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MATHEMATICAL MODEL FOR PORK BONELESS NECK TENDERIZING TO PRODUCE ROMANIAN TRADITIONAL PRODUCT "*CEAFĂ PERPELITĂ*"

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Abstract: *The paper presents a mathematical model to produce Romanian traditional cured-cooked-smoked pork boneless neck product "Ceafă Perpelită" type made after raw meat's mechanical tenderizing. The tenderizing process performed to decrease the duration of cured marinating period consists in passing several times the raw boneless neck among rollers with cutting prongs, and cyclic impulsive pressing of the meat, respectively. The mathematical model is based on force - extension diagrams obtained by using Werner - Bratzler testing method both for raw boneless neck and cured-cooked-smoked final product, too, for no tenderized raw boneless neck and after raw boneless neck mechanical tenderizing. The mathematical model consists in the geometric linear transforming of the characteristic diagrams obtained by using Werner-Bratzler method for the tenderized meat in comparison with the initial no tenderized meat. The model can be used to predict the mechanical characteristics of "Ceafă Perpelită", after boneless neck mechanical tenderizing.*

Keywords: *mathematical model, meat tenderizing, Ceafă Perpelită, Warner-Bratzler testing method*

1. INTRODUCTION

To estimate tenderizing machine's and process' performances, is necessary to determine tenderized meat's mechanical characteristics, which could describe the meat qualitative transformations [12,13]. In principle, meat's tenderization represents the resultant of dynamic interdisciplinary processes consisting in chemical, biochemical and mechanical phenomena [8]. Thus, a mathematical model, represented by a complex system of variables and relationships, could be recommended to analyze meat's mechanical tenderizing [1,11].

In previous paper, Graiver proposed a mathematical model for the absorption of curing salts in pork's meat [2].

According previous research papers, the variables parameters of the mathematical model have to be based on experimental research data of meat diagrams determined by using Warner-Bratzler test method [6,7-9, 12,15].

Taking into account only the mechanical phenomena, a dynamic system involves different transformations of its internal parts under the action of given external forces. The mathematical models of the meat tenderizing process could be studied in further theoretical researches by applying automatic systems theory [3].

According to international and Romanian legislation, sodium nitrite, sodium or potassium nitrate ($NaNO_2$); $NaNO_3$/ KNO_3), are not permitted in traditional cured-smoked-cooked products usual processing, and no brine injection is allowed [4,10]. In principle, the processing technology of these traditional cured-smoked-cooked product in small enterprises consists in: wet curing phase of entire pieces of muscle meat in 15% curing salt concentration, during 2-3 weeks; drying / ripening phase in cold air ventilation for 6-8 hours; cold smoke phase (20°C) for 2-3 days, followed by a short sequence of hot smoke phase (80°C), for 4-6 hours [10]. In order to reduce the wet curing phase, two types of tenderizing machines were used: *four roller tenderizer machine*, and *cyclic impulsive pressing machine* [9,10].

2. MATERIALS AND METHOD

2.1. Experimental method and equipment. In order to determine the influence of mechanical tenderizing method on raw pork bone-less neck tenderness, two different methods / machines were used: *four roller tenderizer machine*, and *cyclic impulsive pressing machine.*

Four roller tenderizer machine (FRT) is designed to increase the effective surface area for the extraction of meat proteins during subsequent compression and stretching processes. In its operation, the machine performs superficial or deep cuts in the piece of meat that passes through two pairs of tenderizer roller. In principle, the machine consists of two pairs of parallel tenderizing rollers (provided with a number of cutting prongs), located at a certain distance, that are rotated in opposite directions by an electromechanical transmission [9,10].

Cyclic impulsive pressing machine (CIP) is a semi-continuous meat press machine for meat's pressing before marinating [10]. If meat pieces are pressed with a significant amount of force applied more or less evenly throughout the piece of meat, it will tenderize the meat piece and condition the meat fibers so that marinade will be absorbed into the meat fibers (with no vacuum or pressure influence).

CIP consists in mechanical-pneumatically equipment, and a programmable automat. In principle, this mechanical-pneumatically equipment consists in an electro-pneumatically system (air compressor, solenoid valve), and two pressing plates (a fixed lower plate, and mobile upper plate). To improve the tenderizing process, each of the two plates (covered with food grade Teflon pad) has pyramidal prongs ($6 \cdot 6 \cdot 6$ mm) [9,10].

In order to determine the tenderizing process influence on pork boneless neck used to produce traditional cured – smoked - cooked product *"Ceafă Perpelită"*, 6 samples (raw pork boneless neck, and *"Ceafă Perpelită"* final product) were processed according four methods:

- no tenderized pork boneless neck (NO TEND);
- pork boneless neck tenderized by ten times successive passing amongst the cutting prongs of the FRT (FRT 10x);
- pork boneless loin tenderized by CIP in 30 pressing cycles, each consisting in 0,5s pressing periods, and 0,5s pauses periods (CIP 30-0,5 -0,5);
- pork boneless neck tenderized by CIP in 30 pressing cycles, each consisting in 10s pressing periods, and 0,5s pauses periods (CIP 30-10-0,5).

To produce *"Ceafă Perpelită"* by using no-tenderized pork boneless neck, the following traditional phases were used: wet curing phase of entire pieces of muscle meat (12% curing salt concentration), during 2 weeks; drying / ripening phase in cold air ventilation 6 hours; cold smoke (approx. 20°C) 10 hours, followed by 4 hours hot smoke (approx. 80°C).

To produce *"Ceafă Perpelită"* by using tenderized pork boneless neck, the tenderized pork boneless neck was processed in the following phases: wet curing (12% curing salt concentration), during *4 days*; drying / ripening phase in cold air ventilation for 6 hours; cold smoke (approx. 20°C) for 10 hours, followed by 4 hours hot smoke (approx. 80°C).

2.2. Tenderness evaluation by using Warner-Bratzler method. One of the most relevant and utilized methods to estimate meat's tenderness is Warner - Bratzler (W-B) shear test method. During W-B test the shear blade acts simultaneously compression and slicing/ shearing of the product [4, 7,8,11-15]. To perform experimentally researches concerning general texture and tenderness analysis, universal testing machine *Lloyd Instruments*

LRXPlus 5 (Unconventional Technologies and Equipment for Agro-Food Industry Lab. - UTEFIL, within Faculty of Agriculture and Horticulture in Craiova) was used. Due to collaboration between UTEFIL and Environmental Eng. Lab. within Faculty of Electrical Engineering, a *Warner - Bratzler experimental equipment* was made: special rigid frame (food- grade Teflon) that permits fast fitting of interchangeable W-B shear blades (W1.4571) [7,8].

During these experiments, 100mm/min cutting speed was used.

Representative W-B test diagrams for pork boneless neck tenderized by using FRT 10 x methods, and for *"Ceafă Perpelită"* obtained by using this tenderized pork boneless, are presented in Figure 1 and Figure 2, respectively.

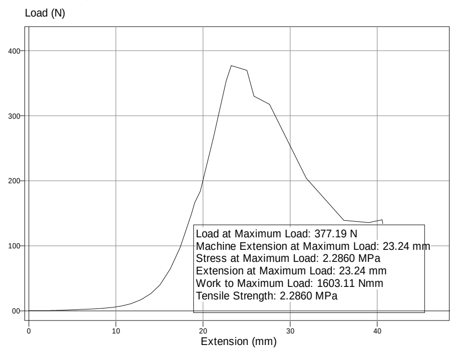

Figure 1. W - B test diagram for tenderized pork boneless neck by using FRT 10x

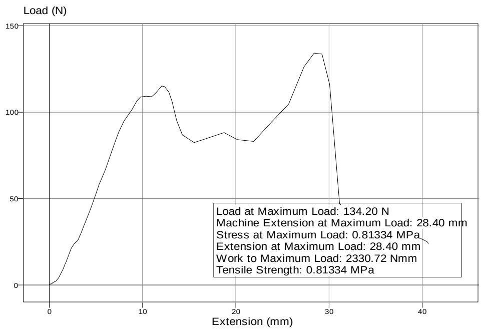

Figure 2. W - B test diagram for "*Ceafă Perpelită*" tenderized by using FRT 10x

3. RESULTS

3.1. Mathematical model for meat tenderizing. The mathematical model to study the influence of tenderizing method on meat tenderness is based on the hypothesis that any meat's final product material can be characterized by numerical curves obtained by mechanical characteristics experimentally determined for each tenderizing method. Resulting numerical curves could differ more or less from those of no tenderized meat samples.

In Figure 1 and Figure 2 is observed the maximum shear force that characterizes each type of pork boneless neck, and *"Ceafă Perpelită"* tenderness'.

Due to the inhomogeneous character of the meat's tissues, the maximum shear force cannot describe all the cutting / shearing process.

Therefore for each untenderized and tenderized pork boneless neck sample, and for each *"Ceafă Perpelită"* obtained by using these meat pieces, too, average curves that describe all evolution of the shearing diagrams obtained by using W - B method were numerical determined (in Figure 3 and Figure 4, for FRT 10x).

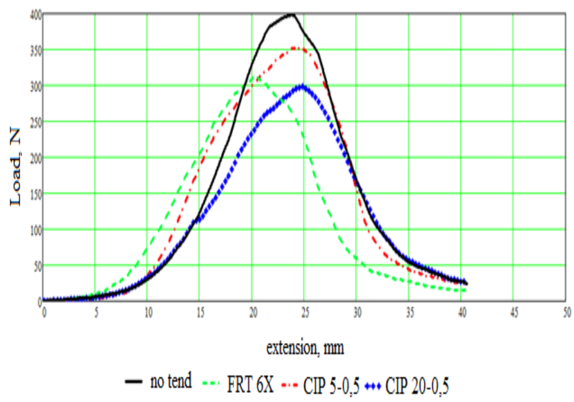

Figure 3. Numerical determined average curves of the four types of pork boneless neck samples NO TEND; CIP 30-0,5-0,5; CIP 30-10-0,5; FRT 10x

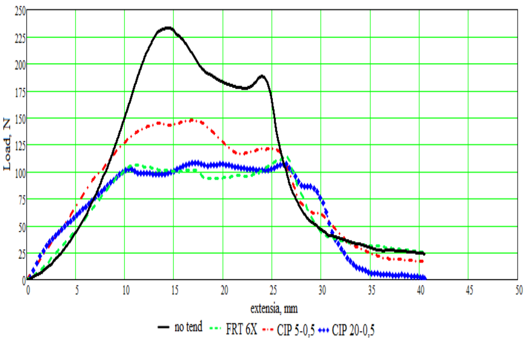

Figure 4. Numerical determined average curves of the four samples "*Ceafă Perpelită*" CEP-NO TEND; CEP-CIP 30-0,5-0,5; CEP-CIP 30-10-0,5; CEP-FRT 10x

The proposed mathematical model is based on the hypothesis that the characteristic curve of the sample (no tenderized, or tenderized by using mechanical methods), is obtained as a linear transformation that can be described by the vectorial equation [10]:

$$\begin{pmatrix} x' \\ F' \end{pmatrix} = T \begin{pmatrix} x \\ F \end{pmatrix} \qquad (1)$$

where: F is the shear force in N, x is the cutting length / extension in mm, before tenderizing (characteristic curve coordinates of the meat sample, before tenderizing); F' and x' represent the shear force and the cutting length/ extension of the same meat sample type (characteristic curve coordinates, after tenderizing).

T is the linear transformation given by the matrix [10]:

$$T = \begin{pmatrix} t_{1,1} & t_{1,2} \\ t_{2,1} & t_{2,2} \end{pmatrix} \qquad (2)$$

where t_{ij}, $i = 1,2$; $j = 1, 2$ are real numbers.

It must be noticed that each force F is re-presented by a pair of coordinates (x_i, F_i), $I = 1, N$, and each force F' is represented by a pair of coordinates (x'_I, F'_i), $i = 1, N$. The matrix elements T are calculated with relation [10]

$$\Im(t_{1,1}, t_{1,2}, t_{2,1}, t_{2,2}) = \sum_{i=1}^{N} [(t_{1,1} x_i + t_{1,2} F_i - x_i^{'})^2 + + (t_{2,1} x_i + t_{2,2} F_i - F_i^{'})^2] \qquad (3)$$

The solutions of relation (3) are determined by canceling the partial derivate in rapport with matrix coefficients' witch defines the linear transformation [10]

$$t_{1,1} = \frac{\left(\sum_{i=1}^{n} x_i^{(0)} x_i^{(1)}\right)\left(\sum_{i=1}^{n} F_i^{(0)2}\right) - \left(\sum_{i=1}^{n} x_i^{(1)} F_i^{(0)}\right)\left(\sum_{i=1}^{n} x_i^{(0)} F_i^{(0)}\right)}{\left(\sum_{i=1}^{n} x_i^{(0)2}\right)\left(\sum_{i=1}^{n} F_i^{(0)2}\right) - \left(\sum_{i=1}^{n} x_i^{(0)} F_i^{(0)}\right)^2} \qquad (4.1)$$

$$t_{1,2} = \frac{\left(\sum_{i=1}^{n} x_i^{(1)} F_i^{(0)}\right)\left(\sum_{i=1}^{n} x_i^{(0)2}\right) - \left(\sum_{i=1}^{n} x_i^{(1)} x_i^{(0)}\right)\left(\sum_{i=1}^{n} x_i^{(0)} F_i^{(0)}\right)}{\left(\sum_{i=1}^{n} x_i^{(0)2}\right)\left(\sum_{i=1}^{n} F_i^{(0)2}\right) - \left(\sum_{i=1}^{n} x_i^{(0)} F_i^{(0)}\right)^2} \qquad (4.2)$$

$$t_{2,1} = \frac{\left(\sum_{i=1}^{n} x_i^{(0)} F_i^{1}\right)\left(\sum_{i=1}^{n} F_i^{(0)2}\right) - \left(\sum_{i=1}^{n} F_i^{(1)} F_i^{(0)}\right)\left(\sum_{i=1}^{n} x_i^{(0)} F_i^{(0)}\right)}{\left(\sum_{i=1}^{n} x_i^{(0)2}\right)\left(\sum_{i=1}^{n} F_i^{(0)2}\right) - \left(\sum_{i=1}^{n} x_i^{(0)} F_i^{(0)}\right)^2} \qquad (4.3)$$

$$t_{2,2} = \frac{\left(\sum_{i=1}^{n} F_i^{(0)} F_i^{(1)}\right)\left(\sum_{i=1}^{n} x_i^{(0)2}\right) - \left(\sum_{i=1}^{n} x_i^{(0)} F_i^{(1)}\right)\left(\sum_{i=1}^{n} x_i^{(0)} F_i^{(0)}\right)}{\left(\sum_{i=1}^{n} x_i^{(0)2}\right)\left(\sum_{i=1}^{n} F_i^{(0)2}\right) - \left(\sum_{i=1}^{n} x_i^{(0)} F_i^{(0)}\right)^2} \qquad (4.4)$$

Based on described linear transformation, for pork boneless neck tenderized by using each method, the matrix T elements are:

- pork boneless neck tenderized by CIP 30-0,5-0,5

$$T = \begin{pmatrix} 0.993 & -0.0002658 \\ -0.816 & 0.846 \end{pmatrix}$$

- pork boneless neck tenderized by CIP 30-10-0,5

$$T = \begin{pmatrix} 1.005 & -0.00005879 \\ 0.165 & 0.816 \end{pmatrix}$$

- pork boneless neck tenderized by FRT 10x

$$T = \begin{pmatrix} 0.999 & 0.0000962 \\ -0.449 & 0.723 \end{pmatrix}$$

The numerical tenderizing curves for pork boneless neck obtained by using the mathematical model are presented in Figure 5, Figure 6 and Figure 7, respectively.

In these three figures it can be observed that the configurations and the maximum amounts of the numerical tenderizing curves are similar with the average curves experimentally determined (Figure 3).

All these similarities validate the mathematical model based on proposed linear transformation.

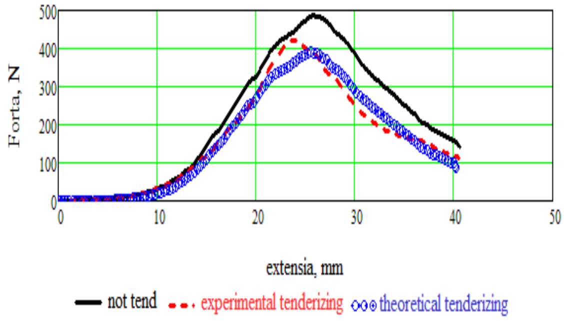

Figure 5. Numerical curves obtained by using the mathematical model for CIP 30-0,5-0,5 tenderizing

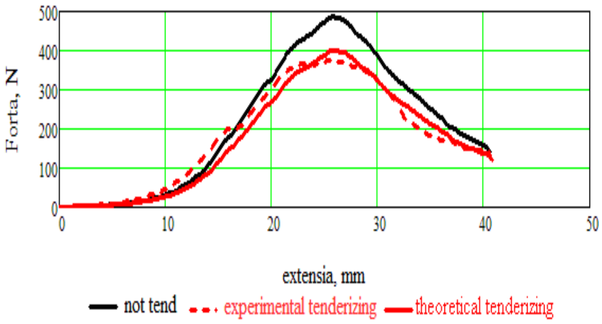

Figure 6. Numerical curves obtained by using the mathematical model for CIP 30-10-0,5 tenderizing

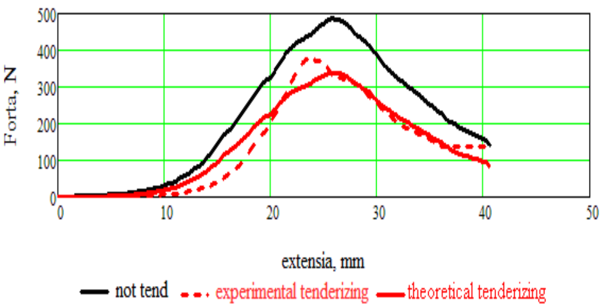

Figure 7. Numerical curves obtained by using the mathematical model for FRT 10x tenderizing

Based on described linear transformation, for *"Ceafă Perpelită"* tenderized by using each method, the matrix T elements are:

- *"Ceafă Perpelită"* tenderized by CIP 30-0,5-0,5

$$T = \begin{pmatrix} 0.999 & 0.0004562 \\ 1.446 & 0.529 \end{pmatrix}$$

- *"Ceafă Perpelită"* tenderized by CIP 30-10-0,5

$$T = \begin{pmatrix} 1.001 & -0.0008085 \\ 1.446 & 0.529 \end{pmatrix}$$

- *"Ceafă Perpelită"* tenderized by FRT 10x

$$T = \begin{pmatrix} 0.992 & -0.000661 \\ 1.096 & 0.451 \end{pmatrix}$$

The numerical tenderizing curves for *"Ceafă Perpelită"* obtained by using the mathematical model are presented in Figure 8, Figure 9 and Figure 10, respectively.

In these three figures, it is observed that the maximum amounts and configurations of the numerical tenderizing curves are similar with the average curves experimentally determined (Figure 4). All these similarities validate the correctness of mathematical model based on proposed linear transformation.

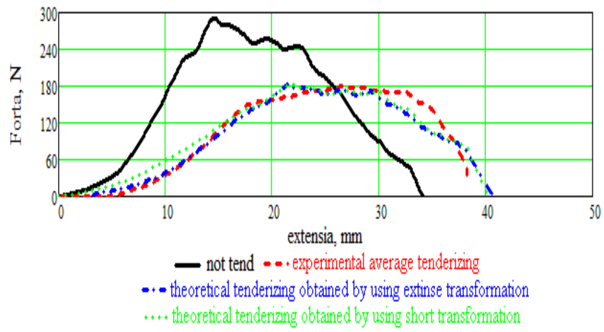

Figure 8. Numerical curves obtained by using the mathematical model for *"Ceafă Perpelită"* CIP 30-0,5-0,5 tenderizing

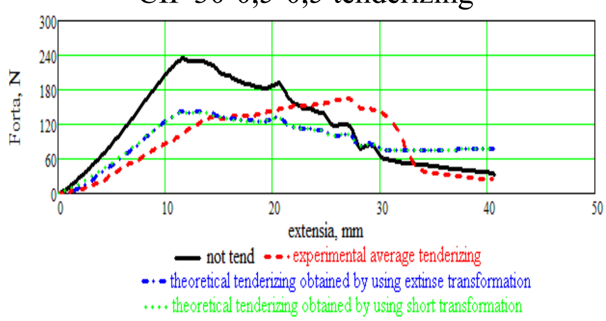

Figure 9. Numerical curves obtained by using the mathematical model for *"Ceafă Perpelită"* CIP 30-10-0,5 tenderizing

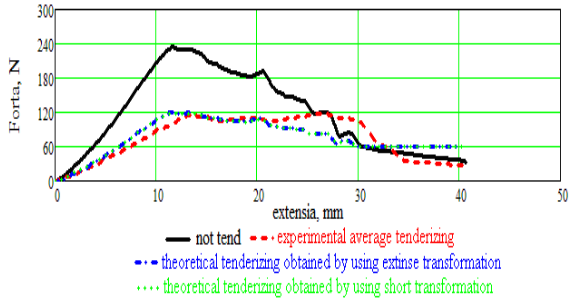

Figure 10. Numerical curves obtained by using the mathematical model for "*Ceafă Perpelită"* FRT 10x tenderizing

4. CONCLUSIONS

Mechanical tenderizing is a process that has to reduce the meat's mechanical characteristics amounts of the final product.

Each tenderizing method determines significant changes of specific strain within the meat's tissues, which determines the "*Ceafă Perpelită"* tenderness' improvement.

The main conclusion drawn in this paper refers the correctness of the mathematical model based on proposed linear transformation, proved both by the curves' configurations and the maximum amounts similarities' between the numerical tenderizing curves, too, and the average curves experimentally determined, respectively.

Further general and specific conclusions could be draw after this mathematical model will be applied for other types of meat, before and after the same or other mechanical tenderizing methods.

The data presented in this paper can be important for all the specialists interested in decreasing the wet curing period of the traditional meat products.

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