Food Research International 69 (2015) 209–215

Contents lists available at ScienceDirect

Food Research International

journal homepage: www.elsevier.com/locate/foodres

Instrumental acoustic-mechanical measures of crispness in apples

L. Piazza [a,*], V. Giovenzana [b]

[a] Department of Food, Environmental and Nutritional Sciences, Università degli Studi di Milano, Via Celoria 2, Milan 20133, Italy
[b] Department of Agricultural and Environmental Sciences - Production, Landscape, Agroenergy, Università degli Studi di Milano, Via Celoria 2, Milan 20133, Italy

ARTICLE INFO

Article history:
Received 16 June 2014
Accepted 23 December 2014
Available online 2 January 2015

Keywords:
Apple
Crispness evaluation
Acoustic-mechanical analysis
Chewing sound
Juiciness
PCA

ABSTRACT

Texture is a quality attribute closely related to the structural properties of the apple cellular tissue and is claimed to be the most important aspect affecting consumer acceptability apart from taste. Instrumental and human-based assessment of apples crispness are presented in this paper. A commercially available acoustic AED detector, interfaced with a TA.XT.plus Texture Analyzer, was used to collect both the acoustic emissions recorded during the instrumental mechanical penetration test, and the acoustic emissions resulting from the first bite of an apple flash, which were accomplished by 10 subjects with random dental state. Seven commercial cultivars of apples with different textural characteristics (Fuji, Golden Delicious, Granny Smith, Pink Lady, Renetta Canada, Royal Gala, and Stark) were analyzed. In order to measure the apple juice content, the expressible fluid released from the apple flash during compression was also quantified.

Merging distinctive parameters taken from the mechanical signals and simultaneously recorded acoustic traces allowed apples to be clustered based on their crispness attributes using principal component analysis (PCA), a qualitative approach for multivariate data set.

Results showed that sounds emitted during the human biting could not be assumed as a capable predictor of the sensory attribute of crispness, while apples can be efficiently distinguished for crispness by means of coupled acoustic and mechanical texture analysis. Finally, the inclusion of juiciness in the acoustic-mechanical PCA data set did not significantly increase the efficiency in cluster separation in terms of the texture crispness property.

1. Introduction

Textural properties of fruit and vegetables are widely used as indices of readiness to harvest (ripeness), to meet requirements for long-term handling and storage and to fix the acceptability by the consumer (Chen & Opara, 2013; Jaeger et al., 1998; Andani, Jaeger, Wakeling, & MacFie, 2001; Daillant-Spinnler, MacFie, Beyts, & Hedderley, 1996). Positive consumers' reaction to crispy, firm, and juicy apples is widely recognized, while dry and floury texture, associated with soft and mealy apples, is usually disliked (Harker, White, Gunson, Hallett, & De Silva, 2006). In particular, mealiness, which has been depicted as a loss of crispness, hardness, and juiciness with an increase in the floury sensation in the mouth, appears to be the worst fitted sensory attribute (Barreiro et al., 1998).

During mastication, dramatic destructive events occur at the macroscale structure level of the cellular tissue. The cell wall breakage is primarily involved, i.e., the pressure of teeth increases the hydrostatic pressure in the nearest cells, whose fracture behavior depends on the elastic response of the cell wall materials upon the applied stress. Finally, the rupture propagation through the apple flesh results in a substantial release of the juice (Waldron, 2004). Puncturing, compression, tension, and bending tests are examples of the prevailing high deformation mechanical tests, which corresponds to the highly destructive process occurring during eating. Among them, the puncturing test is the most popular testing mode to fix the quality standards regulations (Harker, Gunson, Brookfield, & White, 2002; Harker, Maindonald, et al., 2002).

However, there are scarce reports on the correlation existing between the instrumental crispness parameters and the sensory crispness scores (Barreiro et al., 1998; Harker, Maindonald, et al., 2002; Aprea et al., 2012; Zdunek, Cybulska, Konopacka, & Rutkowski, 2011). The reasons could be with respect to the complex strain, strain rate, and stress conditions, which arise in the mouth during mastication, and in the delayed sensory perception of textural attributes, which occurs after tissues are destroyed in the mouth (Ioannides et al., 2007). Variability in human bite and human-specific changes in the sensory evaluation of food texture are important points to be investigated (Dan, Watanabe, Dan, & Kohyama, 2004; Ioannides et al., 2007).

The acoustic emission was described as an alternative analytical tool for the detection of apple crispness (Duizer, 2004). Sound measurement techniques, which are mainly destructive techniques, have been increasingly applied to gain an understanding of the texture and apple fruits quality (De Belie, De Smedt, & De Baerdemaeker, 2000; De Belie & Harker, 2002; Harker, Maindonald, et al., 2002; Zdunek, Frankevych, Konstankiewicz, & Ranachowski, 2008; Zdunek & Bednarczyk, 2006;

* Corresponding author.
E-mail address: laura.piazza@unimi.it (L. Piazza).

http://dx.doi.org/10.1016/j.foodres.2014.12.041
0963-9969/© 2015 Elsevier Ltd. All rights reserved.

Zdunek & Konstankiewicz, 2004; Chauvin, Younce, Ross, & Swanson, 2008; Zarifneshat et al., 2010). Destructive testing consists of recording the sounds produced by instrumental compression probes or by the application of biting or chewing forces in the mouth. Accordingly, De Belie et al. (2000) and De Belie and Harker (2002) performed a mechanical test, also recording and analyzing the sounds produced by panelists during chewing. Chauvin et al. (2008) reported that the reproducibility of the trained panel is related to the setting up of common frames of reference auditory textural scales among panelists.

Among the numerous methodologies meant for measuring crispness and crispness perception, the coupled mechanical-acoustic testing mode promises to offer wide-open chances for defining the perceived crispness in physical terms. In the case of dry cellular-like food materials, it has been found that the combination of acoustic and mechanical techniques more adequately describes food texture than either technique alone (Piazza, Gigli, & Ballabio, 2007; Piazza, Gigli, & Benedetti, 2008). The goal of this study is therefore to assess the texture attribute of crispness in apples by collecting simultaneously acoustic and mechanical spectra upon flash destruction. An analytical tool to monitor crispness in postharvest will be provided which could also be used in breeding programs aimed at the development of new apple varieties engineered to increase crispness profile.

2. Materials and methods

2.1. Materials

Fuji, Golden Delicious, Granny Smith, Pink Lady, Renetta Canada, Royal Gala, and Stark apples were purchased at a local retailer the same days planned for testing. Samples were stored at 20°C without atmosphere control until the testing were performed.

2.2. Instrumental mechanic-acoustic test for crispness assessment

Recording sounds and/or a stress/strain pattern produced during the application of a force to a noisy product is an experimental way to obtain quantitative information regarding crisp sounds and to predict the sensory sensation of crispness. In order to obtain instrumental texture parameters, a mechanical test was performed with the TA.XT.plus Texture Analyser (Stable Micro Systems, Godalming, UK), and the simultaneous acoustic emission was measured with the Acoustic Envelope Detector (AED) (Stable Micro Systems, Godalming, UK), which is combined with the dynamometer.

Regarding the mechanical puncture test, cylinders of apple flesh (17 mm diameter and 10 mm height) were cut with a metal borer. Puncture measurements were carried out using a 4 mm diameter probe, at the cross-head speed of 100 mm/min up to 90% penetration depth in the flesh. A load cell of 50 kg was used. Five cylinders obtained from five fruits were tested. The raw mechanical data were expressed as force (N) vs. strain (%). The cross-head speed is kept constant, and hence, it is possible to establish a relationship between strain (relative height variation of the sample due to compression) and testing time. From the recorded spectra, mechanical and acoustic discrete parameters were extracted by means of the software Texture Exponent Exceed TEE32 (Stable Micro Systems, Godalming, UK). Based on results of a previous study on the acoustic-mechanical testing of dry crisp food products (Piazza et al., 2007), the following discrete mechanical parameters (Table 1) were drawn from the mechanical trace (Fig. 1): Young's modulus (N mm^{-1}, MYM), mechanical linear distance, i.e., the distance between the beginning and the end point of analysis (mm, MD), crispness work, that is the energy related to flash penetration (Nmm, MW), force value at the end of the profile (N, MEF).

The sounds emitted during instrumental deformation of the samples were measured and the energy of the sound was calculated as the acoustic component.

The Acoustic Envelope Detector (AED) is an acoustic emission monitoring system consisting of an electro-acoustic transducer, a pre-amplifier, a signal conditioning system, and a data acquisition system. The AED operates in the frequency range of 3.125–12 kHz. The microphone (ECM-2 005, Monacor) was placed 20 mm far from the axis of the puncture probe and is positioned at mid-height of the cylindrical apple sample, in order to get a standardized acquisition of the acoustic signal.

The literature does not provide a defined method to evaluate the optimum frequency of sound acquisition during mechanical-acoustic or human bite tests. The specific testing conditions typically change as a function of the food matrix investigated and of the experimental method applied. Crispy foods (such as extruded flat breads) were found to generate high pitched sounds that show a high level of frequencies greater than 5 kHz, while crunchy foods (such as raw carrot) generate low pitched sounds with a characteristic peak at a frequency range of 1.25 to 2 kHz (Dacremont, 1995). Using a piezoelectric sensor, the device measures the acoustic vibrations generated during penetration of a probe into a pear sample. The detection range covered the entire audio frequency range (0–25,600 Hz) (Taniwaki, Hanada, Tohro, & Sakurai, 2009). Hence, a preliminary study was undertook in order to identify the best condition for the acoustical spectrum acquisition. The optimum frequency for the current method was 8 kHz (preliminary data not presented in the paper). The air-conducted sound produced by the application of a force on the apple fruit was recorded by means of the AED tool, and the pattern of the acoustic emission was analyzed. The acoustic profile (Fig. 1) is presented as a plot of sound pressure level (SPL) (dB) *vs*. strain (%), where the sound pressure level is defined as the ratio between the measured acoustic pressure level and the reference acoustic pressure level (corresponding to zero acoustic emission), on a logarithmic scale.

The following discrete acoustic parameters (Table 1) were detected from the sound trace: the number of the acoustic peaks (adimensional, APN), the linear distance, a parameter which describes the ruggedness of the sound spectra, i.e., the overall acoustic events taking place during the penetration of the specimen (adimensional, ALD), the average acoustic intensity value (dB, AAI), the maximum value among the acoustic pressure peaks(dB, AMP), and the distance between the beginning and the end point of analysis (mm, AD).

Table 1
List of mechanical and acoustic parameters considered in the experimentation.

Typology	Name	Label	Unit	Description
Mechanical	Young's module	MYM	N mm^{-1}	Elasticity module
	Travel	MD	mm	Distance between the beginning and the end point of analysis
	Area	MW	N mm^{-1}	Total deformation energy
	Final force	MEF	N	Force value at the end of the profile
Acoustic	No. of peaks	APN	Adimensional	Total number of acoustic peaks
	Linear distance	ALD	Adimensional	Linear extension of the jagged acoustic spectrum
	Average sound pressure level	AAI	dB	Average sound pressure level value
	Maximum value of acoustic peaks	AMP	dB	Maximum value among the acoustic pressure peaks
	Travel	AD	mm	Distance between the beginning and the end point of analysis