JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

Quality Assessment of Strawberries (*Fragaria* Species)

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Several cultivars of strawberries (*Fragaria* sp.), grown under different conditions, were analyzed by both sensory and instrumental methods. The overall appreciation, as expressed by consumers, was mainly reflected by attributes such as sweetness and aroma. No strong correlation was obtained with odor, acidity, juiciness, or firmness. The sensory quality of strawberries can be assessed with a good level of confidence by measuring the total sugar level (°Brix) and the total amount of volatile compounds. Sorting out samples using the score obtained with a hedonic test (called the "hedonic classification method") allowed the correlation between consumers' appreciation and instrumental data to be considerably strengthened. On the basis of the results obtained, a quality model was proposed. Quantitative GC-FID analyses were performed to determine the major aroma components of strawberries. Methyl butanoate, ethyl butanoate, methyl hexanoate, *cis*-3-hexenyl acetate, and linalool were identified as the most important compounds for the taste and aroma of strawberries.

KEYWORDS: Strawberry; *Fragaria* sp.; quality; total volatiles; SPME; sensory evaluation; hedonic; flavor; aroma

INTRODUCTION

Consumers often criticize the organoleptic quality of strawberries. According to the information obtained from a large Swiss food retailer (Federation of Migros Cooperatives, Bussigny, Switzerland), 26% of consumers are often disappointed and 33% sometimes disappointed with the quality of strawberries. Agronomic research has so far set its priorities on appearance, and storage and transport resistance as well as on yield increase. Thus, it is not surprising that the sensory properties of strawberries only partly satisfy the expectations of consumers.

Compounds contributing to the flavor of strawberries, especially the volatile ones, have been extensively studied. Nijssen (*1*) identified >360 volatile compounds. About 15−20 of them are believed to be essential for the sensory quality of strawberries, together with the nonvolatile sugars and organic acids (*2*−*8*). Flavor intensity and fruitiness persistence are influenced by the concentrations of sugars and acids (*9*, *10*). Adding strawberry flavor compounds to a sucrose solution induces an increase in the perception of sweetness (*11*). Alavoine and Crochon (*12*) have shown that the total sugar content is correlated with strawberry taste.

Despite extensive research done on strawberry flavor, the responsible substances for aromatic distinction among cultivars have not been fully characterized yet (*2*, *13*). The differences in flavor of the three strawberry cultivars described by Ulrich et al. (*7*) are due to different concentrations and ratios of the key flavor compounds: wild strawberry, with a spicy odor derived from anthranilic acid methyl ester; *Fragaria virginia*, with a fruity aroma characterized by esters; and *Fragaria ananassa*, characterized by Furaneol and 2,5-dimethyl-4-methoxy-3(2*H*)-furanone (*14*). The typical strawberry aroma is not due to a single compound but is rather the result of a complex multicomponent relationship among many aromatic constituents (*15*). The interactive effects of these compounds are still poorly understood.

The aim of the present work was to assess the quality of strawberries. Consumer tests and sensory evaluations by a semitrained panel were performed to establish quality criteria. In addition, a newly developed concept (*16*, *17*) was used to determine the amount of total volatile compounds in strawberries. Sensory evaluation and physicochemical analyses were used as complementary tools to determine and set quality acceptance limits.

MATERIALS AND METHODS

Fruit Samples and Sample Preparation. During three growing seasons (1997, 1998, and 1999), 80 samples representing 24 strawberry cultivars, grown in fields and/or under plastic tunnels, were harvested

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10.1021/jf0200467 CCC: $25.00
Published on Web 12/24/2002

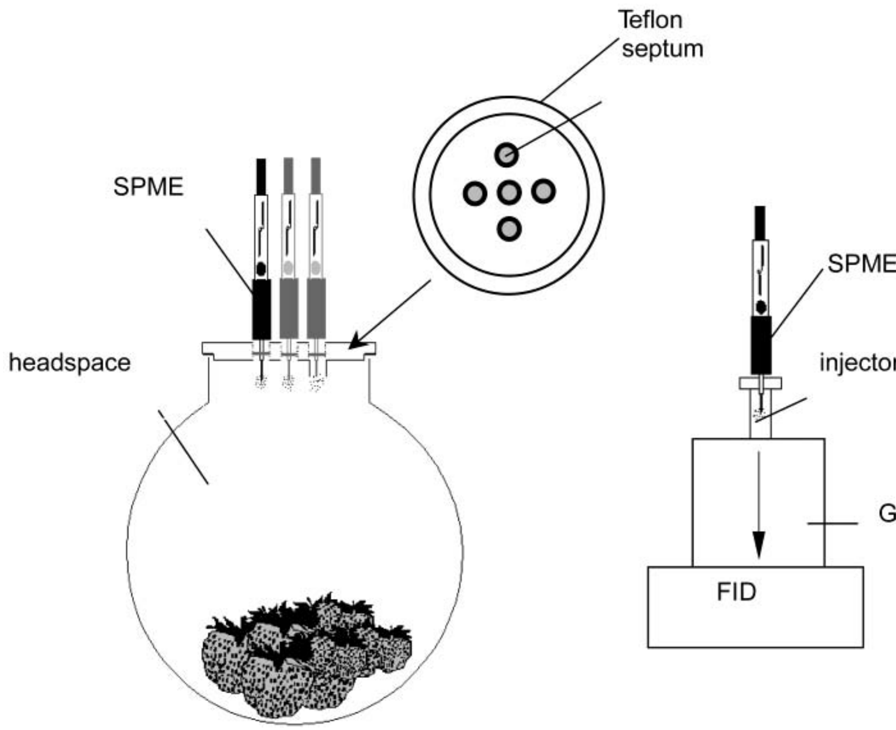

Figure 1. Equipment for the determination of total volatile compounds as specified by Azodanlou et al. (*17*).

at the ripe stage and used immediately for sensory evaluation and instrumental analyses. The following cultivars were analyzed by consumer tests as well: Mara des bois, Carezza, Pegasus, Madeleine, Elsanta, and Marmolada. The samples were obtained either from the Swiss Federal Research Station for Plant Production in Conthey (Switzerland) or from a large Swiss food retailer (Federation of Migros Cooperatives).

Intact fruits were used for sensory evaluation and for determination of total volatile compounds.

Strawberries classified by sensory evaluation were homogenized at high speed in a professional blender (Kenwood Professional, Dublin, Ireland) for ∼30 s to produce a homogeneous puree, which was directly used for instrumental analyses. To inactivate the endogeneous enzymes, 50 g of a saturated ammonium sulfate (purum, Fluka AG, Buchs, Switzerland) solution was added to 50 g of fruit, directly into the blender. Finally, 2-methyl-1-pentanol (Fluka purum; 1 mg/100 g of homogenate) was added as internal standard.

Sensory Evaluation. *Consumer Tests.* Standard hedonic consumer tests with an average of 120 participants were carried out in supermarkets (Federation of Migros Cooperatives) in different Swiss cities (La Chaux de Fonds, Pully, Sion, and Bienne). The test persons were asked to give an overall appreciation of strawberry quality on a 1−9 scale (1 = extremely bad to 9 = extremely good). In the 1999 campaign a modified procedure was adopted. Each fruit was divided into halves; half was used to assess the sensory quality, and the other half was assigned to different baskets according to the score obtained (1−9). The pooled samples were homogenized as described above and used for instrumental analyses. This way of classifying samples is hereafter called "hedonic classification".

Sensory Panel. The sensory panel consisted of 10−15 semitrained subjects. The subjects were asked to rate the following sensory attributes: odor, aroma, sweetness, acidity, firmness, and juiciness. They were also asked to give their overall appreciation. The volatile compounds were evaluated in two ways: first, through the nose (odor) and then by the retronasal way through the pharynx after masticating the sample (aroma). The panel rated the different parameters on a 1−9 scale (e.g., 1 = very weak aroma intensity and 9 = very strong aroma intensity). The same scale was used for the overall appreciation (extremely bad to extremely good). Panelists were given water (Volvic, Puy-de-Dome, France) as a neutralizing beverage between sample testings. The evaluation was carried out in a standard sensory laboratory under well-controlled conditions using red light to mask any color differences.

Instrumental Analyses. *Determination of Total Volatile Compounds.* Fresh intact strawberries (400 ± 1 g) were carefully placed in a 2 L headspace flask with wide opening (NS/160/100) as shown in **Figure 1**. The flask was sealed with a Teflon lid, allowing the simultaneous recovery of the volatile compounds by several SPME fibers. Different types of SPME fibers were used: poly(dimethylsiloxane) (PDMS) with 100 μm thickness (catalog no. 5-7300-U); polyacrylate (PA), 85 μm (catalog no. 5-7304); porous fibers of Carbowax/divinylbenzene (CW/DVB), 65 μm (catalog no. 5-7312); and bipolar fibers PDMS/DVB, 65 μm (catalog no. 5-7310-U), Carboxen/PDMS (CAR/PDMS), 75 μm (catalog no. 5-7318), and CW/CAR/PDMS, 50/30 μm (5-7328-U), all obtained from Supelco Co. (Bellefonte, PA).

The fruits were left at 25 °C for 5 min to obtain the necessary gas equilibrium in the headspace. Aliquots of the volatile compounds were then collected by inserting the SPME needle through a Teflon-coated silicone septum into the headspace of the flask. After 5 min (sampling time), the adsorbed substances were desorbed into a gas chromatograph HRGC-5300 (Carlo Erba S.p.A., Milano, Italy) equipped with a splitless injector port, directly coupled to the flame ionization detector, using a fused silica transfer tube (20 cm in length, 0.1 mm i.d., no. 160-2630, J&W, New Brighton, MN). The following GC conditions were used: helium carrier gas pressure, 150 kPa at a flow rate of ∼5 mL/min; hydrogen and air pressure for the FID, 50 and 80 kPa, respectively; oven temperature, 250 °C; injection port and detector temperatures, 200 and 250 °C, respectively.

A mixture (3 mg/kg) of 1-methoxy-2-propylacetate (Merck, for synthesis), 2-methyl ethyl ketone (Fluka, purum), and butanol (Fluka, puriss.) was used as external standard. The total volatile peak (μV·min) was measured with a Borwin integrator (JMBS Developpements, Grenoble, France). Between analyses, the headspace flask was cleaned by purging with filtered air that had previously passed through a charcoal trap (Supelpure-HC trap, Supelco Co).

Measurements on strawberry puree were carried out by spreading the sample into a crystallizing dish (10 cm diameter, 3 cm height), which was then placed in the 6 L headspace flask. Total analysis time was ∼15 min, including 5 min for both equilibration and sampling. Each sample was analyzed in triplicate. With the above-described experimental conditions measurements of the total volatile fraction gave a coefficient of variation of <5% (*17*).

Identification and Quantification of Volatile Compounds. The volatile compounds of strawberries were extracted by SPME and identified and quantified by GC. The volatiles were extracted as described above, using a 2 L headspace flask and adsorbed on a CAR/PDMS fiber. Desorption was carried out directly into the injector of the GC at 250 °C.

Identification Procedure. A GC (HP 5890, series II, Hewlett-Packard, Palo Alto, CA) linked to a mass selective detector (HP 5971 A) and to an ionization gauge controller (HP 59822 B) was used. Separation was achieved on a glass column (25 m × 0.2 mm i.d.) coated with a 0.33 μm film of diphenyl (5%)/dimethylsiloxane (95%) copolymer (HP-5), using the following conditions: carrier gas, helium, at a flow of 2 mL/min, 100 kPa; temperature program, 40 °C for 2 min, linear temperature gradient from 40 to 190 °C at 4 °C/min, held at 190 °C for 5 min; injector and detector temperatures, 250 and 280 °C, respectively; interconnecting line temperature, 300 °C; MS settings, ion source pressure of 10^{-5} Torr, filament voltage of 70 eV, and scan speed of 1.9 scan/s.

Identification was performed by a combination of Kovats retention indices and a GC-MS library (Flavornet, Geneva, NY). Some components were identified by comparison of retention time and mass spectra with authentic substances. The following reference substances were used: hexanal, butyl acetate, *trans*-2-hexenol, propyl butanoate, butyl butanoate, hexyl acetate, isopropyl hexanoate, 1-octanol, linalool (Fluka); isoamyl acetate, 3-methylbutyl butanoate, 3-phenyl-1-propanol, bornyl acetate (Aldrich, Milwaukee, WI); dimethyl disulfide, ethyl butanoate, *trans*-2-hexenal, ethyl 2-methylbutanoate, 2-methylbutanoic acid, hexyl hexanoate, 4-hydroxy-2,5-dimethyl-3(2*H*)-furanone (Givaudan-Roure, Dübendorf, Switzerland).

Quantification Procedure. A GC (HP 6890) equipped with an FID was used for separation at the same conditions as described for the GC-MS procedure. Hydrogen and air flows for the FID were set at 40 and 450 mL/min, respectively.

Quantification was performed by electronic integration of the peaks (HP Chem-Station) using 2-methyl-1-pentanol (1 mg/kg) as internal standard.

Determination of the Total Sugar and Acid Contents. Two hundred grams of strawberries was homogenized to a puree, and the total sugar content (°Brix) was determined using a refractometer (Atago, PR-1, Atago, Tokyo, Japan). pH and total acidity were measured with a titrator (Mettler DL 25, Mettler-Toledo, Greifensee, Switzerland). For determination of the total acidity, 10 ± 0.1 g of the sample was titrated to pH 8.0 using 0.1 M NaOH. The titrated volume (milliliters) corresponds directly to total acidity expressed as grams per liter of citric acid.

Texture Analysis. The firmness of the strawberries (100 ± 1 g) was determined using a Kramer shear cell operated by a shear test machine (Versa Test + Advanced Forces Gauge, Memesin, Brütsch & Rüegger, Zurich, Switzerland). The device speed was set at 250 mm/min. The fruits were divided in two parts prior to measurements, which were performed in triplicate, at ambient temperature.

Statistical Evaluation. The Statview program (Abacus Concepts Inc., Berkeley, CA) was used for the analysis of variance (ANOVA). Significant differences in instrumental measurements between samples were determined by protected least significant difference (PLSD) with $p \leq 0.05$. When the test of normality failed, the nonparametric test was applied to the individual panel scores for the investigated intensity criteria and then transformed into ranking numbers. The nonparametric test was processed using Kruskall and Wallis values with $p \leq 0.05$. Pearson's correlation analysis was carried out to identify the interdependence between different variables of sensory, instrumental, and chemical data ($p \leq 0.05$).

RESULTS AND DISCUSSION

Consumer tests were carried out to establish an overall appreciation of the quality of strawberries. In addition, a sensory panel was employed to identify quality attributes. The established sensory parameters allowed different cultivars and, most importantly, different quality attributes to be distinguished. A relationship between data obtained by sensory evaluation and instrumental analyses allowed the development of a model for the appreciation of strawberry quality.

Table 1. Comparison of Strawberry Samples by the Sensory Panel[a]

quality descriptor		harvest year: 1997 (16 samples)	1998 (31 samples)	1999 (30 samples)
odor	odor	NS	0.002 SI	0.001 SI
	fermented	NS	NE	NE
taste	aroma	0.004 SI	0.001 SI	0.001 SI
	sweetness	0.001 SI	0.001 SI	0.001 SI
	acidity	0.015 SI	0.001 SI	0.001 SI
	bitter	NS	NE	NE
	herbaceous	NS	NE	NE
	fermented	NS	NE	NE
	persistence	0.005 SI	NE	NE
texture	firmness	NE	0.001 SI	0.001 SI
	juiciness	0.001 SI	0.001 SI	0.001 SI
	fondant	0.001 SI	NE	NE
	crunchiness	0.001 SI	NE	NE
HT[b]	overall appreciation	NE	0.001 SI	0.001SI

[a] *P* values of Kruskall and Wallis: NS, not significant at the <95% level; SI, significant at the ≥95% level; NE, not evaluated. [b] HT, hedonic test.

Table 2. Correlation between Overall Appreciation and Some Sensory Descriptors Defined by the Sensory Panel

sensory descriptor	1998 harvest	1999 harvest
aroma	0.86	0.94
sweetness	0.86	0.87
odor	0.56	0.55
juiciness	0.55	0.49

Sensory Evaluation. A sensory panel was used to set up quality descriptors as outlined above. Eighty strawberry samples of 24 cultivars were used for the identification of the most important quality attributes. Because the normality test failed (large variance of results), the nonparametric test was used for statistical evaluation of the results. In the first year (1997), the panel's objective was to define sensory descriptors such as odor, aroma, sweetness, acidity, firmness, juiciness, fondant, and crunchiness (**Table 1**). Attributes such as fermented odor and taste, bitterness, and herbaceous taste were not retained, because of their low significance ($p > 0.05$). Some attributes such as fondant and crunchiness could not be measured instrumentally and were therefore not further retained.

For the 1998 and 1999 harvests, the large number of fruit samples needed to evaluate the quality by the consumer test prompted us to use the hedonic test by the sensory panel. The descriptors retained were again significant and could be used to explain differences among fruit samples. Descriptors such as aroma, sweetness, firmness, and juiciness turned out to be significant quality attributes to describe the overall quality of strawberries.

The relationship between the overall appreciation and some of the sensory descriptors such as odor, aroma, sweetness, acidity, firmness, and juiciness was confirmed ($p \leq 0.05$) in 1998 and 1999. As shown in **Table 2**, aroma and sweetness are two descriptors that correlate well with the overall appreciation.

Consumer tests were performed on six strawberry cultivars as described above, to obtain a preference score (**Table 3**). Although the sensory score obtained on different days varied

Table 3. Overall Appreciation of Six Strawberry Cultivars by Consumers

cultivar (av score[a]) for consumer test performed		
May 18, 1999	May 25, 1999	June 2, 1999
Mara des bois (6.4)	Mara des bois (7.0)	Mara des bois (7.3)
Carezza (6.1)	Carezza (6.8)	Carezza (6.7)
Pegasus (5.6)	Pegasus (6.2)	Pegasus (6.3)
Madeleine (5.5)	Madeleine (6.0)	Madeleine (5.4)
Elsanta (4.9)	Elsanta (5.9)	Elsanta (4.6)
Marmolada (4.2)	Marmolada (5.5)	Marmolada (3.6)

[a] Score: 1 = extremely bad, 9 = extremely good (mean values).

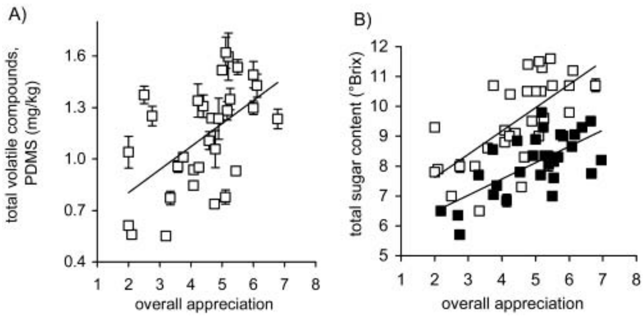

Figure 2. Relationship between (A) total volatile compounds (PDMS fiber) and overall appreciation given by the sensory panel for the 1998 (□) harvest and (B) °Brix and overall appreciation given by the sensory panel for the 1998 (□) and 1999 (■) harvests.

for a given cultivar, it was interesting to note that the ranking of the cultivars was always the same. The comparison among strawberry cultivars from the same harvest season was significantly different ($p \leq 0.05$). Cv. Mara des bois was always judged to have the best quality.

To identify the most relevant quality attributes, sensory panel tests were performed on the same cultivars used in the consumer tests. Sweetness and aroma were the only two attributes that correlated well several times. The results indicate that strawberry fruit is always highly appreciated if its sweetness and aroma intensity are high.

Instrumental Analyses. Several chemical and physicochemical parameters were measured by instrumental methods. Total sugar content (°Brix), pH, and total acidity data were obtained for strawberries of all harvests (1997, 1998, and 1999). The total volatile compounds were determined for the fruits of the 1998 and 1999 seasons, and texture measurements were carried out on strawberries of the 1999 harvest only.

Correlation between Sensory and Instrumental Data. Relationships between data obtained by the sensory panel and instrumental methods have been established. In **Figure 2A** the relationship between the total amount of volatile compounds ($p \leq 0.05$, $r = 0.54$) and the overall appreciation is shown. Because of the weak correlation ($p \leq 0.05$, $r = 0.14$) in the 1999 harvest, only the values for 1998 are presented here. The total sugar content (**Figure 2B**) correlated significantly ($p \leq 0.05$) with the overall appreciation by the sensory panel for both the 1998 and 1999 harvests ($r = 0.68$ and $r = 0.67$, respectively).

It was interesting to note that for a given °Brix (e.g., 8.0), the overall appreciation score varied considerably between the 1998 (2.5) and 1999 (4.8) harvest seasons. The °Brix therefore seems to be more robust than the total volatile compounds in terms of quality evaluation. However, it is clearly not appropriate to set the same °Brix as a quality attribute to obtain customer satisfaction every year.

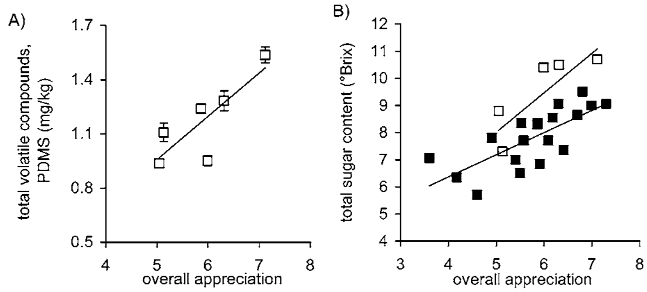

Figure 3. Relationship between (A) total volatile compounds (PDMS fiber) and overall appreciation by the consumers for the 1998 (□) harvest and (B) °Brix and overall appreciation by the consumers for the 1998 (□) and 1999 (■) harvests.

Table 4. Correlation between the Overall Appreciation by Consumers and Instrumental Analyses

	coefficient of correlation			
	June 3, 1998	May 18, 1999	May 25, 1999	June 2, 1999
instrumental measurement				
total sugar content	0.79[a]	NS[b]	0.89[a]	0.92[a]
total acidity	NS	NS	NS	NS
pH	NS	NS	NS	NS
penetrometer	NS	NA[c]	NA	NA
Kramer shear cell	NA	NS	NS	NS
conductivity	NS	NS	NS	NS
total volatile compounds				
CAR/PDMS	0.77*	0.80*	NS	NS
PDMS/DVB	0.68*	NS	NS	NS
CW/DVB	NS	NS	0.75[a]	NS
PDMS	0.81*	NS	0.91[a]	NS
PA	NS	NS	NS	NS
CAR/PDMS/DVB	NA	NS	NS	NS

[a] Significant at $p \leq 0.05$. [b] NS, not significant. [c] NA, not analyzed.

A good correlation ($p \leq 0.05$, $r = 0.81$) was found in 1998 between total volatile compounds and the overall appreciation by consumers (**Figure 3A**). In the 1999 trials, the correlation was less evident ($r = 0.14$), probably because of the higher heterogeneity of the strawberries obtained during the 1999 season (values not shown). The total sugar content (**Figure 3B**) correlated significantly ($p \leq 0.05$) with the consumer ratings for both the 1998 and 1999 harvests ($r = 0.79$ and $r = 0.74$, respectively). Total sugar content and the amount of total volatile compounds seem to be quality indicators for strawberries.

The results obtained by the sensory panel and by the consumer appreciation gave the same relationship with the instrumental data used (°Brix and total volatile compounds). These parameters as well seem to be appropriate for the quality assessment of strawberries. **Table 4** summarizes the results of the comparison between the consumers' appreciation and the instrumental data.

The high correlation between the total sugar content and the overall appreciation, on the one hand, and between the amount of total volatile compounds (measured with some of the SPME fibers) and the overall appreciation, on the other hand, led to the conclusion that the two attributes "sweetness" and "aroma" are determinant for the quality of strawberries.

Hedonic Classification for the Assessment of Strawberry Quality. The main problem in the development of a model for the assessment of the quality of fruits was the heterogeneity of the fruit samples, as has been demonstrated in a previous work (*19*). Introduction of the hedonic classification successfully solved this problem. Indeed, the same fruit sample could be

Table 5. Volatile Compounds in Strawberries, Sampled with SPME (CAR/PDMS), Identified by GC-FID and GC-MS

identification	RT[a]	RRI[b]	RI[c]	OT[d] (mg/kg)	odor characteristics[e]
propyl acetate	4.65	682	716[e]		
methyl butanoate[f]	5.41	714	723[g]	10^{-3}–10^{-2} [h]	fruity, cheese, ethereal
dimethyl disulfide	5.45	718	744,[e] 742[g]		onion
methyl 2-methylbutanote	6.28	742	776[g]		sweet
hexanal	7.89	793	801[g]	10^{-2}–10^{-1} [h]	green, sour, cut grass
ethyl butanoate[f]	8.05	778	771,[e] 804[g]	10^{-6}–10^{-5} [h]	fruity, sweet, cheese, apple
butyl acetate	8.10	800	816,[e] 817[g]	10^{-2}–10^{-1} [h]	apple, glue, pear
isopropyl butanoate	8.50	834	847[g]	10^{-2}–10^{-1} [h]	pungent
trans-2-hexenal	9.57	837	857,[e] 854[g]	0.17[i]	fatty, green, fatty
trans-2-hexenol	10.54	862	862,[i] 887[g]	10^{-1}–1[h]	green leaves, fruity, burnt
ethyl 2-methylbutanoate	10.55	861	846[e]		
isoamyl acetate	10.60	865	876[g]		banana
propyl butanoate	11.70	893	898[g]		pineaple
methyl hexanoate[f]	12.42	909	934[g]	10^{-2}–10^{-1} [h]	fruity, pineapple
2-methylbutanoic acid	13.07	924	838,[e] 873[g]	10^{-2}–10^{-1} [h]	fruity, sourish, sweety
butyl butanoate	14.03	947			
isobutyl butanoate	15.88	990			
cis-3-hexenyl acetate[f]	16.19	998	1009[g]		green banana
hexyl acetate[f]	16.23	999	1008[e]	10^{-2}–10^{-1} [h]	banana, apple, pear
isopropyl hexanoate	16.70	1019	1040[g]		fresh
2-methlybutyl butanoate	17.98	1041			
3-methylbutyl butanoate	17.89	1039	1093[e]		
2,5-dimethyl-4-methoxy-3(2*H*)-furanone	18.39	1051			
1-octanol	18.48	1054	1075,[e] 1072[g]		chemical
linalool[f]	19.98	1086	1101,[e] 1100[g]	10^{-4}–10^{-1} [h]	lemon peel, flowers
hexyl butanoate	22.25	1147	1185[g]		apple peel
3-phenyl-1-propanol	24.34	1200			
bornyl acetate	25.92	1242	1289[e]		
hexyl hexanoate	29.27	1334	1390[g]		apple peel
4-hydroxy-2,5-dimethyl-3(2*H*)-furanone	31.18	1389		10^{-3}–10^{-2} [h]	burnt, sweet, caramel

[a] RT, retention time. [b] RRI, relative retention indices. [c] RI, retention indices. [d] OT, odor threshold. [e] Kovats indices and odor characteristics (*19*). [f] Considered to be an important contributor to fresh strawberry aroma quality. [g] Flavornet (*20*). [h] Odor thresholds: published by Larsen et al. (*4*) and by [i]Ulrich et al. (*6–8*) and in [j]4-hydroxy-2,5-dimethyl-3(2*H*)-furanone.

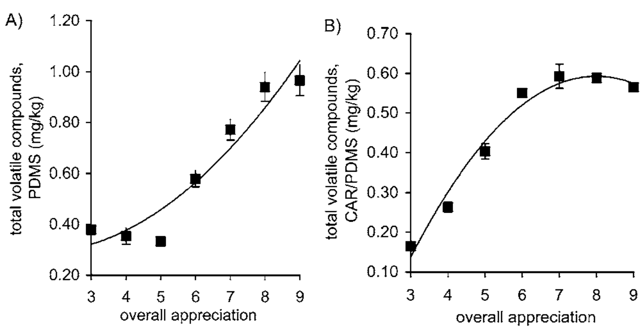

Figure 4. Relationship between total volatile compounds extracted by a PDMS fiber (A) and a CAR/PDMS fiber (B) of hedonically classified strawberry samples and consumer appreciation.

analyzed by instrumental methods and by the consumer, which made possible a direct comparison of the results.

Total Amount of Volatile Compounds. Using the hedonic classification, a good correlation between the total amount of volatile compounds and the consumer overall appreciation was found for nearly all SPME fibers used ($p \leq 0.05$, $r = 0.73-0.94$), compared to correlations of $r = 0.04-0.44$ prior to classification. As examples, the relationship between consumer appreciation and total volatile compounds (milligrams per kilogram) extracted by PDMS ($r = 0.94$) and CAR/PDMS ($r = 0.90$) fibers, using hedonically classified strawberries, are shown in panels A and B, respectively, of **Figure 4**.

The values for total volatile compounds obtained with the CAR/PDMS fiber showed a strong correlation with the consumer ratings ($r = 0.90$) and confirmed the results obtained in 1998 ($r = 0.77$). With the CAR/PDMS fiber, which is porous and slightly more polar than the PDMS fiber, a different behavior was observed. At first, the total amount of extracted volatile compounds was smaller and the curve exhibited a maximum at an appreciation score of 7. The reasons for the observed differences remain to be established; the porosity and polarity of the SPME fibers are thought to play a key role.

Aroma Compounds. The aroma of the strawberry is composed of a large number of substances belonging to different classes of chemicals such as esters, alcohols, and carbonyl compounds (*1*, *6*, *7*, *14*). These substances contribute to the fruity and green notes (herbaceous odor) of strawberries and were identified and quantified by GC-MS and GC-FID as described above. Taking into account the results obtained for total volatile compounds, where it has been shown that the different types of SPME fibers adsorbed the same volatiles, albeit in different amounts, GC analyses were carried out with one SPME fiber type only. The CAR/PDMS fiber was chosen because of its good differentiation ability between the scores of 3 and 6 in the overall appreciation (**Figure 4B**). The results of the aroma analysis are presented in **Table 5**.

Quantification of the most relevant aroma components, such as methyl butanoate (0.12−0.98 mg/kg), ethyl butanoate (0.006−0.7 mg/kg), methyl hexanoate (0.01−0.1 mg/kg), hexyl acetate (0.01−0.7 mg/kg), and linalool (0.006−0.06 mg/kg), clearly indicated that all relevant compounds were present in amounts above their threshold limit taken from the literature (**Table 5**).

As expected, when the peak areas measured by GC-FID were summed, the concentration of the volatile compounds increased up to an appreciation score of 7 and then remained constant. A good correlation (r^*: polynomial correlation) with the consumer appreciation ($r^* = 0.88$) was obtained (**Figure 5A**). An even better correlation ($r^* = 0.97$) was obtained between the total

Table 6. Quality Model with Limit Values (and Intervals) for Total Volatile Compounds, Total Sugar Content, and Firmness

instrumental data	quality class		
	medium	good	very good
total volatile compounds (mg/kg)			
CAR/PDMS	0.21a (0.16–0.28)	0.52b (0.38–0.62)	0.58ab (0.56–0.60)
PDMS/DVB	0.40a (0.31–0.49)	0.60b (0.50–0.66)	0.73b (0.53–0.87)
CW/DVB	0.39a (0.31–0.45)	0.49b (0.36–0.61)	0.50b (0.46–0.55)
PDMS	0.37a (0.32–0.39)	0.56b (0.32–0.81)	0.96c (0.88–1.03)
DVB/CAR/PDMS	0.62a (0.41–0.84)	0.90b (0.65–1.09)	1.09c (1.01–1.18)
total sugar content (°Brix)	6.7a (6.5–7.0)	7.4b (7.1–7.7)	8.3c (8.3–8.4)
firmness (F_{max}, N)	245.7ab (227.6–264.4)	240.7a (173.6–299.7)	226.1b (190.8–258.5)

[a] Level of significance 5%; different letters in a row mean significant differences.

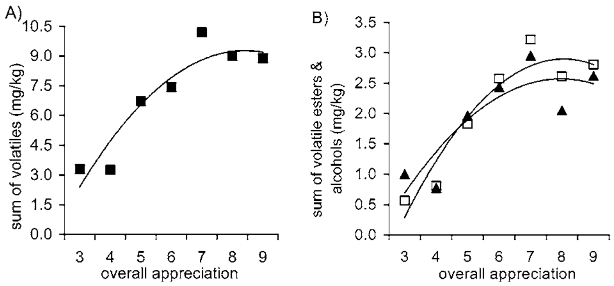

Figure 5. Relationship between overall appreciation and (A) the sum of the volatile compounds (■) and (B) the sum of the volatile esters (□) and the sum of volatile alcohols (▲).

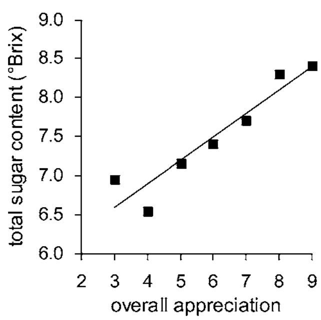

Figure 6. Relationship between total sugar content (°Brix) and consumer appreciation after hedonic classification.

amount of volatile compounds and consumer appreciation. As shown in **Figure 5B**, the esters ($r^* = 0.91$) and the alcohols ($r^* = 0.74$) seem to be major contributors to the appreciation of strawberries.

On the basis of the correlation coefficients, it can be stated that esters contribute essentially to the overall appreciation of strawberry quality ($r^* = 0.91$). Among this group of substances, methyl butanoate ($r^* = 0.81$), ethyl butanoate ($r^* = 0.84$), methyl hexanoate ($r^* = 0.63$), *cis*-3-hexenyl acetate ($r^* = 0.73$), and hexyl acetate ($r^* = 0.44$) play a major role in the aroma of strawberries.

Linalool also showed a good correlation with consumer appreciation ($r^* = 0.57$). The sum of esters and linalool correlated strongly with consumer appreciation ($r = 0.90$).

Total Sugar Content. A very strong relationship ($p \leq 0.05$, $r = 0.94$) between total sugar content (°Brix) after hedonic classification of the samples and consumer appreciation was established, as shown in **Figure 6**. Here again the advantage of the hedonic classification was evident; without hedonic classification the correlation was poor ($r = 0.16$). These results reflect the heterogeneity of fruits well, which was critical in the development of the quality model.

Texture. The correlation between texture data as measured by the Kramer shear cell and the overall appreciation improved considerably with the hedonic classification method (before and after hedonic classification $r = 0.30$ and -0.65, respectively). Nevertheless, the results were not significant for grading the strawberry quality (values not shown).

Development of a Model for the Assessment of Strawberry Quality. On the basis of these results a model containing three quality levels (medium, good, and very good) was developed. The distribution of the samples into the three quality classes was approximately 1:1:1 (33.1%:35.7%:31.1%). The average appreciation for "medium" samples was 4.5 (range = 4−5), for "good" samples, 6 (range = 5−7), and for "very good" samples 8.5 (range = 8−9). In **Table 6** are given intervals and limit values for the different quality attributes.

Two of the six fiber types used, DVB/CAR/PDMS and PDMS, allowed the three quality classes to be distinguished. The total sugar content (°Brix) was shown to be a very good parameter to distinguish among the three quality levels as well, whereas texture measurements (firmness) did not allow a clear-cut distinction in the present study.

For the other instrumental measurements, average values for medium, good, or very good quality samples were always overlapping (values not shown).

Recent work performed by Carlen (not published), who used the hedonic classification method for experiments with the strawberry harvest of the year 2000, confirmed the strong relationship between instrumental methods (total volatile compounds using the PDMS fiber and total sugar content) and consumer appreciation.

Conclusions. The present study has clearly demonstrated aroma and sweetness to be the most important quality attributes for strawberries. Hedonic classification of samples allowed significant improvement of the correlation between instrumental data and consumer appreciation and enabled us to develop a quality evaluation methodology based on three quality levels. Multiple variable analyses enabled us to discriminate among the quality levels. Measurement of the total volatile compounds using the best performing fibers (DVB/CAR/PDMS and PDMS) and determination of total sugar content (°Brix) were shown to be generally sufficient for assessing the quality of strawberries.

The compounds that contributed significantly to the peak area, measured by the total volatile compound analysis, were quantified and identified. Some of the individual compounds were correlated to the consumer appreciation. In particular, esters were found to contribute greatly to the sensory quality of strawberries.

ACKNOWLEDGMENT

We thank Roland Terrettaz and the cooperative Migros in Bussigny for supplying strawberry samples and for organizing and setting up sensory tests.

LITERATURE CITED

(1) Nijssen, L. M. *Volatile Compounds in Food: Qualitative and Quantitative Data*; TNO Nutrition and Food Research Institute: Zeist, The Netherlands, 1996.

(2) Fischer, N.; Hammerschmidt, F. J. A contribution to the analysis of fresh strawberry flavour. *Chem. Mikrobiol. Technol. Lebensm.* **1992**, *14*, 141−148.

(3) Larsen, M.; Poll, L. Odor thresholds of some important aroma compounds in strawberries. *Z. Lebensm. Unters. Forsch.* **1992**, *195*, 120−123.

(4) Larsen, M.; Poll, L.; Olsen, C. E. Evaluation of the aroma composition of some strawberry (*Fragaria-Ananassa* Duch) cultivars by use of odors threshold values. *Z. Lebensm. Unters. Forsch.* **1992**, *195*, 536−539.

(5) Schieberle, P. Heat-induced changes in the most odor-active volatiles of strawberries. In *Trends in Flavor Research*; Maarse, H., Van der Heij, D. G., Eds.; Elsevier Science Publishers: Amsterdam, The Netherlands, 1994; pp 345−351.

(6) Ulrich, D.; Eunert, S.; Hoberg, E.; Rapp, A. Analysis of strawberry aroma with solid-phase microextraction. *Dtsch. Lebensm. Rundsch.* **1995**, *91*, 349−351.

(7) Ulrich, D.; Rapp, A.; Hoberg, E. Analysis of strawberry flavor—quantification of the volatile components of cultivars of cultivated and wild strawberries. *Z. Lebensm. Unters. Forsch.* **1995**, *200*, 217−220.

(8) Ulrich, D.; Krumbein, A.; Rapp, A. Analysis of aroma compounds in strawberry, sour cherry and tomato by gas chromatography after solid phase micro-extraction. *Dtsch. Lebensm. Rundsch.* **1997**, *93*, 311−316.

(9) Bonnans, S.; Noble, A. C. Effect of sweetener type and of sweetener and acid levels on temporal perception of sweetness, sourness and fruitiness. *Chem. Senses* **1993**, *18*, 273−283.

(10) Noble, A. C. Taste−aroma interactions. *Trends Food Sci. Technol.* **1996**, *7*, 439−443.

(11) Reineccius, G. A. Instrumental means of monitoring the flavor quality of foods. In *Chemical Markers for Processed and Stored Fruit*; Tung-ching Lee, Hie-joon Kim, Eds.; ACS Symposium Series 631; American Chemical Society: Washington, DC, 1996; pp 241−252.

(12) Alavoine, F.; Crochon, M. Taste quality of strawberry. *Acta* **1989**, *265*, 449−452.

(13) Hirvi, T. Mass fragmentographic and sensory analyses in the evaluation of the aroma of some strawberry. *Lebensm. Wiss. Technol.* **1983**, *16*, 157−161.

(14) Zabetakis, I.; Holden, M. A. Strawberry flavour: analysis and biosynthesis. *J. Sci. Food Agric.* **1997**, *74*, 421−434.

(15) Nikirov, A.; Jirovetz, L.; Woidich, A. Evaluation of combined GC/FTIR data sets of strawberry aroma. *Food Qual. Prefer.* **1994**, *5*, 135−137.

(16) Azodanlou, R.; Luisier, J. L.; Villettaz, J. C.; Amadò, R. Development of new aroma measurement quantitative device for analysis in fruits. *Trav. Chim. Aliment. Hyg.* **1998**, *89*, 650.

(17) Azodanlou, R.; Darbellay, C.; Luisier, J. L.; Villettaz, J. C.; Amadò, R. A new concept for the measurement of total volatile compounds of food. *Z. Lebensm. Unters. Forsch.* **1999**, *208*, 254−258.

(18) Azodanlou, R.; Darbellay, C.; Luisier, J. L.; Villettaz, J. C.; Amadò, R. Application of a new concept for the evaluation of the quality of fruits. In *Agri-food Quality Management of Fruit and Vegetables*; Hägg, M., Ahvenainen, R., Evers, A. M., Tiililkkala, K., Eds.; Royal Society of Chemistry: Cambridge, U.K., 1999; pp 266−270.

(19) Kondjoyan, N.; Berdagué, J. L. Compilation of relative retention indices for analysis of aromatic compounds; St Genes, Champanelle, France, 1996.

(20) http://www.nysaes.cornell.edu/flavornet/chem.html

Received for review January 14, 2002. Revised manuscript received October 30, 2002. Accepted October 31, 2002. We thank the Swiss Federal Office for Science and Education and the Canton of Valais for their financial support in the context of the COST 915 action (“Improvement of quality of fruit and vegetables, according to the needs of the consumers”).

JF0200467