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Potential use of physical measurements including ultrasound for a better mango fruit quality characterization

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ABSTRACT

The potential use of ultrasound measurements, combined with other physical measurements, has been investigated. The good relationship between soluble solids content (SSC) and ultrasonic wave velocity reported in the literature being confirmed by our study, our main goal was to evaluate the added value of ultrasound measurements around 25 MHz for the determination of biochemical compounds responsible of organoleptic quality of mangoes. Among the main sugar constituents of mango juice, only sucrose content prediction was improved by combining SSC and ultrasonic waves velocity using a PLS model ($R^2 = 0.81$, RMSECV = 12.3, bias = 0.10, RPD = 2.3) when compared to the linear model with SSC only ($R^2 = 0.75$, SEP = 14.05, bias = 0.08). The same conclusion was obtained for titratable acidity PLS model using whole fruit hardness, SSC and ultrasonic wave velocity ($R^2 = 0.82$, RMSECV = 1.84, bias = 0.02, RPD = 2.4) compared to the linear model with fruit hardness only ($R^2 = 0.78$, SEP = 2.07, bias = 0.02). However, the added value of ultrasound measurements was not always found to be significant ($P = 0.05$) when a Wilcoxon statistical tests was conducted on the residuals of the linear and PLS models for both sucrose and titratable acidity.

1. Introduction

According to the World Health organization, fruits and vegetables are important components of a healthy diet. It is recommended that their daily intake must reach at least 400 g per day. Products quality management is of prime importance to promote fresh fruit and vegetable consumption and to deliver high quality products. In order to achieve this aim, quality management tools must be designed, developed, and integrated into the fruit distribution chain from the field to the consumer.

Indeed, during cold storage and as fruit ripening approaches, sugars composition, organic acids and firmness change rapidly and extensively. Monitoring the evolution of the ripening of fruit batches can lead to increase biochemical analysis very time-consuming. Hence, there is a need to develop rapid methods for fruit quality assessment and to integrate them into automatic grading robotic devices for quality control of fruit samples representative of commercial batches.

Physical methods are increasingly used to characterize and assess, often non-destructively, product maturity and quality for various fruits and vegetables. On line sorting equipment integrated into fruit handling chains and automatic grading equipment for quality control approval of commercial batches are now supplied at a commercial scale. Among these physical methods, optical and spectroscopic methods have been the subject of extensive investigations in the recent years. As an example, near infrared spectroscopy (NIRS) has been proposed to evaluate non-destructively the content of the major constituents of fruits and vegetables (soluble solids, dry matter, sugars, organic acids, etc.) for various products (Nicolai et al., 2007; Walsh, 2005). However, even if the NIRS technology is more familiar and its potential interest more known from the fruit industry stakeholders, its uptake into the pre- and post harvest processes is nowadays still limited. This outcome is most likely the result of technical limitations, grower resistance and supply chain limitations (Walsh, 2005). In the same way, the development of mechanical methods, including acoustic and ultrasonic methods, has allowed a better characterization of visco-elastic properties of fresh fruits and a better knowledge of their changes in the course of the pre and post harvest processes. Whatever fruit commodity, these technologies have been studied for addressing the main two problems of the fruit industry i.e. (1) identification of the optimum picking stage and (2) fruit softening process control in order to supply consumers with ready to eat fruits of high aromatic and taste quality.

With regard to ultrasonic technology, several critical reviews have been published in the literature on the principle, the various methods and the potential applications of low power ultrasonic

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Nomenclature

A	echo amplitude of the ultrasound signal
α	ultrasonic attenuation
dB	ultrasonic attenuation
H	fruit hardness
HPIC	high performance ionic chromatography
NIRS	near infrared spectroscopy
RH	relative humidity
SSC	soluble solids content
TA	titratable acidity
V	ultrasonic longitudinal velocity
W_a	penetrometry firmness
Z	axis of ultrasound propagation
CV%	coefficient of variation
LIN	linear model
PCA	principal component analysis
PC1, PC2	first and second principal component
PLS (R)	partial least squares (regression)
RMSEP	root mean square error of prediction
RMSECV	root mean square error of cross validation
R^2	coefficient of determination
RPD	ratio between the standard deviation and the root mean square error of prediction for the prediction data set
SD	standard deviation
SECV	standard error of cross validation
SEP	standard error of prediction

waves (less than 1 W/cm^2) to food materials (Mc Clements and Gunasekaran, 1997). These ultrasonic waves do not alter the food materials and are ideal for nondestructive testing measurements or for quantification of food compounds in solid and liquid food materials. Moreover, ultrasonic sensors are cheap, robust, reliable and can be easily integrated in on line processes. Ultrasonic waves velocity in food materials depends on their structure (presence of air spaces, porosities, fibers, etc.), their biochemical composition and temperature. Ultrasonic attenuation depends on the same parameters as for the velocity, but unlike waves velocity, attenuation is frequency dependant and more sensitive to changes in structure than in composition. Applications in solid food materials have been reported in the literature for solid fat content determination in mackerel (Sigfusson et al., 2001) and chocolate (Saggin and Coupland, 2001). Moisture determination can also be addressed by ultrasonic measurements on honey (Laux et al., 2011) and cheese (Benedito et al., 2000). Applications on liquid food materials have concerned quantification of oil content in aqueous milling waste (Benedito et al., 2004), ethanol in fermented sugar mixtures (Resa et al., 2004), sugars in fruit juices (Contreras et al., 1992; Kuo et al., 2008). Moreover, qualitative applications have been reported in the literature for detection of air spaces or cracks in cheeses, glass-metal or plastic debris in bottled beverages (Zhao et al., 2003), and for quality assessment of frying oil (Benedito et al., 2007).

Due to their heterogeneity and the presence of intercellular air spaces that act as resonant structures, whole fruit and vegetables are generally considered as strong attenuating and scattering materials in the frequency domain ranging from 100 kHz to 100 MHz. As a consequence, ultrasonic waves cannot propagate easily inside their tissues by transmission impeding direct ultrasonic properties determination on the basis of the Beer – Lambert's law. To overcome this problem, a lot of research studies addressing fruit and vegetables quality evaluation by ultrasounds have been oriented toward the use of lowest frequencies (<100 kHz) and to the use of the reflection mode instead of the transmission mode provided the surface is representative of the bulk (Coupland, 2004; Mizrach et al., 1997). In a recent review, (Mizrach, 2008) summarized the main results obtained from ultrasonic measurements primarily performed between 20 and 100 kHz on various fruit and vegetables species (apple, avocado, carrot, kiwifruit, mango, melon, orange, plum, and tomato). The reported results tend to demonstrate that attenuation coefficient is a more relevant parameter than wave velocity when it comes to follow texture modifications and biochemical changes occurring during the course of fruit growth, cold storage or ripening process. As an example, Mizrach et al. (1997) obtained good relationships between attenuation and some quality parameters (firmness, total soluble sugars, and acidity) for fruit undergoing ripening by using a continuous touch ultrasound system in the time domain. According to these authors, the reported equations could enable to determine the sugar content and acidity, and to monitor the softening process of mango fruit directly by nondestructively measuring their ultrasonic attenuation at 50 kHz. However, these good fits were obtained for averaged data related to groups of fruits (10 fruits for each of the 8 storage times) but none equation was reported on the basis of the individual fruits. In addition, the large intervals of confidence for attenuation observed in this study for the softest fruits indicated that attenuation could vary a lot for fruits having the same firmness level (values with small intervals of confidence). Other findings on mango (Mizrach et al., 1999) confirmed that the response of a whole mango in term of frequency spectrum to an ultrasound solicitation at 100 kHz was not very reliable for predicting non destructively firmness (R^2 = 0.64), total soluble sugars (R^2 = 0.67), or acidity (R^2 = 0.71) of individual fruits. In brief, despite their potential interest and the advantages of this technology, ultrasounds are increasingly seen as efficient research tools rather than commercial solutions for on-line fruit quality sorting (Mizrach, 2008).

Failing to perform ultrasonic measurements on whole fruit sufficiently representative of the fruit flesh (not only the skin) and sufficiently highly correlated to the physico chemical quality related parameters, we decided to focus our research work on mango juice characterization rather than on whole fruit. However, even if our approach is far from a nondestructive testing of whole fruit quality because it necessitates the extraction of a clear juice from the fruit and hence its destruction, this approach could be useful for facilitating the quality control approval of commercial fruit batches by integrating ultrasounds measurements in automatic grading equipment such as the "Pimprenelle" robot (Setop, France).

Consequently, the objective of this research work was to investigate the potential use of ultrasound measurements in combination with other rapid physical measurements in order to better assess the quality of mango through a better prediction of sugar, and acid contents from ultrasonic and texture measurements carried out either on the whole fruit or on the resulting clear juice.

2. Material and methods

2.1. Material

Experiments were performed on two commercial mango cultivars, Kent and Keitt. Two batches of Kent mangoes and one of Keitt were purchased from a mango producer in the province