Studii şi Cercetări Ştiinţifice
Chimie şi Inginerie Chimică, Biotehnologii, Industrie Alimentară

2019, **20** (3), pp. 451 – 461

Scientific Study & Research
Chemistry & Chemical Engineering, Biotechnology, Food Industry

ISSN 1582-540X

ORIGINAL RESEARCH PAPER

EFFECT OF WET AGING TIME ON BEEF MEAT AND CORRELATIONS WITH RHEOLOGICAL PROPERTIES, COLOR OF MEAT EMULSIONS, AND TEXTURAL PARAMETERS OF GELS

Elena Todosi Sănduleac*, Gheorghe Gutt

Ştefan cel Mare University of Suceava, Food Engineering Faculty, University Street 13, 720229, Suceava, Romania

*Corresponding author: sanduleacelena@yahoo.com

Received: June, 07, 2019
Accepted: September, 18, 2019

Abstract: The aim of this study was to observe the effects of the wet aging time of beef on the rheological properties of O/W model system meat emulsions. In addition, texture parameters (TPA) of the gels and the color analysis of the meat emulsions were performed to find a possible relationship between dynamic rheological data, with storage modulus (G') and loss modulus (G''), TPA parameters of the gels and color parameters of emulsions obtained from wet aged meat, at different time intervals (2, 7, 12, 17, 21 days). The Ostwald-de Waele model was used to describe the flow properties of meat emulsions. All studied emulsions exhibited non-Newtonian, shear thinning behavior since apparent viscosity decreased with increasing shear rate. Correlations between rheological properties, color of meat emulsions and TPA parameters of gels have been observed.

Keywords: _beef meat, color, gels, meat emulsions, rheological properties, textural properties, wet aging_

INTRODUCTION

Meat is an important source of valuable proteins, whose amino acid composition compensates for the efficiencies of other food raw materials. The particular value of meat is due to its high degree of digestibility and, mainly, to its particular sensory properties. Another important nutritional feature of the meat is its content in absorbable iron, zinc, selenium and in group B vitamins, like: thiamine, riboflavin, niacin and vitamin B_{12}, which plays an essential role in healthy nutrition [1]. The aging is one of the most commonly used methods to improve the quality of beef [2]. During the aging process, many biochemical processes occur, which are responsible for quality enhancement, especially tenderness [3] and flavor development [4].
Different muscles vary in color stability [5]. Muscles with greater color stability are characterized by less oxygen consumption and less lipid oxidation, which is also related to the muscle fiber type [6]. Wet ageing is performed on vacuum pre-packed meat in plastic sheets and maintained at refrigeration temperature. In this case, it is not necessary to monitor the humidity and air velocity parameters. The role of plastic film is to protect against microbial contamination and moisture loss, there by achieving greater conservability and obtaining juicy and tender beef. The disadvantage is that the flavor is less pronounced than in the case of dry aging. The advantages of wet aging process are: it is less expensive, it allows a faster distribution in the marketing units and ensures protection against microbiological contamination [7].
Emulsion type meat products are quite popular, being consumed by millions of people world-wide. Gel formation is one of the most important properties of proteins, and oil-in-water emulsion may be converted from liquid-like to solid-like form by gel formation. Hence, it contributes to the desirable texture and oil-in-water emulsion stabilization in emulsified meat products [8].
Therefore, the aim of this study was to analyze the effect of wet ageing time on the steady-state and dynamic shear properties of oil/water (O/W) model system meat emulsions and to determine the possible relationship between dynamic test data, color and TPA parameters of the gels.

MATERIALS AND METHODS

Materials

Beef meat (Semimembranosus muscle containing: 73.25 % moisture, 20.4 % protein, 5.59 % fat, and 0.61 % ash, and 5.96 *p*H) was purchased from a local slaughterhouse. The refined corn oil was purchased from a local market in Suceava, Romania. Beef meat was vacuum packed and kept under refrigeration conditions (0-5 °C) for 21 days. Table 1 presents the sample coding according to meat aging duration.

Table 1. *Sample coding, according to meat aging duration*

Meat aging duration	**0 days**	**2 days**	**7 days**	**12 days**	**17 days**	**21 days**
Sample code	Control	m_1	m_2	m_3	m_4	m_5

Preparation of oil-in-water (O/W) model system meat emulsions

The beef meat was submitted to wet ageing for different time intervals. After each selected ageing interval, O/W model system meat emulsions were obtained (Table 1), using the two step method described by Zorba *et al.* in 1993 [9]. In general, the fat and water which separates due to stress, the two steps of obtaining the emulsion was used to ensure good emulsion stability. For this purpose, a solution of NaCl 0.4 M was prepared and its *p*H was adjusted until it reached the 6.6 value, with 0.1 M, K_2HPO_4. For each emulsion sample, 25 g of minced meat and 100 mL of cold NaCl solution (0 - 4 °C) were placed in a blender (Blender Star-Light BD-600BS, 600 W, 1.5 L, 5 steps velocity produced by Star Light, Romania) jar and blended for 2 min at 13000 rpm to obtain the slurry. After that, a quantity of 37.5 mL of NaCl solution and 12.5 g of the obtained slurry were placed into the blender and homogenized at 2250 rpm for 10 s. 50 mL corn oil were added in each NaCl-slurry mixture sample during the ten seconds of homogenization.

The temperature was monitored to ensure that the emulsions never exceeded 15 °C. For the preparation of heat treated meat emulsions, the raw emulsions were held for 30 min in a water bath at 80 ± 2 °C until center temperature of emulsions reached 75 °C. All emulsion samples were prepared in triplicate and examined in two replications.

Rheological properties of O/W model system meat emulsions

The rheometric measurements of emulsions were made with a Modular Advanced Rheometer System Thermo HAAKE Mars (HAAKE Co., Germany) equipped with a measuring system formed by cone and plate geometry (diameter: 40 mm, gap: 0.104 mm and cone angle = 2°) [10]. Before performing the measurements, the samples were allowed to equilibrate for 300 s at 25 ± 0.1 °C. All the flow and viscoelastic behavior parameters are the mean of two measurements per each triplicate emulsion sample.

Rheological properties during forced flow conditions

Flow behavior of meat emulsions was measured by recording shear stress values when shearing the samples at shear rates ranging from 1 to 100 s^{-1} through 100 s. The relationship between shear stress and shear rate was described by Ostwald–de Waele model, (Equation 1), which is the most frequently used for engineering application:

$$\eta_{app} = K \cdot \gamma^{n-1} \tag{1}$$

where η_{app} is the apparent viscosity (Pa·s), γ is the shear rate (s^{-1}), K is the consistency index (Pa·s^n) and n is the flow behavior index (*dimensionless*). These calculations were performed using the RheoWin 4 Data Manager software (version 4.20, Haake).

Oscillatory shear properties

Viscoelastic properties of meat emulsions were measured using small amplitude oscillatory shear tests at 25 °C. The linear viscoelastic region (LVR) of emulsions was previously determined by running stress sweeps between 0.1 and 1000 Pa, at a frequency of 1 Hz (6.28 rad·s^{-1}). After that, frequency sweeps at 1 Pa (obtained from stress sweep in the linear region) were performed from 1 to 20 Hz (6.28-125.66 rad·s^{-1}). The oscillatory rheological parameters used to compare the viscoelastic properties of the samples were elastic or storage modulus (G') and viscous or loss modulus (G''). Loss tangent (*tan δ*) was calculated according to the following equation (2), which denotes relative effects of viscous and elastic components in a viscoelastic behavior:

$$\tan\delta = \frac{G'}{G''} \tag{2}$$

Sometimes, the complex modulus (G^*) and the complex dynamic viscosity (η^*) are used for describing the dynamic test data [11]. Complex modulus is used to describe the total resistance to deformation of a material considered to be an elastic solid, while complex viscosity is used to describe the total resistance of a material considered to be a viscous liquid [12]. These parameters are indicator of the overall response of sample against the sinusoidal strain calculated by following equations, (3) and (4) [13]:

$$G^* = \sqrt{(G')^2 + (G'')^2} \tag{3}$$

$$\eta^* = \frac{G'}{\omega} \tag{4}$$

The storage (G') and loss (G'') modulus were modeled as an exponential function of angular frequency (ω), (eqs. (5) and (6)):

$$G' = K' \cdot (\omega)^{n'} \tag{5}$$

$$G'' = K'' \cdot (\omega)^{n''} \tag{6}$$

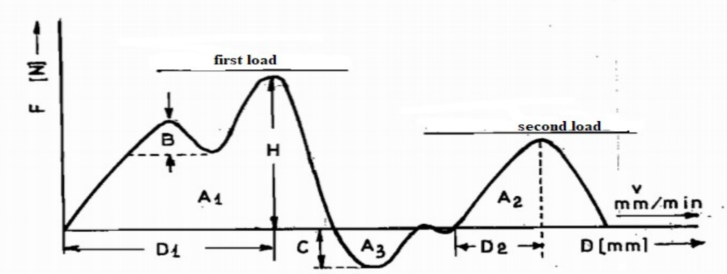
where K' (Pa·s$^{n'}$) and K'' (Pa·s$^{n''}$) are constants, n' and n'' may be referred to as the frequency exponents, ω is the angular frequency (rad·s^{-1}). These calculations were carried out using RheoWin 4 Data Manager software (version 4.20, Haake).

CIE-Lab color determination

The color of the meat emulsions was measured by means of the CIELAB method. The CIELAB color space (also known as CIE L*a*b* or sometimes abbreviated as simply "Lab" color space) is a color space defined by the International Commission on Illumination (CIE) in 1976, where L* (100 = white, 0 = black) represents the brightness, and a* (+ red, - green) and b* (+ yellow, - blue) are color parameters [14]. The determinations were performed using the Konica Minolta Chroma Meter CR-400 device (Konica Minolta Co., Osaka, Japonia). Three determinations were performed for each sample.

Texture profile analysis (TPA)

Forty grams of each emulsion sample was weighed into cylindrical glass jar (diameter: 50 mm, height: 80 mm) with a cap and heated into a water bath at 80 °C until the internal temperature reached 75 °C. After cooling the gels at room temperature (25 °C), these were subjected to texture profile analysis (TPA) using the Texture Analyzer (MARK-10). Two measurements per each triplicate gel were conducted. A double compression cycle test was performed up to 12.5 mm strain compression of the original portion height using an aluminum cylinder probe with 25 mm diameter, at a speed of 1 mm/s. Force versus time plots were used for the calculation of TPA values, such as: hardness, chewiness, gumminess, adhesiveness, springiness and cohesiveness [15]. In Figure 1 is present the texture parameters according to texture profile analysis (TPA) [16].



Parameter texture	Notation
Viscosity	C
Fracturability	B
Hardness	H
Displacement	D_1
Adhesiveness	A_3
Cohesiveness	A_2/A_1
Springiness	D_2/D_1
Gumminess	$H \times A_2/A_1$
Chewiness	$H \times A_2/A_1 \times D_2/D_1$

***Figure 1**. Load diagram in two cycles used for texture profile analysis (TPA) [16]*

Statistical analysis

The statistical analysis was made using Microsoft Excel 2007 and Unscrambler X 10.1 software system (Camo, Norway).

RESULTS AND DISCUSSIONS

Rheological properties during forced flow conditions

Figure 2 illustrates the flow curves (apparent viscosity versus shear rate) of the emulsion samples prepared from wet aged meat for different time intervals (2, 7, 12, 17, 21 days).

The values of apparent viscosity showed a decreasing trend with increasing shear rates, which indicates that all meat emulsions exhibited a shear-thinning behavior. At high shear rate the values of apparent viscosity of samples were lower than those at low shear rates. This could be explained by the structural breakdown induced by shear rates.

As it can be seen in Figure 1, there was a clear trend toward higher viscosities at low shear rates with the increase of the ageing period.

The lowest and the highest values were determined at control sample and, respectively, at emulsions obtained from meat with 21 days of wet aging.

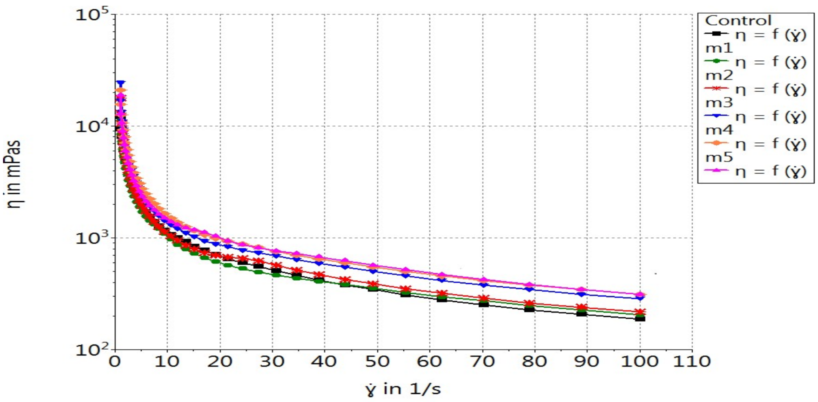


Figure 2. *Effect of meat wet ageing duration on the apparent viscosity of meat emulsions*

The flow curves of emulsions fitted the Ostwald–de Waele model (Eqn. (1), and the values of consistency index and flow behavior index known as *K*, *n* and R^2 of Eqn. (1) are summarized in Table 2, in addition to apparent viscosity at a shear rate of 50 s^{-1}. As it can be observed, the Ostwald–de Waele model was found to be the adequate model (R^2 = 0.9671 – 0.9935) to describe the flow behavior of meat emulsions.

Table 2. *Effect of meat wet ageing duration on consistency index (K) and flow behavior index (n) of meat emulsions (Ostwald–de Waele model)*

Samples	η_{50} [Pa·s]	K [Pa·s^n]	n	R^2
Control	0.344±0.01	11.03±0.42	0.102±0.02	0.9935
m_1	0.353±0.01	10.04±0.22	0.126±0.01	0.9899
m_2	0.386±0.02	16.47±0.37	0.482±0.04	0.9857
m_3	0.502±0.01	22.65±0.38	0.536±0.02	0.9676
m_4	0.548±0.01	19.36±0.26	0.289±0.05	0.9763
m_5	0.573±0.01	16.56±0.20	0.289±0.02	0.9671

Oscillatory shear properties

Stress sweep tests were conducted in the range of 0.1 – 1000 Pa at a constant frequency (6.283 rad·s^{-1}=1 Hz); therefore, 1 Pa (which is in the linear viscoelastic region (LVR)) was selected as a constant stress to conduct frequency sweep.
Dynamic oscillatory shear test can be used to determine the viscoelastic properties of food materials. When all the energy is stored in a perfectly elastic solid, G'' is 0, which means stress and strain are in phase; on the contrary, when all the energy in a liquid having no elastic characteristics is dissipated as heat, G' is 0, which means stress and strain are out of phase by 90° [16].
Dynamic mechanical spectra (G', G'' and η^*) of model system meat emulsions are graphically represented in Figure 3 as a function of frequency (*f*). As it can be seen, the elastic modulus (G') had a lower frequency dependency than viscous modulus (G'') at all the emulsion samples.

The slight dependence of *G′* on the frequency is known as the “plateau region”. This region is an intermediate zone of mechanical spectra between the “terminal” and “transition” zones and it is classified by a decrease in the slope of both moduli [17].

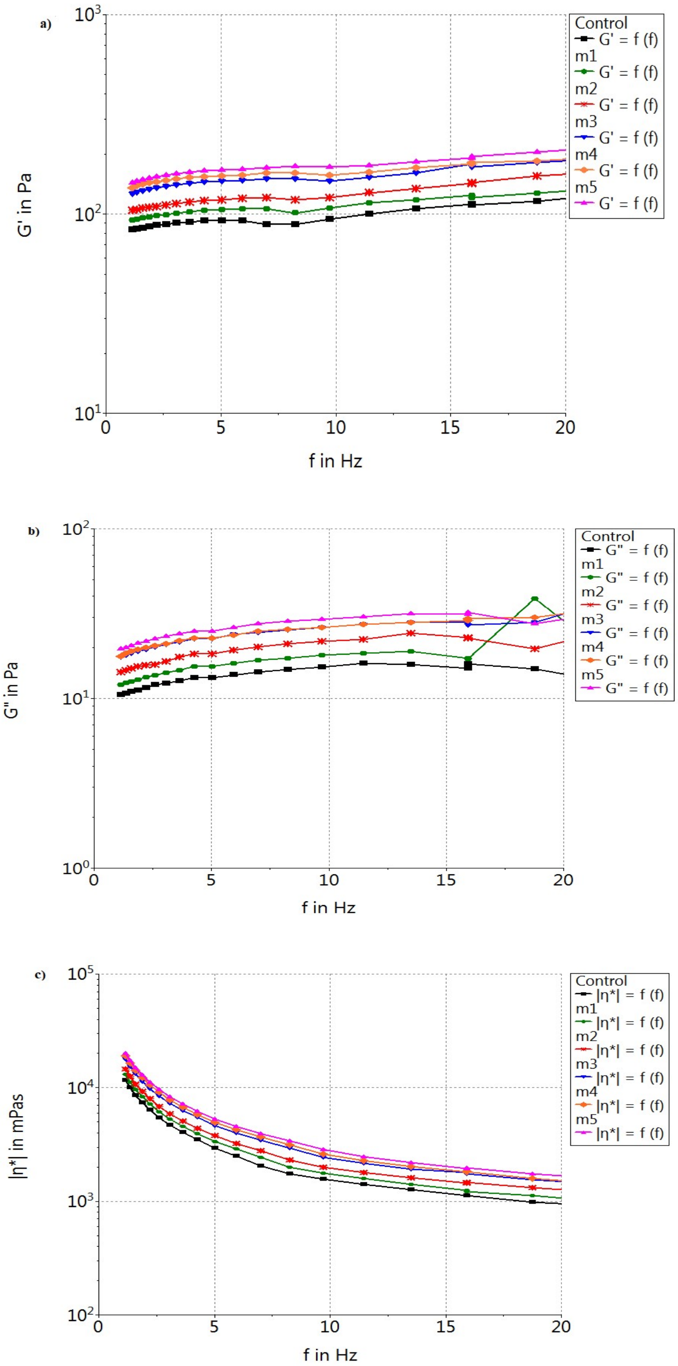


Figure 3. *Effect of meat wet aging duration on:*
a) storage modulus (G'), b) loss modulus (G''), c) complex viscosity (η^*)
of meat emulsions

Dogan *et al.* [17] reported that it is a characteristic behavior of protein-stabilized emulsions because an elastic network occurs due to the presence of an extensive bridging flocculation process. All the emulsion samples showed similar flow characteristics, i.e. shear-thinning behavior following power-law model obtained from G' and G'' against frequency (f) plots. The possible reason of this behavior could be attributed to the fact that the shear-thinning region occurs as a result of a decreasing shear, which causes the structural breakdown related with a mechanism of oil droplet deflocculation.

CIE-Lab color parameters of meat emulsions

The color parameters of the emulsion samples are shown in Table 3.

Table 3. *The color parameters of meat emulsion samples*

Sample	Color parameters					
	L^*	a^*	b^*	$C_{ab}{}^*$	$h_{ab}{}^*$	ΔE^*
Control	71.48±0.1	5.27±0.3	44.43±0.1	44.75±0.1	263.23±0.3	-
m_1	70.61±0.3	5.21±0.2	45.50±0.3	45.80±0.3	263.46±0.1	1.38±0.13
m_2	70.59±0.1	4.95±0.3	45.96±0.2	46.23±0.2	263.85±0.2	1.79±0.30
m_3	70.58±0.2	4.80±0.1	46.19±0.3	46.44±0.3	264.06±0.2	2.03±0.26
m_4	70.43±0.3	4.50±0.1	47.98±0.4	48.19±0.1	264.64±0.1	3.78±0.18
m_5	70.09±0.2	4.47±0.1	48.44±0.3	48.65±0.2	264.73±0.3	4.32±0.27

TPA parameters of the O/W meat gels

Effect of wet aging duration of meat on the TPA parameters of meat gels

The textural properties of the effect of wet aging duration of meat on the TPA parameters of meat gels can be observed in Table 4. As it can be seen, all the textural parameters (hardness, chewiness, gumminess, adhesiveness, springiness and cohesiveness) were significantly affected by the wet aging duration of meat. The highest hardness (0.52 N), chewiness (0.27 N·s), gumminess (0.29 N) and cohesiveness (0.60) were determined for the control sample, and as the aging time increased these values also decreased (Table 4).

Table 4. *The effect of wet aging duration of meat on the TPA parameters of meat gels*

	TPA parameters					
	Hardnes s [N]	Adhesiveness [N·mm]	Cohesiveness	Springiness	Gumminess [N]	Chewiness [N]
Control	0.52±0.02	0.21±0.05	0.60±0.04	0.93±0.02	0.29±0.01	0.27±0.04
m_1	0.46±0.01	0.91±0.02	0.56±0.04	0.82±0.03	0.28±0.03	0.23±0.01
m_2	0.40±0.01	0.36±0.01	0.55±0.01	0.84±0.01	0.22±0.01	0.18±0.06
m_3	0.40±0,03	0.35±0.03	0.49±0.05	1.50±0.02	0.14±0.02	0.22±0.02
m_4	0.32±0.01	0.11±0.03	0.47±0.01	1.72±0.01	0.15±0.02	0.26±0.01
m_5	0.24±0.02	0.54±0.01	0.42±0.01	1.20±0.01	0.10±0.01	0.12±0.01

Similar TPA parameters were determined by Yilmaz *et al.* (2012) [15], who studied the effect of oil concentration on O/W model system meat emulsions. The texture of heat treated meat products is highly dependent on the gelation of myofibrillar proteins [18].

Table 5. *Pearson correlation between the wet aging time, dynamic and oscillatory rheological characteristics, color of meat emulsions and textural parameters of gels*

Variables	Hardness (N)	Adhesiveness (N·mm)	Cohesiveness	Springiness	Gumminess (N)	Chewiness (N)	ΔE*	η_{50} (Pa·s)	η*	G*	tan δ
Hardness (N)	1	0,067	0.958	-0.530	0.906	0.686	-0.982	-0.906	-0.906	-0.954	-0.247
Adhesiveness (N·mm)		1	0.068	-0.548	0.239	-0.352	-0.061	-0.280	-0.250	-0.175	0.107
Cohesiveness			1	-0.670	0.963	0.593	-0.955	-0.971	-0.958	-0.992	-0.240
Springiness				1	-0.723	0.159	0.612	0.812	0.809	0.722	0.025
Gumminess (N)					1	0.564	-0.881	-0.968	-0.971	-0.983	-0.386
Chewiness (N)						1	-0.563	-0.423	-0.434	-0.555	-0.500
ΔE*							1	0.916	0.924	0.950	0.180
η_{50} (Pa·s)								1	0.977	0.984	0.166
η*									1	0.983	0.330
G*										1	0.287
tanδ											1

Relationship between the wet aging time, dynamic oscillatory rheological characteristics, color of meat emulsions, and textural parameters of gels

The Pearson test, Table 5, was used to analyze the correlations between the values of dynamic oscillatory rheological properties of the emulsions prepared from wet aged meat and their TPA parameters after heat treatment. Generally, the TPA parameters showed significant negative correlations ($p < 0.05$) of hardness (coefficient ranging between -0.906 and -0.982), cohesiveness (coefficient ranging between -0.955 and -0.992) and gumminess (coefficient ranging between -0.881 and -0.983) parameters, poorly significant negative correlations of adhesiveness (coefficient ranging -0.240) and chewiness (coefficient ranging between -0.423 and -0.563), and positive correlations ($p < 0.05$) of elasticity (coefficient ranging between 0.722 and 0.812). The color difference of the emulsions showed significant positive correlation with increasing the wet ageing duration of the meat. The color of variables does not change significantly and is not a criterion for characterization of variables. It is concluded that gumminess, hardness and cohesiveness are characteristics that describe significantly the variables (emulsions) analyzed over time.

CONCLUSIONS

In this study, the effects of wet aging time on steady-state and dynamic shear properties of O/W model system meat emulsions and their correlation with color and TPA parameters of gels were evaluated. It can be concluded that all meat emulsions had a shear-thinning behavior, the wet aging time caused an increase in apparent viscosity and meat emulsions behaved as weak gel like macromolecular dispersions, due to much higher values of G' than of G''. On the other hand, the O/W model system meat emulsions fitted the Ostwald-de Waele model.
The similar trend depending on meat wet aging duration was also observed in the TPA of the heat treated model system emulsions. This study also revealed that the textural parameters of the heat treated emulsion samples could be estimated before their thermic process using their material stiffness data calculated from dynamic shear tests. Based on these results, meat processors will be able to estimate the product structure and/or texture profile before a large scale of production is made. Hence, this will enable them to save time and cost when manufacturing a product with acceptable structural or textural characteristics.

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