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A comprehensive approach to evaluate the freshness of strawberries and carrots

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Abstract

Freshness is a quality criterion of great importance to the consumer for the acceptance of fruit and vegetables. However, what the consumer perceives as fresh is not clear. The objective of the present investigation was to uncover sensory attributes influencing consumer perception of the freshness of strawberries and carrots that varied in cultivar, as well as with time and conditions of storage. Product characteristics measured by descriptive sensory and physico-chemical analyses were related to consumer and expert panel (individual and consensus) ratings of freshness. Results showed that a large number of attributes contributed to the freshness of strawberries and carrots and that those were also indicators of the physiological ageing of these products. Our results suggest that consumer evaluation of fruit and vegetable freshness corresponds to an evaluation of this ageing process through the observation of sensory properties. In addition, the freshness of long shelf life fruit and vegetables seemed to be better predicted by sensory characteristics than the freshness of short shelf life products. Finally, consensus ratings of freshness by the expert panel were shown to be the most reliable approach of measuring freshness.

Keywords: Consumer; Expert panel; Sensory panel; Physico-chemical analyses; Storage; Cultivar

1. Introduction

Fresh is a word that is frequently encountered in everyday life and particularly in relation to food. It awakens certain expectations from consumers as it is a critical variable affecting food quality (AgV, 1981). Although freshness has been shown to be of a great importance for consumer choice of fruit and vegetables (AgV, 1981; Wandel and Bugge, 1997; Babicz-Zielinska and Zagorska, 1998; Ragaert et al., 2004; Péneau et al., 2006), there is little published research on its perception by consumers.

Fillion and Kilcast (2000) found sensory properties, in particular texture and appearance attributes, as well as time from harvest, to be the two main components involved in the concept of fruit and vegetable freshness. Péneau et al. (2006), who focused on apples, showed the specific importance of texture for consumer perception of freshness, whereas, time from the product's arrival at the store/market was the primary determinant, according to results of Cardello and Schutz (2003).

Cardello and Schutz (2003) further revealed that the type of food affected judgement of freshness, and both Foissy (1995) and Heiss (1986) suggested that characteristics related to the description of freshness were dependent on the food considered. More specifically, Trenkle (1982) suggested that "fresh" was not used in the same way for different fruit or vegetables. These results indicate that the notion of freshness not only differs between product categories but also within a category of product. From this perspective, it seems, therefore, valuable to investigate the consumer perception of freshness for specific fruit and vegetables.

Péneau (2005) also suggested that the evaluation of the freshness of a product was related to judgement of its physiological ageing. Since changes due to ageing are expected to vary greatly between products exhibiting different shelf lives, investigation of products that specifically differ according to this characteristic is relevant.

Freshness is a multidimensional attribute and its perception seems to be influenced by a number of sensory and non-sensory

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Table 1
Storage conditions of strawberries and carrots

Samples	Cultivars	Storage temperature (°C)	Storage condition	Storage time (days)
Strawberries				
Everest	Everest	0	Without packaging	0, 2, 7, 9
Elsanta	Elsanta	0	Without packaging	0, 2, 7
Evita	Evita	0	Without packaging	2, 7, 9
Carrots				
Bolero A[a]	Bolero	0	In plastic bags	7, 9, 16
Bolero B[a]	Bolero	0	Without packaging	7, 9, 16
Bolero C	Bolero	20	Without packaging	1, 3, 10
Maestro	Maestro	20	Without packaging	1, 3, 10

[a] These samples had been stored 4 weeks before the beginning of the experiments in plastic bags at 0 °C.

characteristics (Fillion and Kilcast, 2000). Focusing exclusively on one group of characteristics, for instance, sensory characteristics will not result in a global view of consumer perception but present the advantage of giving a more detailed map of the underlying sensory attributes influencing freshness. For this purpose, collecting consumer ratings of freshness and relating them to characteristics measured by descriptive sensory or physico-chemical analyses is appropriate. According to Carr et al. (2001), this type of approach avoids what sometimes appears to be contradictory descriptions of products obtained from consumers and trained panels.

It has also been suggested that the meaning of freshness varies according to the background of the person who gives the definition (Cardello and Schutz, 2003). It can therefore be expected that an opinion on freshness differs between professionals and consumers. Sensory attributes generated by a group of individuals specialised in the evaluation of freshness, but without knowledge on quality evaluation of products in general and on sensory analysis in particular, may better predict consumer perception of freshness rather than if these attributes were generated by professionals. In addition, freshness ratings of this small group could be an alternative to consumer tests.

The present study aims at identifying important sensory attributes involved in the consumer perception of the freshness of strawberries and carrots. Strawberry is a typical seasonal product and cannot be kept more than a few days without having its quality impaired. On the other hand, carrots, which are after the tomato, are the most consumed vegetable in Switzerland, can be stored a long time without showing any signs of decay. Different cultivars, time and conditions of storage were used in order to generate variation in product sensory characteristics and in the expected perceived freshness by consumers. Attributes generated by an expert panel were additionally characterised by descriptive sensory and physico-chemical analyses.

2. Methodology

2.1. Products

Experiments involving strawberries were conducted in June and July 2003 and those involving carrots in August and September 2003. Three strawberry and two carrot cultivars obtained from commercial growers in Switzerland were tested (Table 1). Cultivars were selected according to their availability during the whole time span of the study and their differences in sensory properties. Products were stored under different conditions for different time periods in order to induce variation in the sensory properties and consequently, in the expected perception of freshness. Carrot samples were either stored in plastic bags or without packaging. Two samples (Bolero A and B) were stored in plastic bags at 0 °C for 4 weeks prior to the experiment. All strawberry samples were stored in open customary cardboard packings. Storage was however, limited to assure acceptable product quality to consumers. The experimental design was randomised and two replications were carried out. Products from the two replications were harvested in different fields, but each cultivar within a replication was harvested in one field. Strawberries and carrots were washed and graded for uniformity of colour and size. Strawberries were presented whole to the various groups testing the products, and carrots were presented topped and tailed. Each sample was presented on cardboard plates (9 cm × 15 cm) with a three-digit code. A knife and a peeler were given together with the carrot samples.

All types of tests (consumer and expert panel tests as well as analytical sensory and physico-chemical analyses) were carried out on the same day, apart from the consumer tests involving strawberries that were carried out after 1 and 8 days of storage instead of after 0, 2, 7 and 9 days of storage, as was the case for the expert panel, analytical sensory and physico-chemical analyses. Strawberries tested by consumers after 1 day of storage were chosen so as to match those tested after 0 or 2 days of storage. Similarly, strawberries tested by consumers after 8 days of storage were chosen so as to match those tested after 7 or 9 days of storage. As the quality and maturity of the strawberries in each lot varied greatly, it was possible to use this approach. Four test sessions per replication were carried out in the case of strawberries (and only two consumer sessions), whereas, three sessions per replication were carried out in the case of carrots.

2.2. Consumer panel

All consumer test sessions were carried out in two main shopping centres (Migros) in Zurich (Switzerland) apart from the first replication of experiments involving strawberries which was car-

Table 2
Definition of a fresh strawberry or carrot and important characteristics to take into account when evaluating their freshness as described by the expert panel

	Strawberry	Carrot
Definition	Freshness of a strawberry is the sum of the evaluation of appearance, odour, texture in the hand and in the mouth and of flavour	Freshness of a carrot is the sum of the evaluation of appearance, odour, texture in the hand and in the mouth
Characteristics		
Appearance	Sepals: not faded Colour: not very red Surface: shiny No bruises Brighter inside as outside No juice exit	No film No dark bruises Surface: shiny Surface: not shrivelled Moist cutting area Ends not dried
Odour	No fermentation odour	Surface: no carrot odour Cutting area: no sour odour Cutting area: no fermentation odour Cutting area: no strong sweet odour
Texture (Hand)	Firm Elastic	Not gummy Not soft
Texture (Mouth)	Firm Juicy Not spongy	Crisp Juicy Not fibrous
Flavour	Not very sweet Not bitter No fermentation flavour	–

ried out in the entrance hall of a technology transfer enterprise (Technopark) in the same city. For each session the consumers were randomly selected among shoppers. The task consisted of evaluating the freshness of strawberries or carrots on a 9-point scale ranging from "not at all fresh" to "very fresh". The mode of evaluation was left to consumers, meaning that they were not compelled to eat the samples if they did not find it necessary. Each strawberry set consisted of six samples: one warm-up sample of average quality, followed by five test samples presented monadically according to a balanced design. Each carrot set consisted of five samples: one warm-up sample of average quality, followed by four test samples presented monadically and in random order. They were free to consume water or not between the samples.

Information on age, gender and strawberry or carrot consumption was collected at the beginning of the questionnaire. Around 50 consumers took part in each test session involving the different products according to the test design. A total of 167 consumers completed the test on strawberries as follows: 31 (1st test), 41 (2nd test), 47 (3rd test), 48 (4th test)). Mean age of participants was 39.6 ± 15.8 years and ranged from 13 to 75 years. Females represented 50.3% of consumers. Average weekly consumption frequency of strawberries (in June/July) as given by consumers was: <1: 29%; 1–2: 46%; 3–4: 18%; 5–6: 4%; >6: 4%. A total of 295 consumers completed the test on carrots divided as follows: 49 (1st test), 48 (2nd test), 48 (3rd test), 50 (4th test), 50 (5th test), and 50 (6th test). Mean age of participants was 45.7 ± 18.9 years and ranged from 15 to 85 years. Females represented 63.4% of the consumer group. Average weekly consumption frequency of raw carrots as given by consumers was: <1: 39%; 1–2: 35%; 3–4: 17%; 5–6: 5%; >6: 3%.

2.3. Expert panel

The expert panel for the evaluation of freshness consisted of seven individuals (six females, one male, mean age: 32.0 ± 11.0) for the experiment involving strawberries and six individuals for the one involving carrots (three females, three males, mean age: 37.0 ± 11.9). The individuals constituting the groups were recruited under the condition that they had limited contact with the area of food science in general. Communication skills of participants were ensured during recruitment. Each group developed a definition of freshness based on their discussion and on their own perception of freshness. They were not influenced by the opinion of food professionals. As extended discussions were necessary for the development of a definition, a small group was considered more appropriate.

The first task involved the development of a definition of freshness for strawberries and carrots. For this purpose, different cultivars at various stages of maturity were presented in order to assist discussion. Panellists were asked to focus exclusively on sensory properties, and to exclude all non-sensory attributes, possibly influencing the freshness. The group leader's function was almost entirely non-participatory to minimise the influence on the subjects. As a result of the discussions, a definition understood by every group member was developed and agreed with, and a list of attributes was elaborated to assist the evaluation of freshness (Table 2).

The second task consisted of the evaluation of freshness on a 9-point scale ranging from "not at all fresh" to "very fresh". The list of important attributes previously developed was made available to the panellists in order to assist the evaluation of freshness. The evaluation was done under cool white overhead lighting and samples were presented monadically using a balanced design. Each sample set consisted of four to five samples and one of the samples was duplicated, to test the repeatability of freshness measurements. Panellists were asked to rinse their mouth with water between samples. After the individual evaluations, panellists discussed their ratings in the group and a consensus had to be reached. Using consensus allowed for supporting individual ratings and compensating for possible variations due to product or panellist discrepancies.

2.4. Descriptive panel

The analytical panel consisted of 12 panellists who were recruited from the staff of the Institute of Food Science and Nutrition, ETH Zurich. Attributes to be tested were selected by the experimenter based on the list generated by the expert panel for the evaluation of freshness. Strawberry attributes were in this order: withered sepals, colour, shiny, bruises, strawberry odour, fermentation odour, firm (hand), firm (mouth), spongy, juicy, sweet, sour, strawberry flavour and fermentation flavour. Carrot attributes were in this order: colour, film, shiny, shrivelled, gummy, carrot odour, off odour, crisp, juicy, fibrous, bitter, sweet, carrot flavour and off flavour. Panellists were trained during a 4-week period for the use of the attributes and for the evaluation of the different cultivars varying in terms of age. Attribute intensity was scored on a 100 unit line scale, that was 10 cm long and ranged from "not at all" to "very" using the FIZZ software (Version 2.00 E, Biosystèmes, Courternon, France). Samples were given monadically according to a balanced design under cool white overhead lighting. Each sample set consisted of four to five samples and one of the samples was repeated. Panellists were asked to rinse their mouth with water between samples.

2.5. Physico-chemical analyses

2.5.1. Strawberries

Twenty strawberries were tested for firmness. One whole strawberry at a time was centred on the fixed aluminium lower platen of a universal testing machine (Zwick, GmbH and Co., D-Ulm) and compressed with a stainless steel upper platen of 75 mm diameter at a cross-head speed of 50 mm/min. The maximal compression force (F_{max}) required to deform the strawberry to 75% was determined as well as the gradient of the curve (Grad). Both measurements were taken as a characterisation of instrumental firmness. Twenty strawberry halves were squeezed per hand, and juice of each strawberry was separately placed onto a digital refractometer (RFM 300 Serie, UK-Tunbridge Wells) for measurement of soluble solids content expressed in g/100 g. The remaining halves of strawberries were frozen at −20 °C for subsequent measurement of titratable acidity. For this analysis, strawberries were defrosted, reduced to one batch of juice of which 20 g was diluted to 200 mL with deionised water. Acid content was determined by titrating two samples of 25 mL of juice with 0.1 M NaOH (Titrisol, Merck AG, CH-Dietikon) to pH 8.1 (pH Meter 691, Metrohm, CH-Herisau) according to the AOAC norm (1984).

2.5.2. Carrots

Ten carrots were tested for firmness. Two cylinders of 1.5 cm high were cut at 1 cm from the top of the carrot. Cylinders were centred on the fixed aluminium lower platen of the universal testing machine and subjected to the cone penetration test. The maximal force (F_{max}) required by the cone (length: 5 mm, angle: 15°) to penetrate 10 mm into the carrot with a cross-head speed of 50 mm/min was determined as well as the work (WF_{max}) required to achieve this penetration (area under the curve between 0 and F_{max}). Both measurements were taken as a characterisation of instrumental firmness. Another 15 carrots were reduced into juice in a squeezer. The juice of each carrot sample was placed onto a digital refractometer for measurement of soluble solids content expressed in g/100 g. The remaining juice of each carrot was frozen at −20 °C for subsequent analysis of titratable acidity. Acid content was determined by titrating two samples of 25 mL of defrosted juice with 0.1 M NaOH to pH 8.1 according to the AOAC norm (1984).

2.6. Data analysis

Data analysis was carried out using SPSS for Windows (Release 12.0.1., SPSS Inc., Chicago USA). Statistical significance was defined at $P < 0.05$. Data of strawberry and carrot samples were analysed with identical statistical methods. For all analyses of variances (ANOVAs), two-way interactions were considered and non-significant interaction terms were removed from the models.

To test differences in consumer ratings of freshness, a mixed model ANOVA with time of storage as the main factor and consumers as the random factor was performed for each strawberry cultivar and a two-way ANOVA using time of storage and replication as main factors was performed for each carrot sample. Differences in expert panel ratings of freshness were tested with a mixed model ANOVA taking panellists as random factors and time of storage and replication as main factors for each strawberry or carrot sample. Means at different storage times were compared using the Tukey post hoc test. Pearson correlation coefficients were calculated to measure the linear relationship between consumer and expert panel (individual and consensus) ratings of freshness.

Descriptive panel data were averaged over assessors for each sample, storage time and replication and subjected to principal component analysis (PCA) of the covariance matrix. Means corresponding to specific time of storage of each cultivar were projected into the PCA space. To test changes in the sensory characteristics of strawberry and carrot samples with time of storage, a mixed model ANOVA taking panellists as the random factor and time of storage and replication as fixed factors was calculated on the whole data set and for each attribute. Differences in physico-chemical characteristics for each strawberry sample were investigated with a two-way ANOVA using time of storage and replication as main factors. Differences in physico-chemical characteristics for each carrot sample and each replication were investigated with a one-way ANOVA using time of storage as the main factor. Since day × replication interactions were mostly not significant, the results of the two replications were pooled for

Table 3
Consumer and expert panel (individual and consensus notes) evaluation of freshness of strawberries on a 9-point scale

Samples	Storage time (days)	Consumers	Expert panel (individual)	Expert panel (consensus)
Everest	0	6.81 a[a]	7.45 a	7.75
	2	6.38 a	6.58 a	6.00
	7	6.09 a	6.29 a	6.50
	9	5.83 a	5.83 a	6.00
Elsanta	0	6.71 a	7.30 a	7.50
	2	6.33 a	7.29 a	7.25
	7	6.06 a	7.21 a	7.50
Evita	2	6.22 a	7.08 a	6.50
	7	5.69 a	5.79 a	5.25
	9	4.46 b	4.13 b	3.75

[a] Means with the same letter are not significantly different (Tukey, $P < 0.05$).

the presentation of the data in tables and figures, excluding the physico-chemical analyses of the carrot samples, which showed interactions and were consequently considered separately.

Principal component regression (PCR) was used in order to investigate attributes predicting freshness. This method was chosen as it allows coping with multicolinearity problems in multivariate calibration (Marten and Næs, 1989). Both descriptive panel and physico-chemical data were averaged separately over sample, time of storage and replication. Descriptive panel data were subjected to PCA of the covariance matrix, while physico-chemical data were subjected to PCA of the correlation matrix. For each data set, linear regression was carried out with freshness rated by consumer and the expert panels (individual and consensus notes) as dependent variables and principal components (PCs) as independent variables. Only significant PCs were considered. Regression coefficients were further calculated using the attributes scores of the PCA. Scores of the PCs were standardised to make the β values comparable.

3. Results

3.1. Freshness of strawberries

3.1.1. Evaluation of freshness by consumers and the expert panel

Rated freshness of the different strawberry samples tended to decrease with time of storage (Table 3). As shown by the ANOVA, consumer ratings of the freshness of Evita ($P < 0.001$) decreased with time of storage. No significant decrease was observed for Everest within 9 days or for Elsanta within 7 days. In the same way, individual ratings of the freshness of Evita by the expert panel decreased with time of storage ($P < 0.001$), while freshness ratings of Everest and Elsanta did not seem to be affected by storage. However, in the case of Everest, freshness ratings decreased noticeably with storage time, but not significantly. This is likely to reflect the large variation in the sensory properties of these short shelf life fruit within a lot rather than a lack of training of the expert panel. Finally, consensus ratings of the expert panel followed similar trends to those of individual ratings, but with a tendency to be lower.

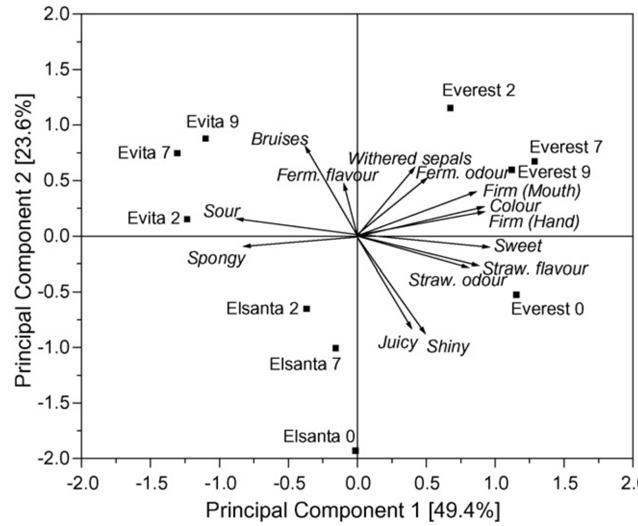

Fig. 1. PCA plot of panel descriptive analysis of strawberries, and the projection of strawberry cultivars at different times of storage ($n = 20$).

Consumer ratings of freshness correlated only moderately with individual ($r = 0.590$, $P < 0.01$) and consensus ratings ($r = 0.536$, $P < 0.05$) of the expert panel. Individual and consensus ratings correlated very strongly ($r = 0.939$, $P < 0.001$). Since strawberry samples varied between replications, the calculation was repeated for each replication and revealed strong correlations between consumer ratings and the individual ratings of the expert panel (Rep 1: $r = 0.833$, $P < 0.01$, Rep 2: $r = 0.790$, $P < 0.01$) as well as between consumer ratings and the consensus ratings of the expert panel (Rep 1: $r = 0.852$, $P < 0.01$, Rep 2: $r = 0.826$, $P < 0.01$).

3.1.2. Sensory descriptive and physico-chemical analyses

Differences in the sensory profile between the strawberry cultivars are clearly visible on the principal component analysis map explaining 73.0% of the variance (Fig. 1), and are greater than differences due to the time of storage. Everest tested immediately after harvesting presented particularly good sensory qualities. Sensory quality of this cultivar decreased to a large extent with storage. The ANOVA showed that withered sepals, bruises ($P < 0.001$), as well as colour, increased with storage time, whereas, shininess ($P < 0.001$), sourness ($P < 0.01$), juiciness and firmness in mouth ($P < 0.05$) diminished. On the other hand, Elsanta was a rather juicy and shiny cultivar which showed small changes in sensory quality during storage with relatively limited sensory quality modifications during storage. The most important loss observed was for shininess ($P < 0.001$) followed by strawberry flavour and strawberry odour ($p < 0.05$), while sepals became more withered ($P < 0.05$). Finally, Evita seemed to be of lower sensory quality. During storage, strawberry colour became more intensive ($P < 0.001$), sepals became more withered ($P < 0.05$), while fermentation odour and flavour ($P < 0.05$) increased. In addition, sourness ($P < 0.001$) and firmness both in mouth and in hand ($P < 0.05$) diminished.

ANOVA showed that there was little significant effect of the time of storage on physico-chemical characteristics of the strawberry samples (Table 4). One measurement of instrumental

Table 4
Physico-chemical characteristics of strawberries ($N = 40$)

Samples	Storage time (days)	F_{max} (N)	Grad (N/mm)	Soluble solids (g/100 g)	Titratable acidity (g citric acid/100 mL)
Everest	0	17.9 a[a]	2.26 a	8.4 b	0.72
	2	19.0 a	1.87 b	9.5 a	0.83
	7	17.2 a	2.03 b	8.3 b	0.75
	9	17.7 a	2.01 b	8.5 b	0.77
Elsanta	0	9.1 a	1.47 a	6.6 a	0.75
	2	9.7 a	1.19 b	7.1 a	0.81
	7	10.2 a	1.31 ab	6.7 a	0.78
Evita	2	11.4 a	1.55 a	6.9 a	1.00
	7	11.1 ab	1.51 a	6.9 a	0.97
	9	9.9 b	1.24 b	7.0 a	1.00

Firmness measurements correspond to a deformation of 75%.
[a] Means with the same letter are not significantly different (Tukey, $P < 0.05$).

firmness (Grad) of Everest decreased with storage ($P < 0.001$), while the second measurement (F_{max}) did not show significant differences. Soluble solids content ($P < 0.01$) and titratable acidity tended to change in a rather inconsistent way with time. Both Elsanta and Evita declined in one measurement of instrumental firmness (Grad) with time of storage ($P < 0.001$), while Evita also decreased in the other measurement of instrumental firmness (F_{max}) ($P < 0.05$). Soluble solids content and titratable acidity seemed to remain constant with time of storage.

3.1.3. Characteristics contributing to freshness of strawberries

In order to investigate which strawberry characteristics influenced freshness rated by consumers and by the expert panel, principal components (PCs) of the PCAs of descriptive sensory and physico-chemical analyses were extracted. Linear regression conducted on the three PCs of the descriptive panel data showed that they all contributed to consumer evaluation of freshness and to a similar degree (PC1: $\beta = 0.305$, $P < 0.05$; PC2: $\beta = -0.302$, $P < 0.05$; PC3: $\beta = -0.342$, $P < 0.05$). Results of the regression carried out on freshness consensus ratings of the expert panel exhibited the same three significant PCs (PC1: $\beta = 0.489$, $P < 0.05$; PC2: $\beta = -0.963$, $P < 0.001$; PC3: $\beta = -0.785$, $P < 0.001$). However, this result differed from that of consumers in two ways: first, regression coefficient values and corresponding significances were higher than those of consumers, and second, the three PCs did not contribute to the same degree. Unlike previous results, individual ratings of freshness by the expert panel showed a contribution of only two PCs (PC2: $\beta = -0.744$, $P < 0.001$; PC3: $\beta = -0.723$, $P < 0.001$), while PC1 was not significant ($\beta = 0.244$, $P > 0.05$). These two significant PCs contributed to the same degree and at a relatively high level. No contribution of physico-chemical measurements, neither in the case of consumers nor of the expert panel ratings of freshness (individual and consensus), was found.

Regression coefficients for each attribute evaluated by the descriptive panel were further calculated for consumers and expert panel data (individual and consensus) (Fig. 2). Several sensory characteristics were shown to contribute to the freshness of strawberries. The attributes influencing freshness were the same when the freshness was rated by consumers and by the expert panel (individual and consensus). Shiny, strawberry odour, firm (hand), firm (mouth), juicy, sweet, and strawberry flavour were shown to positively contribute to freshness, whereas withered sepals, bruises, fermentation odour, spongy, sour and fermentation flavour showed a negative contribution. The contribution of colour was the reverse for the different groups.

Bruises, shiny, spongy, fermentation flavour and juicy in this order were the best predictors of consumer perception of freshness, followed by firm (hand), strawberry flavour, strawberry odour and firm (mouth). Sweet, sour, withered sepals, colour and fermentation odour affected perception of freshness to a relatively limited extent. The important attributes for freshness as rated by the expert panel (consensus) and consumers were similar, although the latter globally exhibited higher regression coefficient values. These groups disagreed concerning withered sepals and firm (mouth): withered sepals were more important for the expert panel than for consumers and the tendency was opposite for firm (mouth). Individual ratings of freshness by the

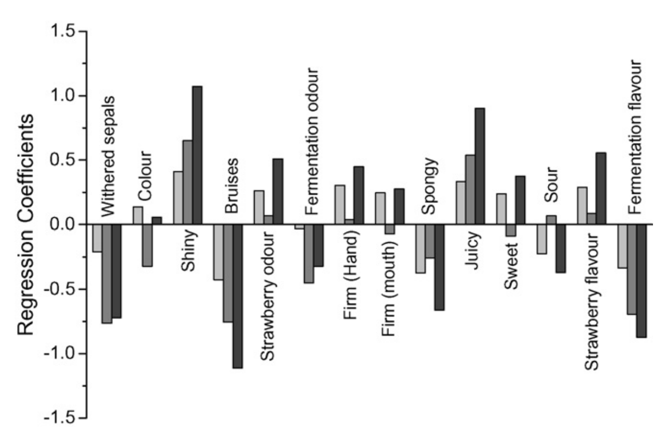

Fig. 2. Regression coefficients of attributes evaluated by the descriptive panel on freshness of strawberries rated by consumers (light grey) and by the expert panel with individual ratings (grey) and consensus ratings (dark grey).

Table 5
Consumer and expert panel (individual and consensus notes) evaluation of freshness of carrots on a 9-point scale

Samples	Storage (days)	Consumers	Expert panel (individual)	Expert panel (consensus)
Bolero A	7	6.28 b[a]	7.73 a	7.50
	9	6.54 b	7.64 a	7.50
	16	7.29 a	8.18 a	8.00
Bolero B	7	4.60 a	6.80 a	6.50
	9	5.32 a	6.36 a	6.50
	16	2.54 b	3.82 b	4.00
Bolero C	1	6.34 a	8.00 a	8.50
	3	5.64 a	6.09 b	6.00
	10	3.78 b	4.91 b	4.50
Maestro	1	6.32 a	8.20 a	8.00
	3	6.39 a	7.82 a	7.50
	10	3.63 b	5.09 b	4.75

[a] Means with the same letter are not significantly different (Tukey, $P<0.05$).

expert panel exhibited several differences in the attributes predicting freshness compared to consensus ratings of the expert panel and consumer ratings. According to individual expert panel ratings, withered sepals and bruises were the best predictors of freshness followed by fermentation flavour, shiny, juicy and fermentation odour. Colour and spongy contributed to a lesser extent to freshness, while the other attributes were not so important.

3.2. Freshness of carrots

3.2.1. Evaluation of freshness by consumers and the expert panel

Rated freshness of the different carrot samples tended to decrease with time of storage (Table 5). ANOVA showed a significant effect of the time of storage on the consumer perception of freshness for all carrot samples: Bolero A ($P<0.01$), Bolero B ($P<0.001$), Bolero C ($P<0.001$) and Maestro ($P<0.001$). However, although Bolero B, Bolero C and Maestro decreased in freshness with storage, freshness of Bolero A was found to increase. Bolero A was stored under optimal conditions at 0 °C and therefore had maintained quality, whereas, other samples showed a decrease in sensory quality. Despite the balanced design, it is likely that the low sensory quality of Bolero B, Bolero C and Maestro influenced participants to give higher ratings of freshness for Bolero A. ANOVA showed a significant effect of the time of storage on the individual ratings of the expert panel for Bolero B, Bolero C and Maestro ($P<0.001$). No significant difference in freshness was observed for Bolero A. Consensus ratings indicated similar trends.

Finally, consumer ratings of freshness correlated strongly with individual ($r=0.881$, $P<0.001$) and consensus ratings ($r=0.873$, $P<0.001$) of the expert panel. Individual and consensus ratings correlated very strongly ($r=0.976$, $P<0.001$).

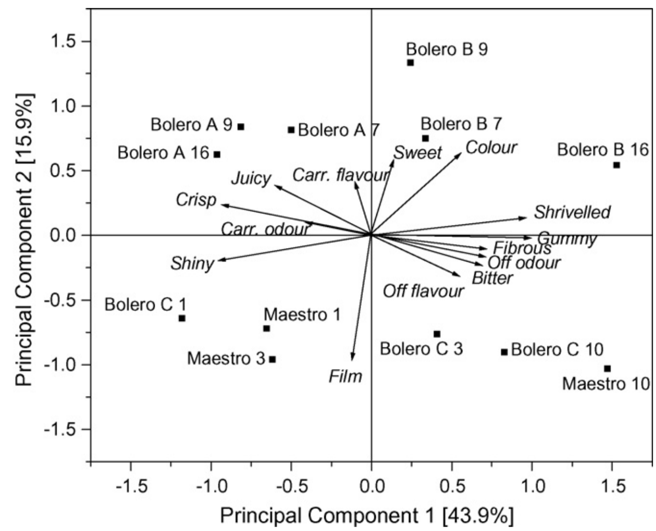

Fig. 3. PCA plot of panel descriptive analysis of carrots, and the projection of carrot samples at different time of storage ($n=24$).

3.2.2. Sensory descriptive and physico-chemical analyses

Carrot samples had different sensory profiles as shown by the descriptive sensory panel. The principal component analysis map explaining 59.8% of the variance indicated high changes due to storage (Fig. 3). Bolero A was a carrot sample with rather good sensory qualities and did not undergo important changes during storage apart from an increase in shininess ($P<0.01$) and a decrease in gumminess ($P<0.05$). These changes were the reverse of those expected. Although samples were presented monadically and according to a balanced design, there might have been a session effect. Within a session, an influence of the other carrot samples having lower sensory quality after a few days of storage is likely to have occurred. Bolero B exhibited relatively good sensory qualities during storage, although its shininess and crispness declined ($P<0.001$) and its gumminess and shrivelled aspect was augmented ($P<0.001$). On the other hand, the sensory quality of Bolero C decreased strongly with storage time. Shininess, crispness and carrot odour ($P<0.001$) of this sample decreased with storage, whereas gumminess, shrivelled appearance ($P<0.001$), fibrousness ($P<0.01$) and off odour ($P<0.05$) increased. Similarly to Bolero C, the sensory quality of Maestro decreased strongly with storage time. A decline in crispness, shininess and juiciness ($P<0.001$) could be observed, whereas, the gumminess, fibrousness, shrivelled appearance ($P<0.001$), as well as off odour and off flavour ($P<0.05$) increased.

ANOVA also showed an effect of storage on the physico-chemical characteristics of the carrot samples (Table 6). Both measurements of instrumental firmness (F_{max} and WF_{max}) indicated similar results. Bolero A exhibited an increase in instrumental firmness with time in replication 1 ($P<0.001$), while it remained constant in replication 2 ($P>0.05$). Bolero C and Maestro decreased in instrumental firmness in both replications ($P<0.001$), while Bolero B decreased in the second replication ($P<0.001$). The changes of Bolero B in the replication 1 were rather inconsistent. Soluble solids contents of Bolero A did not seem to change in the first replication

Table 6
Physico-chemical characteristics of carrots ($N = 40$)

Samples	Storage (days)	F_{max} (N)		WF_{max} (N/mm^2)		Soluble solids (g/100 g)		Titratable acidity (g malic acid/100 mL)	
		Rep. 1	Rep. 2	Rep. 1	Rep. 2	Rep. 1	Rep. 2	Rep. 1	Rep. 2
Bolero A	7	11.8 b[a]	18.3 a	49.0 b	76.8 a	7.7 a	9.8 a	0.047	0.055
	9	14.4 a	18.9 a	59.1 a	79.5 a	7.7 a	9.2 ab	0.048	0.053
	16	14.8 a	18.6 a	60.4 a	78.4 a	7.5 a	9.0 b	0.040	0.057
Bolero B	7	9.7 b	16.0 a	39.8 b	68.1 a	8.3 b	10.0 b	0.051	0.066
	9	12.0 a	14.0 a	50.4 a	60.0 a	8.4 b	10.3 b	0.059	0.060
	16	7.3 c	11.3 b	32.1 c	48.6 b	9.8 a	11.2 a	0.060	0.066
Bolero C	1	15.6 a	18.3 a	66.2 a	75.8 a	9.7 c	9.1 c	0.046	0.084
	3	12.7 b	16.1 b	53.8 b	67.6 b	10.6 b	11.2 b	0.056	0.091
	10	7.6 c	14.3 b	32.3 c	60.6 b	15.2 a	12.3 a	0.093	0.109
Maestro	1	14.6 a	16.5 a	60.7 a	68.0 a	9.0 b	8.4 b	0.055	0.057
	3	13.9 a	15.0 a	58.6 a	62.1 a	9.5 b	9.1 b	0.056	0.074
	10	6.2 b	11.8 b	27.6 b	49.3 b	13.6 a	10.5 a	0.107	0.068

Firmness measurements correspond to a penetration of 10 mm.
[a] Means with the same letter are not significantly different (Tukey, $P < 0.05$).

($P > 0.05$) but showed a decrease in replication 2 ($P < 0.05$). On the other hand, soluble solids contents of Bolero B, Bolero C and Maestro increased with time in both replications ($P < 0.001$). Finally, titratable acidity of Bolero A and Bolero B showed no significant difference during storage, while it tended to increase for Bolero C and Maestro. These rather inconsistent results might reflect the difficulty in selecting a homogenous sample from a lot, as during storage, the ageing of single carrots might differ, and thus, specific product properties.

3.2.3. Characteristics contributing to freshness of carrots

In order to investigate which carrot characteristics measured by the descriptive panel and physico-chemical analyses influenced freshness rated by consumers and by the expert panel, principal components (PCs) of the PCA were extracted. Linear regression analysis with freshness as the dependent variable and the three PCs of the descriptive sensory panel data as the independent variable showed that the first PC contributed to consumer evaluation of freshness ($\beta = -1.428$, $P < 0.001$). Likewise, the first PC of the two PCs extracted from the physico-chemical data was also significant ($\beta = 1.391$, $P < 0.001$). Individual and consensus ratings of freshness by the expert panel showed the same significant PCs with very similar values: individual ratings (PC1 descriptive panel: $\beta = -1.449$, $P < 0.001$; PC1 physico-chemical: $\beta = 1.334$, $P < 0.001$), consensus ratings (PC1 descriptive panel: $\beta = -1.526$, $P < 0.001$; PC1 physico-chemical: $\beta = 1.450$, $P < 0.001$).

Regression coefficients for each characteristic evaluated by the descriptive panel were further calculated for consumer and expert panel data (individual and consensus) and were consistent with each other (Fig. 4). Several sensory characteristics contributed to carrot freshness with different levels of importance: film, shiny, carrot odour, crisp, juicy and carrot flavour showed positive contributions to freshness, while colour, shrivelled, gummy, off odour, fibrous, bitter sweet and off flavour showed negative contributions. Texture was particularly important for freshness, with gummy and crisp as well as, to a lesser extent, fibrous and juicy, presenting high regression coefficients. Appearance was also important for freshness: shrivelled and shiny contributed highly to freshness, and colour and film were less important. Odour and flavour attributes were generally less

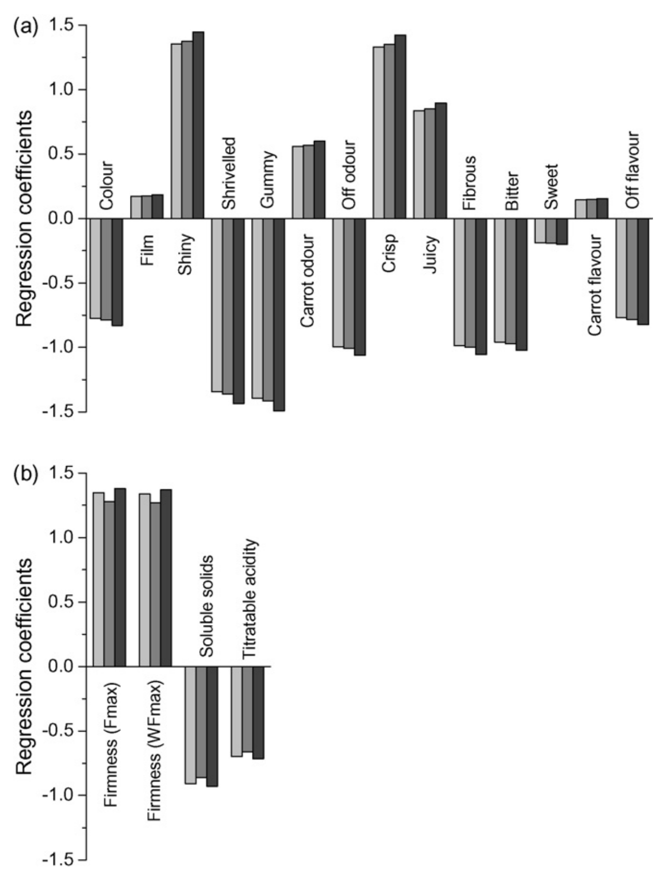

Fig. 4. Regression coefficients of attributes evaluated by the descriptive panel (a) and physico-chemical analyses (b) on freshness of carrots rated by consumers (light grey) and by the expert panel with individual ratings (grey) and consensus ratings (dark grey).

important for freshness: off odour, bitter and off flavour contributed greatly to freshness while carrot odour, sweet and carrot flavour had a limited contribution. Finally, the physico-chemical characteristics measured were observed to contribute largely to freshness of carrots and particularly those relating to texture. The contribution of instrumental firmness (F_{max} and WF_{max}) was positive, while that of soluble solids and titratable acidity was negative.

4. Discussion

4.1. Important characteristics for the evaluation of freshness

In the present study, several sensory characteristics were shown to contribute to the perception of freshness of both strawberries and carrots. Appearance, odour and texture were considered to be important for the description of freshness by the expert panel. Flavour was additionally included in the case of strawberries. Based on regression analyses, three of the five sensory attributes that were of high importance for the evaluation of strawberry freshness according to the expert panel, were related to appearance (Fig. 3). It is therefore assumed that appearance is a dominating aspect in the perception of the freshness of strawberries. In the case of carrots, regression analysis showed that texture, but also appearance attributes, were of particular importance for freshness.

Fillion and Kilcast (2000) also showed the importance of texture (i.e. firm, crisp, crunchy texture) and appearance (i.e. appropriate and bright colour, absence of visual defects) for the freshness of fruit and vegetables, while flavour (i.e. absence of off or stale flavour) was less important. In agreement, Kays (1999) argued that freshness includes the general physical condition of the product, for example, wilting of lettuce or shrivelling of fruit, whereas, other characteristics of freshness, such as odour, would be more elusive.

Because there was no specific category of attributes influencing the freshness of these products but rather a set of attributes, it can be assumed that freshness is related to an overall degree of quality. A first interpretation of this observation is that consumers perceive a product as fresh when it exhibits ideal sensory quality characteristics, e.g. high texture quality, perfect appearance, intensive flavour. However, the list of attributes to be considered when evaluating freshness of strawberries, as generated by the expert panel, shows a large predominance of words with negations. Nine characteristics should not be present in strawberries in order for them to be called fresh whereas only six are expected to be present. This trend is even larger for carrots where 11 characteristics out of 14 show negations. These results are supported to some extent by the regression analysis where it appears that odour/flavour attributes indicating deterioration of the product (i.e. fermentation or off odour/flavour) had a higher contribution to freshness than attributes indicating an optimal sensory quality such as strawberry or carrot odour/flavour. This was however, not the case for texture and appearance attributes for which there was no clear trend towards negative or positive attributes.

From these observations, it can therefore be suggested that freshness would rather be affected by the absence of a set of attributes in the product than by the occurrence of other attributes. Since the characteristics that should not be present in a fresh product generally indicate deterioration, it can be assumed that the evaluation of the freshness of strawberries and carrots corresponds to a measurement of physiological ageing. Similar conclusions were made by Péneau (2005) in the case of apples and by Schwerdtfeger (1979) who generally argued that any deterioration or decline of tissue from a freshly harvested state could be considered as a decline in freshness. In addition, indicators of freshness showing product changes with age were selected among sensory characteristics, such as shrivelling, pitting and decay of tomatillos (Cantwell et al., 1992), turgidity and green colour of strawberry calyx (Saks et al., 1996), or measurement of overall appearance, hypocotyl colour, texture and cotyledon colour of bean sprouts (DeEll et al., 2000).

Similarly, the opinion of 43% of the 1,081 consumers interviewed for their perception of freshness on food labelling was that it referred to the age of the food (MAFF, 2000). Finally, a clear association with the age of the product, is indicated by the Duden German dictionary (1999) with “frisch” (fresh) meaning “besonders von Lebensmitteln: nicht alt, abgestanden, welk” (particularly for food: not old, stale, limp).

An interesting observation that arises from the regression analysis is that the measured sensory characteristics better described the freshness of carrots than the freshness of strawberries. Regression coefficient values of sensory attributes were globally lower than those of carrots, and physico-chemical characteristics did not contribute to freshness of strawberries, whereas, it contributed in the case of carrots. It is possible that the chosen attributes were not appropriate for the evaluation of strawberry freshness. However, it is more likely that these lower values or regression coefficients are due to the larger variability of the strawberry samples. The storage of strawberries, as short shelf life fruit, might be expected to lead to larger variations between single strawberries in a lot. Although care was taken to choose strawberry samples of similar sensory quality and ripeness grade, a substantial variation between samples could not totally be avoided. The fact that consumer tests were not carried out the same day as the ones with the expert panel and the sensory and physico-chemical analyses is also likely to have increased variation. In general, freshness of long shelf life products might be better predictable than the freshness of short shelf life products.

4.2. Comparison of different approaches for assessing important attributes for freshness

Results of the experiments on carrots showed a very strong correlation between the three different approaches of freshness ratings. In addition, attributes evaluated by the descriptive panel and physico-chemical analyses contributed identically to freshness (Fig. 4). In contrast, differences were found in the case of strawberries correlations between individual and consensus ratings of the expert panel and those of consumers were only moderate. This can partly be explained by differences in strawberry quality between the two replications, as the correlation was found to be strong when they were considered separately. Furthermore, individual ratings of freshness by the expert panel were predicted by a different set of attributes than the ratings of the consensus expert panel and the consumer ratings. Since the latter ratings did not differ significantly, it is therefore suggested that variation between fruit has led to the lack of significance in individual ratings of freshness of the expert panel. The small number of panellists composing the expert panel did not allow compensation for product variation when considering individual ratings. The discussion in a group leading to a consensus rating might reduce this problem.

The level of contribution of most attributes to freshness was twice as high for the consensus ratings of the expert panel than for consumers, suggesting the superiority of the former panel for evaluating product freshness, at least for short shelf life products. In contrast to the present investigation, highly trained panels are used in the seafood industry to assess the freshness of products (Botta, 1995). However, this approach does not reflect the consumer view. Köster et al. (1981) argue that consumer panels are more appropriate than expert panels, at least for the evaluation of water drinking quality, since panels in the industry tend to become less motivated in time and often give poor and unreliable results. In the present case, the approach to work with an expert panel specialised in the evaluation of freshness but without particular knowledge on food quality combines the advantages of both consumers and trained panels. However, the reliability of the small consumer group had to be tested further.

In the following, the definition generated by the expert panel for freshness and the results obtained by sensory descriptive and physico-chemical analyses influencing freshness are compared. For this purpose, the more reliable consensus ratings of the expert panel are used as a reference. Most of the attributes appeared to be important for freshness in the regression analysis with the exception of colour in the case of strawberries and film in the case of carrots. The expert panel did not consider flavour attributes as important for the evaluation of freshness, but they were included for the sensory description. Carrot flavour and sweet were consistently shown to be not important by regression analysis, whereas bitter and off flavour were important. These results clearly indicate that there is a discrepancy between what the expert panel considers as important for freshness and what in fact influences their perception of freshness. Similar observations were made in a study on apples where consumers mentioned taste as the most important attribute for freshness, but regression analyses showed texture as more important (Péneau, 2005). In conclusion, the relationship between the evaluation of freshness by consumers or an expert panel, and sensory descriptive profiles contributes to a better understanding of the consumer perception of freshness.

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