A LABORATORY TUMBLER SIMULATOR – SALT PENETRATION IMPROVEMENT DUE TO MEAT MECHANICAL TREATMENT

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Abstract – Tumbling is a key step in the manufacture of processed meat. However mechanical treatment undergone by meat pieces which determine process yield and product quality cannot be characterized in tumblers. This paper describes a new laboratory device to study the effect of controlled mechanical treatments on mass transfer, protein solubilization, histological changes… It was designed to reproduce on an individual piece of meat the constraints and deformations that are promoted in tumblers of various designs and sizes. In addition experiments carried out with pork *Semimembranosus* muscles showed that NaCl transfer is enhanced by mechanical treatment. In comparison to raw meat, apparent NaCl diffusivity is increased by 20 % in samples which were treated beforehand curing and by 200 % in samples treated during curing.

Key Words – tumbling, curing, mass transfer.

I. INTRODUCTION

Tumbling is a key step in the manufacture of marinated or/and cooked meat products; tumbling time vary from 2 to 12 h depending on product type and size. Curing-tumbling is usually performed in rotating drums equipped with baffles; the rotational speed varies from 4 to 16 revolutions per minute. The mechanical energy which is transmitted to meat pieces due to falling and striking against baffles leads to meat deformation and changes in the meat tissue structure [1, 2]. Meat tumbling have been shown to enhance salt apparent diffusion [2, 3], to favor protein solubilization and extraction [4], to improve cooking yield [5] and to be favorable as regards final product tenderness and juiciness [6, 7]. All the works dedicated to meat curing-tumbling were carried out in industrial or pilot tumblers of various types (baffles number and shape) and sizes (drum diameter and length) with a lot of operating conditions (rotational speed, treatment time, possible alternating working and rest periods). Since the mechanical treatment cannot be characterized in those plants it remains very difficult, indeed impossible, to derive general rules to optimize tumbling and it is cautious to transpose the conclusions from one work to another.

Our aim was to develop a laboratory device to simulate tumbling while controlling at best the mechanical action applied to a piece of meat and while measuring the force-strain diagrams. First experiments were carried out using this simulator to examine the enhancement of salt migration due to the promoted deformations.

II. MATERIALS AND METHODS

Principle of the tumbler simulator

Mechanical actions on meat pieces in a tumbler are very complex and vary with time. However this mechanical action can be break down into 2 main actions which can be reproduced separately or in combination by the simulator (Fig. 1):

- The kinetic energy accumulated during a fall (from the top of the tumbler drum to other meat pieces) promotes a brief deformation during which the mechanical energy is dissipated into heat. Thus, this action is proportional to meat piece mass and fall height. This can be assimilated to a very short compression. In the simulator a controlled strain is applied and the force profile is recorded; integration of the force-strain curve gives the energy involved.
- After its fall, a meat piece is driven up by tumbler baffles. During this movement it undergoes a compression, longer and lower than previously, whose amplitude varies with the thickness of the product layer above it and whose duration depends on the drum rotational speed. In the simulator a controlled force is applied for several seconds or longer and the strain is measured.

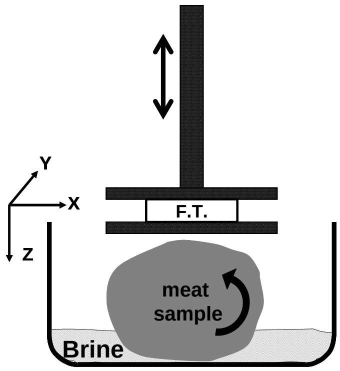

Figure 1: cross section of the tumbler simulator. The arrows indicate the rotation of the sample around its main axis (Y direction) and the linear reciprocating motion of the piston (Z direction). The latter is equipped with force transducers (F.T).

One muscle or piece of meat is wrapped into thin elastic net whose mechanical effect is negligible. This net is tied at each end to a motorized wheel to rotate the sample (4 to 12 rpm) so that its surface is continuously wetted by the brine. Working and rest periods alternate and successive thousands of cycles can be performed during a trial. During the working periods the sample rotation is stopped and a specific mechanical system drives the piston linearly for a single down-and-up movement. There are two operating modes which correspond to the two main mechanical actions in tumblers, but the rest periods last always a few seconds:

1- A short (0.1 to 1.0 s) compression of the sample is applied using a predefined strain; this latter is usually between 10 and 50 % to have the same energy than in a fall. The reaction force of the sample is measured by 2 force transducers (F.T.) placed along direction Y.

2- A long (typically 2 to 6 s) compression using a predefined compression force is applied while the piston position is measured. This compression force can vary from one cycle to another to simulate various thickness of product.

The accuracy of the piston position is better than 0.1 mm. The force transducers (F.T.) accuracy is 1N. The recording frequency is equal to 60 Hz.

Assessment of NaCl apparent diffusivity

A series of trials were carried out with pork *Semimembranosus* muscles (pH = 5.6) to compare NaCl apparent diffusivity in the following cases: static brining of samples excised either from a raw muscle (1) or a mechanically treated muscle with no brine (2), 5h brining in the tumbler simulator without (3) or with (4) mechanical treatment.

The apparent NaCl diffusivity was assessed as detailed in [8] using the measured NaCl content profiles and considering the analytical solution of the second Fick's law for a constant boundary condition at the surface. NaCl content profiles were measured using a chloride analyzer (Sherwood, MHII-926). Measurements were performed after 5 days at 4°C of stating brining with a brine at 5 % (w/w) NaCl content (cases 1 and 2) or at the end of brining in the simulator (cases 3 and 4) with a brine initial NaCl content of 13 % (w/w).

When a mechanical treatment was applied, the first operating mode was used with the following conditions: treatment duration 5 h, temperature 4°C, 2500 cycles, mean compression strain equal to 35 % of the muscle thickness, muscle cross section mean thickness about 5 cm, compression time 0.5 s and rest period duration 6.7 s.

III. RESULTS AND DISCUSSION

Mechanical measurements

Figures 2 and 3 present a few examples of the measurements carried out during mechanical treatments of muscles. Two extreme compression cycles among the 2500 measured during trial 4 (indicated by the black squares in figure 3) are shown in figure 2; the force-strain diagrams are similar to those obtained with raw meat using a compression cell to designed to analyze the rheological properties of the myofibrillar structure [9].

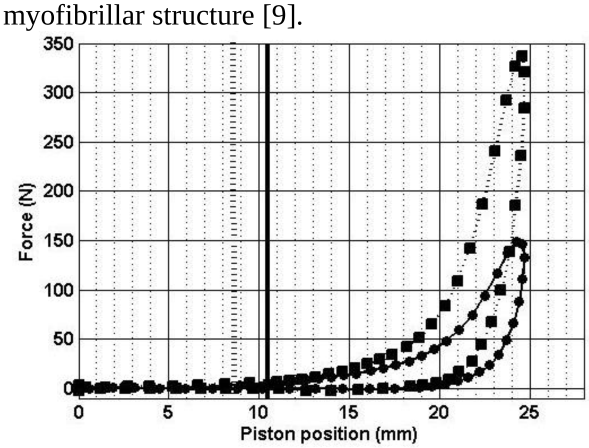

Figure 2: Two compression cycles: compression time 0.5 s and compression strain about 35 %: dotted line (cycle1) and continuous line (cycle2).

The cross section thickness of a muscle is not constant. Thus the reaction force (F) started to increase at different piston positions (vertical lines in Fig. 2): 7.8 mm and 10.5 mm for cycle 1 and 2, respectively. Since the piston stroke was the same for all the cycles the strain varied, here 37.4 and 33,6 %, logically leading to different maximal forces (Fmax): 340 and 150 N. The energy (E) provided to the muscle by one compression is equal to the internal area delimited by the compression curve: 855 and 478 mJ. The Fmax ratio (cycle 1/cycle 2) is higher (2.3) than E ratio (1.8) probably because the difference in Fmax also accounts for a change in the contact area between the muscle and the piston.

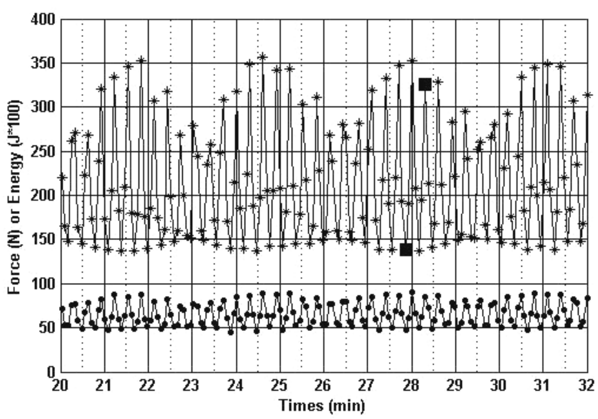

Figure 3: Variation of the maximal force and the mechanical energy during 12 minutes in trial 4.

Figure 3 shows that the change in Fmax with time is almost periodic with a period equal to about 3 minutes. The length of the period varies according to the respective frequency of the compression cycles and of the muscle rotation. This indicates that every 3 minutes the piston hit the muscle surface at the same position and means that the mechanical information can be averaged in relation to the muscle position. Figure 3 shows that the mean compression energy is equal to 0.7 J. This value corresponds to a muscle weighing 500 g or 300g and falling 14 or 24 cm, respectively.

Assessment of apparent NaCl diffusivities (D)

Figures 4 and 5 present the results for case 2 and cases 3-4 respectively (case 1 similar to case 2 not shown). Both surface NaCl content and D were adjusted so that calculations fitted the measured NaCl content profiles. In all cases a good agreement was obtained between measurements and calculations.

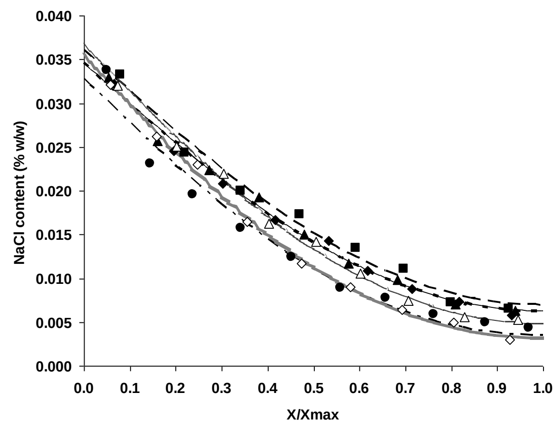

Figure 4: NaCl profiles measured after static brining of 6 mechanically treated samples: measurements (symbols) and calculations (curves)

For static brining the fitted NaCl content at the brined meat surface was equal to that calculated when assuming equality between brine NaCl content and NaCl content into meat water (5 % * 0.73 = 3.65 %). A statistical significant difference ($p < 0.05$) was found between the apparent diffusivities estimated in raw meat and in the sample excised from the mechanically treated muscle; they were respectively equal to 4.5 ± 0.3 and $5.4 \pm 0.4 \, {}^*10^{-10} \, m^2/s$, indicating a 20 % increase due to possible structure modifications.

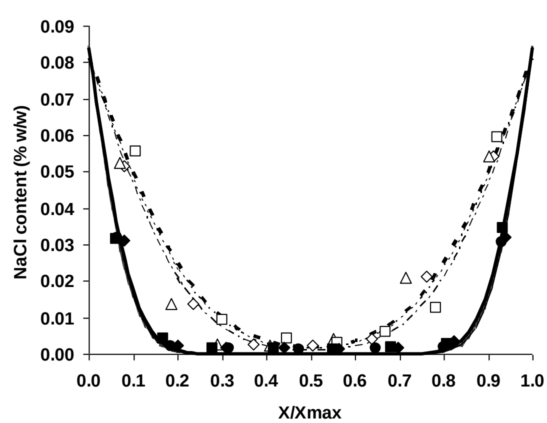

Figure 5: NaCl profiles measured along the 'diameter' within 3 cross sections of muscles brined 5 h in the simulator: white symbols (measurements case 4), black symbols (measurements case 3) and respective curves (calculations).

The effect on NaCl penetration, revealed by the D values, was much more accentuated than previously for cases 3 and 4. The figures in table 1 indicate an increase higher than 200 % which is in coherence with Siro's estimations using a pilot tumbler [2]. This can be explained by two possible phenomena: (1) during brining the structural modifications are enhanced by NaCl presence and (ii) meat deformation promotes brine convection within meat.

Table 1 shows that the estimated NaCl surface contents were equal in case 3 and 4 but lower than the predicted equilibrium value using the initial brine content (8% instead of 13%*0.73 = 9.5%). This was due to the lower meat to brine mass ratio used in the simulator (1) than in the static trials (30); the measured brine NaCl content varied with time in coherence with the previous figures. This also explains that D estimated during brining without mechanical action in case 3 is higher than in static brining of raw meat since the surface NaCl content was underestimated in the calculations in comparison with the actual value.

Table 1: comparison of apparent NaCl diffusivities when the muscle was cured using, or not using, a mechanical treatment.

Tumbling	**YES**			**NO**		
Sample number	**1**	**2**	**3**	**1**	**2**	**3**
D ($m^2/s \cdot 10^{-10}$)	**17.6**	**14**	**21.4**	**4.7**	**5.5**	**4.7**
Mean D	**17.7**			**5**		
Standard deviation	**3.7**			**0.64**		
NaCl Csuf (% w/w)	**8.1**			**8.4**		

IV. CONCLUSION

The tumbler simulator allows applying to meat pieces controlled mechanical treatments that are representative of what happens in actual tumblers. The mass transfer is strongly increased during brining-tumbling due to structural changes in the meat tissue and to convection promoted by deformation. New experiments are in progress to clarify those assumptions and to relate the magnitude of the measured transmitted mechanical energy to both histological and biochemical changes.

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