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Evaluation of Temperature and Mechanical Properties of Beans during Cooking Process

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ABSTRACT

This paper presents a method of monitoring temperature in a MATTSON COOKER during a process of beans cooking. From the kinetic waves, Young's modulus of beans at the precise instant of firing and hardness during cooking are measured. The aim is to understand hard to cook phenomena of beans and we carried out this work in Electronic Laboratory of National School of Agro-Industrial Sciences; Biophysics and food Biochemistry laboratory, for the National School of Agro-Industrial Sciences (University of Ngaoundéré, Cameroon), from December 2009 to June 2011. Electronic thermometer, billed with Whetstone Bright, using a PT100 sensor is introduced in the Mattson cooker containing water and beans (seeds stored (ST) for 12 days firstly and not stored (NST) secondly, for three varieties of beans names BABESSI-1, MAC34, MAC54). The cooker was adapted with potentiometer sensors to register kinetic waves and place on hot-plate. The depth of penetration in beans is measured at times when cooking is progressing with the help of a PNR10 penetrator. Deformation is evaluated on the kinetics of cooked beans, on the field of reversible deformation of the wave. The applied stress is the ratio between a constant forces corresponding to the weight of the piston. The applied surface of this stress was considered as the surface of the piston shape. The Young's modulus is the ratio between the applied stress and deformation recorded.

The temperature in the cooker increases and stabilizes around 80°C after 800 seconds and till the end of the process. Hardness is the percentage of the inverse of the depth noted. It varies with storage (Hard-To-Cook). The Young's modulus (MPa) for BABESSI-1 (NST: 0.014; ST: 0.009); MAC34 (NST: 0.034; ST: 0.015); MAC54 (NST: 0.025; ST: 0.020) decrease with storage therefore, with the hard-to-cook. There is around 33.33mn gap between the cooking times of two groups of beans, so the storage increases the time of cooking.

Storage increases the cooking time due to the hard-to-cook phenomena. The decreasing of Young’s modulus traduces the raise of tensile strength of beans.

Keys word: *temperature cooking; beans hardness; beans Young’s modulus; Hard-To-Cook.*

1- INTRODUCTION

Products designed to alimentation must satisfy the nutritional norms of quality, hygienic and organoleptics (invidious test) without producing healthy damages. Instrumentation of process came to give a considerable amelioration of the quality of a give sample [8]. The University of Ngaoundéré since its creation has stuck on study of agro-alimentary process using apparatus build for the cases. With the aim of understanding the phenomena that appear in foods, many authors have worked on properties of some fruits and foods during and after cooking. Like the penetration and compression test realised in texture and texturing of foods [14]. The results of those studies permitted to predict the comportment of the given foods [2]. In the same order, an instrumentation using a PC has been developed to study beans cooking kinetic [17]. To understand the Hard-To-Cook phenomenon, these studies have evaluated the cooking time of beans Phaseolus vulgaris L., [6] [18], and led to the definition of a constant cooking time of beans and index for Hard-To-Cook [1]. It is clear that time is a very important parameter in cooking process. However, that time itself cannot guarantee specifically the cooking beans; it must also take into account the temperature in the process during cooking and focus on the mechanical properties of grain subject to stress[10][9][5][4]. In the present paper we start by selecting seeds of beans to have uniform samples using a caliper. After, we separate it in two groups: one to be stored following a protocol that we define, and the other to be used directly. Suitable sensor is chosen and combined to a Wheatstone bridge to follow temperature in the cooker. This method of packaging is more precise than current generator circuit or divider of tension [13]. As we consider beans like a mechanical material, we used PNR10 penetrator and Mattson cooker to evaluate mechanical properties of beans at the precise time of firing [3] [17]. We manipulate samples during and till the end of cooking.

2- MATERIALS AND METHODS

Selected samples provided by the Institute of Research for Development (IRAD) of west Cameroon are divided in two groups; one to be stored during 12 days in the storage apparatus, and the other to be cook directly. Figure 1 shows a physical presentation of samples and Table 1 shows the dimensions of those select samples realized using a VERNIER CALIPER (TRICLEBRAND) with characteristics 200*0,02mm and 8*1/1000 in.

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Figure 1: Samples of beans.

Table 1: Dimensions of different types of beans

DIMENSIONS / VARIETY	Length (cm)	Thickness (cm)
MAC 34	1,396 ± 0,076	0,752 ± 0,026
MAC 54	1,384 ± 0,060	0,610 ± 0,034
BABESSI-1	1,218 ± 0,115	0,443 ± 0,030

2.1- Choice of the sensor

Respecting the characteristics of a good measuring instrument that are accuracy and fidelity, the choice was made on PT100 temperature sensor [15] [20]. It has four wires, two red and two white, both types wires are identical and measure 2m. The Length of the metal probe is 500mm and has an internal resistor which increases with the increasing of temperature. So it is a positive coefficient temperature resistor, packaging to be used in liquid milieu [21].

$$R_{pt}=R_0\ (1+\alpha*\theta) \quad (1)$$

Temperature increase is 0.385 per degree. Knowing that the probe measures from -50°C to 200°C, and also knowing that at θ=0°C, the resistance of the sensor R_{pt}= 100Ω, we have, at θ=100°C R_{pt}= 138.5 Ω and at θ=200°C there will be R_{pt}=177Ω. The specificity of this probe with four wires is that it is very precise and can remove during measurement usually all of the errors caused by cable resistance and the temperature variations of the drivers [11] [19]. For α=0.00385Ω/°C, we have the following relationship between sensor resistance and temperature:

$$R_{PT}=100(1+0{,}00385*\theta) \quad (2)$$

2.2- Wheatstone bridge: Packaging of sensor

Sensitivity and precision guided our choice on Wheatstone bridge assembly for the packaging of the sensor. It is a device which allows in specified circumstances, to determine the value of a resistance bridge which is unknown. For the conditioning stage of the sensor, we replace one of the resistors of the bridge by the PT100 sensor so that when its value will change because it is immersed in a milieu where temperature varies; it will also cause the modification of tension in the central branch of the bridge. This information is the of balance tension of the bridge. To calibrate our measuring device we dip the PT100 in ice melting at 0°C. The value of resistance is 100Ω in these conditions. An adjustable potentiometer is set to a value corresponding to the one of the probe to achieve equilibrium of the bridge. This setting is done once and for all [11]. The relationship between temperature θ and of balance tension V_{ab} is give as follows:

$$\theta=[200[V_{ab}+(5/2)]-500]/[1{,}925-0{,}385[V_{ab}+(5/2)]] \quad (3)$$

2.3- Packaging of the receive signal

Packaging of electrical signal provided by Wheatstone bridge is realized with a summing-inverter. This device raises the level of the signal which is generally very low, in the order of mV, to a more appreciable value with a 4.7 ratio. It is built around two µA741 circuits, which offers the possibility of reducing the offset voltage. After this stapes, the new relationship between temperature and the output of the system is given as follows.

$$\theta=[200[(V_s/4{,}7)+(5/2)]-500]/[1{,}925-0{,}385[(V_s/4{,}7)+(5/2)]] \quad (4)$$

The following figure 2 is electronic design for stapes of packaging sensor and packaging electrical signal provided by the bridge. Element of the circuit are defined to provide equations 3 and 4.

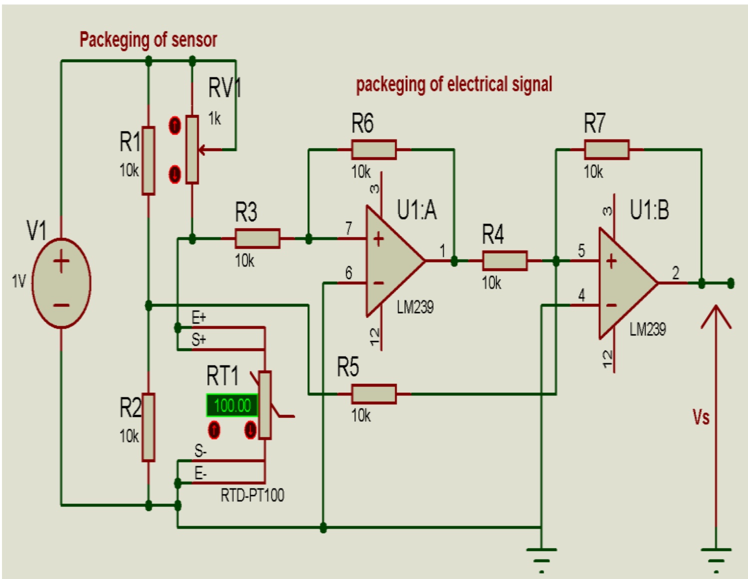

Figure 2: Electronic of packaging of sensor and electrical signal for temperature acquisition

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2.4- Experimental set up of hardness

Selected grains are packed in lots of 40 seeds in nets. These lots are then placed in bowls containing saturated solution of NaCl (sodium chloride), so that the seeds are not in contact with the liquid. The bowls are closed hermetically and disposed in an oven that must raise its temperature to 70° C. For 12 days and at regular intervals of three days samples were removed for testing. During cooking, some seeds are getting out of the Mattson cooker for the penetration test on PNR10 penetrator. We stop this manipulation when the pistons of the Mattson cooker perforate samples, reflecting the cooking. Piston deep traduces the difficulty of his penetration in the selected beans. Hardness is therefore the inverse of percentage of penetration.

2.5- Experimental set up of Young's modulus

Mattson cooker equipped with sensors, powered by a 5V DC source are used to convert the successive movements of the pistons through the beans grains. Cursors of these potentiometers are driven freely when it suspends a mass of at least 220g [3]. A metal device of 152 g on average, placed above each of the weighted piston Mattson cooker increases its mass from 82g to 234g. The potentiometric sensor converts the variation of resistance into a voltage, which is proportional to the resistance and therefore the distance covered by the cursor note. The total distance covered by the cursor from one end to another is: d = (30.6 ± 0.3) mm for the case of linear potentiometers stereo slide M20kBK73M [2]. The corresponding voltage to this variation attacks an acquisition card which transfers data to the computer in an Excel file. During cooking, grains are subjected to compressive forces equal to the weight of the piston floats (2.3814 N) over an area equal to the surface of the tip penetration of the piston ($3.46*10^{-4}m^2$) [16]. The graphical representation of the succession of points recorded gives the curing kinetic of the studied beans.

Young's modulus of a given material is evaluated during the compression test, specifically on their area of reversible deformation [9]. Strain (ε stored or not stored ε_s) incurred by the beans grain is the ratio between the thickness variation (Δe stored or not stored Δe_s) and the initial thickness (e stored and e_s not stored), is the difference between the beginning of the penetration of piston in grains and the moment of it falling. Stress (σ) is the ratio between applied force (F) and the surface (A) of contact with seeds. The applied force is equal to the piston weight and the associated additional weight. Young's modulus is the ratio between stress (σ) and applied strain (ε or ε_s) recorded.

Young's modulus: $E=\sigma/\varepsilon \qquad E_s=\sigma/\varepsilon_s \qquad (5)$

Figure 3 presents the synoptic of the apparatus used to register the displacement of pistons and temperature following during cooking process.

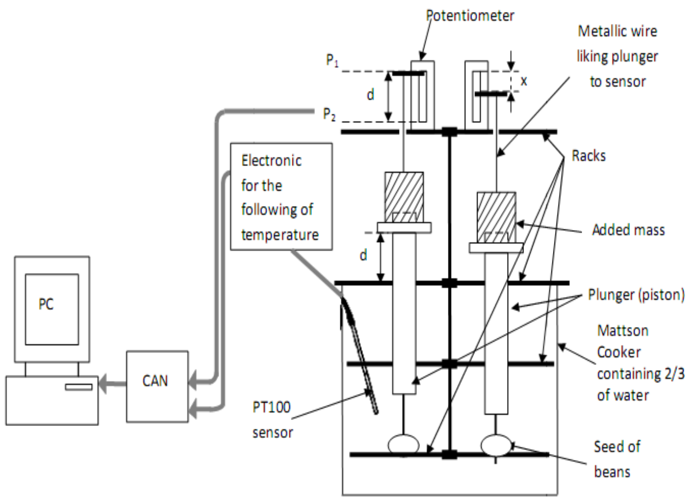

Figure 3: Synoptic of MATTSON cooker equipped with potentiometer and electronic PT100 sensor for penetration register and temperature following

3- RESULTS AND DISCUSSION

3.1-Temperature in MATTSON cooker

Figure 4 shows the output response of our system, function of input temperature of the consider milieu. It confirms the linearity of the output device in the functionality area.

We made statistical analysis to confirm this result and manual analysis name T-test parity [12]. It appears that, since |t|= 0.35338176 > 2.145 (for probability P=0.05 for n-1 elements) we can say that there is no significant difference between the two methods of measurement.

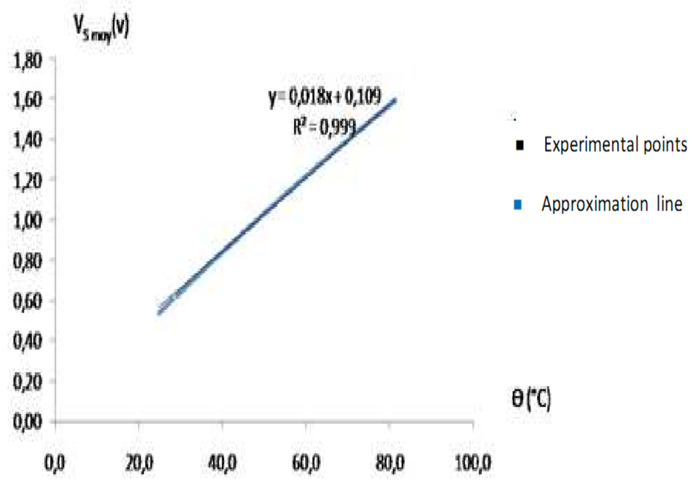

Figure 4: Linearity of our thermometer.

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Figure 5 represents temperature function of elapse time in the cooker.
We clearly distinguish the curves of two tests and the medium curve. They all have an increase allure and have two areas which are:

- a linear zone with a duration of about twenty minutes, which corresponds to an exponential rise in temperature within the cooker from 20°C to about 80° C;
- A zone beyond twenty minutes, which corresponds to a constant temperature of around 80° C in the medium.

All curves start their rising around 25°C which represents the temperature of water in the cooker at the beginning of the test. Temperature can't rise anymore because water has attained the boiling point, were the entire molecular are at the same temperature degree. Beans become tender in our cooker at 80°C.

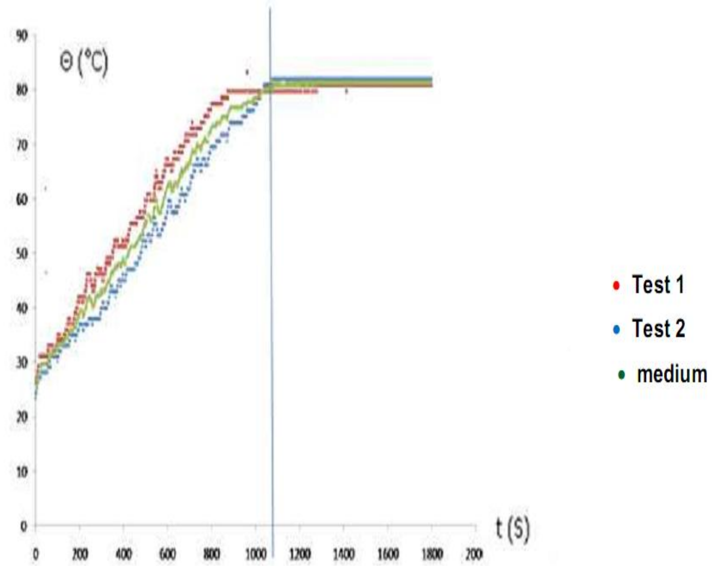

Figure 5: rising of temperature in the cooker.

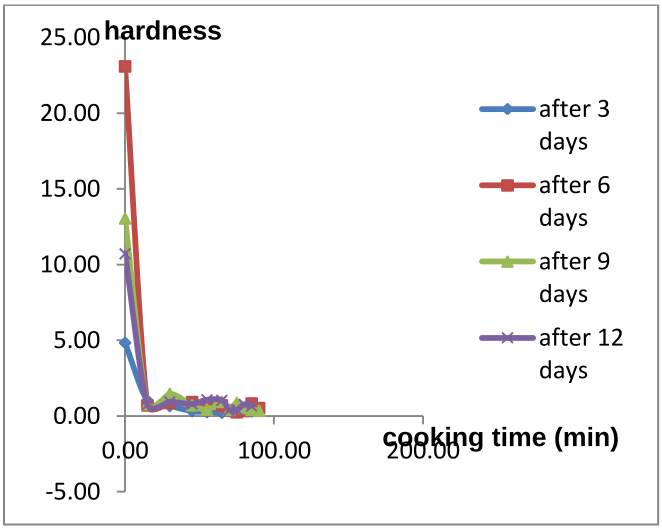

Figure 6: Hardness of Babessi-1 at different days of cooking.

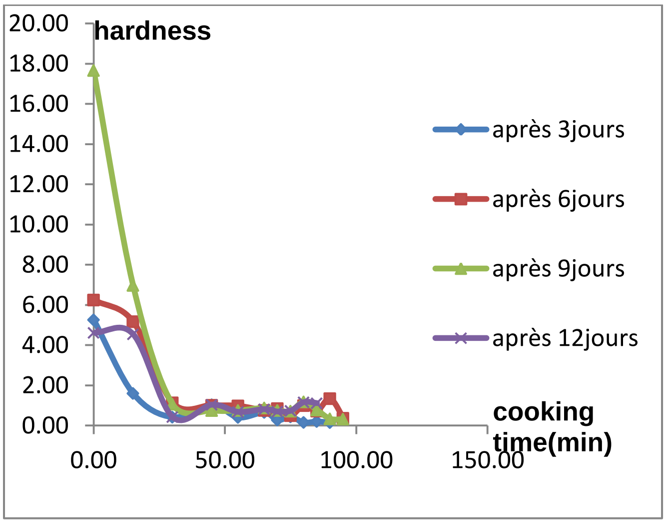

Figure 7: Hardness of MAC 34 at different days of cooking.

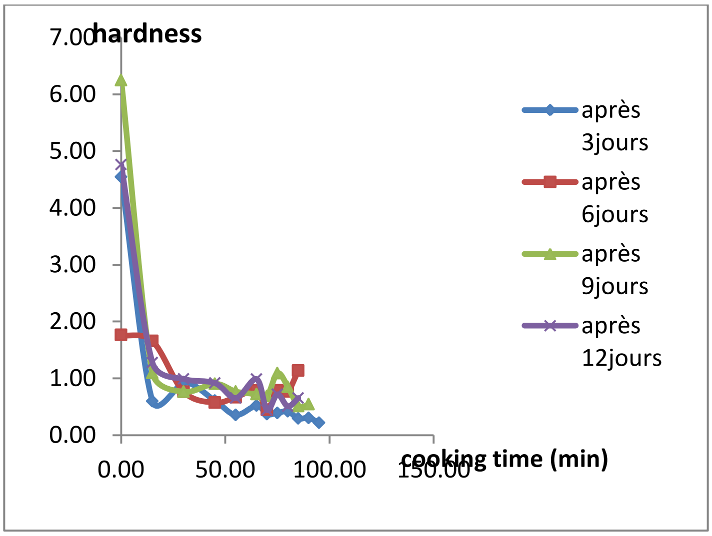

Figure 8: Hardness of MAC 54 at different days of cooking.

3.2- Evaluation of the hardness of bean

The shapes of curves in figure 6, figure 7 and figure 8 are identical for different beans varieties studied. The four curves correspond to the four days of manipulation as shown in the legend. Before cooking and during the first moments of cooking, variable depending on the bean variety (20 minutes or 40 minutes), the hardness depending on the bean varieties and storage time, therefore the degree of Hard-To- Cook. After some time of cooking (from 20 minutes or 40 minutes depending on the varieties of bean), the hardness does not vary significantly with storage time so with the Hard-To-Cook.

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3.3- Evaluation of Young's modulus of beans

On the curve of the curing kinetics (figure 9, figure 10 and figure 11), we measured the thickness variation of the seeds due to mechanical compression of the pistons on the corresponding samples.

The shape of curves has three parts. The Blue curve is the kinetic of not stored grains and violet one is the kinetic of stored seeds. Seeds become tender at around 2500s = 41.67min for not stored seeds and around 4000s= 66.67min for stored seeds, for all varieties of beans. It's shown that there is a difference of around 2000s= 33.33mn between the two curves for all varieties.

Like in mechanics it can be noted on these curves two main parts: the field of reversible deformation that leaves the beginning of the cooking at the moment of collapse of weighted piston. With time, beans hardness decreases under the weight of pistons: this is the area of reversible deformation beans because if the stress is removed beans could cover its original form.

A second part is the transient part. It is reflected on the curve by a sudden change and is the softening and penetration of the seed traducing beans cooking. It is the domain of irreversible deformation of the beans as it has already undergone a structural modification and thus even if the stress is removed, bean may not recover its original shape.

A third part corresponds to the end of cooking, the piston cannot move anymore because it is running late, having pierced the seed of beans.

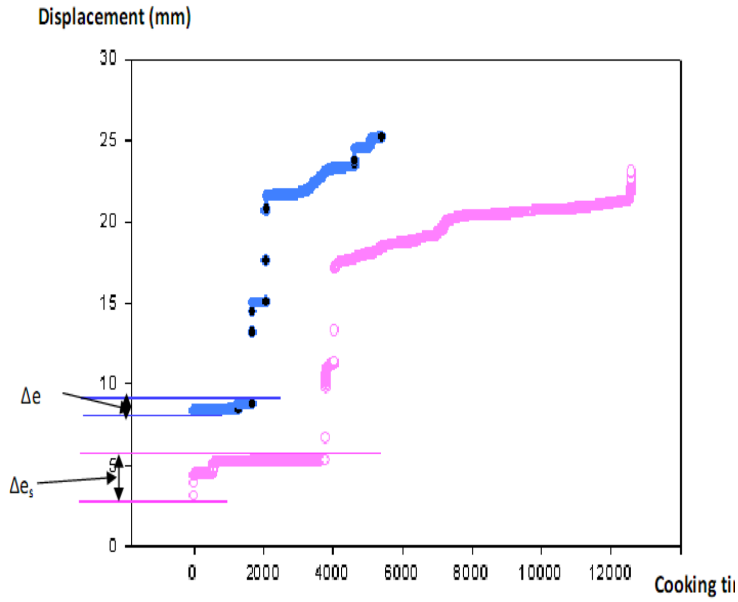

Figure 9: Kinetic of beans MAC 34 (red, store beans and blue, not store).

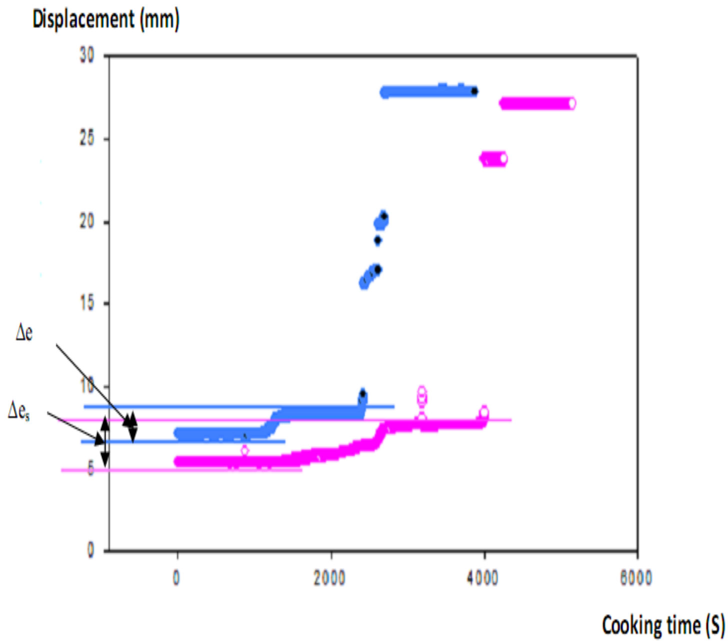

Figure 10: Kinetic of beans BABESSI 1 (red, store beans and blue, not store)

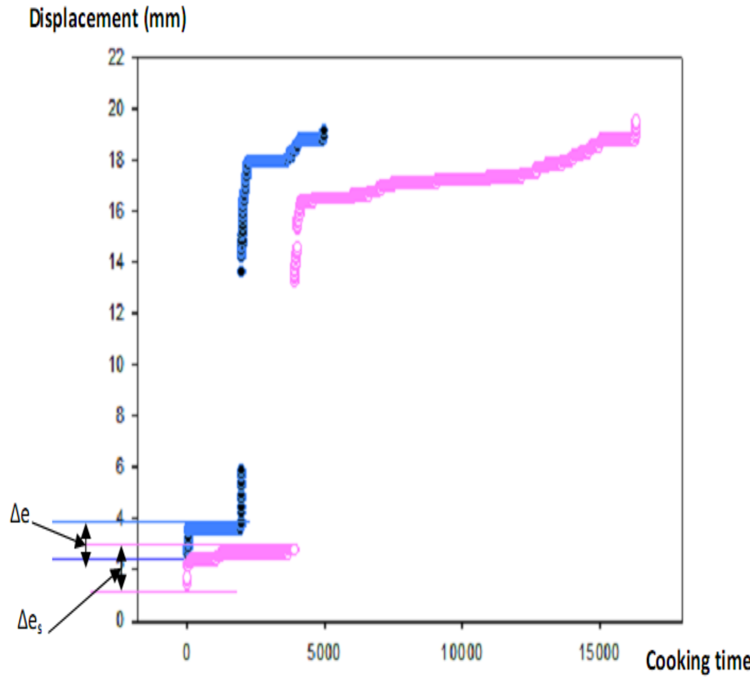

Figure 11: Kinetic of beans MAC 54 (red, store beans and blue, not store)

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Table 2: Constants used for determination of Young's Modulus

VARIETY OF BEANS	BABESSI-1		MAC 34		MAC 54	
	Not stored	Stored	Not stored	Stored	Not stored	Stored
thickness e(cm)	0,443 ± 0,030	0,443 ± 0,030	0,752 ±0,026	0,752 ± 0,026	0,610± 0,034	0,443 ± 0,030
Variation Δe or Δe_s (cm)	0,2	0,3	0,15	0,35	0,16	0,2
Deformation $\mathcal{E}$= (Δe/e) or (Δe_s/e)	0,5	0,75	0,2	0,46	0,26	0,32
Apply Force F (N)	2,3814	2,3814	2,3814	2,3814	2,3814	2,3814
Space of contact A (10^{-4} x m^2)	3.4618	3.4618	3.4618	3.4618	3.4618	3.4618
Stress σ_s=σ=F/A (N/m^2)	6878,98	6878,98	6878,98	6878,98	6878,98	6878,98

Table 2 show the whole variables used to evaluate Young's modulus. In general, it appears in table 3 that Young's modulus of stored seeds is lower than the one of not-stored seeds. This can be explained by the fact that storage reduces the amount of water contained in the sample. So the more you store beans the harder it becomes and this hardening is reflected by the decrease of Young's modulus.

Table 3: Young's Modulus of Beans

Beans variety	BABESSII-1		MAC 34		MAC 54	
	Not stored	Stored	Not stored	Stored	Not stored	Stored
Young's modulus (MPa)	0,014	0,009	0,034	0,015	0,026	0,020

However, results we obtained are different with the results found by Legrand *and al*., 2007. They founded that Young's modulus of dry beans is upper than the one of cook bean. So process of cook decreases the Young's modulus of beans. This difference can be justified by the following reasons. The entire parameters we defined came out of curves and the consequence of that original method of analysis is that Young's modulus was determined at the precise time of cook not after as did Legrand *and al*., 2007, who first cook their beans before proceed to analysis. The compression force applied on the seed was equal to the weight of piston and associated mass, 2.3814N, different from 10N used by them. In addition, seeds that we used were different from Phaséolus vulgaris L. used by Legrand *and al*., 2007 during their analysis as we presented in table 1.

4- CONCLUSION

Evaluation of temperature and mechanical properties of beans during cooking process allow us to familiarize ourselves initially to electronics and practice through the selection of appropriate components and the achievement of a functional and operational device till the present day. We found that beans become tender in our cooker at 80°C, at around 2500s = 41.67min for not stored seeds and around 4000s= 66.67min for stored seeds, for all varieties of beans we study. In consequence, storage increases the time of cooking of beans. Failing to have special equipment we have circumvented the problem by putting electronics on charge of agro-alimentary. Variation of Hardness is in the first 20 to 40 min of cooking; hence the Hard-To-Cook phenomena. After this time hardness does not changes significally. Sigmoid kinetics we obtained is typical in this domain. Young's modulus for all the varieties of beans reduce with Storage, inversely with Hard-To-Cook phenomena.

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