

# Measurement of rheological properties in raw and cooked meat aged with a controlled dry-aging system

Marika Di Paolo<sup>1</sup>, Giulia Polizzi<sup>1</sup>, Lucia Vollano<sup>1</sup>, Aniello Anastasio<sup>1</sup>, Giovanna Bifulco<sup>1</sup>, Claudia Lambiase<sup>2</sup>, Alessandro Cuomo<sup>3</sup>, Raffaele Marrone<sup>1</sup>

<sup>1</sup> Department of Veterinary Medicine and Animal Production, University of Naples Federico II, 80137, Naples, Italy

<sup>2</sup> Department of Agricultural Sciences, University of Naples Federico II, 80055, Portici (Na), Italy

<sup>3</sup> Arredo Inox S.r.l., Crotone, Italy

## ABSTRACT

Texture of meat is a critical parameter of consumer's acceptability. In this regard, aging technology has become essential to enhance meat tenderness and flavour. The present study evaluated the effect of dry-aging on the rheological properties of cooked and raw meat (*Longissimus dorsi*) using objective instrumental measurements: colorimeter (CIEL\*a\*b\*), texture profile analysis (TPA-test) and Warner Bratzler shear force test (WBSF-test). In this study, a monitored refrigeration device was used for 60 days of dry aging of meat. Physical-chemical analyses were also evaluated on raw meat. The analyses were carried out at 2 ( $T_0$ ), 15 ( $T_1$ ), 30 ( $T_2$ ) and 60 ( $T_3$ ) days post-slaughter. During dry aging,  $a_w$  values tended to decrease while the pH values increased. The mayor color changes occurred in the first 15 days of dry aging. As regard the texture traits, significant differences were found between the cooked and raw meat mainly due to the effect of temperatures on collagen. The correlation data showed significant positive correlations between WBSF and hardness values. Results showed that aging time and cooking tended to decrease the hardness and shear force implying more tender meat for the consumer.

**Section:** RESEARCH PAPER

**Keywords:** Warner Bratzler shear force test; Texture Profile Analysis; quality, colour

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**Corresponding author:** Marika Di Paolo, e-mail: [marika.dipaolo@unina.it](mailto:marika.dipaolo@unina.it)

## 1. INTRODUCTION

Tenderness, juiciness, and flavour define meat quality traits based on consumer preferences [1]. Among the eating qualities, meat tenderness has been found to be the most important parameter for consumers [2]. Thus, the tender meat making is primary goal to meat science and meat industry. In this regard, new aging methods and devices have become essential to improve meat tenderness and flavour and to answer to the customer expectations [2], [3]. Several studies [4]-[6] have been conducted on buffalo and cow meat to evaluate the aging processes and to measure their effects on rheological properties. During the aging process it is very important the climatic control (drying temperature, relative humidity, and airflow) thank to which take place several biochemical changes that allow to

decrease meat shear force values mainly as a result of the proteolysis of myofibrillar proteins [7]. Generally, the way to measure meat acceptability is to collect consumer's satisfaction judgments based on subjective and expensive parameters through consumer's panel test. Other way includes objective measurements of tenderness with the Warner Bratzler shear force test (WBSF) and the texture profile analysis (TPA). WBSF-test is predictor test of tenderness characteristics based on measuring of three parameters: WBSF (Kgf), Work (Kgf-mm) and initial force (Kgf). However, WBSF-test not fully imitate the complexity of the chewing motion [8] unlike TPA-test that, recognizing this limitation, simulates the mechanical process of mastication. Texture profile analysis (TPA) is an instrumental method has been used by researchers for many meats kind like poultry, beef, buffalo to rheological evaluation of texture profile

[4], [6], [9]. For TPA-test, the measured parameters are hardness, springiness, cohesiveness, adhesiveness, cohesion, resiliency, gummies, and chewiness. There is limited information comparing TPA and WBSF test during the aging meat [8], [10]. Therefore, the present study aims to apply and compare these tests to evaluate the effect of dry aging on the rheological properties (colour and texture) of cooked and raw meat.

The paper is organised as follows. In section 2 the experimental design, the materials and methods were described. Section 3 and sub-sections show results and discussions. Finally, the key points of the work are summarised in the section 4 where the future steps are outlined.

## 2. MATERIALS AND METHODS

### 2.1. Samples preparation and meat aging process

*Longissimus dorsi* (LD) muscles were obtained from three cattle ((22 ± 1.54) month-old crossbreeds and live weight of (662 ± 20.21) kg) taken at 48 hours ( $T_0$ ) postmortem sourced from an EU-licensed slaughterhouse. The LD muscle (from the 6th to the 13th thoracic vertebrae) underwent dry aging until 60 days using a Maturmeat® (Figure 1) at the same conditions reported by Di Paolo et al. [6]. The Maturmeat® is equipped with a sensor system for telemetry monitoring allowing the management of data (pH, temperature, relative humidity, and air flow) during aging time. During the aging period, three samples were tested at 48 hours ( $T_0$ ), 15 ( $T_1$ ), 30 ( $T_2$ ) and 60 days ( $T_3$ ) post-slaughter. At each aging time the steaks cut from each LD muscle were assigned to one of the measurement techniques (4 cm-thick for WBSF-test and 3 cm-thick for TPA-test and colour analysis) and physical-chemical analyses. On each sampling time, the muscle section of LD was deboned. For texture measurement techniques (WBSF-test and TPA-test), samples were analysed both raw (RW) and cooked (CK). Samples were cooked on an open electric griddle (Farberware, Walter Idde and Co., Bronx, NY), preheated to 200 °C until a core temperature of 70 °C was reached. For each LD muscles, a total of 24 steaks were collected, three at each aging time: 12 steaks of meat for WBSF-test and 12 steaks of meat for TPA-test, colour, and chemical analysis.

### 2.2. Physical-chemical analysis

Physical-chemical analyses were performed only on raw meat at each sampling time ( $T_0$ ,  $T_1$ ,  $T_2$  and  $T_3$ ). Official methods were used for moisture, protein, and fats content determinations [11].



Figure 1. *Longissimus dorsi* (LD) muscles during dry-aging process using a Maturmeat®.

Water activity ( $a_w$ ) and pH analyses were carried out by using Aqualab 4 TE – Dec-agon Devices (Inc., USA) and a pH-meter (Crison-Micro TT 2022, Crison Instruments, Barcelona).

### 2.3. Instrumental Colour (CIEL\*a\*b\*)

The instrumental colour was measured on the surface of raw meat at three different points of LD muscles at each aging time ( $T_0$ ,  $T_1$ ,  $T_2$  and  $T_3$ ) by using a Konica Minolta CM-2500d (Konica Minolta Sensing Inc., Osaka, Japan). Value of Chroma and Hue angle were calculated using equations (1) and (2), respectively:

$$\text{Chroma} = \sqrt{a^{*2} + b^{*2}} \quad (1)$$

$$\text{Hue\_Angle} = \arctan \frac{b^*}{a^*} \quad (2)$$

During dry-aging, changes in colour meat were determined calculating the colour differences coefficient  $\Delta E$  as follows:

$$\Delta E = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \quad (3)$$

The values of  $\Delta L^*$ ,  $\Delta b^*$  and  $\Delta a^*$  were determined for the following differences between two aging times:  $T_0 - T_1$ ,  $T_1 - T_3$ ,  $T_1 - T_2$ , and  $T_2 - T_3$ .

### 2.4. Texture Profile Analysis (TPA)

Texture profile analysis (TPA) was performed on raw (RW) and cooked (CK) meat, at each aging time ( $T_0$ ,  $T_1$ ,  $T_2$  and  $T_3$ ). The TPA test on cooked meat was carried out after cooling (24 hours at 4 ± 1 °C). The TPA test was performed by using the texturometer EZ-Test Shimadzu (Shimadzu Corporation, Japan) equipped with a cylindrical 25 mm-diameter probe of ebonite (Figure 3, b). The samples were placed under the probe that moved downwards at a constant speed of 50 mm/s. The test was performed with two compression cycle: the probe arrived an 80 % of the sample thickness and returned to the initial point and stopped for a set period of time before the second compression cycle.

The resistance of the sample was recorded and drawn in a force-time plot to have the following parameters [4]: hardness, springiness, gumminess, chewiness, resilience, and adhesiveness (Figure 2). Each measurement was performed 7 – 10 times, and the average values were used for statistical analysis.

### 2.5. Warner-Bratzler Shear Force (WBSF)

Warner-Bratzler Shear Force (WBSF) was performed on raw (RW) and cooked (CK) meat, at each aging time ( $T_0$ ,  $T_1$ ,  $T_2$  and  $T_3$ ). The WBSF test on cooked meat was carried out after cooling (24 hours at 4 ± 1 °C). The test was applied by using the same equipment (Figure 3, a) reported in Marrone et al. [4]. At least

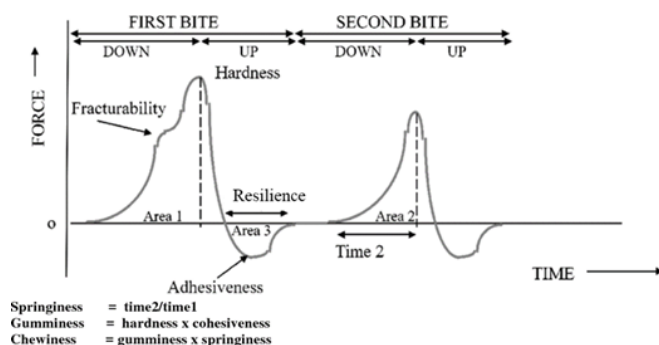


Figure 2. Texture profile analysis (TPA) graph show various TPA parameters..

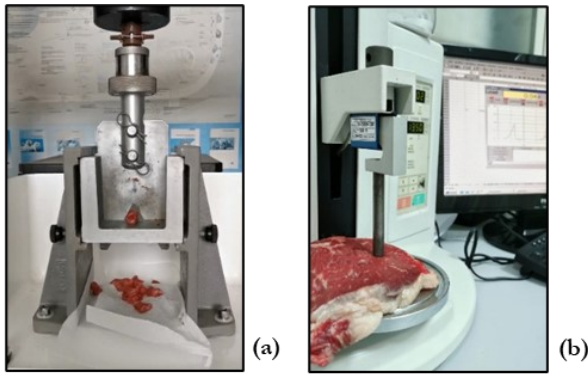


Figure 3. Texture measurement techniques Warner Bratzler shear force (a) and texture profile analysis (b).

seven cores/sample (1.27 cm in diameter and 4 cm in length) were obtained using a well-sharpened handhold coring device that was oriented parallel to the longitudinal pattern of muscle fibres. The cuts mean values were used for statistical analyses.

### 2.6. Statistical analysis

Statistical analyses were performed using SPSS program, version 28 (IBM Analytics, Armonk, NY, USA). Physicochemical and rheological (texture traits and colour) data were statistically analysed with general linear model (GLMs), including fixed effect of aging time ( $T_0$ ,  $T_1$ ,  $T_2$  and  $T_3$ ) and meat status (raw, RW and cooked, CK). The statistical significance of means was evaluated by Tukey's test for  $p < 0.05$ . All data were presented as the mean  $\pm$  standard error. Moreover, Pearson's correlations were calculated between hardness and WBSF parameters. Statistical significance was predetermined at  $p < 0.01$ .

## 3. RESULTS AND DISCUSSIONS

### 3.1. Physical-chemical analysis

The pH,  $a_w$  and chemical composition of beef muscles are shown in Table 1. During the dry aging, the  $a_w$  tended to decrease, but difference was not significant ( $p > 0.05$ ). On the contrary, the pH value increased ( $p > 0.05$ ) probably as a result of the proteolysis that allowed the production of nitrogenous compounds during the aging periods [12], [13]. Biochemical reactions, that occur during the aging process, improved meat palatability and flavour as a consequence of chemical breakdown of proteins and fats Dashdorj et al. [14]. In this study, fat, and protein contents, according to Cho et al. [12] increased as a result of the moisture decrease. In fact, the moisture content (%) of LD beef decreased during dry aging (from  $69.09 \pm 2.54$  at  $T_0$  to  $65.70 \pm 3.28$  at  $T_3$ ) as a consequence of moisture evaporation. nitrogenous compounds during the aging periods [12], [13]. Biochemical reactions, that occur during the aging process, improved meat palatability and flavour as a consequence of chemical breakdown of proteins, and fats [14]. In this study, fat, and protein contents, according to Cho et al. [12], increased as a result of the moisture decrease. In fact, the moisture content (%) of LD beef decreased during dry aging (from  $69.09 \pm 2.54$  at  $T_0$  to  $65.70 \pm 3.28$  at  $T_3$ ) as a consequence of moisture evaporation.

### 3.2. Effect of dry aging on Meat Colour (CIEL\*a\*b\*)

An important parameter of beef quality is the colour that influence the consumer's decision [2]. Moreover, it represents an important feature in evaluating the degree of meat-aging due to several colour changes that occur in beef muscles during the

Table 1. Physical-chemical changes in raw meat during dry-aging.

Items	$T_0$	$T_1$	$T_2$	$T_3$
pH	$5.56 \pm 0.06$	$5.60 \pm 0.06$	$5.66 \pm 0.07$	$5.71 \pm 0.05$
$a_w$	$0.980 \pm 0.00$	$0.979 \pm 0.00$	$0.979 \pm 0.00$	$0.970 \pm 0.01$
Moisture, %	$69.09 \pm 2.54$	$71.33 \pm 1.31$	$69.83 \pm 3.23$	$65.70 \pm 3.28$
Fat, %	$5.44 \pm 2.42$	$4.28 \pm 2.01$	$6.11 \pm 3.75$	$7.67 \pm 4.11$
Protein, %	$20.61 \pm 1.02$	$19.63 \pm 4.07$	$21.79 \pm 1.22$	$22.34 \pm 2.19$

$T_0 = 48$  h,  $T_1 = 15$  days,  $T_2 = 30$  days, and  $T_3 = 60$  days.

Table 2. Colour values during dry aging in raw meat.

Items	$T_0$	$T_1$	$T_2$	$T_3$
$L^*$	$40.41 \pm 7.85$	$40.69 \pm 5.41$	$43.43 \pm 8.05$	$43.99 \pm 6.39$
$a^*$	$15.82 \pm 3.90$	$18.25 \pm 0.99$	$17.80 \pm 2.95$	$16.15 \pm 3.57$
$b^*$	$16.64 \pm 5.94$	$27.14 \pm 13.40$	$17.39 \pm 1.28$	$13.94 \pm 4.64$
Chroma	$23.03 \pm 6.81$	$23.99 \pm 2.18$	$25.01 \pm 1.35$	$21.46 \pm 5.62$
Hue angle	$45.83 \pm 4.69$	$53.13 \pm 14.21$	$44.57 \pm 6.69$	$40.28 \pm 3.55$

$T_0 = 48$  h,  $T_1 = 15$  days,  $T_2 = 30$  days, and  $T_3 = 60$  days.  $L^*$  = lightness,  $a^*$  = redness and  $b^*$  = yellowness.

aging process [15]. Table 2 shows that no significant colour changes occurred during the maturation of the meat. In the first 15 days the redness ( $a^*$ ), yellowness ( $b^*$ ) and chroma tended to increase while lightness ( $L^*$ ) did not change. Extending the aging period, the meat became brighter and the other colour parameters tended to decrease according to Marrone et al. [4].

Changes in meat colour during aging are evaluated using the  $\Delta E$  coefficient. Variation of meat colour  $\Delta E$  is expressed by the difference between successive measurements during dry-aging and is shown in Figure 4. Total colour change  $\Delta E$  increased with aging period ( $T_0 - T_3$ ) according to Di Paolo et al. [6]. The greatest colour changes occurred in the first 15 days ( $T_0 - T_1$ ) of dry aging while at the end of the process,  $\Delta E$  showed lower values.

### 3.3. Effect of dry-aging on Texture Profile Analysis (TPA) and Warner-Bratzler Shear Force (WBSF)

Aging time and cooking are factors that influence meat tenderness [16]. In order to optimize the aging process and obtain desirable textural characteristics it is important the evaluation of texture traits of raw and cooked meat. WBSF and TPA are two objective methods for measuring meat tenderness [6]. In this study, the texture traits of meat were evaluated by using both instrumental methods (WBSF and TPA). The effect of dry aging on raw and cooked meat is shown in Table 3. No significant differences ( $p < 0.05$ ) were found during the aging period for all texture parameters in both raw and cooked meat. However, significant differences were found between the cooked and raw meat in texture traits. Regardless aging time, the cooking process increased all texture traits typical of aged meat hardness.

This aspect is due to the effect of the cooking temperature whereby the myofibrillar proteins coagulate and the constriction of the collagen increases the meat's hardness [17]. Therefore, chewiness it has a similar pattern to hardness due to water loss [17]. During dry aging, the values of hardness, chewiness and gumminess in cooked meat decreased at the end of the process ( $T_3$ ) compared to what happens in raw meat. At the same time, the data showed an increase in adhesiveness and cohesion according to Di Paolo et al. [6].

The marbling, aging time, and cooking have positively influenced the tenderness of the meat. As shown in Table 3,



Table 3. Changes in texture profile analysis (TPA) and Warner-Bratzler shear force (WBSF) during dry-aging.

Items	State	T <sub>0</sub>	T <sub>1</sub>	T <sub>2</sub>	T <sub>3</sub>
WBSF, Kg	RW	2.41 ± 1.74	3.28 ± 0.98	3.57 ± 1.10	3.57 ± 0.58
	CK	7.94 ± 5.81	5.12 ± 2.28	3.34 ± 0.48	3.06 ± 0.42
Hardness, N	RW	12.92 ± 1.86 <sup>x</sup>	15.00 ± 5.41 <sup>x</sup>	14.04 ± 0.62 <sup>x</sup>	15.77 ± 3.22 <sup>x</sup>
	CK	51.81 ± 4.46 <sup>y</sup>	46.16 ± 8.93 <sup>y</sup>	48.24 ± 5.69 <sup>y</sup>	43.21 ± 8.07 <sup>y</sup>
Gumminess, N	RW	4.51 ± 0.81 <sup>x</sup>	5.27 ± 1.67 <sup>x</sup>	5.18 ± 0.36 <sup>x</sup>	5.29 ± 0.87 <sup>x</sup>
	CK	21.51 ± 1.90 <sup>y</sup>	21.26 ± 5.11 <sup>y</sup>	21.34 ± 6.39 <sup>y</sup>	16.80 ± 3.78 <sup>y</sup>
Chewiness, N × mm	RW	3.50 ± 0.58 <sup>x</sup>	3.95 ± 1.42 <sup>x</sup>	3.48 ± 0.11 <sup>x</sup>	3.56 ± 0.32 <sup>x</sup>
	CK	15.30 ± 1.09 <sup>y</sup>	16.11 ± 3.31 <sup>y</sup>	15.65 ± 4.23 <sup>y</sup>	13.54 ± 2.18 <sup>y</sup>
Springiness, mm	RW	0.78 ± 0.01	0.74 ± 0.04	0.67 ± 0.04	0.68 ± 0.07 <sup>x</sup>
	CK	0.71 ± 0.07	0.76 ± 0.02	0.74 ± 0.06	0.81 ± 0.06 <sup>y</sup>
Cohesion	RW	2.26 ± 0.18 <sup>x</sup>	2.24 ± 0.38 <sup>x</sup>	2.43 ± 0.47 <sup>x</sup>	2.98 ± 0.49 <sup>x</sup>
	CK	5.89 ± 1.89 <sup>y</sup>	5.19 ± 0.73 <sup>a,y</sup>	6.16 ± 0.94 <sup>y</sup>	7.61 ± 0.91 <sup>b,y</sup>
Resilience	RW	0.11 ± 0.02	0.14 ± 0.07	0.11 ± 0.02	0.09 ± 0.001
	CK	0.10 ± 0.03	0.10 ± 0.01	0.11 ± 0.01	0.12 ± 0.06
Adhesiveness	RW	-0.99 ± 3.90	-2.98 ± 1.22	-1.99 ± 0.97	-3.03 ± 0.88 <sup>x</sup>
	CK	-6.54 ± 4.46	-4.02 ± 1.20	-7.86 ± 5.08	-12.42 ± 7.14 <sup>y</sup>

Statistical analysis was performed comparing meat status (raw, RW and cooked, CK) at each sampling time (T<sub>0</sub>, T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub>) along the aging period. A–b Mean values in the same row (aging time) with different letters differ significantly for  $p < 0.05$ . x–y Mean values in the same column (different status meat at the same aging time) differ significantly for  $p < 0.05$  (small) or  $p < 0.01$  (capital).

aging time improved the tenderness of meat, even if no significant differences were found during aging time in raw meat. Our results showed that the compression and shear force responses are the same regardless of the instrumental measurement method used. We found a positive correlation (0.508;  $p < 0.05$ ) between WBSF and hardness values, arguing that WBSF and TPA test can be used as instrumental measurements of tenderness on raw and cooked meat samples (Figure 5).

#### 4. CONCLUSIONS

The tender meat making is primary goal to meat industry to answer to the customer expectations and obtain optimal results. New device for dry aging methods have become essential to improve meat tenderness and flavour. In this regard, the evaluation of texture measurements for meat is important in order to evaluate its quality. Our results suggest that aging time and cooking tended to decrease the hardness and shear force implying more tender meat for the consumer. Overall, there are no significant changes in nutritional and colour of meat highlight the good effect of the aging process only on meat tenderness traits. However, further investigations are needed to investigate deeply possible interaction between instrumental measures (WBSF-test and TPA-test) and the sensorial assessment of meat tenderness.

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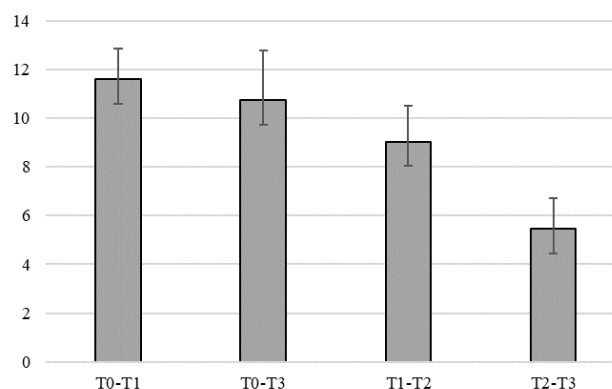


Figure 4. Variation of colour ( $\Delta E$ ) during dry aging assessed between subsequent measurements.

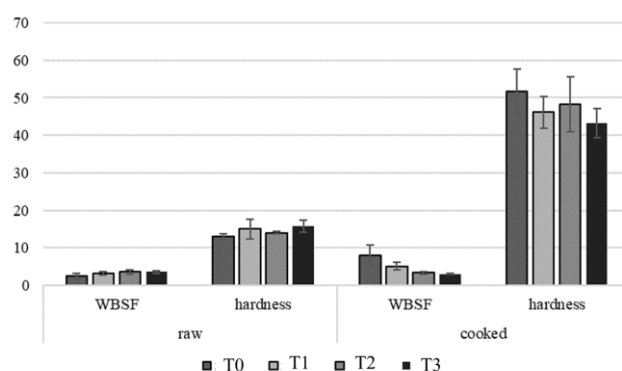


Figure 5. Rheologic property of meat as affected by aging time.

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