COMPARISON BETWEEN SENSORY AND INSTRUMENTAL MEASUREMENTS FOR MEALINESS ASSESSMENT IN APPLES. A COLLABORATIVE TEST

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(Manuscript received December 8, 1997; in final form May 18, 1998)

ABSTRACT

Definition and establishment of assessment procedures for mealiness of apple fruits using sensory and instrumental measurements were performed on 'Boskoop'. 'Cox's Orange Pippin' and 'Jonagold' samples with varying degrees of mealiness. The sensory procedure profiled mealiness as a loss of crispness, hardness, and juiciness, with an increase in the floury sensation in the mouth. High correlations between the sensory descriptors and instrumental parameters was shown through principal component analysis. The instrumental procedures (confined compression of fruit cylinders and acoustic impulse response) gave coefficients of determination for juiciness and crispness of 0.85 and 0.71, respectively. This level of accuracy indicates the possibility of establishing

several commercial mealiness stages (as lack of crispness and of juiciness) based on instrumental analyses.

INTRODUCTION

Texture is an aspect of the consistency of the vegetative tissue determined by the way the cells are joined by the middle lamella. When a load is applied to the plant tissues with a strong middle lamella, the cell walls break preferentially (Sone 1972; Haard and Salunkhe 1975), liberating juice giving a sensory sensation of crispiness and juiciness. When the middle lamella has been weakened by the action of pectin degrading enzymes breakage occurs in the middle lamella without cell rupture and juice liberation (Sone 1972; Haard and Salunkhe 1975) so a mealy fruit is nonjuicy to the consumer. In addition, there is a higher percentage of intercellular spaces filled with air rather than juice in mealy apples when compared to nonmealy apples (Harker and Hallet 1992) indicating the importance of free water in the juiciness sensation. Occurrence of mealiness in apples is associated with cultivar (Lapsley *et al.* 1992) and with late harvest combined with cold storage. Development of mealiness during long term cold storage is variable (Harker and Hallet 1992).

Abbott *et al.* (1984) studied the relationship among selected sensory textural attributes and data from texture profiles (force-deformation curves) obtained from compression of tissue cylinders and found that the combination of several variables of the texture profiles in regression equations improved prediction of sensory attributes when compared to single parameters. Mealiness appeared to be the worst fitted sensory attribute while crispness and hardness were the best fitted sensory parameters.

Harker and Hallet (1992) showed that a segregation of 'Braeburn' apples by background colour led to significant differences in mealiness onset after 16 weeks of cold storage (from 20% to 80% of mealy fruits). The greatest differences at harvest for these batches of apples were found for the soluble solid content (higher for the most mealy susceptible apples), for the cell wall content (higher for most susceptible apples), and for compression rupture test (maximum force from 84 N for the less susceptible to 76.9N for the most mealiness susceptible apples).

Paoletti *et al.* (1993) found a high correlation between sensory mealiness and instrumental cohesiveness ($R = -0.704$) and juiciness ($R = -0.744$) in different apple cultivars, assessing both instrumental parameters on fruit probes. The Magness-Taylor penetration test and the instrumental hardness were less related to sensory mealiness.

Barreiro and Ruiz-Altisent (1996) showed that apple cylinders could be used to segregate three types of textural groups of fruits: elastic, plastic and mealy.

Besides the interest of achieving a destructive reference test for mealiness assessment, nondestructive techniques should be developed. Acoustic vibration techniques provide a good perspective in apples as they have shown a high correlation with several mechanical attributes such as the elasticity modulus (Armstrong *et al.* 1990) or the maximum compression force in compression or puncture (Abbott *et al.* 1995). Finally, Harker *et al.* (1997) indicate that the validity of an instrumental measurement of texture should be based on how well it predicts sensory analysis. In this sense the shape of the force-deformation curve along with maximum force were able to provide comprehensive characterization of texture.

The objective of this study was to define the sensory perception of mealy texture in apples and to use this definition to identify optimum instrumental procedures for mealiness assessment.

MATERIAL AND METHODS

Material

A factorial design with two factors: variety and mealiness stage were chosen:

(1) *varieties*: 'Boskoop', 'Cox s Orange Pippin' and 'Jonagold'

(2) *mealiness stages*: three degrees corresponding to a combination of harvest date and room temperature conditions (95% R.H. and 20C).

No more than ten apples (1/4 of apple) could be assessed by each member of the sensory panel during one session. A sample size of six fruits where each fruit was tasted by two panellists. Therefore only 1 average sensory measurement was achieved for every 6 fruits, that is, per sample.

Three replicates were carried out over one week. Thus 9 samples * 6 fruits/sample * 3 replicates = 162 fruits (40 kg approx.) were used in this experiment. The samples were provided by V.B.T (Verbond van Belgische Tuinbouwveilingen). The material provided by VBT showed a high variability in mealiness onset as expected. Remarks on their firmness and their sugar content at harvest was included in the labelling of the samples (see Table 1). The apples were removed from cold storage (3C $\pm$ 0.5C) 7-12 h before any sensory or instrumental assessment.

Methods

The tests were carried out in the following order:

Acoustic Impulse Response Technique (KU Leuven). The test was performed with KULART (Galili and Baerdemaeker 1996). The system records in the frequency range of 200 to 1600 Hz. Each apple was hit by a little rod at three different points on the equator, and the resonance frequency (FREQ) recorded by means of a microphone. After correction for the fruit weight (WEIGHT, which was measured by a scale) the resonance frequency is used to calculate the stiffness index (STIFF) as $FREQ^2*WEIGHT^{2/3}$. Therefore 3 parameters were obtained through this test.

TABLE 1.
MATERIAL DESCRIPTION AND ENCODING EMPLOYED FOR THE CURRENT RESEARCH. THE MATERIAL WAS PROVIDED BY V.B.T. FIRMNESS AND SOLUBLE SOLID CONTENT REFER TO THE MATURITY STAGE OF THE SAMPLES AT THE TIME OF HARVEST.

Variety	Date of harvest	Mealiness enhancement duration (weeks)	Firmness at harvest Magness-Taylor (N)	Soluble solids content at harvest (°BRIX)
Boskoop	25-9-96	0	78.40	11.6
	30-9-96	1	70.56	12.4
	11-10-96	2	61.74	13.3
Cox	23-9-96	0	73.50	12.5
	30-9-96	1	65.66	13.6
	4-10-96	2	51.94	14.0
Jonagold	2-10-96	0	70.56	12.8
	15-10-96	1	59.78	13.9
	24-10-96	2	56.84	14.7

Sensory Protocol (IFR + SD). The panel consisted of 12 females between the ages of 30 and 60. On the first day, a discussion was held to select descriptors that would adequately characterise the sensory characteristics of the nine samples (3 varieties*3 mealiness stages). Sensory tests were performed over the next two days. The apple samples were peeled, quartered and cored, and presented on coded plastic coated white paper plates; the samples were balanced for order and carry-over effects. The panellists were requested to eat dry crackers and drink water between samples to cleanse their palates. For profiling, each panellist was presented with a quarter of an apple in a taste booth where the light, temperature, humidity and noise are controlled. Each panellist was asked to rate the list of 41 sensory attributes (Table 2) generated in the discussion session, at their own pace, and to record their results using the sensory computer programme Taste (MacFie and Bratchell 1989; Daillant-Spinnler *et al.* 1996).

TABLE 2.
SENSORY DESCRIPTORS USED BY THE TRAINED PANEL. EACH ATTRIBUTE WAS EVALUATED WITHIN A 100 DEGREE SCALE FROM 0 TO 99. BOLD DESCRIPTORS WERE USED FOR PRINCIPAL COMPONENT ANALYSIS

	SENSORY DESCRIPTOR
TEXTURE	
1st bite	**1, Juiciness**
	2, Hardness
chewing	**3, Crispiness**
	4, Juiciness
	5, Toughness/Chewiness
	6, Density of flesh
	7, Fibrous
	8, Granular
	9, Floury
	10, Pulpy
	11, Slimy
FLAVOUR	
chewing	**12, Green apple**
	13, Red apple
	14, Sweet
	15, Acidic/sour
	16, Bitter
	17, Stale
	18, Pear Drops
	19, Floral
	20, Watery
	21, Off Flavour
FLAVOUR	
chewing (cont.)	22, Plum/cherry
	23, Unripe apple
	24, Pear-like
	25, Cox -like
	26, Cooked apple
Afterswallow	27, Bitter
	28, Astringent
	29, Drying
	30, Residue
INTERNAL APPEARANCE	**31, White**
	32, Green
	33, Yellow
	34, Green lines
	35, Juicy
	36, Fluffy
INTERNAL ODOUR	
	37, Grassy
	38, Unripe
	39, Damp twigs
	40, Pears
	41, Cooked apple

Confined Compression Test (UPM). Using a Texture Analyser TA-XT2 a maximum deformation of 2.5mm was applied at 20mm/min on cylindrical specimens of 1.7 cm height and diameter. They were decompressed at the same speed rate. Cylinders were confined in a disk which had a hole of the probe size (see Fig. 1). The rod employed for the compression test was 15.3 mm diameter to avoid any contact with the disk during testing. A filter paper (Albet n° 1305 of 78 g/m^2) about the size of the disk was placed beneath the disk in order to recover the juice extracted during the compression test.

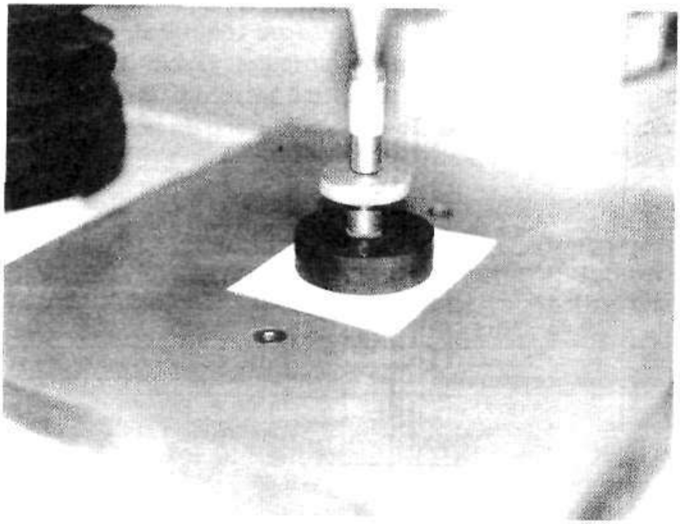

FIG. 1. CONFINED COMPRESSION TEST ON FRUIT CYLINDERS

The following parameters (the name within brackets refers to later nickname of the variables) are registered through this test: Maximum force (F1, N), first peak with 0.5N threshold; Deformation for F1 (D1,mm); Hardness (FD1, N/mm) force-deformation slope for F1 and D1; Force for 2.5mm (F2, N); Elastic deformation (ELAS, mm), recoverable deformation after compression; Degree of permanent deformation (PERM, mm), calculated as 100 minus the percentage of elastic deformation (2.5mm); Absorbed energy during compression (AREA 1), area below the force-deformation loading curve; Restitution elastic energy after compression (AREA2), area below the force-deformation unloading curve; Slope F2/DELAS (GRAD 2:3); and Juice area (JUICE, mm^2) recovered in the filter paper placed underneath the probe during the test.

Ultrasonic Wave Propagation (KU Leuven). The tests were performed with an USD 10 NF system from Krautkramer, using 2 probes (true transmission technique) at 50 khz. Samples of 15 and 11 mm height and 17 mm diameter were cut by means of a cork borer. Plexiglas adapters were used to concentrate the wave and obtain a higher input signal. The following parameters were registered through the test: transmission time (microseconds) and amplitude of the received wave (dB). With these parameters the velocity of the waves (VEL) inside the material was calculated (Mizrach *et al.* 1989).

Data Analysis

Principal Component Analysis was used to compute the relationship between sensory and instrumental parameters. The principal components with eigenvalues above 1 were used because eigenvalues below 1 are less explicative than single original variables. The cumulative determination coefficient of instrumental and sensory variables was used to recognise the percentage of representation of variables by the principal components in those cases where no major contribution to a single factor is found. Stepwise multilinear regression was used to model sensory attributes out of instrumental parameters.

RESULTS AND DISCUSSION

Variability of the Sensory Descriptors

Of the 41 sensory descriptors, 19 were identified to be the most relevant ones by the sensory panel on the basis of the standard deviation: *better evaluation for wider standard deviation as the samples were selected in order to cover a wide range of mealiness stages (see Fig. 2)*: juiciness (1) and hardness (2) at first bite, crispness (3), juiciness (4), toughness (5), density of flesh (6), fibrous (7), granular (8) and floury (9) sensations during chewing, green (12) and red (13) apple flavour, sweet (14), acidic (15), stale (17), watery flavour (20), unripe apple flavour (23), astringent flavour after-swallow (28), and yellow (33) and juicy (35) internal appearances.

Description of the Mealy Treatment and Variety Effects

Sensory and instrumental characteristics of the material are summarised in Table 3. The number of items per average at instrumental parameters is 6 times the number of items per average computed for the sensory attributes because only 1 sensory measurement was obtained per sample (6 fruits) while the instrumental measurements are performed on individual fruits. Therefore, the standard deviation of the sensory data does not give any information of the inherent variability of the characteristics of fresh fruits.

Increasing mealiness development is associated with decreasing sensory hardness and juiciness. ANOVA indicates that sensory characteristics as acidity are more affected by variety than by the mealiness level itself (though both are significant at 1% level), while for sensory hardness it is the opposite. Similar results for sensory and instrumental were obtained for the ANOVA indicating that both methods are able to segregate between cultivars and stages of mealiness development. For both sensory and instrumental hardness, the effect of the mealiness level is greatest despite the cultival effect, while both sensory and instrumental juiciness are more affected by the cultivar effect than by the mealiness level.

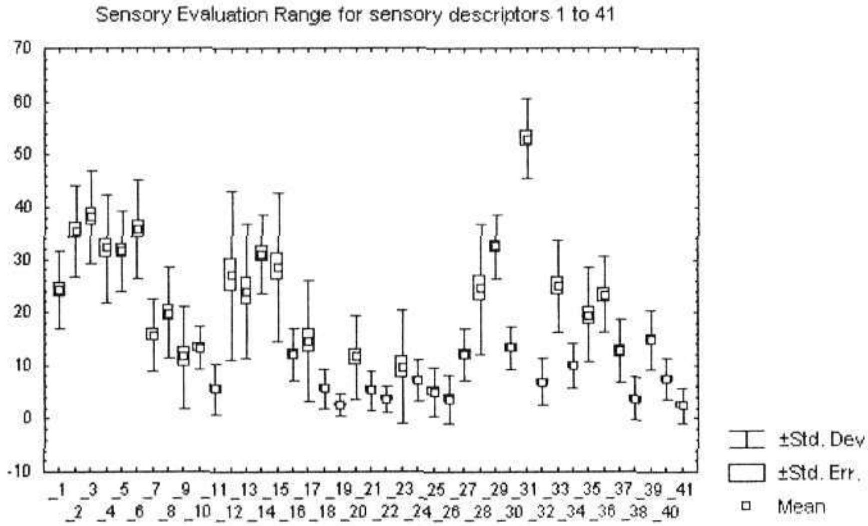

FIG. 2. RANGE OF VARIABILITY OF THE SENSORY DESCRIPTORS FOR THE TOTAL NUMBER OF 27 SAMPLES (3 VARIETIES * 3 MEALINESS STAGES * 3 REPETITIONS)
The numbers refer to the descriptors indicated in Table 2.

Instrumental Measurements Versus Sensory Mealiness Descriptors

Principal Component Analysis was carried out on the 27 averages (3 varieties * 3 mealiness stages * 3 replicates) 19 selected sensory descriptors plus the 14 instrumental to analyse the relationships between them. The results are summarised as follows:

Within the first three principal components (PC) 78% of the total variance can be explained (see Table 4).

The 1st PC gathers textural parameters both instrumental and sensory with correlation coefficients higher than 0.80 (see Table 4). Those parameters can be summarised as follows.

Instrumental: from Confined Compression. Maximum force (F1), instrumental hardness (FD1), maximum force at 2.5mm deformation (F2), absorbed energy during compression (AREA 1), restitution energy after compression (AREA 2) and F2-elatic deformation ratio (Grad 2:3).

Instrumental: from Acoustic Impulse Response. Stiffness (STIFF).

Sensory Descriptors. Hardness (2), crispiness (3), density (6), floury (9) and the internal yellow colour of pulp (33); the highest contribution to the first principal component from all the sensory texture attributes corresponds to crispness (R=0.88).

TABLE 3.
AVERAGE VALUES, STANDARD DEVIATIONS AND NUMBER OF OBSERVATIONS FOR SEVERAL SENSORY AND INSTRUMENTAL MEASUREMENTS. COLUMNS MARKED WITH ** REFER TO 1% SIGNIFICANCE LEVEL UNDER ANALYSIS OF VARIANCE.

	SENSORY			INSTRUMENTAL		
	hardness (2)	1st bite juiciness (4)	acidic (15)	hardness (FDI)	juice area (JUICE)	stiffness (STIFF)
BOSKOOP						
mealy level 1	**46**	**37**	**54**	**31.6**	**4.87**	**21.4**
	4	1	7	4.3	1.20	2.3
	3	*3*	*3*	*18*	*18*	*18*
mealy level 2	**35**	**26**	**45**	**25.4**	**3.82**	**10.2**
	5	4	0	5.5	0.82	3.2
	3	*3*	*3*	*18*	*18*	*18*
mealy level 3	**36**	**21**	**38**	**18.3**	**2.57**	**4.1**
	3	1	2	5.5	0.64	0.9
	3	*3*	*3*	*18*	*18*	*18*
COX						
mealy level 1	**39**	**34**	**27**	**24.5**	**3.61**	**19.4**
	3	4	4	4.7	0.81	2.5
	3	*3*	*3*	*18*	*18*	*18*
mealy level 2	**23**	**25**	**17**	**19.2**	**3.73**	**6.7**
	1	3	2	3.2	0.83	1.8
	3	*3*	*3*	*18*	*18*	*18*
mealy level 3	**24**	**16**	**12**	**14.1**	**3.05**	**4.6**
	1	8	2	5.2	0.95	0.8
	3	*3*	*3*	*18*	*18*	*18*
JONAGOLD						
mealy level 1	**46**	**45**	**30**	**26.2**	**5.42**	**25.5**
	2	4	3	4.2	1.79	1.7
	3	*3*	*3*	*18*	*18*	*18*
mealy level 2	**40**	**45**	**19**	**22.1**	**5.84**	**16.1**
	1	1	1	2.3	0.90	2.1
	3	*3*	*3*	*18*	*18*	*18*
mealy level 3	**28**	**37**	**15**	**21.8**	**4.81**	**13.8**
	2	8	1	3.3	1.31	1.9
	3	*3*	*3*	*18*	*18*	*18*
ANOVA Factor :	F values	F values	F values	F values	F values	F values
variety	39.17**	37.25**	194.40**	24.82**	47.52**	247.62**
mealy level	68.58**	16.93**	52.24**	62.61**	17.72**	775.23**
interaction.	5.72**	1.48	0.13	5.09**	4.37**	11.14**

TABLE 4.
LOADING FACTORS FOR THE SENSORY AND INSTRUMENTAL VARIABLES ON PRINCIPAL COMPONENT FACTORS (CORRELATION COEFFICIENT BETWEEN EACH VARIETY AND FACTOR); *LOADINGS LESS THAN 0.7 OMITTED.*

FACTOR ANALYSIS	factor loadings		
VARIABLES	FACTOR 1	FACTOR 2	FACTOR 3
Sensory			
1 Juiciness, 1st bite			
2 Hardness	0.87		
3 Crispness	0.88		
4 Juiciness, chewing			
5 Toughness/chewiness	0.72		
6 Density	0.87		
7 Fibrous			
8 Granular	-0.76		
9 Floury	-0.84		
12 Green apple	0.78		
13 Red apple			
14 Sweet		0.80	
15 Acid/sour	0.70		
17 Stale	-0.75		
20 Watery			
23 Unripe apple		--0.74	
28 Astringent	0.75		
33 Yellow	-0.84		
35 Juicy internal appearance			
Confined compression			
F1	0.89		
D1			
FD1	0.90		
F2	0.89		
Area1	0.85		
ELLAS			-0.80
Areac2	0.88		
PERM			0.80
GRAD 2:3	0.90		
JUICE			
Acoustic resonance	0.76		
FREQ			
STIFF	0.80		
VEL			
Explained Variance %	52.86	18.92	8.00

The 2nd Principal factor is a variety axis, gathering mainly the sensory variables: sweetness (14, $R=0.8$) and unripe (23, $R=-0.74$). The variety aspect of this PC is extracted from the individuals representation (each point refers to the average value of a sample of a total number of 27; see Fig. 3) where the individuals of the variety 'Boskoop' are clearly segregated from those of 'Cox' and 'Jonagold' individuals. The movement of the individuals within the plane (see arrows) indicates the loss of texture and juiciness for increasing mealiness stages.

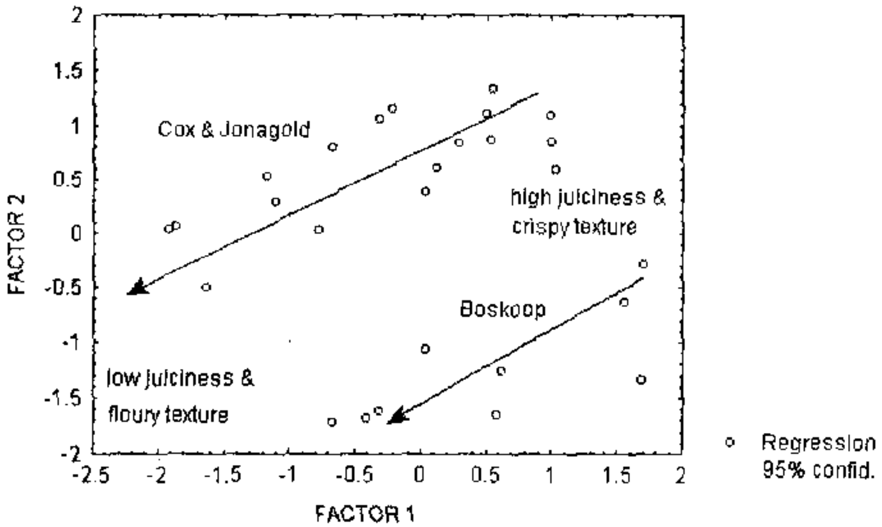

FIG. 3. REPRESENTATION OF THE 27 SAMPLES (3 VARIETIES * 3 MEALINESS STAGES * 3 REPLICATES) WITHIN THE 1ST PRINCIPAL COMPONENTS PLANE

Some variables are well correlated within the 1st-2nd PC plane (see Fig. 4) though there is not a predominating relationship with any of the PC Factors. The level of representation of a variable can be measured through the cumulative determination coefficient also defined as commonalities (see Table 5). This is the case for: *confined compression*: juice area (JUICE; $R^2=0.73$), *acoustic impulse response*: frequency (FREQ, $R^2=0.86$), *sensory analysis*: 1st bite juiciness (1, $R^2=0.83$), juiciness during chewing (4, $R^2=0.88$), toughness (5, $R^2=0.71$), green colour (12, $R^2=0.93$), red colour (13, $R^2=0.85$), acid (15, $R^2=0.91$), stale (17, $R^2=0.75$), astringent (28, $R^2=0.87$).

Further results obtained through the PC Analysis are:

(1) the sensory descriptors dealing with juiciness (1&4) are highly correlated with the juice area (JUICE) measured under confined compression ($R=0.85$ & $R=0.87$, respectively);

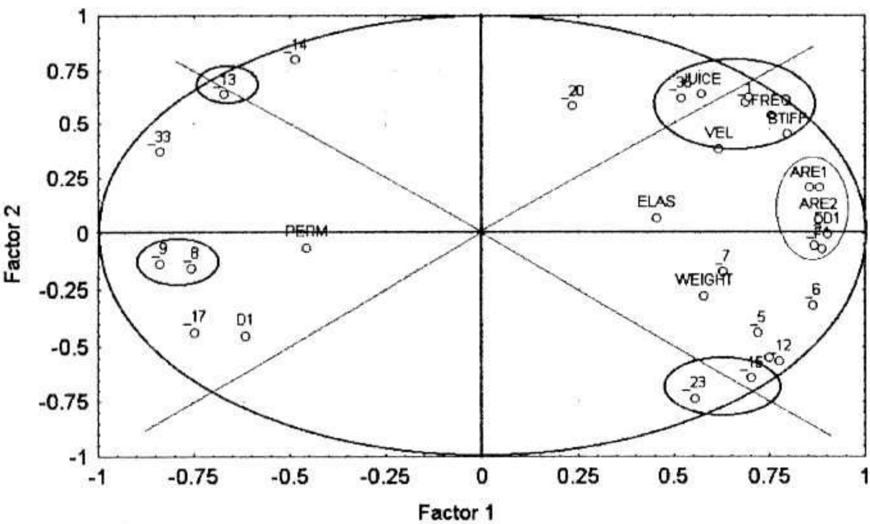

FIG. 4. VARIABLES REPRESENTATION WITHIN THE 1ST AND 2ND PRINCIPAL COMPONENTS PLANE

The best represented variables are those close to the borders of the circle

TABLE 5.
LEVEL OF REPRESENTATION (CUMULATIVE R^2) OF THE SENSORY AND INSTRUMENTAL VARIABLES WITHIN THE MAIN 3 PRINCIPAL COMPONENTS OR FACTORS

FACTOR ANALYSIS	commonalties		
VARIABLES	FACTOR 1	FACTOR 1&2	FACTOR 1&2&3
Sensory			
1 Juiciness, 1st bite	0.473	0.831	0.847
4 Juiciness, chewing	0.488	0.876	0.887
5 Toughness/chewiness	0.520	0.715	0.788
7 Fibrous	0.399	0.428	0.690
9 Floury	0.573	0.598	0.743
12 Green apple	0.604	0.927	0.934
13 Red apple	0.449	0.854	0.867
15 Acid/sour	0.496	0.911	0.911
23 Unripe apple	0.309	0.851	0.851
28 Astringent	0.563	0.869	0.870
35 Juicy internal appearance	0.271	0.654	0.672
Confined compression			
DI	0.378	0.584	0.640
JUICE	0.328	0.734	0.743
Acoustic resonance			
FREQ	0.574	0.863	0.864
Explained Variance %	52.86	18.92	8.00

(2) the sensory descriptor named as stale (17) is more highly correlated with the sensory attributes dealing with juiciness (1, R=-0.84 & 4, R=-0.86) than with any other sensory parameter;

(3) the variables Stiffness (STIFF) and Frequency (FREQ) measured through acoustic impulse response show a significant correlation with the sensory attributes of juiciness (in all cases $r>0.8$); and

(4) the sensory descriptor named as floury is correlated with the variables forming the 1st PC (R=-0.87 with the crispiness descriptor, 3) and with the sensory attributes dealing with juiciness (R=-0.78 and R=-0.71, respectively). This fact confirms that the floury sensation in the mouth is related to a combination of loss of texture and of juiciness. We propose that a combination of at least two groups of sensory attributes, one describing texture and one describing juiciness, should be used to characterise mealiness. The results obtained through the Factorial Analysis show that the sensory attributes: crispness, floury and juiciness during the first bite and during chewing should be preferred to characterise mealiness.

The 3rd Principal Component is formed mainly by the instrumental parameters: degree of permanent deformation (PERM) and the elastic deformation (ELAS) with R=0.80 and R=-0.80, respectively. This fact indicates the absence of any linear relationship between these variables and those well correlated under the 1st Principal Components Plane.

The parameter named "transmission velocity" (VEL) measured under ultrasound wave propagation is the parameter showing the weakest relationship with any other sensory or instrumental parameters measured. However, it correlates significantly with the resonance frequency (R=0.85) and the deformation registered for F1 during confined compression (R=0.72).

Assuming that sensory mealiness is a combination of the texture loss (low crispness and high floury, variables 3 and 9, respectively) and of the juiciness loss (low values at variables 1 and 4), some prediction models have been developed using instrumental measurements (see Fig. 5 and 6) by stepwise linear regression.

Sensory modelling using the *confined compression test*:

1st Bite Juiciness = f (JUICE, Area2, F1, D1)	*r2adjusted=0.83, linear*
Juiciness during chewing = f (JUICE, Area2)	*r2adjusted=0.74, linear*
Crispness = f (FD1, JUICE)	*r2adjusted=0.67, linear*
Floury = f (Area2, D1, JUICE)	*r2adjusted=0.67, exponential*

Sensory modelling using the *acoustic impulse response test*:

1st Bite Juiciness = f (FREQ) *r2adjusted=0.67,linear*
Juiciness during chewing = f (FREQ) *r2adjusted=0.71, linear*
Crispness = f (STIFF) *r2adjusted=0.63, linear*
Floury = f (STIFF) *r2adjusted=0.50 linear*

Sensory modelling combining the *confined compression* and the *acoustic impulse response tests*:

1st Bite Juiciness = *No improvement from confined compression modelling*
Juiciness during chewing = f (JUICE, FREQ) *r2adjusted=0.85, lineal*
Crispness = f (STIFF, Area1, Area2) *r2adjusted=0.71 lineal*
Floury = *No improvement from confined compression modelling*

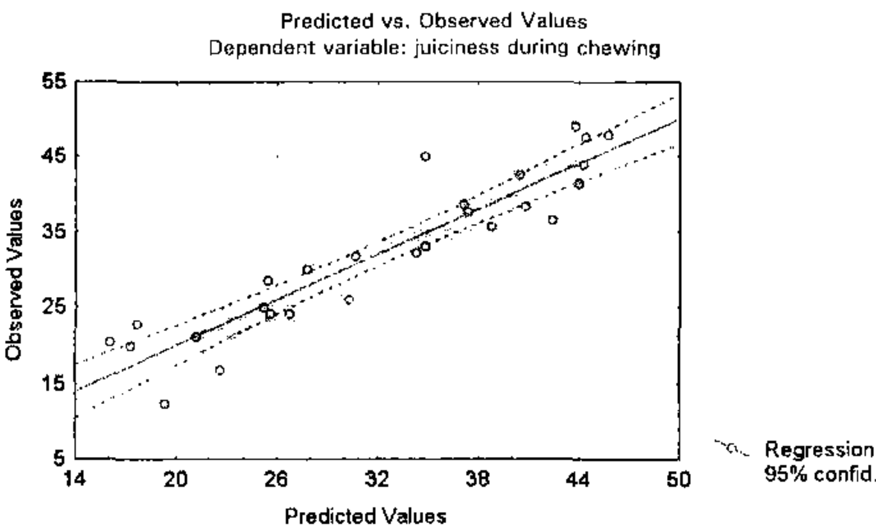

FIG. 5. SENSORY JUICINESS MODELLING USING TWO INSTRUMENTAL PARAMETERS: JUICE AREA (JUICE) REGISTERED UNDER CONFINED COMPRESSION AND RESONANCE FREQUENCY (FREQ) THROUGH ACOUSTIC IMPULSE RESPONSE
The model achieves a determination coefficient of 0.85. Solid line represents the regression model, broken lines are 95% confidence limits.

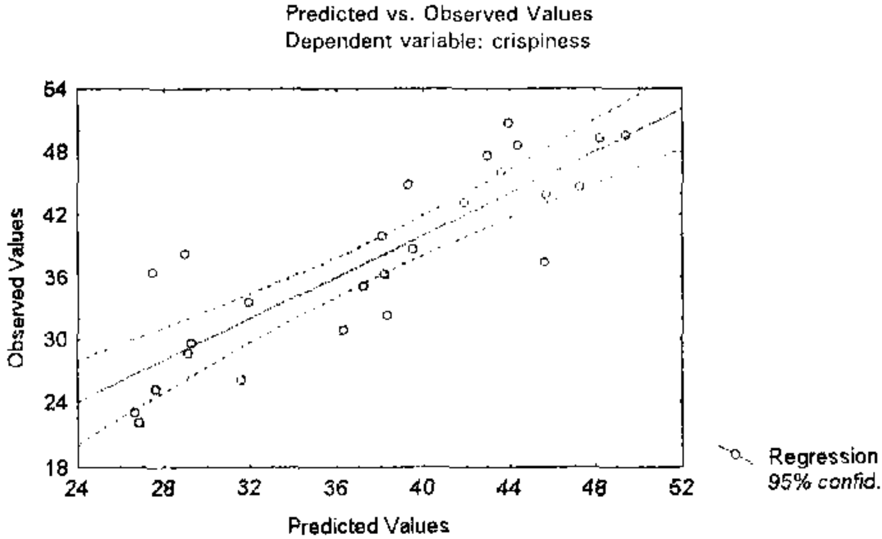

FIG. 6. SENSORY CRISPNESS MODELLING USING THREE INSTRUMENTAL PARAMETERS: ABSORBED ENERGY (AREA 1) AND RESTITUTION ENERGY (AREA 2) FROM CONFINED COMPRESSION, AND STIFFNESS (STIFF) FROM ACOUSTIC IMPULSE RESPONSE

The model achieves a determination coefficient of 0.71. Solid line represents the regression model, broken lines are 95% confidence limits.

CONCLUSIONS

(1) Mealiness in apples is a negative texture quality aspect that cannot be described by a single sensory descriptor. It can be described through a combination of 4 sensory attributes which are: "crispness", "floury", "first bite juiciness" and "juiciness during chewing".

(2) A confined compression cylinder test and an acoustic impulse response test on whole apples, correlates highly with sensory attributes, crispness, floury, and juiciness (1st bite and during chewing). Therefore these tests can be recommended as instrumental reference tests for mealiness assessment in apples.

(3) A *Statistical modelling of the sensory attributes: crispness, floury, and* juiciness (first bite and during chewing), was performed using a combination of parameters acquired from the confined compression test and the acoustic impulse response test. Determination coefficients not higher than

0.85 for juiciness and than 0.71 for crispness were obtained with those statistical models. Although these statistical models do not allow at this stage to predict accurately the sensory attributes selected to describe mealiness, they should be used in further research to establish different commercial mealiness stages.

(4) Any improvement in instrumental assessment of mealiness should focus on the development of nondestructive instrumental techniques. In this sense the acoustic impulse response gives encouraging results. Fusion of different instrumental techniques should always be considered as it can provide complementary information to better model the sensory aspects.

ACKNOWLEDGMENTS

Financed by the European Project FAIR CT-95-0302 entitled: Mealiness in fruit: consumers perception and means for detection.

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