Measurement of Textural Properties of Apples and their Prediction by near Infrared Reflectance Spectroscopy

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Abstract

In this trial we studied the ability of penetrometry and uniaxial compression for measuring texture changes of three apple cultivars during cooled room (CR) and shelflife (SL) storage. A large set of physical parameters has been extracted and analyzed. Finally, because these tests remained destructive for fruits we attempted to predict the most efficient physical parameters by near infrared reflectance spectroscopy which is a non destructive method. Experimental Young modulus *parameter* (E*) from penetrometry and F_c^1, $Grad^1$, F_c^2 from uniaxial compression were the most efficient ones to describe storage effect whatever the apple cultivar. Some other parameters as F_p, D_p were only correlated to one of the three studied cultivar, showing the differences existing between cultivars and the complementarity of parameters. This complementarity lights the composite nature of fruit texture and justify a multifactorial approach. NIRS showed a good ability to predict E* whatever the cultivar with R value of 0.91, 0.85, 0.83 and RMSECV values of 0.95, 0.74, 1.02N.mm^{-1} for *Ga*, *Sm* and *El* cultivar, respectively. parameters from compression test showed poor correlation with NIRS data.

INTRODUCTION

Texture is an important parameter for assessing the apple fruit quality. Several sensory attributes like firmness, juiciness, crunchiness… can describe the apple texture but the acquisition of these descriptors remains difficult and time consuming (Harker *et al.* 1997). Different mechanical tests are also able to quantify some rheological properties of food products (Duprat *et al.*, 1995). On apples, the maximal force necessary to puncture the fruit with a metallic cylindrical probe remains the main measure commonly used (Duprat *et al.*, 1995; Harker *et al.*, 2002; Hoehn *et al.*, 2003; Johnston *et al.*, 2001a). However, this unique parameter poorly describes the multifactorial nature of fruit texture. Other way consists to rely on the modifications of different types of optic or acoustic signals propagating through the fruits and their biochemical or physical properties (De Belie *et al.*, 2000; Duprat *et al.*, 1997). Some of these non-destructive methods and especially near infrared reflectance spectroscopy (NIRS) are now well known to evaluate soluble sugar content in fruits (Ventura *et al.*, 1998; Waslsh *et al.*, 2004) but must be developed for textural properties.

In previous works, the rheological properties of apples, described with few parameters, more often with Magness Taylor measurements, remained poorly correlated to NIRS data (Schmilovitch *et al*, 2000; Mc Glone *et al.*, 1998; Mc Glone *et al.*, 2002; Lu *et al.*, 2000).

This work aimed to study the capability of NIR spectroscopy to predict the variability of texture measured by a large number of parameters extracted from different mechanical tests. First, the parameters were compared in order to select the most efficient ones to detect the fruits texture differences. Then, ability of NIRS to predict these selected parameters has been studied. Variability in fruits texture was obtained by varying the storage conditions of fruits.

MATERIALS AND METHODS

Fruits

In order to maximize the variability of textural properties, fruits of three apple cultivars: Gala (*Ga*), Elstar (*El*) and Smoothee (*Sm*), stored either in cooled room (CR: 02°C, 95% relative humidity) or in shelf life (SL: 20°C, ~ 40% relative humidity), have been analyzed at different dates (day0, 7th day, 14th day, 28th day, 60th day, 90th day, 120th day and 7th day, 14th day , 28th respectively for CR and SL conditions,respectively). A total of 450 fruits has been used (15 fruits/sample).

Texture measurement

Rheological properties of each apple fruit were defined from two mechanical tests:

- A penetrometric test performed on unpeeled apples with a 4mm diameter probe fitted on a texture analyzer (TA-XT2): the probe was moved from the surface of the fruit through the peel and flesh to a final depth of 15mm, at a constant speed of 3.3mm.sec^{-1}. The force measured in Newton was expressed as a distance function (figure 1). 5 parameters have been extracted from this curve (table 1).

- A uniaxial compression test performed with a cylindrical plane probe of 50mm diameter fitted on a texture analyzer (TA-XT2): two successive compressions at constant speed were applied on each fruit with reversion of movement when probe has moved along 5% of caliber. The forces measured in Newton were expressed as a distance function (figure 2). 13 parameters have been extracted from this curve (table 2).

NIR collection

Spectra were directly acquired, in reflectance mode, on whole apple fruits using a Vis./NIR spectrometer (NIRSystems, Model 6500, Perstorp Analytical), in direct contact analysis mode. Spectral data were expressed in light absorbency according to wavelengths with a 2nm increment from the visible (400-800nm) until near infrared spectrum range (800-2498nm).

Chemometric analysis

The parameters extracted from force/displacement curves of penetrometric and uniaxial compression tests have been gathered in a common matrix $\boldsymbol{X}$ ($\boldsymbol{n}$ x $\boldsymbol{p}$ with $\boldsymbol{n}$= 450 fruits and $\boldsymbol{p}$ = 18 parameters). This matrix has been normalized and then processed in a principal component analysis (PCA) with the '*durations of storage'* as qualitative groups

Concerning the spectral data, two pre-treatments of NIR spectra have been tested in order to cope the variations of spectra baseline: SNV and second derivative. These data and physical parameters were then processed in a partial least squares regression (PLS). A

10 times cross-validation was managed by taking [2/3] of individuals as training set and the remaining [1/3] as validation set. The accuracy of prediction has been estimated by the correlation coefficient (R) and the root mean square error of cross validation (RMSECV).

All the statistical procedures were carried out using the Matlab environment (The MatWorks, Inc., 3 Apple Hill Drive, Natick, MA 01760-2098 USA).

RESULTS

Measurement of physical properties of apple texture

Figure 3 shows the PCA maps on the first two principal components (A1 and A2) for the three studied cultivars. A1 which explained 68,7% of the total variability allowed a correct and chronological classification of fruits from starting point (day 00) until 120th days of storage whatever the considered cultivar. A2 allowed to distinguish fruits according to the storage conditions (CR and SL).

Four parameters: E* (penetrometry) and F_c^1, $Grad^1$, F_c^2 (compression) were strongly correlated to the first component (R>0.9), whatever the cultivar (table 3). Two others parameters from penetrometric tests (F_f and D_p) were also correctly correlated to the first principal component, but only for one cultivar: F_f in the case of *Ga* and D_p for *Sm*. The second component was mainly correlated with parameters related to peel properties: F_p for *El* and *Sm* and W_p for *Ga*.

Prediction ability of texture parameters by NIRS

NIR spectra of apples and physical parameters, previously identified as good descriptors of apple changes during storage, have been processed in a PLS regression analysis, separately for each cultivar. Table 4 shows the pre-treatment of selected spectral data and the accuracy of the predictions.

The better results have been obtained for the penetrometric parameter E* (figure 4A) with high regression coefficients and weak predictive errors (R = 0.91, 0.85, 0.83 and RMSECV = 0.95, 0.74, 1.02 $N.mm^{-1}$ for *Ga*, *Sm* and *El* cultivar, respectively)

Sm cultivar showed the most accurate prediction in term of R values. Parameters from compression tests (F_c^1, $Grad^1$, F_c^2) showed less ability for prediction by NIRS. The model did not manage to predict the others rheological parameters by NIR data, either because of too high RMSECV values (figure 4B) or because of a bimodal distribution of values into separated clusters which hedge results (figure 4C).

DISCUSSION

Efficiency and complementarity of physical parameters

The results of rheological measures allow to study the role of the 18 tested parameters to characterize the variations of texture known to appear during fruit’s storage, and to select the better ones. These parameters can be divided into three groups according to the fruit compartment which is mostly implied in the measure: peel, flesh or whole fruit (peel and flesh).

In our model, the four best parameters to characterize differences of texture were E*, F_c^1, F_c^2 and $Grad^1$. They all belong to the third group and are related to the fruit elasticity. E* could be considered as the experimental Young modulus (Tu, 2000) and is a local measure of elasticity whereas F_c^1, F_c^2, $Grad^1$ measure the whole apple fruit elasticity. In this way, we conclude that elasticity measurements are very efficient indicators to discriminate differences of texture for the three tested cultivars and especially the differences occurring during storage.

The firmness (F_f) has been considered as measurement similar to the MT firmness (*Magness Taylor*) which is the most currently measure used in apple industry and by growers. The efficiency of F_f to detect texture variability seems to depend on cultivar: it was conclusive for *Ga* but poor for *Sm*. This result could explain the shortfall of models previously explored, generally based on Magness Taylor values.

The parameters linked to skin properties, particularly the force needed to fail apple peel (F_p) and deformation at failure point (D_p), are less efficient than parameters of elasticity. Nevertheless they give complementary informations, being able to distinguish storage conditions or special cultivar behaviour. For example, while F_p value of *Ga* decreased without D_p variation, D_p value of *Sm* enhanced without great decrease of F_p.

We conclude that E* is the better parameter, among those tested, to measure apples texture. Nevertheless, this unique parameter is not able to explore all the variability. This result is not surprising if we consider the number of fruit characteristics implied in texture like the thickness and permeability of epidermis or the water and turgid status of parenchyma. Further studies are necessary to better define the biological significance of each parameter. Concerning the two tests, it seems that the parameters extracted from the compression tests are quite redundant with those from penetrometric. Thus, the first test could be leave unless new parameters are defined.

Ability of prediction by NIRS

The second objective of this work was to predict the rheological values by NIR spectrometry. Among the four parameters able to characterise the texture of the three cultivars (E*, F_c^1, F_c^2 and Grad^1), E* showed the best ability to be correctly predicted by NIRS. This result indicates that NIR spectroscopy is an efficient tool to analyse the apple texture in a non destructive manner.

CONCLUSION

This work concludes about the interest of the experimental Young modulus measured from penetrometric test (E*) which appears to be a better indicator of texture changes than flesh firmness (*Magness Taylor*) commonly used by growers and industrials. E* is correctly predicted by NIR with high R values, similar of those obtained for sugar prediction in previous works (Ventura *et al.*, 1998; Waslsh *et al.*, 2004). In this way, such a prediction of E* values could be interesting for a first in-line evaluation of apple fruit texture.

Nevertheless, others analysis from rheological tests must be performed to define new parameters able to describe some specific behaviours of apple cultivars or other sources of texture variability.

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Citations and Literature Cited

De Belie, N., Schotte, S., Coucke, P., De Baerdemaeker, J. 2000. Development of an automated monitoring device to quantify changes in firmness of apples during storage. Postharv. Biol. Technol. 18: 1-8.

Duprat, F., Grotte, M., Pietri, E., Loonis, D. 1997. The acoustic impulse response method for measuring the overall firmness of fruit. J. agric. Res. 66: 251-259.

Duprat, F., Grotte, M., Pietri, E., Studman, C.J. 1995. A multi-purpose firmness tester for fruits and vegetables. Computers and electronics in agriculture. 12: 211-223.

Harker, F.R., Maindonald, J., Murray, S.H., Gunson, F.A., Hallet, I.C., Walker, S.B. 2002. Sensory interpretation of instrumental measurements 1: texture of apple fruit. Postharv. BIOL. Technol. 24: 225-239.

Harker, F.R. , Stec, M.G.H., Hallet, I.C., Bennett, C.L. 1997. Texture of parenchymatous plant tissue: a comparison between tensile and other instrumental and sensory measurements of tissue strength and juiciness. Postarv.Biol.Technol. 11: 63-72.

Hoehn, E., Gasser, F., Guggenbühl, B., Künsch, U. 2003. Efficacy of intrumental measurements for determination of minimum requirements of firmness, soluble solids, and acidity of several apple varieties in comparison to consumer expectations. Postharv. Biol. Technol. 27: 27-37.

Johnston, J.W., Hewet, E.W., Banks, N.H., Harker, F.R., Hertog, M.L.A.T.M. 2001. physical change in apple texture with fruit temperature: effects of cultivars and time of storage. Postharv. Biol. Technol. 23: 13-21.

Lu, R., Guyer, D., Beaudry, M. 2000. determination of firmness and sugar content of apples using near-infrared diffuse reflectance. J.Text.Stud. 31: 615-630.

Mc Glone, V.A. 2002. Vis/NIR estimation at harvest of pre- and post-storage quality indices for 'Royal gala' apple.

Mc Glone, V.A., Kawano, S. 1998. Firmness, dry-matter and soluble solids assessment of Postharvest kiwifruit by NIR spectroscopy. Postharv. Biol. Technol. 13: 131-141.

Tu, K. Nicolaï, B.,D Baerdemeaker, J. 2000. Effects of relative humidity on apple quality under similated shelf life temperature storage. Scientia Horticulturae. 85: 217-229.

Schmilovitch, Z., Mizrach, A., Hoffman, A., Egozi, H., Fuchs, Y. 2000. Determination of mango physiological indices by near-infrared spectrometry. Postharv. Biol. Technol. 19: 245-252.

Ventura, M., De jager, A, De Putter, H., Roelofs, P.M.M. 1998. Non-destructive determination of soluble solids in apple fruit by near infrared spectroscopy (NIRS). Postharv. Biol. Technol. 14: 21-27.

Waslsh, K.B., Golic, M., Greensill, C.V. 2004. Sorting of fruit using near infrared spectroscopy: application to a range of fruit and vegetables for soluble solids and dry matter content. J. Near Ifrared Spectrosc. 12: 141-148.

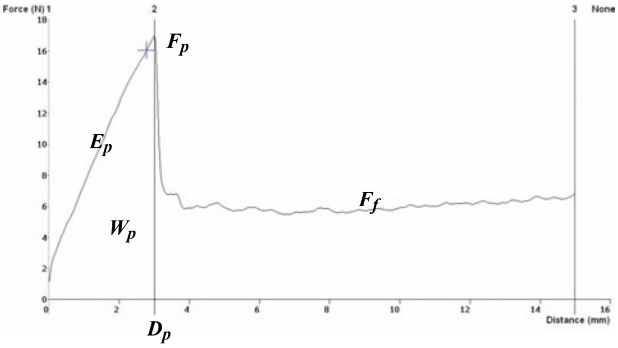

Fig 1. Force/Displacement curve recorded from a penetrometric test. F_p, E_p, W_p, D_p and F_f are the parameters extracted from the curve (table 1).

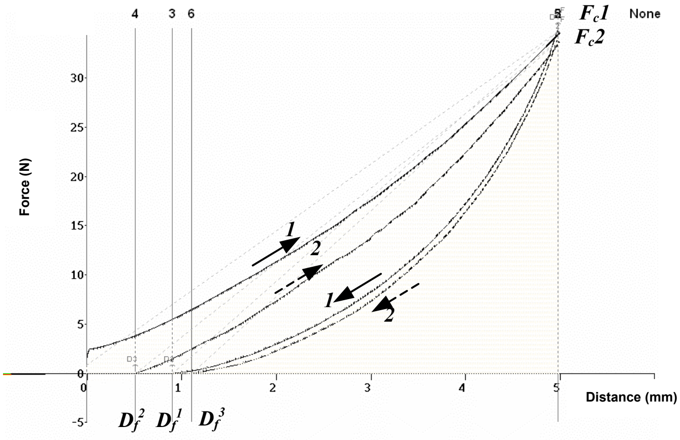

Fig 2. Force/Deformation curve recorded from a compression test. Two successive compression cycles were realized (1 and 2). These cycles include two loading and unloading stages. The parameters extracted from the curve are defined in table 2.

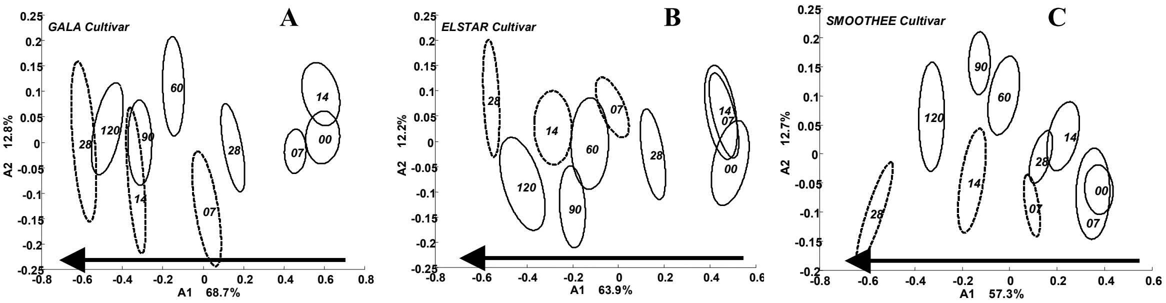

Fig.3 (***A, B***, ***C***) Factorial maps of storage duration for each apple cultivar (*Ga*, *El* and *Sm*, respectively) according to the first two principal components. Ellipses of confidence of centroïds of each qualitative group are presented for a probability threshold of *0.05*. The number included in each ellipse indicates the duration of storage (in days). Full line: CR storage, dotted line: SL storage.

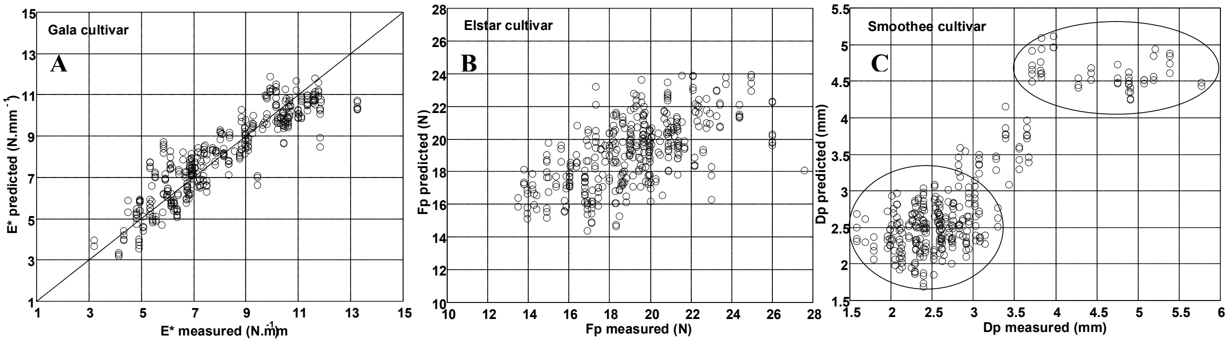

Fig.4 (**A**) E* *parameter* measured vs. E* *parameter* predicted by NIRS in *Gala* PLS model. (**B**) F_p *parameter* measured vs. F_p *parameter* predicted by NIRS in *Elstar* PLS model. Density of data points shows high RMSECV values. (**C**) D_p *parameter* measured vs. D_p *parameter* predicted by NIRS in *Smoothee* PLS model. The ellipses show the distribution in two clusters of predicted *vs*. measured D_p *parameter*.

Table 1. Definition of parameters extracted from penetrometric test

Parameters	Units	Definition
F_p	N	Force needed to fail the apple skin
D_p	mm	Deformation underlying by the fruit before the skin be fails
W_p	N.mm	Mechanical work needed to fail the apple skin
E_p	$N.mm^{-1}$	Experimental Young modulus
F_f	N	Force measured during apple flesh penetration

Table 2. Definition of parameters extracted from uniaxial compression test

Parameters	Units	Definition
F_c^1	N	Maximum force measured at the end of the first loading stage (5mm compression)
W_c^1	N. (mm)	Mechanical work measured during the first loading stage (to reach F_c1)
$Grad^1$	$N. (mm)^{-1}$	Slope of the curve measured during the first loading stage (to reach F_c1)
D_f^1	mm	Apple deformation measured at the end of the first unloading (F~0N)
W_c^2	N. (mm)	Mechanical work measured during the first unloading stage
$Grad^2$	$N. (mm)^{-1}$	Slope of the curve measured during the first unloading stage
D_f^2	mm	Apple deformation measured at the beginning of the second loading (F~0N)
F_c^2	N	Maximum force measured at the end of the second loading stage (5mm compression)
W_c^3	N. (mm)	Mechanical work measured during the second loading stage (to reach F_c2)
$Grad^3$	$N. (mm)^{-1}$	Slope of the curve measured during the second loading stage (to reach F_c2)
W_c^4	N. (mm)	Mechanical work measured during the second unloading stage
$Grad^4$	$N. (mm)^{-1}$	Slope of the curve measured during the second unloading stage
D_f^3	mm	Apple deformation measured at the end of the second unloading (F~0N)

Table 3. Correlation between the first two principal components (PC) of PCA and physical parameters. The inertia of each PC has been noticed in parenthesis. Most important correlations have been noticed in black and less important ones in grey.

Texture parameters	Gala		Elstar		Smoothee	
	PC1 (68.7%)	PC2 (12.8%)	PC1 (63.9%)	PC2 (12.2%)	PC1 (57.3%)	PC2 (12.7%)
F_p	0,69	-0,70	0,16	0,95	-0,03	-0,95
	-0,12	-0,95	-0,69	0,65	-0,74	-0,62
E*	0,97	-0,03	0,96	0,14	0,94	-0,24
D_p	-0,68	-0,64	-0,88	0,35	-0,91	-0,34
F_f	0,92	-0,21	0,85	0,38	0,59	-0,61
F_c^1	0,97	0,12	0,99	0,02	0,98	-0,03
D_f^1	0,14	-0,16	0,23	0,14	0,22	-0,15
$Grad^1$	0,98	0,15	0,99	0,01	0,98	-0,01
D_f^2	-0,33	0,31	-0,32	-0,45	-0,58	-0,20
F_c^2	0,98	0,15	0,98	0,01	0,94	-0,10

Table 4. PLS regression values. NIR T^T: spectra pre-treatment, R: regression coefficient, RMSECV: root mean square of cross validation, LV: number of introduced latent variables in PLS model.

Texture parameters	Elstar cultivar				Smoothee cultivar				Gala cultivar			
	NIR T^T	R	RMSECV	LV	NIR T^T	R	RMSECV	LV	NIR T^T	R	RMSECV	LV
Fp	*SNV*	0.68	2.20	9	*SNV*	0,37	2,53	7	*SNV*	0.77	2.82	9
E*	D_2	0.83	1.02	8	*SNV*	0.85	0.74	5	*SNV*	0.91	0.95	5
Dp	*SNV*	0.78	0.65	8	*SNV*	0.88	0.43	5	*SNV*	0.62	0.54	12
Ff	D_2	0.78	1.37	7	*SNV*	0.50	1.35	7	D_2	0.86	1.36	7
F_c^1	D_2	0.76	20.26	7	*SNV*	0.86	12.71	8	*SNV*	0.82	19.36	7
$Grad^1$	D_2	0.74	5.83	10	D_2	0.84	12.97	4	D_2	0.84	5.55	5