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Application of agglomerative hierarchical clustering to identify consumer tomato preferences: influence of physicochemical and sensory characteristics on consumer response

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Abstract: A multiple regression model was developed to predict the acceptability of the four tomato varieties studied (Aranka, Cherry, Beef and Pitenza). Agglomerative hierarchical clustering showed the presence of four consumer clusters. One cluster preferred small tomatoes (Aranka and Cherry) and another cluster the larger tomatoes (Beef and Pitenza). In the sensorial analysis Aranka was the preferred variety, scoring more highly in taste, odour, acidity, sweetness and hardness. In the physicochemical analysis Aranka also obtained the highest values for titratable acidity (TA) and sugars (SSC), confirming that these parameters are important in tomato flavour. Lower values for both sets of parameters were reflected by lower consumer acceptability, with Beef and Pitenza receiving the lowest score for these flavours attributes (except odour). A significant correlation between the sensorial and physicochemical parameters was also observed: odour was positively correlated with calibre, while taste, acidity, hardness and acceptability were negatively correlated with calibre, pH and SSC/TA and positively correlated with SSC and TA.

Keywords: tomatoes; flavour; acceptance; principal component analysis; agglomerative hierarchical clustering

INTRODUCTION

The consumption of vegetables in general has increased because they are related to health, while both fruit and vegetables are important constituents of the Mediterranean diet. The tomato is an important vegetable in the Mediterranean diet and a pillar of the Spanish horticultural economy, with 14% of the sector's area being dedicated to its production which, in turn, represents about 23% of the sector's economic value.[1] A relationship has been established between tomato intake and protection against colorectal cancer[2] and prostate cancer.[3] Furthermore, the organoleptic quality of tomato fruit involves a set of flavour and texture attributes that can be evaluated either by sensory analysis or by instrumental measurements.[4]

Consumers are becoming more demanding as regards fruit and vegetable quality and visual, nutritional and sensory characteristics are increasingly important. Until now, the decision to cultivate a particular tomato variety has been made according to its yield, blight resistance, length of time for which the fruit can be kept and the appearance of the product. However, tomato flavour results from a complex interaction between the taste components, aroma and volatiles. Unfortunately, the lack of flavour in supermarket tomatoes is a common consumer complaint.[5–7]

The tomato market has changed recently. Increases in production levels are associated with the technological improvements that accompany greenhouse systems, and have conditioned changes in consumer demand because of increased choice (e.g. the development of Aranka and Pitenza on the vine, and Cherry).[8]

Several studies have shown that there are no differences in the physicochemical parameters of tomatoes cultivated with or without soil[9] and that consumers cannot distinguish between the quality of the resulting fruit.[10] Studies have also shown there are no quality differences between tomatoes produced in a greenhouse and those grown in the field.[11]

In this study we analysed hydroponically grown tomatoes produced in the greenhouse to protect them from the effects of rainfall, sunlight, season, soil nutrients, temperature fluctuations and pests, among other variances that might affect their quality.[12] These

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tomatoes were certified by AENOR (Spanish Association of Normalization and Certification) through the norm UNE:155001:2001,[13] which regulates the production of tomatoes for fresh consumption. The purpose of this study was to evaluate the physicochemical and sensory properties of four varieties of tomato and to correlate these with consumer acceptability. One variety was a traditional Beef tomato. Two other varieties were new kinds of tomato (Aranka and Pitenza) because these tomatoes have lower size and are presented on the vine in trays under plastic film. This size and form of presentation meant that consumers considered these varieties as new. The last variety was Cherry tomato.

MATERIALS AND METHODS

Plant materials

Commercially planted tomatoes (*Lycopersicon esculentum*), Cherry, Beef, Aranka and Pitenza varieties (Fig. 1), were grown in Mazarrón (Spain) under a flood hydroponic system on cocoa fibre substrate in a greenhouse. The tomato production system was certified by AENOR through the norm UNE 155001-2001,[13] which establishes the specific requirements for the production of tomato destined mainly for fresh consumption. Tomatoes were harvested at the light-red stage (this stage was assessed with a ColorFlex version 1.72 colorimeter (Hunterlab, Reston, Virginia, USA) certified by ISO 9001[14] and measured as CIELAB coordinates), washed and sorted for defects before carrying out the physicochemical and sensory analyses.

Physicochemical analysis

Twenty-five tomatoes of each variety were measured. The weight was measured by precision balance (Sartorius, model BP 1200, Goettingen, Germany) certified by ISO 9001[14] (International Standardization Organization). Tomato diameter (calibre) was measured by vernier calliper. Firmness was measured using a digital HPE (Shore HPE-A/HPE-P, DGM 93 18 389.5, Borâs, Sweden). The soluble solids content (SSC) was measured in tomatoes without removing the skins using a portable refractometer (Comecta, SA, model C3, Barcelona, Spain), while pH and conductivity measurements were made using a digital pH-meter (WTW, Inolab, model level 1, Weilheim, Germany) with crystal electrode (Crison 52.02), after homogenizing the samples. Titratable acids (TA), expressed as citric acid (mg mL^{-1}), was determined in 3 g of tomato supernatant after centrifuging the homogenate for 5 min at $5000 \times g$, and by titration to pH 8.2 ± 0.05 with a 0.1N NaOH solution. The SSC/TA ratio was calculated because it relates better to sourness than TA itself.[15,16] All instruments were calibrated before the analysis.

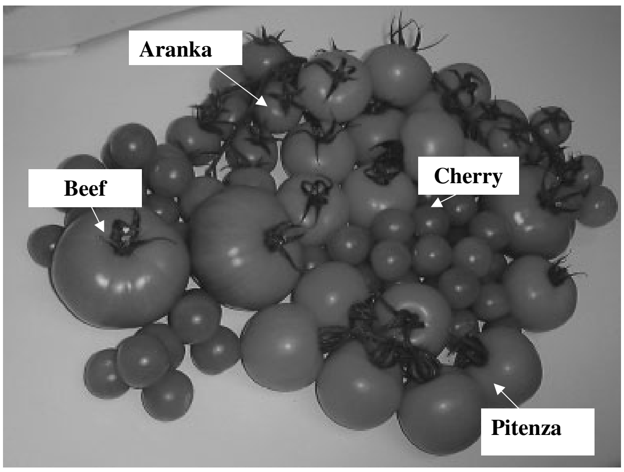

Figure 1. Commercially planted tomato fruits. Cherry and Pitenza were considered by consumers as new tomato varieties (*Lycopersicon esculentum*).

Sample preparation for sensory analysis

Sample preparation depended on the size of the varieties: the large varieties (Beef and Pitenza) were sliced to provide slices with approximately the same weight as a Cherry tomato, while Aranka was cut into two halves, one of which was used for the experiment. As regards Cherry, the whole tomato was cut into two halves, so that all the varieties were used in equal conditions. The weight served for each variety was 18.17 g (SD 0.5) for Beef tomato, 17.52 g (SD 0.3) for Pitenza tomato, 21.42 g (SD 0.6) for Aranka tomato and 20.11 g (SD 0.2) for Cherry tomato.

The samples were served in plastic cups covered with aluminium foil to capture the volatiles and coded with a different three-digit number for each measurement and tomato. The samples were prepared about 1 h before the session and kept at room temperature.

For these measurements the tomato varieties were presented one by one and the order of presentation followed a Williams Latin Square design balanced for order and first order carry-over effects.[17]

Sensory analysis

A panel of staff and students from San Antonio Catholic University of Murcia was trained over a period of one month by taste, odour and trigeminal perception tests (ISO 1993)[18] in the perception of different attributes and in the application of the scoring scale employed. The panellists had to pass selection tests consisting of a set of triangle tests for fundamental tastes and trigeminal sensations and an odour identification set (ISO 1993).[18] At the end of this period the panel was formed by 14 panellists (57% men and 43% women).

The session, which lasted about an hour, involved blind tasting to prevent the appearance of the tomatoes from influencing the evaluation, by using a green light in the sensory room. Panellists were asked about their perception of the global odour intensity (odour), global taste intensity (taste), sweetness, acidity and hardness of the tomatoes so that the relative importance of these attributes in their perception of the quality could be assessed. Samples were evaluated twice on a 10 cm unstructured line scale with anchor points 'none' on the left side and 'very much' on the right side. The grades on these scales were converted into numbers (on a scale from 0 to 10) by measuring the distance between the left-hand side of the scale and the subject's mark.

Consumers

A consumer study was conducted in the San Antonio Catholic University of Murcia using 96 consumers (41% men and 59% women, aged between 18 and 40 years) recruited by a small advertisement. Only those who said they consumed tomatoes at least twice a week were selected for the panel.

During the session, which lasted about an hour, consumers filled in a questionnaire about their tomato-eating habits and their knowledge of Cherry and on-vine tomato varieties, before starting the sensory evaluation. A blind tasting session was carried out to prevent the appearance of the tomatoes from influencing the evaluation. Consumers were asked to record the acceptability of the tomatoes on a 10 cm line labelled on the left end 'I don't like it at all' and on the right 'I like it very much'. The grades on these scales were converted into numbers (on a scale from 0 to 10) by measuring the distance between the left-hand side of the scale and the subject's mark.

The physicochemical, sensorial and consumer analyses were carried out on the same day in order to avoid variability due to tomato ripening.

Statistical analysis

To study the differences between the four varieties of tomato, an analysis of variance (ANOVA) was performed. The data from the physicochemical analysis were evaluated by one-way factor while the data from the sensory evaluation were evaluated by two-way factors (variety and subject). Duncan's Multiple Range test was used to separate the means in both the physicochemical and sensorial analysis. Agglomerative hierarchical clustering (AHC) was applied to the acceptability data in order to identify particular clusters of consumers who preferred one particular type of tomato or quality attribute. This analysis was made using the Euclidian distance and with Ward's method as aggregation criterion. The coordinates of the cluster centroids were used to calculate a principal component analysis (PCA) in order to characterize the preferences of each cluster for particular tomatoes.

A theoretical modelling for predicting tomato acceptability was made with multiple linear regression using variety, sex, age, taste intensity and hardness. Consumer knowledge about the new tomato varieties was also taken into account. Knowledge variable was calculated taking into account the items of the questionnaire: for each item that the consumer answered 'Yes' (I know on-vine tomato, I know Cherry tomato, I bought on-vine tomato and I bought Cherry tomato) he/she was scored with one point. Consumers with a high level of knowledge concerning these varieties scored four (high knowledge) and conversely consumers that didn't know these varieties scored zero (none knowledge).

$$\begin{aligned}\text{Acceptability } (Y) &= \text{intercept} + \text{Variety } (X_1)\\ &+ \text{Sex } (X_2) + \text{Age } (X_3) + \text{Tomato knowledge } (X_4)\\ &+ \text{Taste intensity } (X_5) + \text{Hardness } (X_6)\\ &+ \text{Variety}^*\text{Sex } (X_7) + \text{Variety}^*\text{Age } (X_8)\\ &+ \text{Knowledge}^*\text{Age } (X_9) + \text{Knowledge}^*\text{Sex } (X_{11})\end{aligned}$$

This model was validated with a cross-validation. For this validation we used 10% of the data (chosen at random by SPSS) in order to calculate the shrinkage of the model.[19] Shrinkage is calculated using the difference between the determinant coefficient of the estimated model (R^2) and the square of the simple correlation coefficient (r^2) between the theoretical value of the model obtained using the estimated model, and the dependent variable.

Pearson correlations and a PCA between the physicochemical, sensory and acceptability data were also applied.

These analyses were carried out using SPSS version 12.0 (SPSS Inc., Chicago, IL, USA) and XLSTAT version 5.1 (Addinsoft, New York, USA).

RESULTS AND DISCUSSION

Physicochemical analyses

An analysis of variance for the physicochemical data revealed significant differences between the four varieties for each of the parameters analysed ($P < 0.001$). A Duncan test applied to the same parameters showed that weight and calibre were significantly higher ($P < 0.001$) in Beef and Pitenza (Table 1). For SSC/TA ($P < 0.001$) and pH ($P < 0.05$) the highest values were obtained for Beef and Pitenza (Table 1). Cherry was the least firm variety. SSC and TA were scored higher in Aranka and Cherry (Table 1). Among all the tomato varieties, Aranka had the highest conductivity and was significantly ($P < 0.05$) different from the other varieties (Table 1). There were no significant differences in physicochemical parameters between Beef and Pitenza (Table 1) except for weight and calibre. No significant differences were found for the colour parameters because the tomatoes were all at the same colour stage (Table 1).

A Pearson correlation showed that SSC was negatively correlated ($P < 0.001$) with the SSC/TA ratio, pH, firmness and calibre (Table 2). In contrast, SSC was positively correlated ($P < 0.001$) with TA and conductivity (Table 2).

These results were consistent with those of Granges,[11] who studied some quality parameters in different varieties of tomatoes (Aranka being one of these varieties) and the influence of variety and

Table 1. Duncan test of physicochemical parameters of tomato varieties

Compositional parameters[a]	Tomato varieties			
	Beef	Pitenza	Aranka	Cherry
Weight (g)***	285.57a	102.91b	32.82c	14.68d
Calibre (cm)***	69.12a	41.84b	23.52c	13.32d
TA (mg mL^{-1} citric acid)*	0.33a	0.36a	0.63b	0.716c
PH*	4.4073a	4.41a	4.05b	4.086c
Conductivity (mV)*	145.12a	146.08a	165.30b	163.13c
SSC (°Brix)***	5.15a	5.13a	7.88b	8.068b
SSC/TA***	15.67a	14.25ab	12.15b	11.64b
Firmness (N)***	81.57a	80.66a	80.23a	73.21b
L^{ns}	42.33a	42.43a	45.85a	46.77a
a^{ns}	37.01a	38.25a	33.48a	34.52a
b^{ns}	33.96a	34.59a	32.56a	33.89a

[a] Chemical composition parameters with different letters are significantly different between varieties at 5% level according to Duncan's Multiple Range Test.
* $P < 0.05$; *** $P < 0.001$.
TA, titratable acidity; SSC, soluble solids content.
Different letters mean the existence of significant differences between samples for this parameter.
L^{ns} describes the lightness of the colour. A positive value of a^{ns} describes the redness of the colour, a negative a^{ns} the greenness. Similarly, yellowness or blueness is expressed by coordinate b^{ns} which is positive for yellow and negative for blue.

cultivation practices on these parameters. This author found similar values to those recorded in the present study in the case of Aranka: similar pH and SSC values, a negative correlation between pH and SSC and between pH and TA, and a positive correlation between SSC and TA.

Calibre was negatively correlated with the concentrations of sugars and acids (Table 2). Tomatoes with the lowest calibre (Cherry and Aranka) were the most acid and sweet (Table 2). In contrast, the largest tomatoes (Beef and Pitenza) were the firmest and showed the highest pH (Table 2).

These results suggested that lower calibre could concentrate components like sugars and acids. The correlations between acidity and SSC with conductivity could support this idea.

Sensorial analyses

As regards the physicochemical parameters, analyses of variance of the sensorial attributes revealed for the factor 'variety' a significant difference between the four varieties for all the attributes evaluated ($P < 0.001$). For the factor 'panellist' there were no significant differences, nor for the interaction 'panellist * variety'. The Duncan tests showed that differences in odour were due to Beef and Aranka, which had higher scores than Pitenza and Cherry (Table 3). For taste and acidity, Aranka and Cherry were scored higher than Beef and Pitenza (Table 3). For sweetness and hardness, Aranka was scored higher.

Table 3. Duncan test of sensory parameters of tomato varieties

Sensorial analysis[a]	Tomato varieties			
	Beef	Pitenza	Aranka	Cherry
Global odour intensity (odour)***	6.2084b	4.7307a	6.3648b	4.5437a
Global taste intensity (taste)***	3.4995a	4.0931a	7.5930b	5.3258b
Acidity***	2.0535a	1.9148a	5.5605b	4.2820b
Sweetness*	3.9990a	4.4768ab	5.0683b	4.4519ab
Hardness***	3.5020a	3.2585a	7.4660b	5.2971c

[a] Sensorial analysis parameters with different letters are significantly different at the 5% level according to Duncan's multiple range test.
* $P < 0.05$; *** $P < 0.001$.

Consumer acceptability

The knowledge of consumers concerning Cherry and on-vine tomatoes and the parameters they take into account when buying tomatoes were evaluated by means of a questionnaire. Analysis of the responses to the different items produced an alpha coefficient of readability of 0.733.[20]

The principal factors taken into account by consumers in buying tomatoes were, in the first place, colour, then texture, and finally size and shape (Fig. 2). Colour and texture are related to the maturity index and consumers rejected much ripened tomatoes. Size and shape are becoming important factors for consumers when they buy tomatoes, a fact that can be explained by the recent appearance of new varieties with different sizes.

As regards knowledge of Cherry and on-vine tomato, 64.18% of women recognized on-vine tomato versus 42.91% of men, although 28.36% of women and 16.75% of men actually consumed them. In the case of Cherry, 73.13% of women and 60.78 of men

Table 2. Pearson correlations between physicochemical parameters of tomato varieties

	Calibre (cm)	SSC (°Brix)	pH	Conductivity (mV)	TA (mg mL^{-1} citric acid)	SSC/TA	Firmness (N)
Calibre (cm)	1	−0.879**	0.852**	−0.840**	−0.918**	0.985**	0.720**
SSC (° Brix)	−0.879**	1	−0.994**	0.991**	0.990**	−0.947**	−0.629**
PH	0.852**	−0.994**	1	−10.00**	−0.969**	0.929**	0.542**
Conductivity (mV)	−0.840**	0.991**	−10.00**	1	0.963**	−0.920**	−0.523**
TA (mg mL^{-1} citric acid)	−0.918**	0.990**	−0.969**	0.963**	1	−0.967**	−0.730**
SSC/TA	0.985**	−0.947**	0.929**	−0.920**	−0.967**	1	0.694**
Firmness (N)	0.720**	−0.629**	0.542**	−0.523**	−0.730**	0.694**	1

* $P < 0.05$; ** $P < 0.01$.

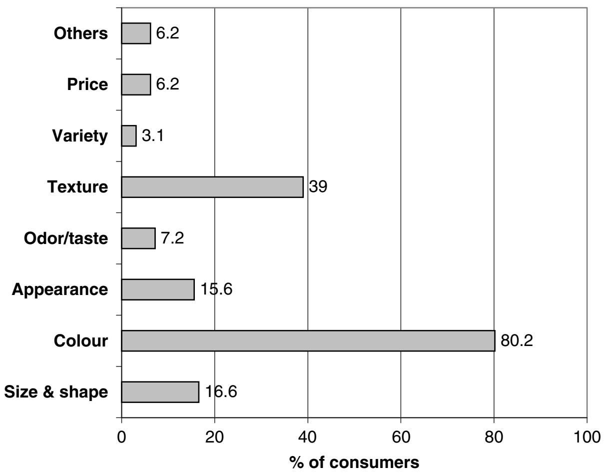

Figure 2. Principal factors taken into account in consumer tomato purchase.

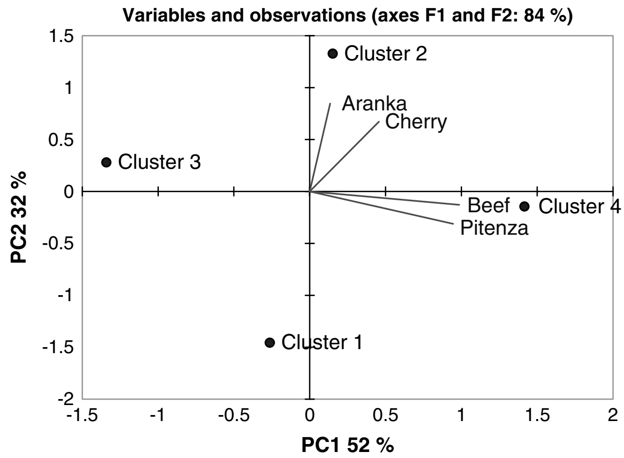

Figure 4. PCA consumer tomato preferences constructed with cluster centroid coordinates. Cluster 2 preferred the small size tomato, whereas Cluster 4 preferred the largest tomato.

recognized this variety but only 34.85% of the women and 22.24% of men consumed it.

The Dendogram (Fig. 3) generated by the AHC showed the presence of four clusters: cluster 1 with 28 subjects (7.0% of the men and 21.8% of the women), cluster 2 with 27 subjects (8.3% men and 19.8% women), cluster 3 with 21 subjects (6.2% men and 15.6% women) and cluster 4 with 20 subjects (8.3% men and 12.5% women).

The coordinates of the cluster centroids were analysed by PCA (Fig. 4) and it was seen that cluster 2 preferred the small tomatoes (Aranka and Cherry), while Cluster 4 preferred the larger ones (Beef and Pitenza). Cluster 2 preferred tomatoes more acid, sweeter and harder than Cluster 4.

The regression findings were presented in standardized regression coefficient form and the variables shown to be significant beyond the 0.05 level were identified with an asterisk.

$$Y = 2.242 + 0.182X_1 - 0.607X_2 - 0.056X_3 - 0.484X_4 + 0.735X_5{}^* + 0.110X_6{}^* - 0.156X_7 + 0.010X_8 - 0.001X_9 + 0.406X_{10}{}^*$$

The coefficient of determination of the regression model was 0.612, which means that 61.2% of the variance of the dependent variable was explained.

Three variables were shown to be significant in reducing the unexplained variance in acceptability toward these four tomato varieties. The significant variables were 'intensity of taste', 'hardness' and 'knowledge * sex'. The interaction between knowledge

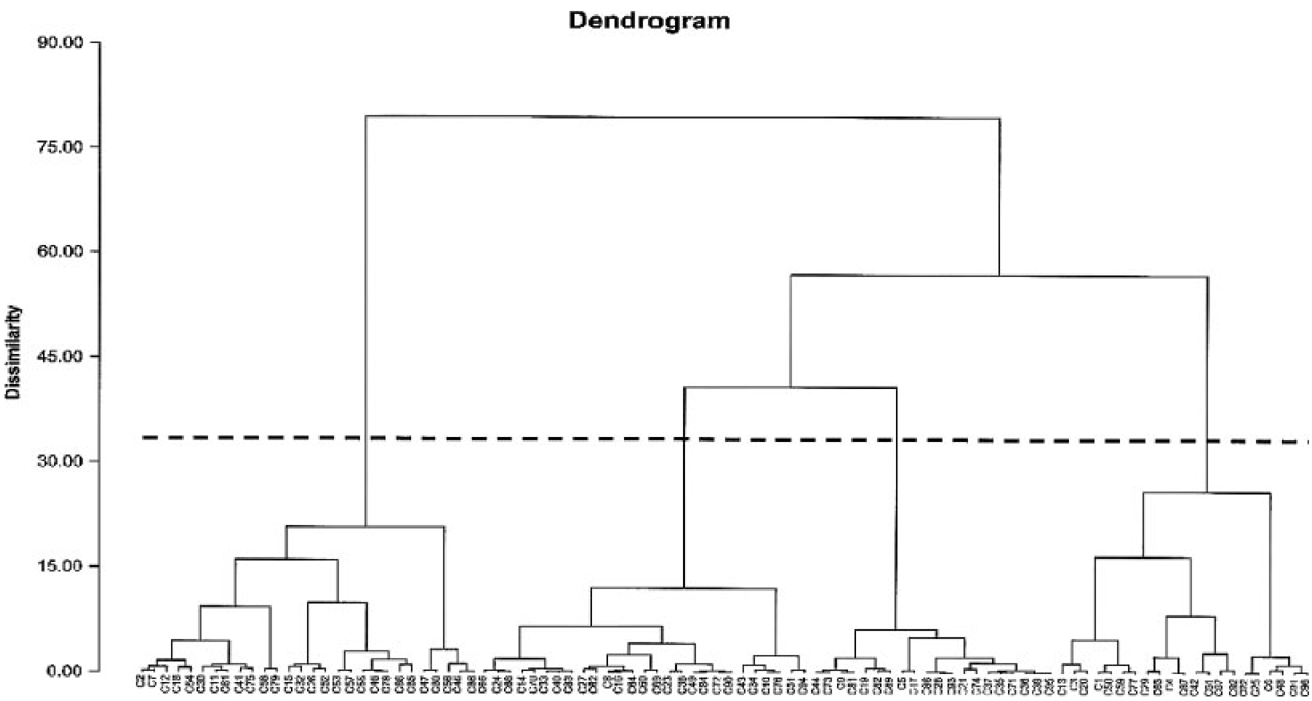

Figure 3. Dendrogram of AHC showing the presence of four groups in consumer tomato preferences.

Table 4. Pearson correlations between sensorial parameters of tomato varieties

	Odour	Taste	Acidity	Sweetness	Hardness	Acceptability
Odour	1	0.381**	0.177**	0.161**	0.118*	0.239**
Taste	0.381**	1	0.472**	0.314**	0.119	0.697**
Acidity	0.177**	0.472**	1	−0.148**	0.431**	0.241**
Sweetness	0.161**	0.314**	−0.148**	1	0.148**	0.418**
Hardness	0.118*	0.119	0.431**	0.148**	1	0.398**
Acceptability	0.239**	0.697**	0.241**	0.418**	0.398**	1

* $P < 0.05$; ** $P < 0.01$.

Table 5. Pearson correlations between physicochemical and sensorial parameters of tomato varieties

	Odour	Taste	Acidity	Sweetness	Hardness	Acceptability
Calibre (cm)	0.131*	−0.400**	−0.443**	−0.096	−0.404**	−0.352**
SSC (°Brix)	−0.013	0.461**	0.539**	0.090	0.518**	0.403**
pH	−0.016	−0.490**	−0.557**	−0.097	−0.547**	−0.425**
Conductivity (mV)	0.024	0.493**	0.559**	0.098	0.552**	0.428**
TA (mg mL^{-1} citric acid)	−0.056	0.422**	0.508**	0.083	0.473**	0.373**
SSC/TA	0.089	−0.440**	−0.493**	−0.099	−0.462**	−0.385**
Firmness (N)	0.218**	−0.067	−0.191**	−0.003	−0.097	−0.081

* $P < 0.05$; ** $P < 0.01$.
http://www.elastocon.se/nordic/instruments/pdf/db-barhard.pdf

and sex could be explained by females with low knowledge who scored less (mean 4.71; SD 2.22) than males (mean 4.89; SD 2.34) in contrast with females with a high level of knowledge who scored higher (mean 5.10; SD 2.86) than males (mean 3.96; SD 1.86).

Cross-validation showed a shrinkage of 0.097 (9.7%); thus the model could be considered acceptable as the loss of prediction did not surpass 10%.[19]

A Pearson correlation was made between the sensorial properties and the acceptability scores (Table 4). Most sensorial properties were significantly correlated with acceptability and with each other ($P < 0.05$, $P < 0.01$), while sweetness and acidity were the only parameters to be negatively correlated.[11] Granges[11] also correlated taste with acceptability. These results are consistent with those of Granges[11] and Jones and Scoot,[21] who demonstrated that fresh market tomato acceptability was greatly affected by perceived sweetness and acidity.

Correlation between physicochemical and sensorial analysis and consumer acceptability

Sweetness was not correlated with any physicochemical parameter (Table 5), in contrast to the findings of Bisogni *et al.*[22] and Kader *et al.*[23] but agreeing with those of Watada and Aulenbach.[24]

Baldwin *et al.*[16] mentioned how the correlation of physicochemical measurements with sensory analysis gives meaning to instrumental data. The Pearson correlation made for this purpose (Table 5) showed that odour was positively and significantly correlated with calibre ($P < 0.05$) and firmness ($P < 0.01$). Taste, acidity, hardness and acceptability were negatively correlated with calibre, pH and SSC/TA

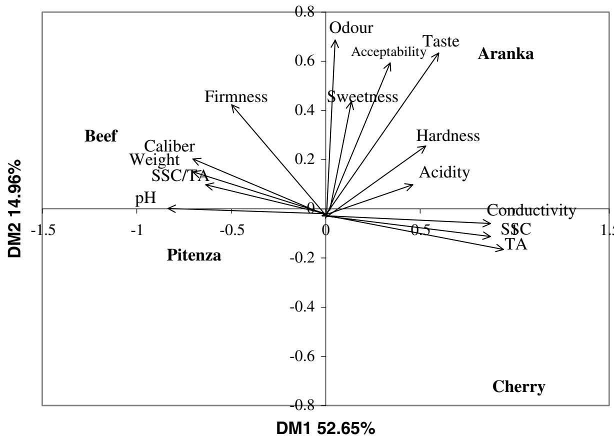

Figure 5. PCA obtained from physicochemical and sensorial parameters.

($P < 0.01$) and positively correlated with SSC, conductivity and TA ($P < 0.001$). Acidity was also negatively correlated with firmness ($P < 0.001$). The relationship between acidity as perceived in the tasting tests and TA was consistent with the results of Bisogni *et al.*[22] and Maul *et al.*[25]

The PCA plot obtained from physicochemical and sensorial descriptors (Fig. 5) showed a split between the large (Beef and Pitenza) and small (Cherry and Aranka) tomatoes (dimension one). It should be noted that Cherry deviated from the other tomatoes. However, most of the sensory characteristics evaluated in tomatoes can be observed for Aranka, which was the most accepted variety and was the sweetest, hardest and most acidic (Table 3). As in Granges,[11] Aranka had the most taste and odour and was the most accepted by consumers. These results (Fig. 5) were also consistent with the findings of Maul *et al.*[25] and, like Jones and Scott[21] Stevens *et al.*[26], we found that the SSC or TA were important for flavour.

CONCLUSIONS

The principal factors taken into account by consumers when they bought tomatoes were in first place colour, then texture, and finally size and shape. The presence of four consumer clusters indicated the existence of differences in preference.

Consumers preferred Aranka variety for its greater odour, taste, acidity, sweetness and hardness. Cherry, with high levels for all the sensorial parameters evaluated except odour, was also liked by consumers. These results show how all the sensory attributes evaluated, even acidity (which some studies have found to be negatively correlated) were important for consumer acceptance. Consumers preferred tomatoes with a hint of acidity.

The principal sensorial characteristic for the consumers who preferred Aranka or Cherry was intensity of taste.

There were significant correlations between sensorial and physicochemical parameters: odour was positively correlated with calibre and weight, while taste, acidity, hardness and acceptability were negatively correlated with calibre, pH and SSC/TA, and positively correlated with SSC and TA.

Our results revealed that taste and hardness had a great impact on the perception of quality that also depends of the size of these tomatoes. The regression model predicts the consumer acceptability of tomato by their sex, age and knowledge about these tomato varieties.

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