ACOUSTICS 2012

The maturity characterization of orange fruit by using high frequency ultrasonic echo pulse method

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In this present work, our objective is to study the feasibility of the control of the maturity of orange fruit by the ultrasonic echo pulse method with immersion in water. This study relates to two varieties of orange (Navel and Mandarin) which are the most harvested particularly in the region of Souss-Massa-Drāa in Morocco. Contrary to the works already published in this field, we worked in the high frequencies by the means of a focusing transducer with 20MHz as a central frequency. By taking into account the strong attenuation of the ultrasounds in the texture of fruits and vegetables, we limited our study only to the characterization of the external layer called the flavedo characterized by its very small thickness. The use of the high frequencies will allow us a characterization of high resolution of the orange peel with a high space resolution. This control is based mainly on the measure of the ultrasonic parameters eventually velocity and attenuation in order to check the aptitude of this ultrasonic method to detect the degree of maturity of the fruit without passing by penetrometric and biochemical measurements which are mostly correlated with human perception concerning the firmness of the fruit but they are generally destructives.

1 Introduction

Increasingly rigorous than ever, the standards of quality are today factors essential to respect to ensure the competitiveness of the fruit and vegetables. The quality control thus occupies an important place in the agricultural process. The objective of this study is to develop an ultrasonic technique as a new method of non destructive testing which will be after associated with biochemical measurements in order to follow the degree of maturity of the fruit along its chains of production. This method must make possible to determine the moment when the fruit reached its optimal maturity for a transformation or of its transport towards areas of consummation. The fruit concerned with this study is the orange fruit, more collected particularly in the area Souss-Massa-Drâa in Morocco: various varieties of orange fruit (mainly Navel and Mandarin).

To measure maturity, the producers and the agents in charge with the conditioning and the quality control must be able to have simple means, applicable in the point of inspection and requiring only material relatively inexpensive. An objective index is preferable than an index of subjective nature, and the ideal is to have recourse to nondestructive methods. The tests of penetration (Magness-Taylor, force/deformation, Kramer multiblade shear) applied directly to the surface of the fruits are the most acceptable methods to measure the firmness of the fruit and vegetables [1, 2]. Measurements of the penetrometer are largely used, because they are rather well correlated with the human perception of firmness and the shelf life, but there are problems involved in the use of probes of varied geometries. In addition, the devices used for measurements of test of deformation are expensive, and these techniques are slow, destructive and not very adaptable for the sorting on line of the fruit and vegetables.

In the last decades, the possibility of replacing the penetrometric methods by nondestructive ultrasonic methods was documented in several studies [4, 5, 6, 7, 9, 10, 11,12]. The propagation velocity and the attenuation [8] are the basic ultrasonic properties which can be in correlation with the indices used for the evaluation of the quality of the fruit and vegetables [1, 3]. The use of nondestructive ultrasonic methods represents a great progress in technology in order to follow the state of the quality of the fruits at the moment of harvest, the storage and the points of distribution. Moreover, the ultrasonic technique has other advantages: rapid, entirely automated and carried out on line.

In the recent publications, we find that the ultrasonic technique by transmission is very used, Camarena and Martinez used this technique initially to evaluate the firmness of the pulp of the Salustiana variety of orange fruit by showing a good correlation between the ultrasonic parameters and the mechanical parameters of the pulp, thus in the second time Camarena and Martinez exploited the same technique to examine the relation between the physic-mechanical characteristics and the ultrasonic parameters of the pulp of the Navel variety during its complete dehydration under the environmental conditions. In these two studies, Camarena and Martinez worked in the range of the low frequencies (100 - 50) KHz by using two identical sensors of contact to cure the problem of the strong attenuation of the ultrasonic waves in vegetables tissues due to the complex structure of the pulp and the existence of intercellular spaces containing the air which produces the dispersion of the ultrasounds.

Accordingly, our major objective in this study is to develop the ultrasonic technique by reflection with immersion in water like a new alternative technique for nondestructive maturity assessment of two varieties of orange: Navel and Mandarin. We worked in the range of the high frequencies by the means of a focusing transducer with 20MHz as a central frequency. Being given the strong attenuation of the ultrasounds in the texture of the fruit, we limited our study only to the characterization of the external layer called the flavedo characterized by its low thickness. The use of the high frequencies will allow us a characterization of high resolution of the orange peel with a high resolution.

2 Anatomy of orange peel

The orange fruit presents several distinct zones for their biological functions and of their physical nature. The part most external of the fruit is the external peel called the flavedo. This layer has a solid structure with a high percentage of water; it has the characteristic of orange color of the fruit. The flavedo layer is made up of two layers: the layer called epidermis which consists of some lines of cells and the hypodermis layer which contains the oil glands. Towards the interior, another layer called the albedo. This layer is clearly differentiated compared to the first layer; it has a solid and porous structure of white color with a few millimeters in thickness. Below the albedo, we found the area called the endocarp which contains orange juice.

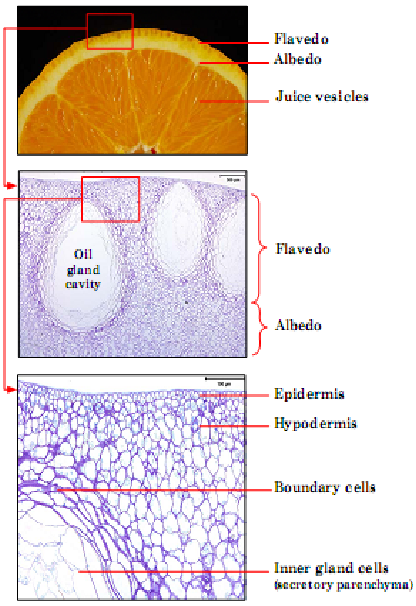


Figure 1: Anatomy of the navel orange rind (Lindhout [13]).

Being given the multi-layer character of the orange peel which is composed of two layers. These layers differ in their biological and physical properties, thus they need to be examined individually during the characterization of the peel. In this present study, we are interested only to the characterization of the flavedo layer, because by taking into account the strong attenuation of the ultrasounds in the peel and the range of the high frequencies used, it will be reasonable that the echoes of the backscattered ultrasonic signal are specific only to the flavedo layer.

3 Experimental setup

3.1 The experimental device of ultrasonic measurements by immersion in water

The figure.2 shows the experimental setup of ultrasonic measurements used in this work. The transducer and the samples were immersed in a bath containing water. The focusing transducer of 20 MHz as a central frequency (Panametrics PI20-2 20; 0.25 F=2.00 0690004) plays the role of transmitter and receiver at the same time. It transmits ultrasonic longitudinal waves to the orange peel through the water, after it receives the ultrasound waves backscattered from the sample. The transducer is excited with a pulse generator (Pulser-Receiver model 5052PR Sofranel) which also acts as an amplifier of the signal backscattered. The generator is connected to an oscilloscope (54600B HP, 100MHz) to view the backscattered signals. The signals displayed on the oscilloscope are recovered on a computer using a data card acquisition (National Instrument) through a GPIB connection (IEEE 488 Bus). The data acquisition card is controlled by the LabView software, thus we developed a platform under the convivial environment of this software to treat the ultrasonics signals acquired in order to deduce from them the ultrasonics parameters of orange peel.

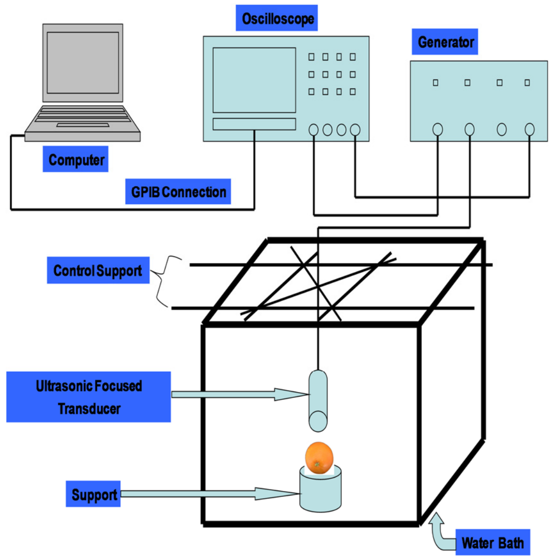


Figure 2: Diagram of the ultrasonic measuring system.

3.2 Ultrasonics measurements

It is difficult, even impossible, to detect ultrasonic waves behind a whole fruit because they are attenuated considerably while passing through the fruit because of the high percentage of air and the large intercellular vacuums in the fruit peel. Thus, the reflection method was used to measure the speed of longitudinal waves in the orange peel and ultrasonic attenuation caused by it. This nondestructive technique is very interesting to try the possibility of assessing the internal quality of orange fruit by controlling only its outer layer, knowing that the quality of orange can be deduced from the characterization of its peel. Since we work at high frequencies, this will increase the sensitivity of ultrasound in the structure, composition and viscoelastic properties of orange peel. It is however interesting to announce that it is not been easy to evaluate the ultrasonic parameters because of the forms and the irregular sizes of the studied samples, and of the non-uniform structures such as the peel thickness which does not keep a uniform thickness in the same sample. Another difficulty is to insonify the sample at normal incidence which is not simple enough to be validated because of the quasi-spherical shape of orange fruit, so we try to look for each sample in its equator the locations that give a better level configuration of the signal backscattered by the orange peel. It is not as the case of the plates of the material whose normal incidence is simple to carry out and the focal distance from the sensor is respected due to the simple structure of the sample. In the case of the orange fruit it is necessary to keep the focal distance from the sensor and to keep the excitation of the peel under a normal incidence. Thus the best signals backscattered to treat for deducing the ultrasonics parameters from them are those acquired with respect of these two conditions.

a- Ultrasonic velocity measurement

To measure the speed of the ultrasonic waves in the flavedo, we measure the time of flight necessary to the wave to propagate the thickness of this layer from the ultrasonic signal backscattered by the peel. Thus speed is calculated by using the following formula:

$$V = \frac{2d}{t_v} \qquad (1)$$

- d: Thickness of the flavedo.
- t_v: Time of flight.

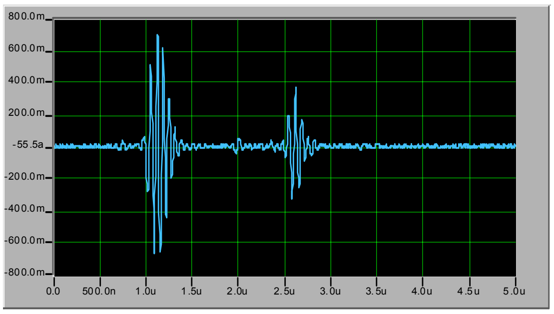


Figure 3: Example of ultrasonic signal backscattered by a sample of the Navel orange.

To obtain a precise measurement of the time of flight, we used the cross correlation method. The principle of this method consists in taking the first echo of the signal backscattered as a reference. Being $R(t)$ the cross correlation function both reference signal and the backscattered ultrasonic signal, and $H(t)$ its Hilbert transform, the cross correlation envelope is given by:

$$E\big(R(t)\big) = \sqrt{R(t)^2 + H(t)^2} \qquad (2)$$

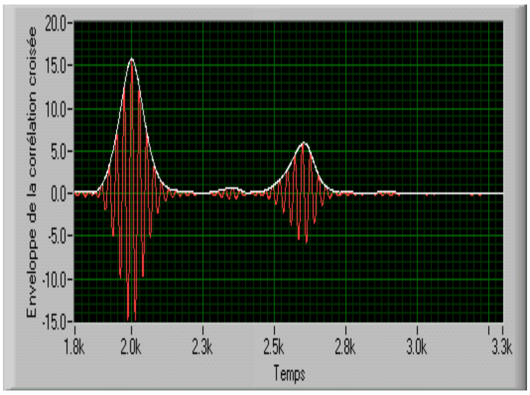


Figure 4: The envelope of the cross correlation between reference and backscattered ultrasonic signal.

The effectiveness of this method is shown above in figure 4. The envelope follows correctly the peaks each time an echo is present independently of its phase. In this way, the time of flight between the echoes is exactly measured. After by applying the relation (1), we go up at the speed in the flavedo.

b- Ultrasonic attenuation measurement

The ultrasonic attenuation coefficient α(dB/mm) is measured from the frequency domain. The method used consists initially in isolating the first echo A_1 and the second echo A_2, then we calculate the FFT each echo alone, after we deduce from the FFT the spectral amplitude corresponding to each echo:

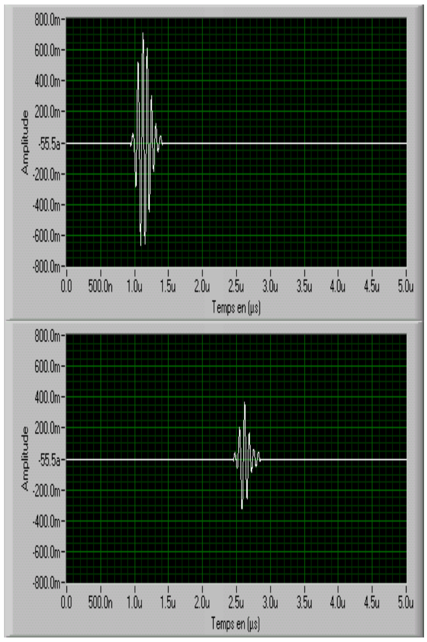


Figure 4: Isolation of the first echo $A_1$and the second echo A_2.

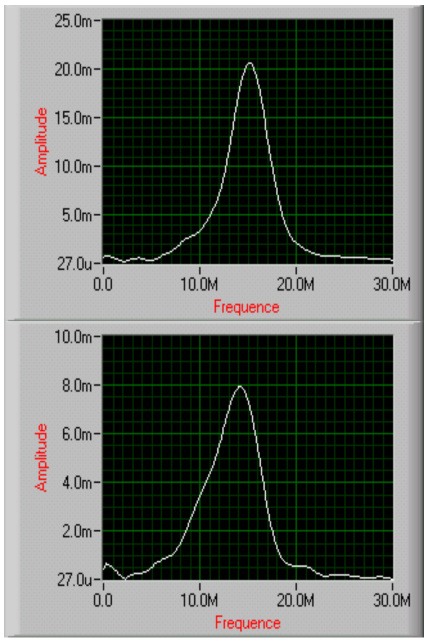


Figure 5: Spectral amplitude of the first echo $A_1$and the second echo A_2.

Finally we deduce the attenuation by the following formula:

$$\alpha = \frac{20}{2d} * Log\left(\frac{A_2}{A_1}\right) \qquad (3)$$

- A_1: Spectral amplitude of the first echo backscattered in the interface water / peel,
- A_2: Spectral amplitude of the second echo backscattered in inside the peel at the interface flavedo/albedo,
- d: Flavedo layer thickness,
- $2d$: Path length propagated by the ultrasonic wave.

4 Results and discussion

The tables 1 and 2 show various ultrasonic signals backscattered by the various orange samples studied and the measurements of the ultrasonic parameters corresponding to each sample.

Table 1: Ultrasonic parameters measurements of Navel.

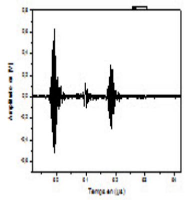
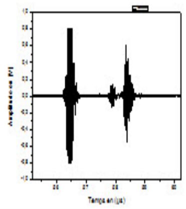
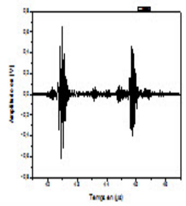
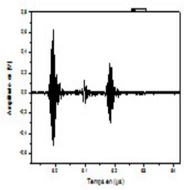
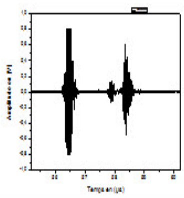
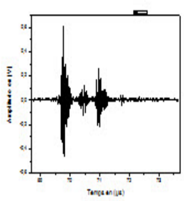
		Backscattered Signal	Flight time (µs)	Thickness (mm)	Velocity (m/s)	Attenuation (dB/mm)
Navel	Sample 1		1.51	1.8 ± 0.02	1325.08	4.15
	Sample 2		1.74	1.2 ± 0.02	1149.41	1.11
	Sample 3		2.41	1.9 ± 0.02	830.59	2.08

Table 2: Ultrasonic parameters measurements of Mandarin.

		Backscattered Signal	Flight time (µs)	Thickness (mm)	Velocity (m/s)	Attenuation (dB/mm)
Mandarin	Sample 1		1.47	1.8 ± 0.02	1028.34	1.14
	Sample 2		1.63	1.9 ± 0.02	1030.06	0.99
	Sample 3		1.08	1.7 ± 0.02	1854.29	2.15

The measurements collected in the two tables above make the average of three successive measurements in the equator of each sample i.e. we take three measurements for the speed of the longitudinal waves and three measurements for the attenuation, and finally we make the average of three measurements for each ultrasonic parameter for each sample.

We notice that the values of speed of longitudinal waves differ largely with those found by Camarena and Martinez [5]. The difference is about of a multiplication factor equal to 10, Camarena and Martinez [5] found velocity values which included between 130 and 240 m/s in the peel of various types of orange fruit. For us, the results of the velocity measurements vary from 1000 until 2000m/s in the peel of the two types of orange studied in this work. Thus, it is clear that our measurements of longitudinal velocity differ to the results found by Camarena and Martinez [5] within a multiplication factor equal to 10.

We can explain this difference by two reasons: the first reason is the frequency domain used for this study, we worked in the field of the high frequencies by the means of the focusing transducer of 20 MHz, thus Camarena and Martinez [5] worked in the low frequencies whose order is 200 Khz. The second reason is the detected thickness, Camarena and Martinez [5] does not have a problem with the thickness because the frequency domain used allows the detection of the thickness entirety of the peel and moreover they worked by the method of transmission, in this manner the problem of detected thickness is avoided. On the other hand, the high frequency that we used obligates us to carry out of ultrasonic measurements only on the external layer of the peel instead of the whole peel. Therefore, it is obvious that the results of the velocity measurements will be different because the detected thickness and the time of flight carried out to propagate this thickness are different.

For the results of measurements of the ultrasonic attenuation, we notice that our measurements are in the same order as the results found for the ultrasonic attenuation by Camarena and Martinez [5]. Thus the results of measurements of the attenuation are included between 2 and 5 dB/mm for the two types of orange fruit studied in this work. It is practically in this same interval where are included the attenuation values measured by Camarena and Martinez [5]: the attenuation coefficient includes between 1,8 and 3,7 dB/mm according to the type of studied orange.

It is always essential to note that when we work by the reflection method to characterize the peel of the orange fruit in the field of high frequency, the accurate measurement of the thickness corresponding to the experimentally measured time of flight is not accurate, although we considered that the backscattered ultrasound signal corresponds exactly to the flavedo layer based on the signal shape and the structure of this layer. The thickness of peel is not uniform throughout the sample and the interface between the two layers (epidermis and hypodermis) composing the external layer is not always clear, indeed there are interferences between these two layers and that influences the shape of the backscattered signal and consequently to the measure of the time of flight, the longitudinal speed and the attenuation because these three parameters are all related to the thickness. The absence of precise information in the measure of thickness corresponding to the measured time of flight constitutes the major defect of this method in spite of its nondestructive aspect which gives him a crucial importance in order to develop a new ultrasonic technique of nondestructive testing and in line of the maturity assessment of the orange fruit.

5 Conclusion

In this work we try to highlight a new ultrasonic technique to follow in real time the maturity of the orange fruit without passing by mechanical tests and biochemical tests generally destructives in order to measure the degree of maturity of the fruit. The high frequency ultrasonic characterization provides a high spatial resolution for local measurements of speed velocity and attenuation in the orange peel. The behaviour of high attenuating of the orange peel has forced us to restrict the ultrasonic characterization to the outer layer only instead of characterizing the whole thickness of the peel. It is for this reason the results of measurements that we carried out differ from those previously published especially on the longitudinal speed of the ultrasounds in the orange peel. For the measurement of the attenuation, we exploited the frequency domain to deduce it and the found results are in agreement compared to the results already published.

The important result of this study consists in the detection of the two layers composing the external layer (flavedo) of the peel by the ultrasonic technique used in the high frequencies. Thus, we propose in our next work to choose shorter windows with various depths to analyze the specific backscatter to each layer. The integrated analysis of backscatter is a valid tool for distinguishing between the various characteristics of the peel. This method can be employed to study the differences of the water content in the peel with the age i.e. the analysis of the state of hydration of the peel like a decisive criterion to detect the degree of maturity of the fruit.

6 References

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