste to the fruit (Zushi and Matsuzoe, 1998). It has been suggested to use sugar/acid ratio as an index for tomato fruit taste (Adams, 1991). However, contrasting results have been shown too, due to the buffering effects of cations and anions (Kader et al., 1978).

Growers often use the Brix value to indicate sugar contents in tomato fruit. However, Brix is not a reflection solely from sugars, it also reflects other soluble solids in the fruit, including organic acids. Therefore, using Brix as a representation of total sugar content can be misleading. Furthermore, sweetness is not only reflecting the sugar concentration because perception of sweetness is different for each sugar; fructose is the sweetest natural carbohydrate and glucose is only 60% as sweet as fructose (Hanover and White, 1993).

In addition to sugars and acids, some free amino acids should considerably affect tomato taste. 'Umami' has been proposed as a source for the taste of deliciousness (Lindemann, 2001). L-Glutamate, an amino acid, has been known as a major ingredient for 'umami', or delicious taste (Ikeda, 1909) and its receptor on the human tongue has been characterized (Chaudhari et al., 2000).

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Therefore, the relation between physiological/biochemical backgrounds and consumer preference in tomato fruit is not yet fully clarified, and there are few comprehensive reports on the relation between taste of tomato grown with NaCl enriched nutrient solution and chemical composition. In the present study we examine effects of NaCl enrichment of the nutrient solution on chemical and physical properties of tomato fruit in relation to taste panel grading.

## 2. Materials and methods

### 2.1. General procedures

Seeds of *Lycopersicon esculentum* Mill. (cv. 'Momotaro Fight', Sakata, Kyoto, Japan) were sown on 4 July 2002 in a Petri dish, supplied with de-ionized water, and placed in an incubator maintained at 25 ± 0.6 °C. Germinated seeds were transplanted into plastic pots (5 cm diameter) filled with commercial soil media (Metromix 250, The Scotts Company, Marysville, OH, USA) on 10 July and placed in a glasshouse. The greenhouse did not have any cooling system and its temperature was controlled by ventilation. Average, maximum, and minimum temperatures in the greenhouse were 26.3 ± 0.2, 31.6 ± 0.3 and 22.6 ± 0.2 °C, respectively. Seedlings were transplanted to rockwool cubes (75 mm × 75 mm × 50 mm) on 3 August, and placed onto rockwool slabs (910 mm × 300 mm × 100 mm) on 1 September. Basal parts of plants, rockwool slabs and cubes containing root system, were covered with silver plastic sheet. Nutrient solution was supplied by a drip irrigation system three to five times daily depending on plant size and environmental conditions. A total of 50 plants were divided into two groups, 25 plants each to the Control (CT) and the NaCl (NT) treatments. Each plant was handled individually as a replicate. A half strength of commercial nutrient solution with electric conductivity (EC) of 1.4 dS $m^{-1}$ (Otsuka Chemical Co. Ltd., Tokyo, Japan; N, P, K, Ca and Mg = 9.3, 2.6, 4.3, 4.1 and 1.5 mequiv./l in the applied concentration) was applied both to CT throughout the experiment and to NT until 9 October. On 10 October, the EC of the nutrient solution for NT was adjusted to 5 dS $m^{-1}$ by adding NaCl to a half strength of the commercial nutrient solution (described above). The nutrient solution was independently circulated in each treatment, monitored and renewed as needed. Every other day, flowers at anthesis were vibrated manually to stimulate pollination and labeled for later investigation. The experiment continued until 31 December, 2002. Harvested fruit was weighed and subjected to taste paneling and chemical analysis.

### 2.2. Taste paneling

Red stage fruit were cut in six pieces of wedge shape, and served to a taste panel. Sixty-six volunteers were randomly selected at the campus of the College of Agriculture and Biological Science, Osaka Prefecture University, and served as taste panels. The panel consisted 29 males and 34 females, ranged from 21 to 60 years old. Average age of the panel was 28.1 years old. The panel graded juiciness, peel hardness, fruit hardness, sweetness, acidity, umami, aroma, and overall preference as 1–5 (5 as the strongest). Grades obtained were statistically analyzed using Wilcoxon's signed rank test.

### 2.3. Physical and chemical investigation

Firmness was measured by a penetrometer with the 1 mm diameter plunger (NRM-2002J, Fudoh, Rheo Tech Co. Ltd., Tokyo, Japan). Five fruit from each treatment group were subjected for the measurement.

Five red stage fruit each from the CT and NT were randomly selected for Brix reading measurement, cut into six wedge shape pieces. A piece from each fruit was homogenized and centrifuged at 9200 × *g* for 20 min, then supernatant was collected and used for Brix and titratable acidity measurements. Brix was measured with the refractometer (N-20, Atago Co. Ltd., Tokyo, Japan).

For titratable acidity measurement, 10 ml of supernatant was dispensed and supplied for titration by 0.1N NaOH until pH 8.1. The amount of NaOH in ml was recorded to calculate titratable acidity in the following equation, which is expressed as the amount of citric acid (mg) in 100 ml of fruit liquid (Moradshahi et al., 1977)

$$T \times 6.4 \times 100/10$$

where $T$ is the amount of 0.1N NaOH in ml used in titration, the value 6.4 represents the amount of citric acid neutralized by 1 ml of 0.1N NaOH, the value 100 represents the conversion into 100 ml of fruit liquid and the value 10 represents the amount of fruit liquid used in measurement.

For sugars, organic acids, and amino acids analysis, five fruit each from both treatments were selected. For each fruit, fresh fruit weight was measured, 10 g of sample was further cut into smaller pieces and placed into a conical flask with 20 ml of 99.5% ethanol. After heating in boiling water bath for 15 min, flasks were ice-bathed and then the samples were homogenized. Filtrated liquid was collected and brought up to 50 ml with 99.5% ethanol.

For sugar analysis, 10 ml ethanol extract liquid, with 1 ml of 1% inositol solution as an internal standard, was dried by rotary evaporator and then brought up to 10 ml with distilled water. Twenty-five microliters of sample filtered by Sep-pak (Waters Corporation, Milford, MA, USA) was subjected to HPLC (LC10A, Shimadzu, Kyoto, Japan). Samples were run on a NH2P-50 (Showa Denko, Tokyo, Japan) column at 0.8 ml/min with a column temperature at 30 °C and the mobile phase was 75% acetonitrile. Concentration of fructose, glucose, and sucrose was detected by RID-6A (Shimadzu, Kyoto, Japan).

For measurement of organic acids except ascorbic acids 5 ml ethanol extract, as in sugar analysis, added with 0.5 ml of 0.5% glutaric acid as internal standard was dried by rotary evaporator, then brought up to 5 ml with distilled water. Fifty microliters of the solution sample was filtered and subjected to HPLC analysis (LC10A, JASCO Corporation, Tokyo, Japan) after filtration. Samples were run on a C-811 (Showa Denko, Tokyo, Japan) at 0.3 ml/min with column temperature set at 60 °C. For gradient elution separation, 3 mM perchloric acid