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CONSIDERATIONS ON COMPRESSION STRENGTH OF TENDERIZED PORK MEAT BY USING MECHANICAL PROCESSING

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ABSTRACT

The paper presents a mathematical model for compression strength for of tenderizedpork meat by using mechanical process. The mathematical model is based on compression characteristic diagrams that are experimentally determined during pork meat tenderization by using statically pressing. In order to decrease the wet curing / marinating period,the tenderizing process consists in several pressing of the pork meat, before the wet currying tenderizing for a certain period. The paper presents characteristic shear force amount obtained by using Werner - Bratzler testing method for the cured - smokedfinal product pressing tenderized, in comparison with the no tenderized cured-smoked final product sample.

INTRODUCTION

Tenderizing is a process to break down collagens in meat to make it more palatable for consumption. There are several ways to tenderize meat: mechanical tenderization, such as pounding or piercing; the tenderization that occurs through cooking, such as braising; tenderizers in the form of naturally occurring enzymes, which can be added to food before cooking (examples of enzymes used for tenderizing: papain from papaya,bromelain from pineapple and actinid in from kiwifruit; marinating the meat with vinegar, wine, lemon juice, buttermilk or yogurt; brining the meat in a salt solution (brine); dry aging of meat at 0 to 2°C [2,12].

Cohesion of the muscles takes place thanks to the myofibrillar proteins which have been extracted during the manufacturing process and which are found on the surface of the muscle. These proteins form the exudates and, due to their gelling capacity, act as glue between the muscles. It has been widely demonstrated in the pertinent literature that the greater number of proteins extracted, the greater the stability between muscles and therefore the better the sliceability and mastication. Extraction of myofibrillar proteins is achieved through two actions [12]:

- Chemical action: in brine composition, the presence of salt and phosphates increases the pH and the ionic strength of the medium, giving rise to the opening of the protein chains and facilitating their extraction.

- Mechanical action: application of the mechanical process causes relaxation of the muscle structure and breaking up of the cells, making the membranes more permeable and increasing mobilization of the proteins up toward the surface of the muscle. The degree to which the muscle structure is opened will determine the final quantity of proteins present in the exudates. This opening of the structure is done by means of tenderization, pre-massage and massage.

Tenderization is the mechanical action of producing multiple cuts in the meat muscle in order to increase the surface area and thereby facilitate extraction and solubilization during the massaging phase. Softening of the muscle is also obtained, making the meat more adaptable to the cooking moulds. Tenderization, pre-massage and massage are closely inter-related, and not all products require the same mechanical action. Thus the mechanical action must be intensified and adapted in order to compensate for some of the negative consequences that may result in the product's quality. This will depend on the rest of the process and, above all, on the presentation and final quality of the product itself. In low-injection products where meat content represents more than 80% of the final composition, meat quality is a determining factor in mastication, while in more highly injected products, this is not as important as the process and technology used [12,14,15,17].

By means of certain additives, aside from the above-mentioned salt and phosphates, such as carrageenan and vegetable gums, muscle texture can be slightly hardened and/or "plastified", however this alone will not be sufficient to compensate for the meat's lack of firmness. It has been observed that the mechanical action of tenderization does have a positive effect on this type of meat, because the texture is less fragile due to an increased surface of contact between muscles.

Using commercial meat without muscle selection, in order to standardize the tenderizing processes,previous research studied the effect that tenderization has on consumer' mastication in whole muscle cooked products [12,14,15].

Raw meat material used for *cured-cooked meat* products is mainly pork derived from hind leg, shoulder or loin. In some regions, lean muscle meat from other species may also be processed to local cured-cooked specialties. For high quality products and regional delicacies, entire pieces of muscle meat are cured and cooked. These meat pieces may consist of defined muscle groups, such as ham or large back muscle. There are slight differences in the processing technology of cured-cooked products, mainly depending on the size of the meat parts used for product manufacture. Curing brine is administered in all products. This is usually done by brine injection. Even distribution of the injected brine is achieved by treating the injected meat pieces in a meat tumbler, and when no tumbler is available, "resting periods" for the meat pieces are needed [2,4,14].

For some raw-cured products smaller amounts of curing brine are injected directly into the muscle tissue to accelerate the curing process. This fast curing technique significantly shortens curing periods, as curing substances migrate in both directions, from outside to inside and from central to less central parts. But because of this accelerated process, the curing flavor remains less intensive and *texture of these products remains softer then in products applying dry or wet curing*. The shelf life is also reduced significantly and most products are kept refrigerated. Typical products of this fast-cured type are *cured-smoked pork loin.* Fast curing with injection of curing brine will therefore remain the method of choice for *rapid turnover cured-cooked meat products*only [2,4,14].

Dry curing and w*et curing* are the main methods practiced in order to facilitate a standardized curing process in bigger meat cuts.

Dry-salting is the traditional favored method for raw-cured meat. Meat cuts (entire pieces of muscle meat) are rubbed with curingsalt, thereafter these meat pieces are packed in curing tanks and *piled* on top of each other with layers of curing salt between them and stored at low temperatures (0 to +4°C) [2,4,7,14].

During *wet-salting* process, the curing salt solution infiltrates the meat tissue and at the same time liquid from the meat tissue is extracted by the salt surrounding the meat. Depending on the size of the meat cuts, the *curing process* alone can last up to several weeks for equal penetration of the meat cuts with curing salt (at temperatures of about +4°C, a pork shoulder takes about two weeks, a leg of pork about four weeks). As exception to the common technology of using curing salt (containing nitrite or nitrate, or a mixture of both), some well-known traditional cured-raw ham products (e.g.*"Parma Ham"* and *"San Daniele Ham"* in Italy, *"Jinhua Ham"* in China, *"Jamon Serrano"* in Spain, *"JambonSavoie"* in France), are made without nitrite, using common salt only. For these products carefully selected pork hind legs with bone are used. Although *no nitrite is used*, a stable red color is achieved in these cured-raw ham products. This red color derives from the natural meat color intensified by the drying and ripening process [2,3,4,14].

In principle, four different types of tenderization are used by food processors [7,8]:

- *Blade head* consists of a head incorporated to the injector. It has 350 blades ø5 mm that deeply penetrate the meat, softening it without producing tearing or separation of muscles.
- *Dual - roller tenderizer* consists of two counter cutting rollers through which the meat is forced, producing cuts on both sides of the muscle, while simultaneously applying pressure on the entire piece.
- *Rollers with prongs*: alternative to the blade head because deep cuts are produced without tearing the muscle, but with a sharper blade and making cuts on both sides. Used for low injection products in which the muscle should be kept as whole as possible.
- *Rollers with knives*: sharp serrated knives that produce quickly multiple cuts and a certain degree of muscle tearing, depending on the separation between rollers. This type of tenderization is the one that results in greater protein extraction, but is also the one that may have greater impact on the appearance of the product.

MATERIAL AND METHOD

Processing method and equipment

In order *to reduce as much is possible the wet curing phase*, two types of tenderizing machines were realized and tested by a small meat processor in Romania: four roller tenderizer machine, and cyclic impulsive pressing machine.

In principle, *Four roller tenderizer machine*consists of a pair of parallel tenderizing rollers, located at a short distance and rotated in opposite directions by a electro-mechanical transmission, with the rollers fitted with a number of cutting prongs emerging from their surfaces, defining an elongated aperture through which the pressed meat passes, driven by the rollers and gravity. The distance between the prongs' bottoms of twin roller is 45mm, and 25mm between the prongs' edges of twin roller, respectively [8].

Cyclic impulsive pressing machine is a semi-continuous pressing machine for meat's tenderizing before wet curing phase.

In principle,*Cyclic impulsive pressing machine*consists in a mechanical - pneumatical equipment, and a control programmable automat. The mechanical - pneumatical equipment consists in a mobile upper plate, a fixed lower plate, two guiding / sliding columns, two slidingbearing guide clamp, upper fixed crosshead, pneumatical system (pneumatical cylinder, air compressor, 5/3 and 5/2 solenoid valves, and speed / sense controller)To improve the tenderizing process, each of the two plates is covered with a food grade Teflon pad; each pad has pyramidal prongs (6 x 6 x 6 mm). The machine's operation involves positioning the boneless meat pieces between the mobile pad and the fixed pad, respectively, these pads exerting nearly the same pressure in all directions around the meat [8].

In order to determine the efficiency of these machines on final meat product, in recent papers are approached considerations on mathematical model concerning Romanian traditional cured-cooked-smoked pork boneless loin product "*CotletPerpelit*" type made after raw meat's mechanical tenderizing. The tenderizing process performed to decrease the wet curing period's, consists in passing several times the raw meat among rollers with cutting prongs, andcyclic impulsive pressing of the meat, respectively. The mathematical model is based on force-extension diagrams obtained by using Werner-Bratzler testing method of no tenderized "*CotletPerpelit*", and after mechanical tenderizing process [3,9,10,11].

In principle, both of these methods are based on the meat's tissues compression that occurs between rotative rollers, and two cyclic moving plates, respectively.

In order to reduce as much is possible the wet curing phase, this paper presents a new tenderizing method based on meat pressing during low speed compression process.

In order to produce traditional cured-smoked-cooked product "*CotletPerpelit*", 2 pieces of pork boneless loin was used (according Animal Slaughter Certificate:2 pigs, 12 months, 70…80 kg in carcass, large farm). Each piece of pork boneless loin was cut in 3 equal parts (aprox. dimensions: length x width x height = 180 x 90 x 40 mm).

The meat compression is realized between a fixed plate and a mobile plate (with no prongs) that is actuated by the crosshead of universal testing machines *LBG 10* (within Environmental Engineering Laboratory into Faculty of Electrical Engineering).

For these experiments, 200 mm/min compression crosshead speed was used.

In this experiment, the meat was stressed with 2000 N and 2250 N, respectively, compression force (for 180 x 90 mm cross area, the equivalent pressuring of the meat is 0,123 MPa, and 0,154 MPa, respectively) from initial height to 25...30 mm final height, the testing machine's software plotted force - extension diagrams.

In preliminary experiments it was observed that when a larger compression force is applied, the meat's tissues are too much damaged, and the too small final height of the final product could be often not accepted by the consumer.

After tenderizing process by using compression, the tenderized pork boneless loin pieces were cured-smoked-cooked as following phases: wet curing phase of meat in 15% curing salt concentration, during only 3 days; drying / ripening phase in cold ventilation for 6 hours; cold smoke phase (around 20°C) for 2 days, followed by 4 hours short sequence of hot smoke phase (around 80°C). In order to observe the influence of compression stress on final alike "*CotletPerpelit*" product, these tenderized pork boneless loin pieces were cured-smoked-cooked in the same time and technological conditions with "*CotletPerpelit*" when tenderized pork boneless loin pieces by using *Four roller tenderizer machine* (meat passing 6 successive times amongst the cutting prongs), and *Cyclic impulsive pressingmachine* (5 pressing cycles, each consisting in 0,5s pressing periods, and 0,5s pauses periods; 20 pressing cycles, each consisting in 0,5s pressing periods, and 0,5s pauses periods), respectively [8,9,10,11].

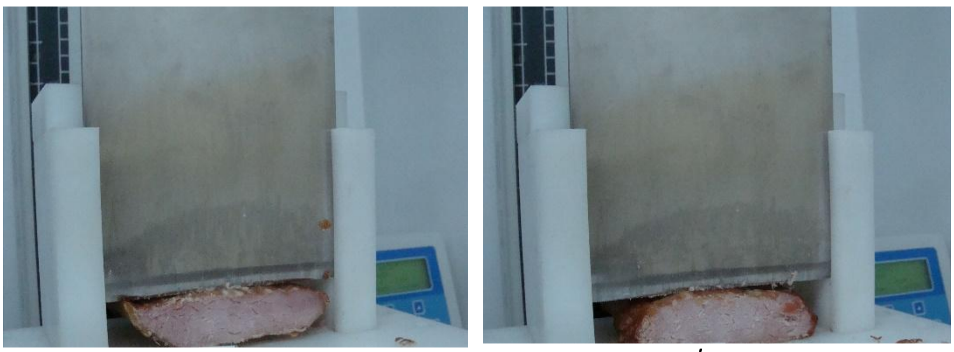
Tenderness evaluation by using Warner - Bratzler method

The most relevant and utilized methods to estimate meat's tenderness are compression test, and Warner - Bratzler shear test. During Warner - Bratzler test the shear blade acts simultaneously both compression and slicing / shearing of the product [13,16].

To perform inter-disciplinary researches concerning general texture and tenderness analysis, universal testing machines*Lloyd Instruments LRXPlus 5* (Unconventional Technologies and Equipment for Agro-Food Industry Laboratory - UTEFIL, within Faculty of Agriculture and Horticulture in Craiova) was used.

Due to collaboration between *UTEFIL* and Environmental Engineering Laboratory within Faculty of Electrical Engineering, a *Warner - Bratzler experimental equipment* was made: special rigid frame that permits fast fitting and sliding of interchangeable Warner - Bratzlershear blades (DIN W1.4571) [5,6,7]. During these experiments, 100mm/min cutting speed was used.

Warner - Bratzler testing shear force for"*CotletPerpelit*" obtained by using pork boneless loin tenderized by using 2000 N and 2500 N compression force (COMP – 2000, and COMP – 2250), are presented in Figure 1.



a *b*

Figure 1. "CotletPerpelit"during Warner - Bratzler

shear force test (a. COMP- 2000; b. COMP- 2250)

Mathematical model to determine the compression strength of the tenderized meat

The compression strength behavior is represented by the internal stress within the meat when certain compression force determines the decrease of the sample height's amount (deformation).

In this paper, a mathematical method based on MathCAD software was proposed to study the compression strength' behavior [1].

Therefore, to determine the deformation's variation diagrams when a certain force is applied, experimental data were used to describe the compression force matrix

$$M := \begin{pmatrix} F_1^5 & F_1^4 & F_1^3 & F_1^2 & F_1 \\ F_2^5 & F_2^4 & F_2^3 & F_2^2 & F_2 \\ F_3^5 & F_3^4 & F_3^3 & F_3^2 & F_3 \\ F_4^5 & F_4^4 & F_4^3 & F_4^2 & F_4 \\ F_5^5 & F_5^4 & F_5^3 & F_5^2 & F_5 \end{pmatrix}, \quad (1)$$

and the vectors that define the appropriate deformations

$$v := \begin{pmatrix} d_1 \\ d_2 \\ d_3 \\ d_4 \\ d_5 \end{pmatrix}, \quad (2)$$

where each $d := k, k + m...l$, (k :=0; m := 0,5; l := 10).

After several preliminary analytical calculi, it was observed that the nearest functionwhich approximates the experimental force - deformation diagram, is the fifth degree polynomial function defined by the relation

$$F(d) = \alpha \cdot d^5 + \beta \cdot d^4 + \gamma \cdot d^3 + \delta \cdot d^2 + \varepsilon \cdot d \, , \quad (3)$$

where $\alpha,..., \varepsilon$ represent influence coefficients that have to be determined solving the relation

soln := lsolve (M, v) (4)

The mechanical work when compression force is applied, has to be determined by solving the equation

$$W_{mec} = \int_{d_1}^{d_2} F(d) \cdot d(d) \quad (5)$$

RESULTS AND DISCUTIONS

In order to determine the influence of compression processing on meat's strength and the final product tenderness' too, the meat was stressed with 2000 N and 2250 N, respectively, compression force. The experimental diagrams are presented in Figure 2, (for 2000 N), and in Figure 4 (for 2250 N).

For 2000N compression force, by using rel. (1), rel. (2) and rel. (4), were determined

$$M := \begin{pmatrix} 0{,}140^5 & 0{,}140^4 & 0{,}140^3 & 0{,}140^2 & 0{,}140 \\ 2{,}503^5 & 2{,}503^4 & 2{,}503^3 & 2{,}503^2 & 2{,}503 \\ 4{,}996^5 & 4{,}996^4 & 4{,}996^3 & 4{,}996^2 & 4{,}996 \\ 7{,}478^5 & 7{,}478^4 & 7{,}478^3 & 7{,}478^2 & 7{,}478 \\ 9{,}963^5 & 9{,}963^4 & 9{,}963^3 & 9{,}963^2 & 9{,}963 \end{pmatrix}; \; v := \begin{pmatrix} 4{,}768 \\ 193{,}170 \\ 566{,}260 \\ 1200{,}50 \\ 1981{,}80 \end{pmatrix}; \quad \text{so } ln = \begin{pmatrix} -0{,}045 \\ 0{,}915 \\ -5{,}726 \\ 28{,}063 \\ 30{,}238 \end{pmatrix}$$

and after solving rel. (3), it wasobtained the particular polynomial function that best describes the diagram's evolution of meat's deformation when compression force is applied

$$F(d) = -0{,}045 \cdot d^5 + 0{,}915 \cdot d^4 - 5{,}726 \cdot d^3 + 28{,}063 \cdot d^2 + 30{,}238 \cdot d \qquad (6)$$

After similar calculi, the particular polynomial function that best describes diagram's evolution of meat's deformation when 2250 N compression force is applied

$$F(d) = -0{,}158 \cdot d^5 + 2{,}479 \cdot d^4 - 13{,}818 \cdot d^3 + 69{,}781 \cdot d^2 + 17{,}076.d \qquad (7)$$

In Table 1 there are presented the experimental mechanical work and the mechanical work determined by using the mathematical model, when compression forces 2000 N and 2250 N, respectively, are applied. The differences between the mechanical work determined by using experimental method and the mathematical model are smaller than 0,87% for 2000 N, and 1,01% for 2250 N, which confirm the mathematical model correctness'.

These small differences could be explained by visco-elastical deformation of the tissues'structure when meat is stressed during compression force test.

Table 1

Mechanical work when compression force is applied

Method	**Mechanical Work, N·mm**	
	Compression force, N	
	2000	2250
Experimental	7287	6048
Mathematical Model	7351	5987

The force - deformation diagrams plotted by using rel. (6) for 2000 N, respectively rel. (7)for 2250 N, are presented in Figure 3 (for 2000 N), and in Figure 5 (for 2250 N), respectively.

The comparisons between diagrams both in Figure 2 and Figure 4 when 2000 N compression force is applied, and in Figures 3 and Figure 5 when 2250 N compression force is applied, confirm the mathematical model correctness'.

The efficiency of meat's compression method on cured-smoked-cooked"*Cotlet Perpelit*"final product, the Warner - Bratzler shear force determined for this processing method were compared (Table 2) with the shear force amounts experimentally obtained for a similar method such as handmade traditional method or when *Cyclic impulsive pressingmachine* were used: 5 pressing cycles, each consisting in 0,5s pressing periods, and 0,5s pauses periods (CP-CIP 5-0,5); 20 pressing cycles, each consisting in 0,5s pressing periods, and 0,5s pauses periods (CP-CIP 20-0,5) [9,10].

Warner - Bratzler shear force diagrams for compressed meat are presented in Figure 6 and Figure 7.

In Table 2 are presented the maximum shear force amount and the shear force average for each "*Cotlet Perpelit*" type. In Table 1 there are presented too, the decrease of percentage average shear force (in comparison with traditional homemade "*Cotlet Perpelit*"'s tenderness) by using each processing method, that demonstrate the final product tenderness' increasing.

Table 2

Warner - Bratzler shear force for "*Cotlet Perpelit*"

Sample code	Maximum shear force min…max amount, N	Shear force average, N	Decrease of shear force average, %
TRAD	231,56...280,67	255,33	-
CP-CIP 5-0,5	142,13...186,88	164,91	35,68
COMP 2000	147,27...175,73	160,74	36,82
COMP 2250	135,67...164,34	151,96	40,39
CP-CIP 20-0,5	131,45...160,59	145,47	43,13

Table 2 represents a synthesis of the influence of cyclic vacuum process on "*Cotlet Perpelit*" final tenderness':

- in comparison with traditional homemade "*Cotlet Perpelit*" tenderness', COMP 2000 method determines 36,82% increasing of the final product tenderness', that is comparable with CP-CIP 5-0,5;

- instead, in comparison with traditional homemade "*Cotlet Perpelit*", COMP 2250 method determines an important fast increasing to 40,39% increasing of the final product tenderness', that is comparable with CP-CIP 20-0,5.

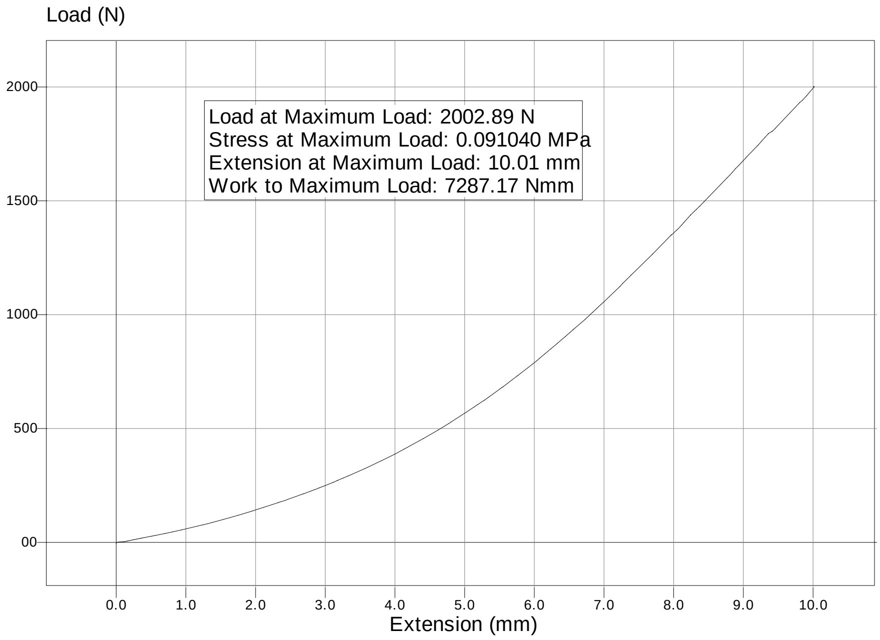


Figure 2. Experimental force - deformation diagram for 2000 N meat's compression

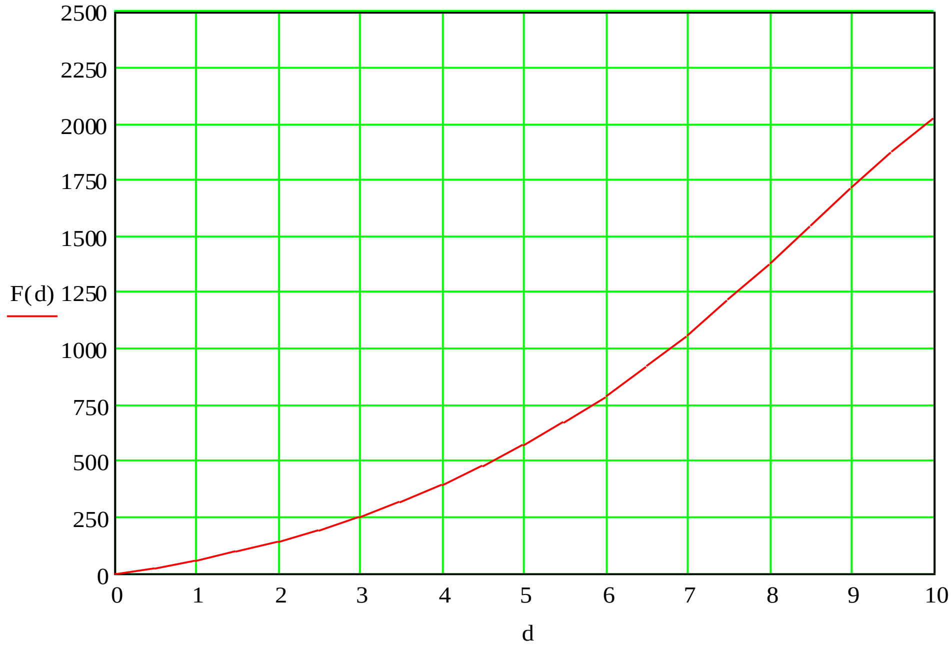


Figure 4. Mathematical model force - deformation diagram for 2000 N meat's compression

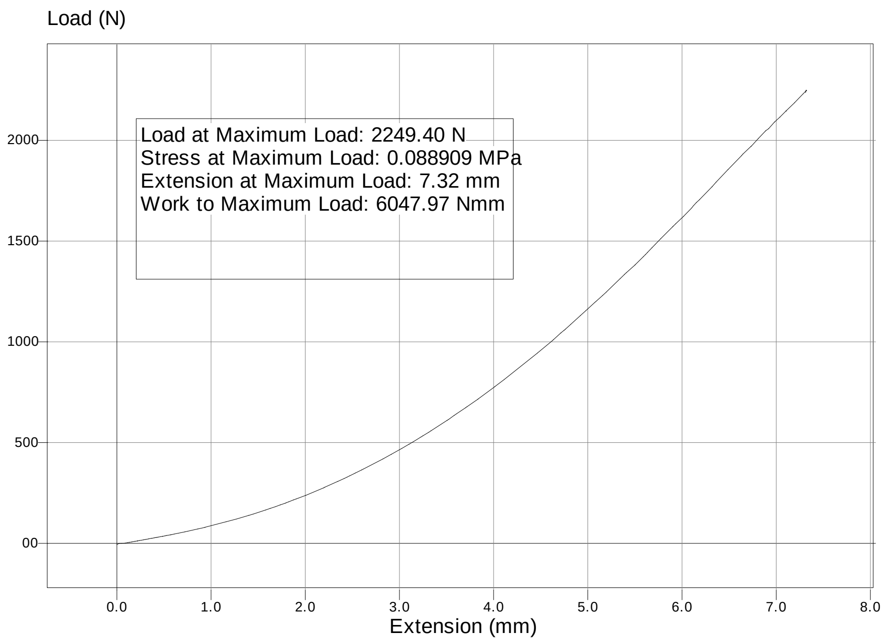


Figure 3. Experimental force - deformation

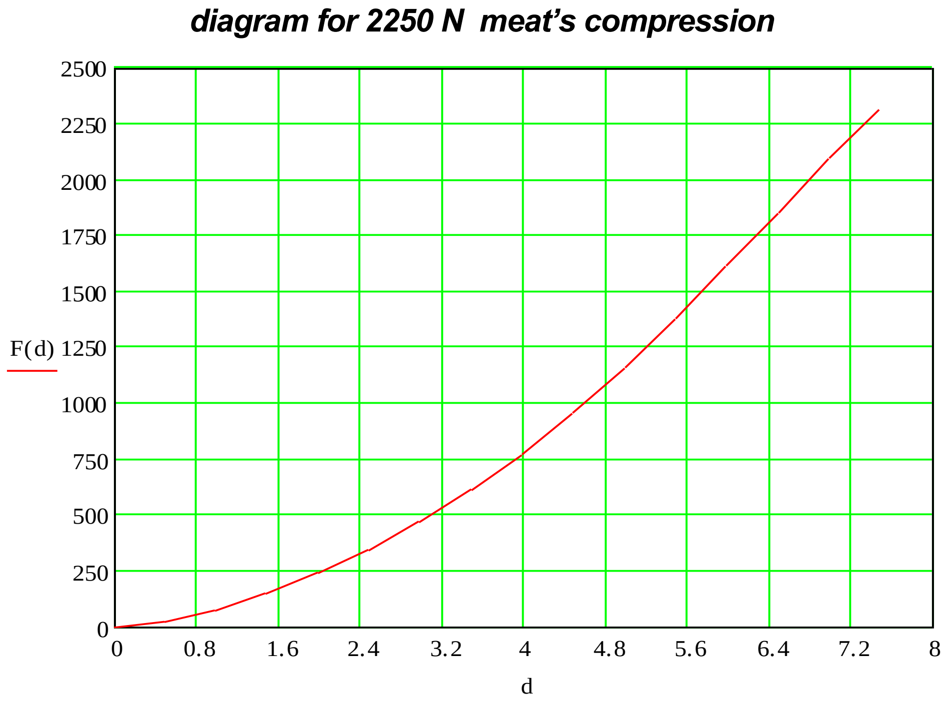


Figure 5. Mathematical model force - deformation diagram for 2250 N meat's compression

CONCLUSIONS

In order to improve the final product "*Cotlet Perpelit*" tenderness', compression force represents an alternative tenderizing method with comparable effect when cyclic impulsive pressing is used. Due to much intensive osmosis phenomena when compression force is applied, meat's compression strength decreasing determines faster brine's infusion into the meat' tissues.

As one of the most recommended analyze method, the Warner - Bratzler shear force test offered objective results concerning the influence of compression force on meat final products tenderness'.

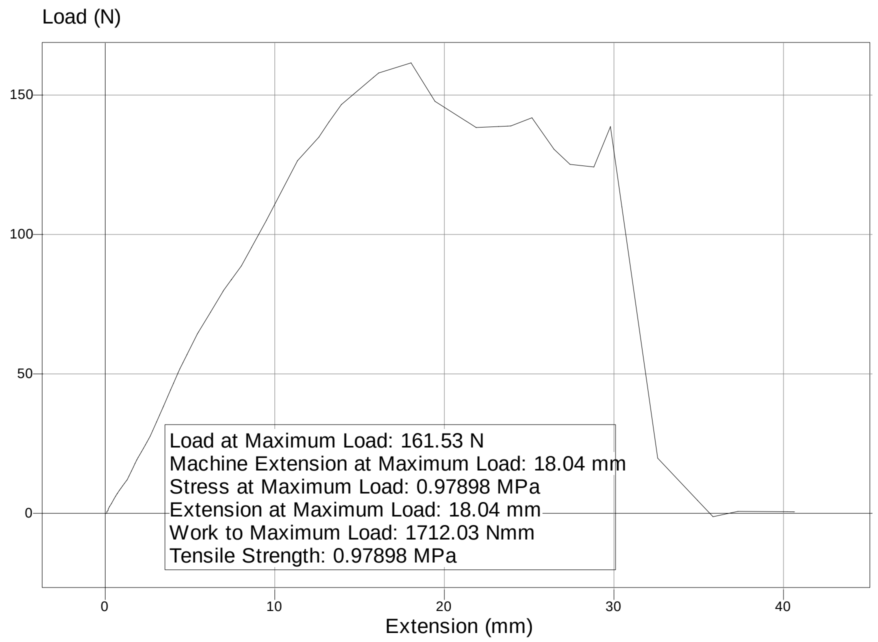


Figure 6. Warner - Bratzler shear force test diagram

for"Cotlet Perpelit"made by using 2000 N compression force

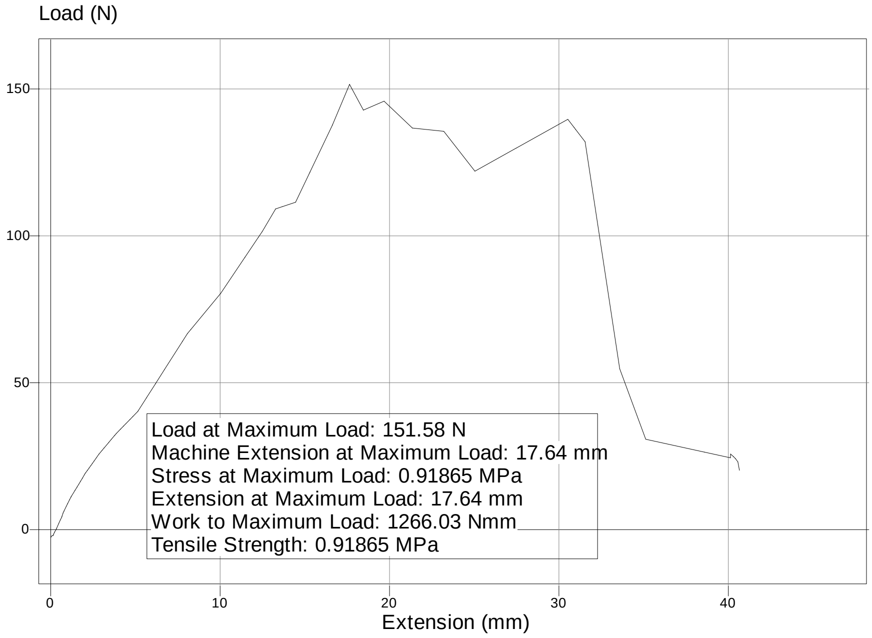


Figure 7. Warner - Bratzler shear force test diagram
for "Cotlet Perpelit"made by using 2250 N compression force

In main, the compression tenderizing process has two important advantages:

- reducing the *wet curing phase* from 2...3 weeks to 3 days;
- improving the tenderness of Romanian traditional cured – smoked - cooked "*Cotlet Perpelit*" product (36,82...40,39%), in comparaison with the final product with no tenderized meat.

This paper opens further experimental researches concerning the influence of compression process (higher force amount, shorter or longer compression speed, too) to produce "*Cotlet Perpelit*", by using other much more tenderless parts of animal's carcass.

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