Complementary Measurements for Apple Texture Discrimination: Mechanical Tests

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Abstract

Force-Displacement and Force-Time curves loaded from penetrometric and compression tests, receptively, were analyzed for their ability to discriminate the apple texture. The parameters extracted from the curves of each measurement, were processed in a single factorial discriminant analysis (FDA) in order to identified five apple progenitors. The correct identification of each apple progenitor, using both penetrometric and compression data curve, were realized with a discrimination accuracy of 100% for X4956, X6908, X2033, 6064 and 95% for X2888. This study showed that the identification close to 100% was due to the complementary information given by these two kinds of measurements.

INTRODUCTION

For few years, apple texture has been an important feature among quality attributes. Thus, fruit behavior under strain and stresses, measured as firmness, has been used as empirical useful guide for the quality assessment of apple fruits. The evaluation of this single criterion has ever been processed by the measurement of the maximal penetration force needed to penetrate the flesh of fruit until a determine depth, with a cylindrical metallic probe fitted on a penetrometer (Hertog, 2001; Johnston, 2001; Harker, 2002; Hoehn, 2003).

In the aim to analyze the rheological properties of apple fruits, several methods have been used as sensometry (Duprat et al., 1997; De Belie et al., 2000), twist test (Studman et al., 1992), compression test (Rodriguez et al., 1990) or puncture test (Duprat, 2000). However, traction and compression tests remained two of the main measurements used until today.

In order to identify five apple progenitors, this study measured the potentially complementary information that could be obtained by a penetrometric and a compression test. In this way, the discrimination ability of each test was analyzed.

MATERIALS AND METHODS

Plant Material

Five apple progenitors from the European program HIDRAS were used in this study: X4956, X2033, X2888, X6908 and X2888. These five progenitors present the genotypic variability analyzed in this work.

Texturometer Set Up

A Stable Micro Systems TA-XT2 Texture Analyser was used in this study. Two different tests, penetrometry and compression, have been processed on each apple fruit.

First, penetrometric test has been realized with fitting a cylindrical hemispherical metallic probe of 4 mm diameter. The probe progressed at a constant speed of 3.3 mm.sec^{-1} to reach a final depth of 15 mm in fruit parenchyma. The stepwise motor

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displacement of the texturometer allowed the measurement of the force every 0.01 sec. The forces, expressed in Newton, measured overall the probe displacement resulted in the computation of a Force-Displacement curve.

Second, compression test consisting in a single cycle compression, has been processed by the displacement of a cylindrical plane probe of 50 mm diameter. The probe progressed at a constant speed of 3.3 mm.sec^{-1} to reach a compression rate equal to 5% of the whole apple fruit caliber. The stepwise motor displacement of the texturometer allowed the measurement of the force every 0.01 sec.

Penetrometric Measurement

Two measurements were realized on the equatorial part of each fruit. Five parameters, identified as Fs, Stifp, W1p, Dp and Ff (Table 1), have been extracted from the 'Force-Displacement' curve (Fig. 1). The two measurements of each fruit were averaged prior data analysis.

Compression Measurement

Two measurements were also realized on the equatorial part of each fruit. Five parameters, identified as Fmax1, W1c, W2c, Stifc and Grad2 (Table 1), have been extracted from the Force-Time curve (Fig. 2). The two measurements of each fruit were averaged prior data analysis.

Data Analysis

Penetrometric and compression parameters were pooled in a single matrix X dimensioned [n x p] where n is the rows number and p the number of columns. Each row contains the averaged measurement of both penetrometric and compression tests and each column contains the five parameters. The matrix X has been processed in a Factorial Discriminant Analysis (FDA) where the qualitative group to be discriminated was the five apple progenitors (Bertrand et al., 1990). A criterion of the efficiency of the texture measurements was the proportion of correctly identified observations in validation sets. These validation tests were carried out by dividing the data matrices into a training and a validation set. The FDA model was computed on the calibration set. The observations of the validation set were then classified using the established model. The observations correctly identified in the validation set were then counted. Such validation tests were independently carried out 10 times, placing [2n/3] of the observations in the calibration set and the remaining ones [n/3] in the validation set. The eventual results were the percentage of observations correctly classified and the confusion matrices taking into account the 10 validation sets. All the statistical procedures were carried out using the Matlab environment (The MatWorks, Inc., 3 Apple Hill Drive, Natick, MA 01760-2098 USA).

RESULTS AND DISCUSSION

Discrimination Accuracy

For measuring the discrimination accuracy of each test, parameters extracted from penetrometric and compression tests were separately processed in a FDA. Then, in order to light the complementary information given by these two kinds of measurements, both penetrometric and compression parameters were pooled in a same matrix (X) and processed in FDA. The discriminant ability of the parameters was evaluated from the percentage of correct classification in the validation set.

FDA on penetrometric data allowed a discrimination accuracy of 100% for X6908 and X6064. X4956 and X2033 were identified at more than 88% and 82%, respectively (Fig. 4). Otherwise, it was impossible to correctly identity X2888 (45% of discrimination accuracy).

Compression data allowed a correct discrimination for X6908 and X2888 with more than 90% of correct identification (Fig. 4). X4956 was also correctly identified with about 78%. Contrary, it was impossible to correctly identity X2033 (60%) and X2888 (46%).

The discrimination accuracy was strongly enhanced with processing all parameters (matrix **X**) in the same FDA. The analysis allowed 100% of correct identification for X4956, X6908, X2033 and 6064 and 95% for X2888 (Fig. 4). The confusion matrix (Table 2) shows the percent of individuals included in the validation sets which were correctly classed.

Parameters Correlation

Force-Displacement curve can be divided in two steps, a first linear compression until apple peal failure which was described by Fs, Stifp, W1p and Dp parameters. Fs, Stifp and W1p were highly correlated between them whereas Dp showed no correlation with these paramters. These parameters gave an information on apple peal and flesh underlying properties. After peal failure, the second part of the curve namely 'relaxation forces', was characterised by Ff parameter which is a flesh firmness approximation. The information given by Ff was more precisely linked to parenchyma properties. Ff parameter showed no correlation with the others ones (Table 3).

Parameters extracted from Force-Time curve showed a high correlation between some of them. Fmax1 was highly correlated with W1c, Stifc and W2c (R^2 = 0.96, 0.77 and 0.96, respectively). However, Grad2 parameters showed no correlation with any parameter (Table 3).

Finally, penetrometric parameters extracted from the first part of the curve showed no correlation with compression parameters whereas Ff showed a correlation with Fmax1, W1c and W2c with R^2 value of -0.53, -0.63 and -0.52, respectively (Table 3). In first approximation, these correlations indicate that Ff from penetrometry and the compression parameters allowed an apple flesh study whereas parameters from the first part of penetrometric curve are preferentially linked to the apple peal and underlying cell properties.

Complementary Information of Penetrometric and Compression Parameters

Fig. 3 presents the factorial map from the FDA. Using the three first factorial components (FC), it was possible to identify the five groups corresponding to the five apple progenitors. The variability occurring between the three groups: X6908 only, X2888, X6064 and X4956 and X2033 only was mainly explained by the second FC whereas the first factorial component (FC1) explained the variability occurring between the three groups: X4956 alone, X6064 and the three other ones.

In order to characterize this variability, the Table 4 showed the correlation between the parameters extracted from penetrometric and compression measurements and factorial scores of FDA.

The second factorial component (FC2) showed an important correlation with two parameters of compression (W1c and W2c) and also with Ff extracted from the second part of penetrometric curve, during the relaxation forces measurement. All these parameters refer to the apple flesh properties. Thus, this discrimination allowed to conclude to a higher flesh firmness for X6908 than X2888 and X2033. Few flesh firmness difference was measured between the X2888, X6064 and X4956 (Fig. 3A).

Complementary, the first part of penetrometric curve and more precisely Fs parameter, showed a high importance to discriminate according the third factorial component (FC3). This result allowed to conclude that apple peal was more important in apple firmness measurement for X2888 than X2033, X4956 or X6908, and than X6064 (Fig. 3B).

CONCLUSIONS

As it's well known, texture is a complex and composite feature of quality. The present experiment showed that penetrometric and compression data analysis have been necessary and sufficient to reach a correct identification of each apple progenitor texture.

More important, we noticed that it was the complementary information, given by these two kinds of measurements, which allowed an enhanced discrimination accuracy between apple texture. This complementarity allowed a discrimination accuracy close to the perfection with 100% for four of the five tested apple progenitors.

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Tables

Table 1. Parameters extracted from Force-displacement and Force-time curves. N: Newton, sec: seconds, mm: millimeters.

Parameters	Units	Explications
Fs	N	Force needed to fail the apple peal
Stifp	$N.mm^{-1}$	First derivative: **dFs/Dp** (Dp is the deformation at Fs)
Dp	mm	Deformation measured until apple peal failure
Wp1	N.mm	Work needed to fail the apple peal
Ff	N	Mean value of the force describing a plateau, after peal failure
Fmax1	N	Force needed to reach a compression rate of 5% of the fruit caliber
Wc1	N.sec	Work measured during loading step, needed to reach Fmax1 (between anchor I and II)
Wc2	N.sec	Work measured during unloading step (between anchor II and III)
Stifc	$N.sec^{-1}$	First derivative: **dFmax1/Time** (between anchor I and II)
Grad2	$N.sec^{-1}$	Slope during unloading step (between anchor II and III)

Table 2. Confusion matrix showing the discrimination accuracy in percent of correctly classed.

		Predicted groups (cultivars)				
		X4956	H318	X2033	X6064	X2888
Actual groups	X4956	**100**	0	0	0	0
	H318	0	**100**	0	0	0
	X2033	0	0	**100**	0	0
	X6064	0	0	0	**100**	0
	X2888	0	0	5	0	**95**

Table 3. Table of correlation of penetrometric and compression parameters.

	PENETROMETRY					COMPRESSION				
	Fs	**Dp**	**Wp1**	**Stifp**	**Ff**	**Fmax1**	**Wc1**	**Stifc**	**Wc2**	**Grad2**
Fs	**1**	0.84	0.96	0.66	0.21	-0.06	-0.08	0.08	-0.02	0.31
Dp		**1**	0.91	0.15	0.07	0.08	0.10	0.04	0.15	0.32
Wp1			**1**	0.50	0.16	0.01	0.00	0.07	0.06	0.31
Stifp				**1**	0.31	-0.25	-0.31	0.07	-0.26	0.12
Ff					**1**	-0.53	-0.63	-0.09	-0.52	-0.10
Fmax1						**1**	0.96	0.77	0.96	-0.22
Wc1							**1**	0.59	0.94	-0.11
Stifc								**1**	0.67	-0.44
Wc2									**1**	0.02
Grad2										**1**

Table 4. Correlation between factorial scores and parameters extracted.

	Fs	**Dp**	**Wp1**	**Stifp**	**Ff**	**Fmax1**	**Wc1**	**Stifc**	**Wc2**	**Grad2**
F1	-0.29	0.18	-0.12	-0.73	-0.28	0.58	0.57	0.30	0.60	-0.15
F2	-0.51	-0.41	-0.50	-0.33	0.55	-0.59	-0.64	-0.36	-0.63	-0.41
F3	0.75	0.71	0.74	0.45	0.56	-0.26	-0.37	0.05	-0.23	0.12

Figures

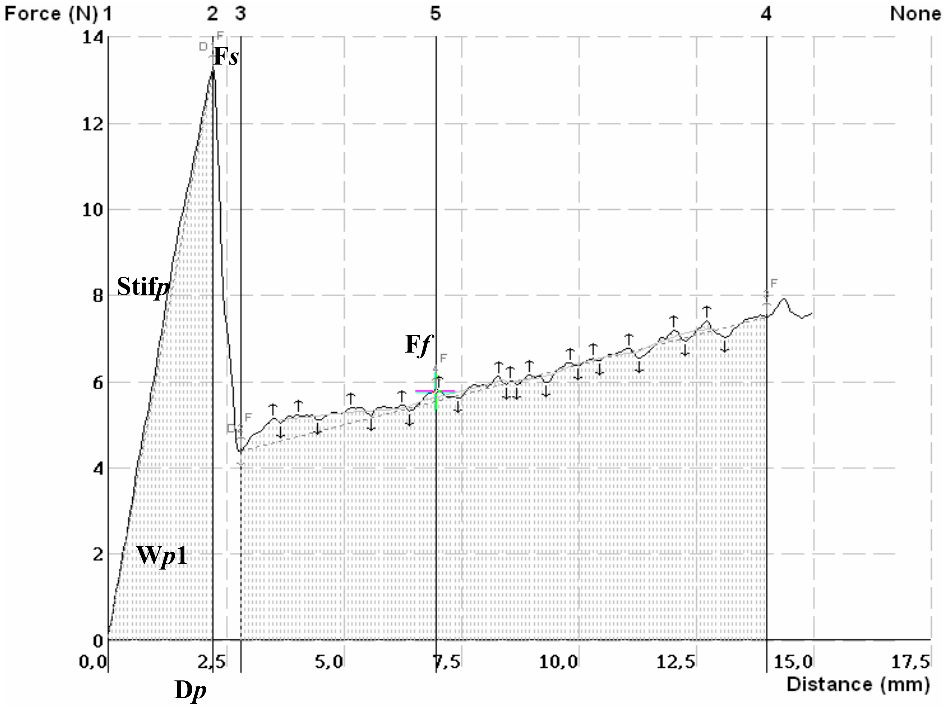

Fig. 1. Force-displacement curve from penetrometric measurement.

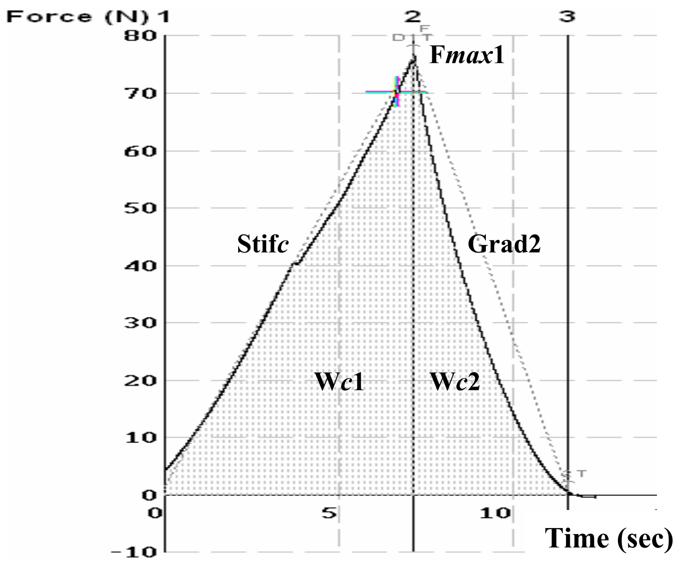

Fig. 2. Force-time curve from compression measurement.

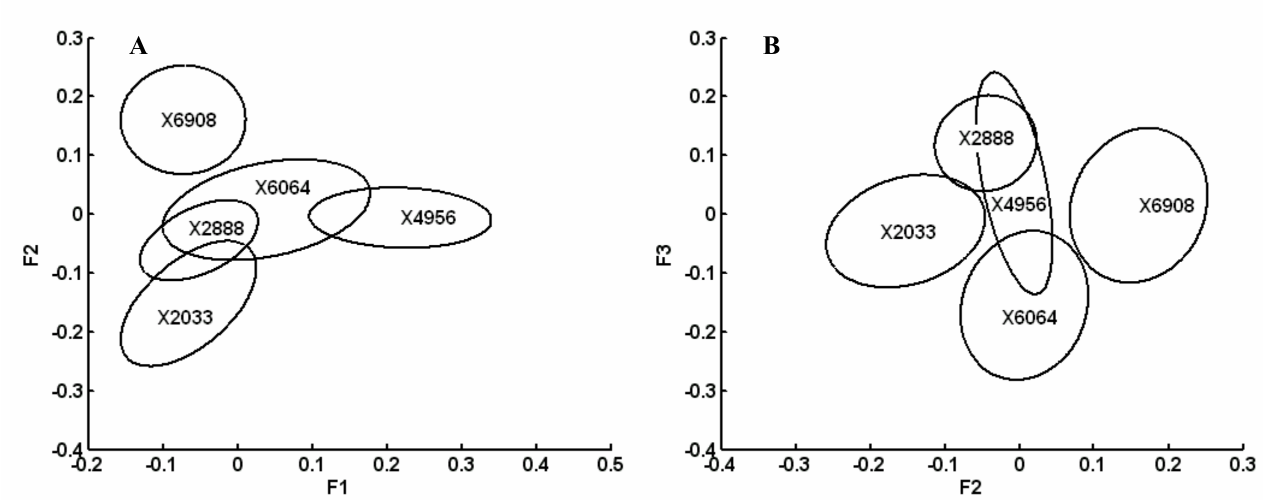

Fig. 3. Factorial map according the first and second factorial component (**A**), and the second and third factorial component (**B**).

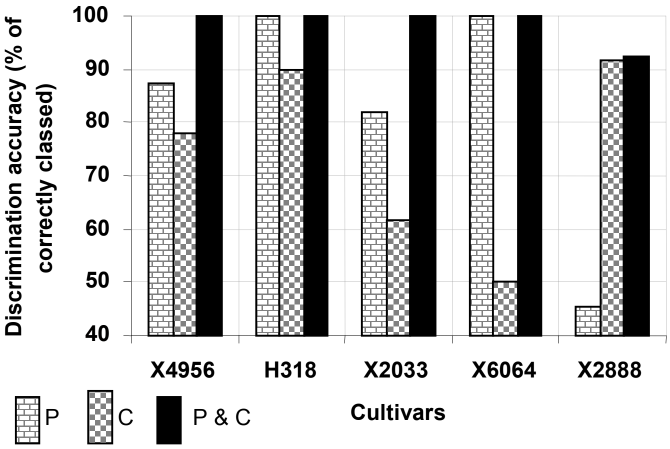

Fig. 4. Discrimination accuracy of apple progenitors for FDA using only penetrometric data (P), compression data only (C) and both penetrometric and compression data (P & C).