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Sensory analysis, sugar and acid content of tomato at different EC values of the nutrient solution

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Abstract

The influence of three concentrations of nutrient solution (electrical conductivity, EC: 1.0, 3.5 and 6.0 dS m⁻¹) on the sensory properties of tomato was investigated. Two tomato cultivars representing two types—a conventional round tomato (cv. Counter) and a round longlife tomato (cv. Vanessa)—were harvested from a closed hydroponic system with recirculating nutrient solution. The same products were investigated by quantitative descriptive analysis with trained panellists and by an acceptance test with consumers. Furthermore, the contents of reducing sugars and the titratable acid of fruits were analysed. To find explanations for consumer preferences relationships between the results of quantitative descriptive analysis, consumer acceptance tests and the sugar and acid contents of the fruits were investigated.

The quantitative descriptive analysis revealed changing intensities of sensory attributes of appearance, firmness by touch, flavour, aftertaste and mouthfeel with increasing nutrient solution EC. However, the change of different sensory attributes was different for the two cultivars. Intensity of unfavourable flavour attributes such as *mouldy*, *spoiled sweetish* and *bitter* was stronger only for the longlife cultivar when cultivated at high EC. Higher EC values resulted in higher contents of reducing sugars and titratable acid, which influenced the intensity of several sensory attributes of smell, flavour and aftertaste evaluated by the descriptive panel.

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Consumers preferred the flavour from those fruits of both cultivars that were cultivated at EC 3.5 dS m⁻¹. Acceptance in the characteristics flavour, aftertaste and mouthfeel of fruits of the longlife cultivar grown at EC 6.0 dS m⁻¹ was diminished. There were significant correlations between the results of the hedonic consumer assessment of the products and the quantitative descriptive analysis, which could contribute to explain preferences. In most cases, the sensory changes caused by increasing nutrient solution EC from 1.0 to 6.0 dS m⁻¹ improved the quality of the conventional round cultivar but not that of the longlife one. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Consumer preference; Inner compounds; *Lycopersicon esculentum* Mill.; Nutrient solution EC; Sensory analysis

1. Introduction

Sensory properties are very important for the assessment of vegetable quality by consumers and for their purchase behaviour. At the market, only those products that correspond to the expectations of the consumers can survive. Therefore, it is necessary to investigate and to consider factors influencing fruit quality and their effect on sensory properties during production and after harvest.

For the intensive production of tomato (*Lycopersicon esculentum* Mill.) in greenhouses, soilless cultivation systems are used. A practical possibility to influence fruit quality is to change the concentration of the nutrient solution and its electrical conductivity (EC; Cornish, 1992; Hendriks, 1993; Janse and Schols, 1994; Janse, 1995). Some years ago an EC level of 2.0–2.5 dS m⁻¹ was suggested (Göhler and Drews, 1989). Nowadays advisers recommend an EC between 3.0 and 4.5 dS m⁻¹ (De Kreij et al., 1997). It is expected that the higher EC will result in a better flavour caused by a higher content of total soluble solids, acids, sugars and aroma volatiles (Stevens et al., 1979; Adams, 1988; Holder and Christensen, 1988; Sonneveld and Welles, 1988; Cornish, 1992; Solimann and Doss, 1992). It is also supposed that tomato cultivars respond differently to different levels of nutrient solution EC. However, it is not clear, that the effect always improves the sensory properties of the fruits. Hence, to produce high quality fruit, knowledge is necessary about the quantitative and qualitative sensory changes of the product and about the consumer acceptance of the product. Consumers define quality. However, consumer acceptance tests only tell us what products consumers like and they give us no idea about the reasons why (Heintz and Kader, 1983; Lyon et al., 1992). Therefore, a trained descriptive panel is needed, which enables the determination of qualitative and quantitative sensory properties of a product. In addition, a search for connections between the results of the sensory analysis by a trained panel and the hedonic judgement of the products by consumers is necessary.

The aims of our investigations were:

1. to analyse the sensory properties of the fruits of two tomato cultivars by quantitative descriptive analysis and to compare the sensory alteration as affected by different EC levels of the same nutrient solution composition;
2. to determine the acceptance for those tomato fruits by a consumer acceptance test;
3. to measure the reducing sugars and titratable acid in these tomato fruits and to analyse their influence on the sensory attributes of smell, flavour and aftertaste; and
4. to search for possible explanations for the consumer preferences.

2. Material and methods

2.1. General treatment conditions

The tomato cultivars ‘Counter’ and ‘Vanessa’ (Table 1) were grown hydroponically in a 1500 m² steel-glass-greenhouse with climate control according to recommendations of Lanckow (1989) at the Institute of Vegetable and Ornamental Crops e.V. in Grossbeeren (Germany, lat. 52°N). Twelve-day old seedlings were transplanted to rockwool cubes, and then transferred and put in troughs in the greenhouse when 50 days old on February 7 in 1995. Always two troughs were provided with the same closed nutrient circle. 108 plants per cultivar were grown in each row (plant density 2.1 plant/m²). Rockwool cubes were covered with the trough. The experiment was carried out with three different concentrations of nutrient solution (EC-values 1.0, 3.5 and 6.0 dS m⁻¹).

The nutrient solution composition in the closed recirculating system was chosen according to the recipe of Sonneveld and Straver (1988). The nutrient solution was mixed and applied with a commercially available but modified mixing unit. After mixing, the solution was pumped into 400 l supply tanks for each treatment and replicate. Solution was supplied at a system frequency depending on global

Table 1

Origin and characteristics of the tomato cultivars grown based on information of the breeders (unpublished)

Description	cv. Counter	cv. Vanessa
Breeding company	De Ruyter, The Netherlands	Zeraim Gedera, Israel
Type	light fruit type	light fruit type
Fruit	classic globe shape	small to medium size, flattened globe shape
Hybrid	yes	yes
Shelf live	good	long life (2 weeks)
<i>rin</i> or <i>nor</i> gen	no	no
Fruit chambers	2–3	3–4
Mean fresh matter	80 g	85 g

radiation, 20 ml per application and plant via a capillary drip system directly in front of the rockwool cube. At the end of the two troughs, excess solution was collected in a drainage tank. New nutrient solution was prepared from excess solution by adding rainwater ($EC < 0.1 \text{ dS m}^{-1}$) and/or stock solution.

Cultivation corresponded to conditions close to commercial production but no carbon dioxide was applied (Schwarz and Kuchenbuch, 1996). The greenhouse had a transmission coefficient of 55% and the mean daily global radiation amounted to 12.5 MJ m^{-2} during the 125 days growing period before harvest for analysis.

For each, sensory and chemical analysis, tomatoes of both cultivars and of the three EC treatments were picked at only one harvest day June 12. Fruits were selected when red-ripe, stage 8–9 of the colour screening scale for tomato (Anonymous, 1992).

2.2. Sensory investigations

Comprehensive analyses of sensory attributes of tomato fruits with quantitative descriptive analysis by a trained panel (Stone et al., 1974; Stone and Sidel, 1993) and the acceptance test by consumers were both part of the sensory investigations.

The descriptive panel, consisting of 10 trained panellists, established a sensory profile of the product tomato with 58 attributes of six characteristics described in Table 2. Panellists distinguished between first impression during bite off and second impression during mastication of the fruit pieces for the flavour attributes *tomato-like*, *sweet* and *sour*.

The intensity of all sensory impressions of each product sample was evaluated using an unstructured scale with the anchor points 0 — ‘not perceptible’ and 100—‘strongly perceptible’.

In the consumer acceptance test 100 housewives evaluated the products. They assessed products for first impression, appearance, smell, flavour, aftertaste and mouthfeel using unstructured scales with the anchor points 0— ‘unpleasant/bad’ and 100—‘pleasant/good’ (values of acceptance).

All products were presented monadically in random order to both trained panellists and consumers. In all sensory tests, the assessors received one whole fruit for the evaluation and worked in a sensory laboratory in single cabins under defined conditions of $20 \pm 2^\circ\text{C}$, 60–70% relative humidity and diffuse daylight. Both panellists and consumers halved the fruits to assess the characteristic smell. Panellists repeated the analysis and used Computer Aided Sensory Analysis software (Oliemans and Punter, Netherlands).

2.3. Chemical analysis

Chemical analyses were carried out as double estimations per product using 15 homogenised fruits per sample. The content of titratable acid was determined by

Table 2
Overview of sensory characteristics and attributes used for the quantitative descriptive analysis

Characteristics	Attributes
Appearance	
external	notches, blossom end raised, shape, colour intensity, colour uniformity, translucency, mechanical damage, stains, small cracks, gloss
internal	pulp colour intensity, pericarp thin/thick, locular portion green, seed number, seed darkness,
Firmness by touch	firmness (finger pressure), firmness uniformity, tight
Smell of the cut fruit	intensive, tomato-like, tomato leafs, sweetish, sour, fruity, mouldy, raw potato, fresh cut grass, green banana peel
Flavour	intensive, tomato-like ^a , sour ^a , sweet ^a , mouldy, spoiled sweetish, fresh cut grass, raw potatoes, bitter, fruity
Aftertaste	intensive, tomato-like, sweet, sour, bitter, sweetish, burning, mouldy, fresh cut grass
Mouthfeel	pericarp firm, juicy, mealy, granular, gristly, slimy-pulpy; peel firm

^a Subdivided into first and second impressions.

potentiometric titration with 0.1 M NaOH (LMBG, 1983), and the content of sugar by enzymatic detection of glucose and fructose (Boehringer Mannheim GmbH, 1986), summarised to reducing sugars. Results were converted to 1 g fresh matter basis.

2.4. Statistics

Results of chemical analysis were analysed by analysis of variance, and sensory results were tested by non-parametric procedures for independent samples at $p = 0.05$ (Kruskal–Wallis and Mann–Whitney) using SPSS[®] for Windows (version 6.1.3., SPSS Chicago). Results were related by nonparametric procedure with Spearman's rank correlation coefficient. Data points in figures are treatment means. In column charts different letters show significant differences of the EC treatments between the results of one cultivar.

3. Results

3.1. Quantitative descriptive analysis

The three EC levels affected the intensity of some sensory attributes of both cultivars. Table 3 summarises the significant changes in 15 attributes of the sensory characteristics, external and internal appearance, firmness by touch, flavour, aftertaste and mouthfeel for both the cultivars and the EC levels

Table 3

Significant differences between the intensity of sensory attributes belonging to different characteristics of two cultivars representing two tomato types grown at different nutrient solution EC; quantitative descriptive analysis

Sensory characteristics	Attributes of characteristics	Cultivar 'Vanessa'		Cultivar 'Counter'	
		A ^a	B ^b	A ^a	B ^b
Appearance: external internal	Small cracks on the fruit surface	+*	+*		
	Locular portion green	+***	+***		
	Seed colour: spotted			-***	-*
Firmness by touch	Firmness (finger pressure)			+**	
Flavour	Mouldy	+*			
	Spoiled-sweetish	+**			
	Bitter		+**		
	Fruity			+*	
Aftertaste	Tomato-like	-*	-*		
	Sour			+*	+*
	Burning	+*	+*		
	Mouldy	+**			
Mouthfeel	Fruit flesh firm			+**	+*
	Fruit flesh juicy	-*		-*	
	Peel firm			+*	

^a Comparison between EC 1.0 and 6.0 dS m⁻¹.

^b Comparison between EC 3.5 and 6.0 dS m⁻¹.

+ Higher magnitude at higher EC.

- Lower magnitude at higher EC.

* $p = 0.05$.

** $p = 0.01$.

*** $p = 0.001$.

investigated. These EC levels affected different sensory attributes in each cultivar. Only the mouthfeel attribute *fruit flesh juicy* was equally influenced in both cultivars. Between EC 1 and 3.5 dS m⁻¹ no significant differences were found.

No attributes of smell characteristic of cut fruits changed with changing EC levels of the nutrient solution.

To show trends in the evaluation of attributes by the panellists caused by increasing the nutrient solution EC, results for flavour and mouthfeel characteristics were depicted for each cultivar as spider-web-graphics (Fig. 1(a) and (b), Fig. 2(a) and (b)).

For 'Vanessa', the flavour attribute *intensive* (including all sensations of flavour) was stronger with increasing EC (Fig. 1(a)). Other attributes of flavour, *mouldy*,

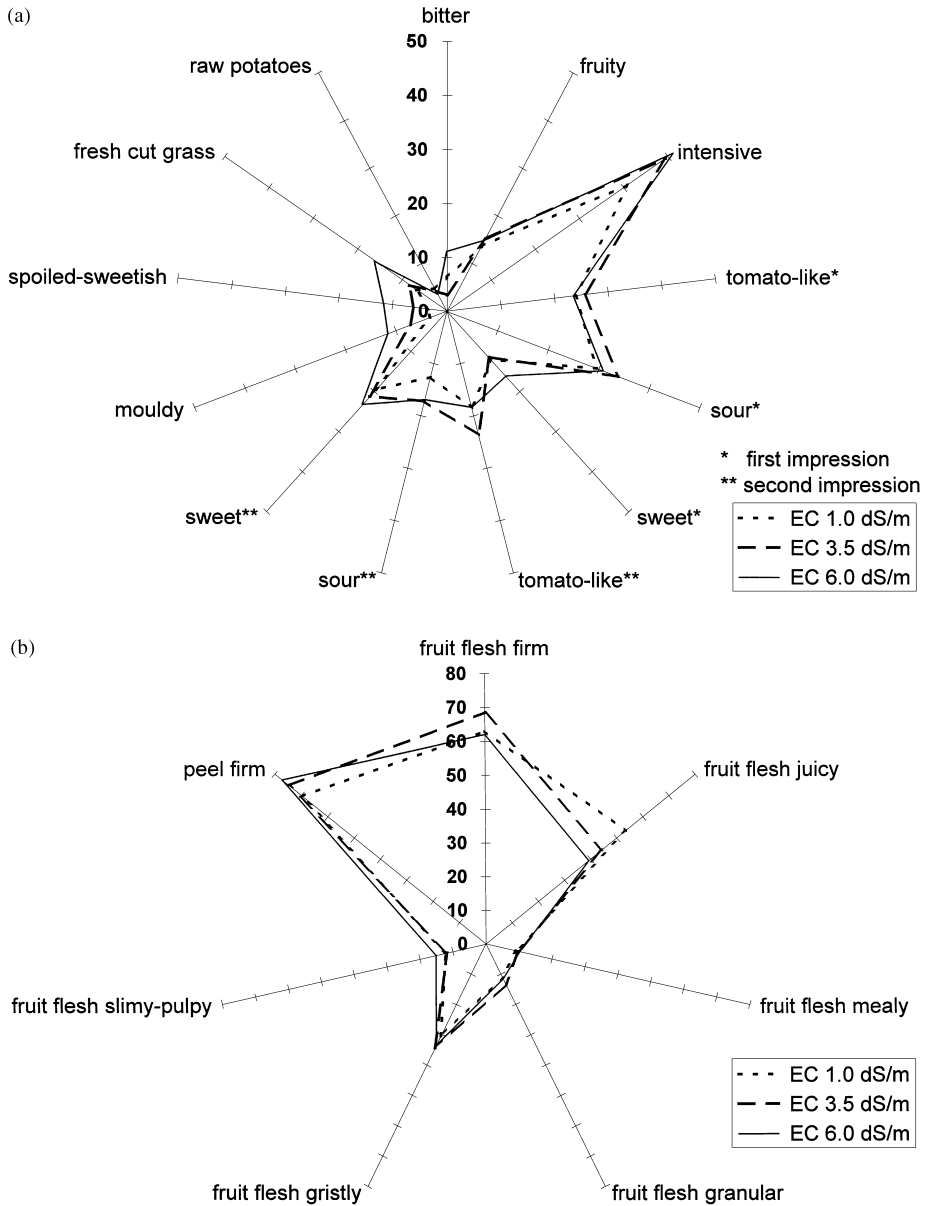


Fig. 1. (a) Quantitative descriptive analysis of Flavour attributes of the longlife tomato cultivar 'Vanessa' grown at different nutrient solution EC. (b) Quantitative descriptive analysis of mouthfeel attributes of the longlife tomato cultivar 'Vanessa' grown at different nutrient solution EC.

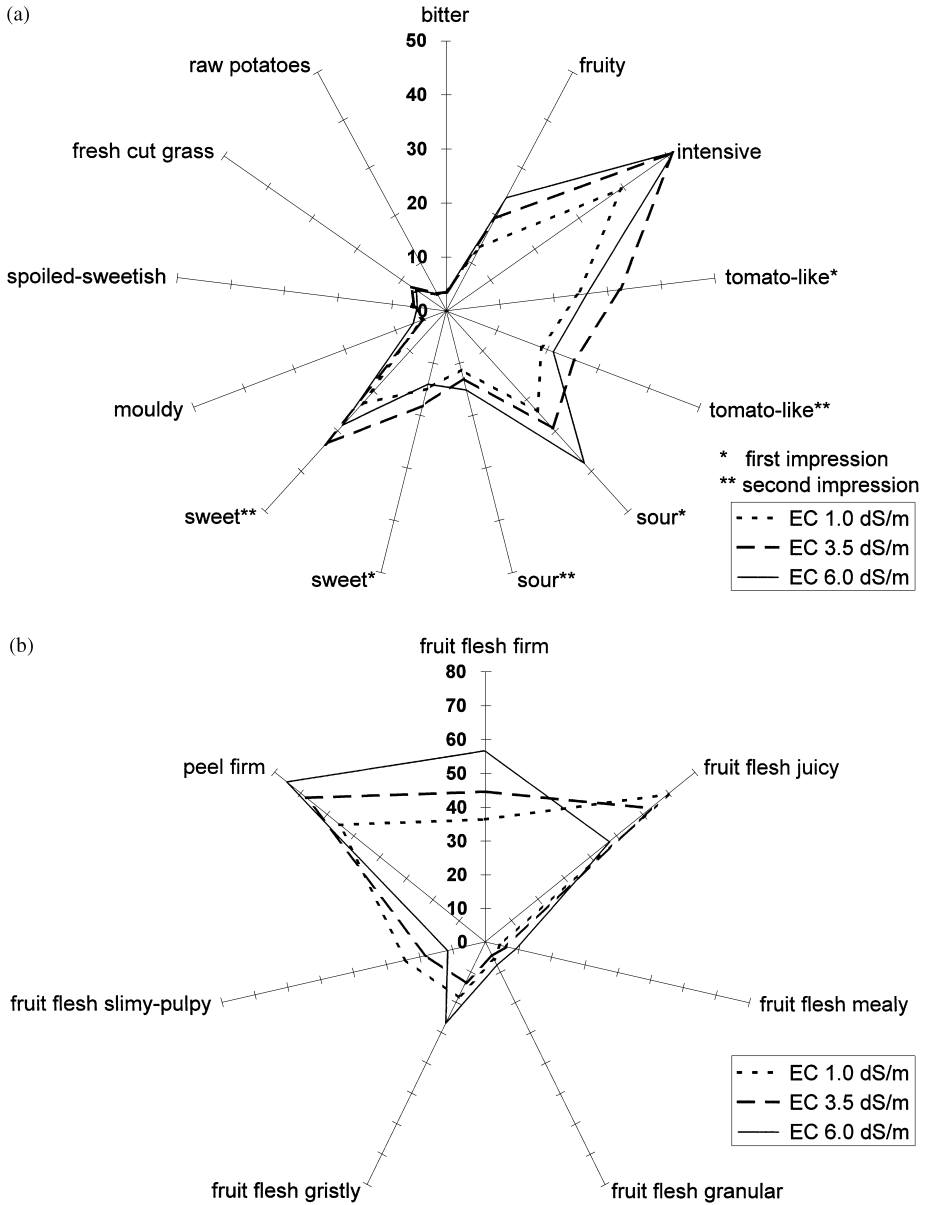


Fig. 2. (a) Quantitative descriptive analysis of Flavour attributes of the round tomato cultivar 'Counter' grown at different nutrient solution EC. (b) Quantitative descriptive analysis of mouthfeel attributes of the round tomato cultivar 'Counter' grown at different nutrient solution EC.

spoiled sweetish, fresh cut grass and bitter, intensified as well as aftertaste attributes like *burning* and *mouldy*. The strongest sensory perception was for fruits from plants grown in nutrient solution EC 6 dS m⁻¹. Only *tomato-like* and *sour* were smaller in fruits from plants grown at nutrient solution EC 6 dS m⁻¹.

For the mouthfeel characteristic the attribute *fruit flesh juicy* declined with increasing EC level (Fig. 1(b)). Other attributes of mouthfeel did not change their intensity for 'Vanessa'.

In 'Counter', the increased EC level of the nutrient solution intensified the flavour attributes *intensive*, *sour*, and *fruity* (Fig. 2(a)). As for 'Vanessa', fruits of 'Counter' at EC 3.5 dS m⁻¹ had the most intensive flavour attribute *tomato-like*. The intensity of *sour* aftertaste was raised. In addition, enhanced *firmness* of the fruit flesh and the peel and a decreased *juiciness* were noticed for mouthfeel characteristic at higher EC levels (Fig. 2(b)).

In general, the increased EC level resulted in a much more distinct change for 'Counter' than for 'Vanessa', especially for mouthfeel attributes.

3.2. Consumer acceptance test

Results of the consumer acceptance test are summarised in Fig. 3. Fruits of both cultivars of the EC treatments 1 and 3.5 dS m⁻¹ had similar acceptance for the characteristics first impression and appearance. Compared to fruits grown at EC 1 dS m⁻¹, consumers valued fruits of 'Counter' 13% and those of 'Vanessa' 26% lower when grown at EC 6 dS m⁻¹. For appearance characteristics, values were 14% lower and 29% lower, respectively. Smell, flavour, aftertaste and mouthfeel of fruits of 'Vanessa' grown at EC 6 dS m⁻¹ had significantly lower acceptance than all other fruits. Flavour and aftertaste acceptance of both cultivars were highest in fruits grown at EC 3.5 dS m⁻¹. For mouthfeel, only fruits of 'Counter' were favoured at EC 3.5 dS m⁻¹. 'Vanessa' was assessed with the same acceptance level for mouthfeel at EC 1 and EC 3.5 dS m⁻¹.

In general, the consumers preferred 'Vanessa' fruits grown at EC 1 and 3.5 dS m⁻¹ in their external appearance rather than 'Counter' fruits. However, acceptance of 'Counter' was higher for appearance when grown at EC 6 dS m⁻¹ and for flavour, aftertaste and mouthfeel grown at all EC levels compared with fruits of 'Vanessa'. Consumers disapproved of fruits of 'Vanessa' grown at EC 6 dS m⁻¹ with acceptance values lower than 50 for the flavour, aftertaste and mouthfeel characteristics.

3.3. Chemical analysis

The higher the concentration of the nutrient solution the higher were the contents of reducing sugars and titratable acid of the fruits of both cultivars (Table 4). Sugar and acid contents of the fruits differed significantly among EC

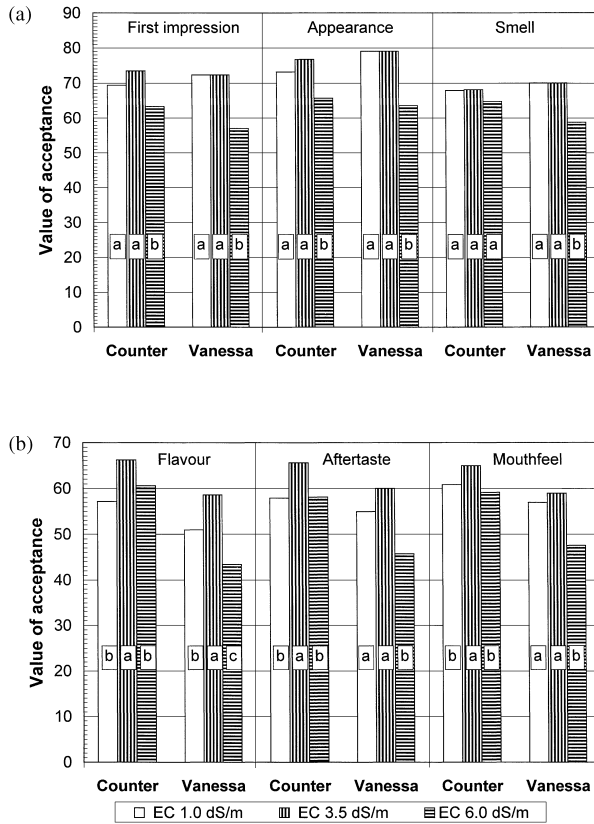


Fig. 3. Results of the consumers assessment test of the tomato cultivars 'Counter' and 'Vanessa' grown at different nutrient solution EC.

Table 4

Means of fresh matter based contents of reducing sugars and titratable acids of two cultivars representing two tomato types grown at different nutrient solution EC

Cultivar	EC (dS m ⁻¹)	Reducing sugars (mg g ⁻¹)	Titratable acids (eq g ⁻¹)
'Vanessa'	1.0	28.95c ^a	0.627c
	3.5	31.43b	0.788b
	6.0	35.05a	0.890a
'Counter'	1.0	26.80b	0.621c
	3.5	30.77a	0.704b
	6.0	32.17a	0.785a

^a Different letters represent significant differences.

treatments and cultivars. Only fruits of ‘Counter’ from the EC treatments 3.5 and EC 6 dS m⁻¹ did not differ significantly in reducing sugar contents. Fruits of ‘Counter’, EC 6 dS m⁻¹, had 20% higher sugar content than fruits from EC 1 dS m⁻¹, and 26% more acid. Differences for ‘Vanessa’ were 21% for reducing sugars and 42% for titratable acid.

3.4. Chemical versus quantitative descriptive analysis

Some characteristics from quantitative descriptive analysis and chemical analyses were significantly correlated. *Sweetish* smell, *tomato-like*, *mouldy* and *fresh cut grass* flavour and *intensive* aftertaste were correlated to reducing sugar content ($R \geq 0.70$). Titratable acid content correlated with *mouldy* flavour and *intensive* aftertaste (Table 5).

Table 5

Significant correlations between the content of reducing sugars and titratable acid of tomatoes, respectively, and sensory attributes of the quantitative descriptive analysis

Sensory characteristics	Attributes	Correlation coefficient (Spearman's <i>R</i>)	
		reducing sugar	titratable acid
Smell	Sweetish	0.75	
Flavour	Tomato-like ^a	0.74	
	Mouldy	0.77	0.81
	Fresh cut grass	0.74	
Aftertaste	Intensive	0.68	0.78

^a First impression.

Table 6

Significant correlations between results of tomato fruits assessed by consumer assessment test and by quantitative descriptive analysis ($p = 0.05$)

Consumers sensory characteristic	Panellists sensory characteristic and attributes	Correlation coefficient (Spearman's <i>R</i>)
First impression	Appearance: shape	0.87
Flavour	Flavour: tomato-like ^a	0.76
	Taste: bitter	-0.80
Aftertaste	Flavour: tomato-like ^a	0.78
	Taste: bitter	-0.71

^a First impression.

3.5. Quantitative descriptive analysis versus consumer acceptance

Consumer's first impressions were positively correlated with *regular shape* appearance of fruits. Liking of flavour was positively correlated with *tomato-like* flavour and negatively with *bitter* taste. Aftertaste was positively correlated with *tomato-like* flavour and negatively with *bitter* taste (Table 6). With $R = 0.65$ a further relation was found between mouthfeel reported by consumers and the *fruit flesh juicy* attribute reported by trained panellists.

4. Discussion

Increase in nutrient solution concentration led to a general change of intensity of sensory characteristics of tomato fruits and to an increase in sugar and acid contents. This result was found for both cultivars. Janse (1995) and Kersten and Van Veen (1998) mentioned the importance of cultivar for the enhancement of fruit quality via increase of nutrient solution EC. Quantitative descriptive analysis results agree with the statement mentioned above. In addition, they show in detail how increasing EC levels influence the fruit characteristics of two cultivars. Except the *fruit flesh juicy* attribute of mouthfeel, all sensory attributes were changed differently for the longlife cultivar than for the round cultivar (Table 3).

In contrast to 'Counter', the change of sensory attributes of the longlife type 'Vanessa' in response to higher EC were unfavourable. For 'Vanessa', higher EC led to a much stronger intensity of flavour attributes like *mouldy*, *spoiled sweetish*, *bitter* and of the aftertaste attributes like *mouldy* and *burning*, sensory attributes that contribute to off-flavour (Fig. 1(a)). In contrast, for 'Counter' the more intense *fruity* flavour, increased firmness of the whole fruit, and of the fruit flesh, and increasing juiciness were assessed to improve fruit quality by consumers (Fig. 3).

Verkerke et al. (1991, 1993) reported an increase of skin firmness connected to more soft fruits with raising EC levels from 1 to 8 dS m⁻¹, whereas Cornish (1992) did not find any firmness change in fruits of two tomato cultivars grown in the field in a similar EC range. Concerning our opposite results for the two cultivars two reasons could be found: a physiological mechanism involved in cultivar differences in salt tolerance can cause different reactions of cultivars to salinity (Solimann and Doss, 1992), and the ability of tomato genotypes to adapt to salinity depends on the presence or efficiency of a mechanism for regulating internal chloride and sodium concentrations (Bolarin et al., 1993). While the nutrient solution used by Bolarin et al. (1993) was made by adding sodium chloride to a basis nutrient solution, our solution was made by increasing the total ion concentration in the solution.

Some assessments of characteristics by consumers were strongly related to attributes the trained panellists evaluated. The external appearance of tomato fruits strongly affected the consumers' assessment of first impression characteristics. The more intensive the *tomato-like* flavour and aftertaste and the less *bitter* the fruits, the higher was the acceptance of the fruits. Different authors mention the importance of texture, aroma, mealiness, juiciness, and sweetness as quality criterion for tomato (Baldwin et al., 1991; Janse, 1995; Kersten and Van Veen, 1998). The correlation we found between juiciness, mealiness and gristliness of the fruit flesh and the mouthfeel of the consumers verify these results. Correlations were significant, but coefficients were 0.60 and 0.67. Therefore, they are not mentioned in Table 6.

Our own results, as well as others, show very clearly a general enhancement of sugar and acid contents of fruits with increasing EC levels of the nutrient solution (Cornish and Nguyen, 1989; Gough and Hobson, 1990; Cho et al., 1997). Content of various sugars, acids, and aroma volatiles essentially determine taste and overall flavour of tomato (Stevens et al., 1977; Jones and Scott, 1983; McGlasson, 1989; Baldwin et al., 1995; Ke and Boersig, 1996). As Stevens (1979) reported based on investigations with five tomato cultivars, sourness was highly correlated with content of titratable acid and sweetness with content of reducing sugars. Although acid and sugar contents increased with increasing EC levels, the quantitative descriptive analysis did not show significant differences in the fruit assessment for the *sour* or *sweet* taste attributes. The sweetest fruits were recorded by the trained panellists analogous to the highest sugar content of 'Vanessa' grown at EC 6.0 dS m⁻¹. But fruits of 'Counter' from treatment at EC 3.5 dS m⁻¹ were evaluated as sweetest although they did not have the highest sugar content. Possible explanations could be:

- Different relative levels of sugar and acid contents in fruits of the two tomato cultivars.
- Other compounds or the ratio of internal compounds not only sugar and acid content of the fruits determine the intensity of *sour* and *sweet* sensory perception. Krumbein and Auerswald (1998) found a relation between aroma volatiles and *sweet* and *sour* attributes.
- Furthermore, Brückner and Auerswald (1999) demonstrated a significant relation between *sweet* attribute on one hand and sugar content in combination with *juiciness* attribute on the other hand.

Acid and sugar contents not only affected *sweet* and *sour* taste attributes but also overall flavour as perceived by trained sensory judges (Kader et al., 1977, 1978; Stevens et al., 1977; Jones and Scott, 1984; Hobson and Bedford, 1989). Our results show relations between sugar and acid contents, and assessments of the quantitative descriptive analysis for different flavour attributes, including *mouldy*, *tomato-like*, and *fresh-cut grass* for their formation aroma volatiles are also important.

The general different sensory changes of the varieties investigated at different EC levels could be due to differences in the ripening characteristics. Janse (1995) concluded after investigations of numerous cultivars that tomato cultivars with the *rin* gene (ripening inhibition) have only moderate flavour characteristics although sugar and acid content were similar compared to cultivars with good flavour characteristics. Probably, this is connected with the absence or otherwise with the intensified presence of some aroma volatiles (McGlasson et al., 1987). Our investigated cultivar 'Vanessa' belongs to the group of longlife tomatoes but it has no *rin* gene (Table 1). The ripening inhibition is caused by an increased diameter of the cell wall (unpublished, Zeraim Gedera company). Based on investigations with different tomato cultivars including 'Vanessa', Krumbein and Auerswald (1998) found relations between sensory flavour and aftertaste attributes, e.g. *tomato-like* and *bitter*, and aroma volatiles. But the influence of nutrient solution EC on aroma volatiles has not been investigated yet.

The perceived firmness of the fruit flesh and peel and their EC-induced changes were found to be different in the two cultivars. This also may be due to the increased cell wall diameter which led to the increased firmness of 'Vanessa' fruits and delayed the softening process during ripening. The physiological processes behind the effect of increased nutrient solution EC on strengthening cell wall and tissue firmness may be almost solely effective in the case of 'Vanessa', whereas it counteracts a faster softening process in the case of 'Counter', where a broader range facilitates the expression as an altered mouthfeel property.

Especially, those sensory attributes related to appearance, flavour and aftertaste, were affected by the increase of the EC from 1 to 6 dS m⁻¹.

In general, it was possible to affect the intensity of sensory attributes and the content of reducing sugar and tritrate acid by increasing nutrient solution EC from 1 to 6 dS m⁻¹. The induced sensory changes were predominantly favourable for 'Counter' but not for 'Vanessa'.

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References

- Anonymous, 1992. Kleur-stadia tomaten. Centraal Bureau van de Tuinbouwveilingen in Nederland (Ed.), 2803 PE Gouda.
- Adams, P., 1988. Some response of tomatoes grown in NFT to sodium chloride. Proceedings of the Seventh International Congress on Soilles Culture, Flevohof, NL, 13–21 May, pp. 59–70.

- Baldwin, E.A., Nisperos-Carriedo, M.O., Moshonas, M.G., 1991. Quantitative analysis of flavor and other volatiles and for certain constituents of two tomato cultivars during ripening. *J. Am. Soc. Hortic. Sci.* 116(2), 265–269.
- Baldwin, E.A., Scott, J.W., Malundo, T.M., Shewfelt, R.L., 1995. Instrumental and sensory analysis of tomato flavor. *HortScience* 30(4), 786.
- Boehringer Mannheim GmbH, 1986. Methoden der biochemischen Analytik und Lebensmittelanalytik, Biochemica, Mannheim Deutschland. pp. 37–38.
- Bolarin, M.C., Perez-Alfocea, F., Cano, E.A., Estan, M.T., Caro, M., 1993. Growth, fruit yield, and ion concentration in tomato genotypes after pre- and post-emergence salt treatments. *J. Am. Soc. Hortic. Sci.* 118(5), 655–660.
- Brückner, B., Auerswald, H., 1999. Instrumental data—consumer acceptance. In: Shewfelt, R.L., Brückner, B. (Eds.), *Fruit and vegetable quality: An integrated view*. Technomic Publishing, Lancaster, PA, USA, in press.
- Cho, J.Y., Lee, B.S., Park, S.G., Chung, S.J., 1997. Effect of NaCl in nutrient solution during seedling stage and after transplanting on the fruit quality of aeroponically grown tomato plants, *Lycopersicon esculentum* L. In: *Proceedings of the 7th ISHS Symposium on Vegetable Quality*, Seoul (Korea), pp. 240–244.
- Cornish, P.S., Nguyen, V.Q., 1989. Use of high soil solution electrical conductivity to improve the quality of fresh market tomatoes from coastal New South Wales Australia. *Aust. J. Exp. Agric.* 29(6), 893–900.
- Cornish, P.S., 1992. Use of high electrical conductivity of nutrient solution to improve the quality of salad tomatoes (*Lycopersicon esculentum*) grown in hydroponic culture. *Aust. J. Exp. Agric.* 32, 513–520.
- De Kreijl, C., Voogt, W., van den Bos, A.L., Baas, R., 1997. Voedingsoplossingen voor de teelt van tomaat in gesloten teeltsystemen. Proefstation voor Bloemisterij en Glasgroente, Naaldwijk, The Netherlands VG2, pp. 21.
- Göhler, F., Drews, M., 1989. Hydroponische Verfahren bei der Gemüseproduktion in Gewächshäusern. Landwirtschaftsausstellung der DDR, agrabuch, 1. Auflage, pp. 108.
- Gough, C., Hobson, G.E., 1990. A comparison of the productivity, quality, shelf-life characteristics and consumer reaction to the crop from cherry tomato plants grown at different levels of salinity. *J. Hortic. Sci.* 65(4), 431–439.
- Heintz, C.M., Kader, A.A., 1983. Procedures for the sensory evaluation of horticultural crops. *HortScience* 18(1), 18–22.
- Hendriks, L., 1993. Bon Appetit: Marktgericht Tomaten telen. *Groenten en Fruit/Glasgroenten* 23, 10.
- Hobson, G.E., Bedford, L., 1989. The composition of cherry tomatoes and its relation to consumer acceptability. *J. Hortic. Sci.* 64, 321–329.
- Holder, R., Christensen, M.H., 1988. The effect of electrical conductivity on the growth and composition of cherry tomatoes grown on rockwool. *Proceedings of the Seventh International Congress on Soilles Culture*, Flevothof, NL, 13–21 May, pp. 213–228.
- Janse, J., Schols, M., 1994. Bon appetit doet naam alle eer aan. *Groenten en Fruit/Glasgroenten* 4(7), 11.
- Janse, J., 1995. Flavour of tomatoes. In: XXX. Vortragstagung der Deutschen Gesellschaft für Qualitätsforschung (Pflanzliche Nahrungsmittel), Heilbronn, Deutschland, 27–28. März 1995, pp. 179–194.
- Jones, R.A., Scott, S.J., 1983. Improvement of tomato flavor by genetically increasing sugar and acid contents. *Euphytica* 32(3), 845–855.
- Jones, R.A., Scott, S.J., 1984. Genetic potential to improve tomato flavor in commercial F1 hybrids. *J. Am. Soc. Hortic. Sci.* 109, 318–321.

- Kader, A.A., Stevens, M.A., Albright-Holton, M., Morris, L.L., Algazi, M., 1977. Effect of fruit ripeness when picked on flavor and composition in fresh market tomatoes. *J. Am. Soc. Hortic. Sci.* 102, 724–731.
- Kader, A.A., Morris, L.L., Stevens, M.A., Albright-Holton, M., 1978. Composition and flavor quality of fresh market tomatoes as influenced by some postharvest handling procedures. *J. Am. Soc. Hortic. Sci.* 103, 6–13.
- Ke, D., Boersig, M., 1996. Sensory and chemical analysis of tomato flavor. *HortScience* 31(4), 599.
- Kersten, M., Van Veen, L., 1998. Ras veel belangrijker voor smaak dan EC. *Groenten en Fruit/Glasgroenten* 8(7), 16–17.
- Krumbein, A., Auerswald, H., 1998. Characterization of aroma volatiles in tomatoes by sensory analysis. *Nahrung* 42(6), 395–399.
- Lanckow, H.-J., 1989. Modernes Produktionsverfahren Gewächshaustomate. *Landwirtschaftsausstellung der DDR, Markkleeberg (iga-Empfehlungen für die Praxis/agrabuch)* 1. Aufl. pp. 94.
- LMBG, 1983a. Bestimmung des Gesamtsäuregehaltes von Tomatenmark (potentiometrische Methode). L.26.11.03-4.
- Lyon, D.H., Francombe, M.A., Hasdell, T.A., Lawson, K., 1992. Guidelines for sensory analysis in food product development and quality control. Chapman and Hall, London, New York, Tokyo, Melbourne, Madras, pp. 131.
- McGlasson, W.B., Kast, J.H., Shaw, K.J., Meldrum, S.K., 1987. Influence of the non-ripening mutants *rin* and *nor* on the aroma of tomato fruit. *HortScience* 22(4), 632–634.
- McGlasson, W.B., 1989. Objective measurement of quality of fresh market tomatoes. *Acta Hortic.* 247, 373–376.
- Schwarz, D., Kuchenbuch, R., 1996. Growth analysis of tomato in closed recirculating systems in relation to EC value of the nutrient solution. *Acta Hortic.* 450, 169–176.
- Solimann, M.S., Doss, M., 1992. Salinity and mineral nutrition effects on growth and accumulation of organic and inorganic ions in two cultivated tomato varieties. *J. Plant Nutr.* 15(12), 2789–2799.
- Sonneveld, C., Straver, A., 1988. Voedingsoplossing voor groenten en bloemen in water of substraten. Consulentenschap voor de Tuinbouw. Proofstation voor Tuinbouw onder Glas, Naaldwijk 11, 36.
- Sonneveld, C., Welles, G.W.H., 1988. Yield and quality of rockwool-grown tomatoes as affected by variations in EC-value and climatic conditions. *Plant Soil* 111, 37–42.
- Stevens, M.A., 1979. Tomato quality: potential for developing cultivars with improved flavor. *Acta Hortic.* 93, 317–329.
- Stevens, M.A., Kader, A.A., Albright-Holton, M., Algazi, M., 1977. Genotypic variation for flavor and composition in fresh market tomatoes. *J. Am. Soc. Hortic. Sci.* 102, 680–689.
- Stevens, M.A., Kader, A.A., Albright, M., 1979. Potential for increasing tomato flavor via increased sugar and acid content. *J. Am. Hort. Sci.* 104(1), 40–42.
- Stone, H., Sidel, J.L., Joel, O.S., Woolsey, A., Singleton, R.C., 1974. Sensory evaluation by quantitative descriptive analysis. *Food Technol.* 28, 24–34.
- Stone, H., Sidel, J.L., 1993. Descriptive Analysis. Chapter 6 In: Taylor, S.L. (Ed.), *Sensory evaluation practices*. Academic Press, San Diego, CA, second edn., pp. 202–242.
- Verkerke, W., Giesleben, W., Engelaan, R., 1991. Langer houdbaar door stevigere schil. *Groenten en Fruit/Glasgroenten* 2, 22–23.
- Verkerke, W., De Kreij, C., Janse, J., 1993. Keukenzout maakt zacht, maar lekker. *Groenten en Fruit/Glasgroenten* 51, 14.