

Creep and Recovery Characteristics of Chicken Meat Frankfurters

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ABSTRACT

The effect of temperature on the viscoelastic behavior of chicken meat frankfurters was assessed by creep recovery tests. Compression creep-recovery tests were performed at room temperature (20°C) and refrigeration (5°C) on samples of cylindrical shape. The viscoelastic behavior of samples was characterized based on the parameters of the four-element Burgers Model. During the compression phase, greater deformation was observed in samples analyzed at higher temperature, and it was demonstrated by a drop in elastic modulus and internal viscosity values of Kelvin-Voigt elements with an increase in temperature. The final percentage recovery of frankfurter samples decreased with an increase in temperature. The differences in compliance between samples analyzed at different temperatures can be attributed to temperature-induced changes in the properties of frankfurter fat.

Keywords: Burgers Model, Compliance, Viscoelastic behavior.

INTRODUCTION

Meat have the largest share of the global food market. The food industry produces a wide range of products, including emulsion-type meat products such as cooked sausages and frankfurters. According to the Polish Standards (PN-A-82007, 1996), sausages can be divided into three groups based on the method of meat fragmentation: finely ground (e.g. frankfurters), medium ground (e.g. thin dry-smoked pork sausages) or coarsely ground (e.g. Polish ham sausage). The main components of sausages are meat, protein, water and fat as well as other technological additions such as NaCl and phosphates. Additional ingredients may include offal and spices (Ripoche *et al.*, 2001). The structure and texture of food products are the main determinants of quality from the perspective of both the manufacturer and the consumer. Texture is

one of the most important characteristics of meat products, and it can be altered by external factors (Damez *et al.*, 2008). The microstructure of the ingredients has a significant impact on the rheological properties of foods, including meat and processed meats. A sound knowledge of the rheological properties of meat is required to determine the effect of various production processes, such as cutting, packaging and storing, on the final product. It also supports machine design and a variety of other processes in the food industry. It is also useful for the consumer acceptance evaluation.

The viscoelastic properties of emulsion-type food systems are generally studied by oscillation tests to determine the elastic modulus, loss modulus, and complex viscosity (Dolz *et al.*, 2006). Dolz *et al.* (2008) recommended the use of shear creep recovery tests to assess the internal structure of a system. For this purpose, creep and

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recovery tests were performed where a food product was deformed over a predetermined time period under constant shear stress, and the resulting deformation was measured as a function of time (Dolz *et al.*, 2008; Kuo *et al.*, 2000). Yilmaz *et al.* (2012a) characterized the viscoelastic behavior of emulsion-type meats based on the parameters of Burgers Model. A robust knowledge of the viscoelastic properties of foods supports the design of continuous manufacturing processes, the development of new products and quality control during the processing of emulsion-type foods (Dolz *et al.*, 2008; Yilmaz *et al.*, 2012a). Many authors have relied on the shear creep test and Burger's Model to describe the viscoelastic behavior of various ingredients of emulsion-type products, including mixtures of gum arabic and corn starch (Jiménez-Avalos *et al.*, 2005), meat emulsions (Yilmaz, 2012b) and cheese (Kuo *et al.*, 2000). To date, the viscoelastic properties of frankfurters have not been investigated based on a mechanical approach involving compression testing and creep analysis. Therefore, the aim of this work was to study the rheological properties of frankfurters at refrigeration and ambient temperatures based on the compression creep recovery test and Burger's Model.

MATERIALS AND METHODS

Materials

The experimental material comprised fresh pasteurized chicken frankfurters produced by a commercial poultry processing plant and purchased in a local supermarket. According to the manufacturers' data, the sausages consisted of mechanically separated chicken meat (47% (g 100 g⁻¹)), chicken skins, water, semolina, modified starch (acetylated starch adipate), soy protein, spices, NaCl and preservatives (sodium nitrite). The protein, fat and carbohydrate content of the sausages was 11, 22, and

3% (g 100 g⁻¹), respectively, in agreement with American definitions and standards (US-GPO, 2011). Cylindrical-shaped samples with a diameter of 19±1 mm and a height of 15±1 mm were punched out using a short plastic tube, 20 mm in inner diameter and 15 mm in length. A frankfurter was placed inside the tube and cut with a knife at both ends of the tube to ensure that both ends were parallel. The edges with a higher protein denaturation and drying were removed in the preparation of samples. The prepared samples were divided into two groups of 20 pieces each. The first group was stored at room temperature of 20±1°C, and the second group at refrigeration temperature of 5±1°C. The samples were stored at a given temperature for 20 hours before testing for thermal stabilization.

Rheological Testing

Creep tests were performed with the TA.HD Plus Texture Analyzer (Stable Micro Systems, UK) and Exponent 5.1.2.0 software. The cylindrical probe with a diameter of 0.036 m (SMS P/36R) was used in all tests. In the creep test, constant stress was applied instantaneously to the material, and the resulting deformation was measured as a function of time. After a certain period of time (creep time), stress was discontinued, and strain recovery was measured in the sample. Constant stress was set at 35 kPa, and creep time and recovery time were 1 min each. Sample temperature was measured with the EMT-50-K portable thermometer (CZAKI THERMO-PRODUCT, UK) equipped with a sensor PT 100. The temperature of samples stored at room temperature was determined directly before the creep test. The temperature of samples stored at refrigeration temperature was measured twice: immediately before and immediately after the creep test. Creep tests were performed in 20 replications.

Modeling

The compression creep behavior of sausages was described by the four-element Burgers Model (Figure 1). Creep data acquired under constant compression stress (σ) over time (t) may be expressed by the creep compliance (J) function, as shown in Equation (1), in terms of compression deformation (ϵ):

$$J = \frac{\epsilon}{\sigma} \quad (1)$$

Compression Phase

The viscoelastic behavior of frankfurters is described by the compression creep deformation curve of the sample and covers three stages (Yilmaz *et al.*, 2012a). The first stage shows the beginning of elastic deformation over a very short period of time, the second stage represents viscoelastic behavior characterized by a decreasing strain rate in response to constant loading stress, whereas the third stage shows strain recovery of the sample after discontinuation of stress and low strain levels at the end of the test. The creep of the analyzed samples was expressed based on Burgers Model during compression phase, and it is given by Equation (2) (Yilmaz *et al.*, 2012a; Steffe, 1996; Moshenin, 1986):

$$J(t) = \frac{1}{E_0} + \frac{1}{E_1} \left(1 - \exp\left(-\frac{E_1}{\eta_1} t\right) \right) + \frac{t}{\eta_0} \quad (2)$$

Where, $J(t)$ (MPa^{-1}) is overall creep compliance at any time t (s), E_0 (MPa) is the instantaneous elasticity modulus, E_1 (MPa) is the retarded elasticity modulus, η_0 (MPa s) is the viscosity of the dashpot component of the Maxwell component, and η_1 (MPa s) is the viscosity of the dashpot component of the Kelvin-Voigt part. Equation (2) shows the change in creep compliance [$J(t)$] of the material as a function of time.

The values E_0 , E_1 , η_0 and η_1 (Figure 1) are calculated to compare the internal structure of various systems which are characterized by specific behavior in response to a given load (Dolz *et al.*, 2008; Yilmaz *et al.*, 2012a). Springs and dashpots shown in Figure 1 represent Hooke and Newton elements, respectively.

Recovery Phase

The viscoelastic properties of a system are recovered upon the discontinuation of compression stress. In theory, the recovery process is complete only in purely elastic systems. In viscoelastic materials such as emulsion-type meats, irreversible deformation persists after infinite recovery time (Dolz *et al.*, 2008). There are two approaches to rheological modeling of food behavior during the recovery phase of a creep test. The first approach relies on the same mathematical model, i.e. Burgers Model, for describing the viscoelastic behavior of a sample during both compression and recovery phases (Sozer, 2009; Bockstaele *et al.*, 2011). In the second approach, the recovery phase is fitted to a semi-empirical Equation (3) derived from Burgers Model (Dolz *et al.*, 2008; Yilmaz *et al.*, 2012a; Bayarri *et al.*, 2009):

$$J(t) = J_{\infty} + J_{KV} \exp(-Bt^C) \quad (3)$$

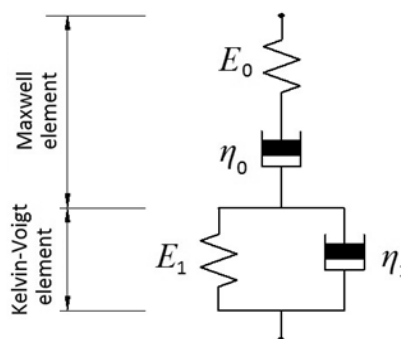


Figure 1. Diagram of the four-element Burgers Model composed of Maxwell and Kelvin-Voigt elements in series.



Where, J_{∞} is residual compliance corresponding to the permanent deformation of the Maxwell dashpot, J_{KV} is the recovery due to Kelvin-Voigt elements, t is time, and B and C are the parameters fitted in the model (3). According to Bayarri *et al.* (Bayarri *et al.*, 2009), compliance during the recovery phase does not follow Burgers Model, and in this study, the second approach was applied. Dolz *et al.* (2008) and Yilmaz *et al.* (2012a) fitted all parameters in Equation (3) from experimental data, whereas Bayarri *et al.* (2009) assumed that C in Equation (3) was equal to 0.5. In this study, it was assumed that parameter C in Equation (3) was equal to 1.0 in order to obtain a better fit of the model to the experimental data.

The deformation resulting from the Maxwell spring (J_{SM}), was the initial compression compliance at the recovery phase which can be described by the following equation (Kuo *et al.*, 2000):

$$J_{SM} = J_{MAX} - (J_{\infty} + J_{KV}) \quad (4)$$

Where, J_{MAX} is the maximum deformation which corresponds to the compliance value for the longest time (60 seconds) in the transient creep analysis.

Model Regression and Statistical Analysis

The parameters of models (2) and (3) and the effect of sample temperature on the modeled parameters were determined with the use of Statistica ver. 10 software (StatSoft, USA). The resulting model parameters were analyzed by the Kolmogorov-Smirnov test and the Shapiro-Lillefors-Wolf test to determine whether the data was normally distributed. Normality tests were performed at a significance level of $P \leq 0.05$. The results were processed by one-way analysis of variance (ANOVA), and the significance of differences was determined by Duncan's multiple range test.

RESULTS AND DISCUSSION

Compression

Two batches of samples were subjected to creep and recovery tests. A creep test run, which was performed at refrigeration temperature and demonstrated typical behavior at distinct loading and unloading phases, is shown in Figure 2. The influence of temperature on the creep compliance of 20 sausages at refrigeration and room temperature is shown in Figure 3. A

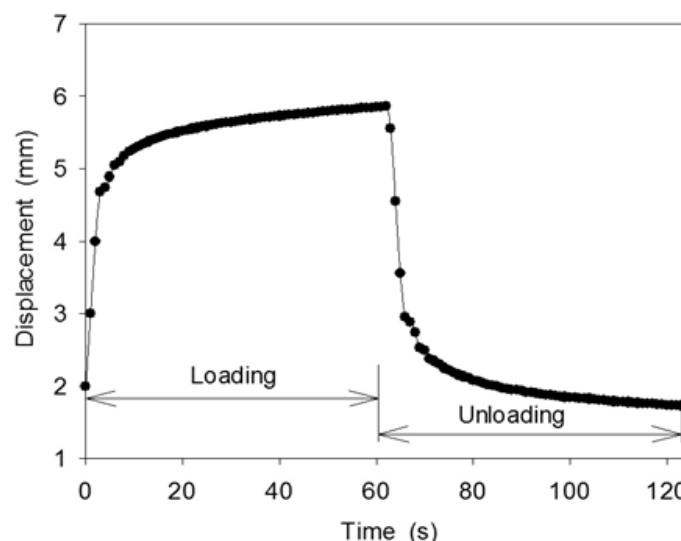


Figure 2. Creep behavior of a frankfurter sample analyzed at refrigeration temperature.

univariate analysis of variance demonstrated the effects of sample temperature on the parameters of Burgers Model (Table 1). An analysis of the results in Table 1 points to statistically significant differences between the moduli of elasticity (E_0 and E_1), and viscosity damping elements (η_0 and η_1) of the samples tested at room and refrigeration temperatures. In this study, greater deformation was observed in samples analyzed at higher temperature, and it was demonstrated by a drop in elastic modulus (E_1), and internal viscosity (η_1), values of Kelvin–Voigt elements with an increase in temperature. In case of Maxwell Model elements (E_0 , η_0) an increase in their values with increasing temperature was observed (Table 1). The data shown in Figure 3 indicates that the creep compliance of frankfurter samples stored at both refrigeration and room temperature

increased over time during the creep phase. However, maximum compliance values after 60 seconds of compression were noted in samples stored at higher temperature, and they were determined as 11.12 and 9.48 MPa^{-1} in samples stored at refrigeration and room temperature, respectively. Savadkoohi *et al.* (2013) observed that temperature induced changes in the elasticity of raw sausage emulsions during shear tests, leading to transformations between a weak gel structure and a stronger gel network. The temperature range in the cited study was relatively high at 10 to 60°C, whereas in our experiment, frankfurter samples were analyzed at lower temperatures of 5 and 20°C. In our study, both E_0 and η_0 of the Maxwell Model increased, whereas a minor decrease in the values of E_1 and η_1 of Kelvin–Voigt elements was noted with an increase in temperature from 5 to 20°C. A

Table 1. Parameters of Burgers Model (2) derived for refrigeration and room temperature.^a

T (°C)	E_0 (MPa)	E_1 (MPa)	η_0 (MPa·s)	η_1 (MPa·s)	R^2
5	0.263±8 ^a	0.215±6 ^a	52.1±4.0 ^a	0.457±32 ^a	0.990
20	0.284±7 ^b	0.146±2 ^b	74.4±6.3 ^b	0.366±12 ^b	0.997

^a In the columns, mean values with the same lowercase letters in the superscript are not significantly different ($P \leq 0.05$).

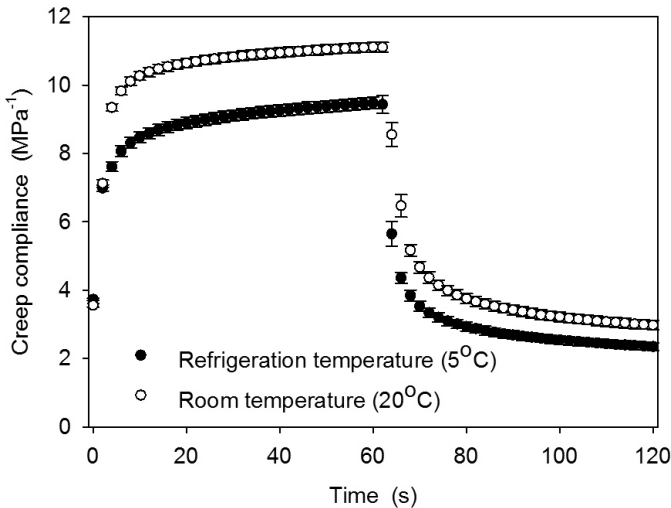


Figure 3. Creep compliance curves of frankfurter samples analyzed at refrigeration and room temperature during compression and recovery phases. The bars indicate standard errors.



similar observation was made by Yilmaz *et al.* (2012a) for an O/W Model of meat emulsions tested over a similar temperature range and they attributed their results to opposite behavior of the emulsion system where oil droplets were deformed under constant shear stress. Their findings cannot be directly compared with the results of our study which analyzed animal fat rather than oil. The consistency and mechanical properties of animal fats stored at refrigeration temperature may be significantly changed even with a small change in temperature (Niñoles *et al.* 2010), and the changes in fat properties may affect the rheological properties of frankfurters. Kanagaratnam *et al.* (2013) found that temperature influenced the mechanical properties of palm oil fat. In their study, an increase in the heating temperature of fat with constant tempering decreased the solid fat content, fat hardness, compressibility and adhesiveness. Choi *et al.* (2009) demonstrated that vegetable fats significantly affected the mechanical properties of meat products. Campos *et al.* (2002) observed that the mechanical properties of animal fats were influenced by their cooling rate. The combined total fat and added water content of sausages should not exceed 40%, whereas the former standard for sausages was 30% fat and 10% added water (US-GPO, 2011). Rezler *et al.* (2005) observed that at room temperature the solid phase of fat significantly affected the rheological properties of the stuffing. The changes in solid phase of meat stuffing caused by the temperature rise led at initial stage to fluidity of fats and release of the water dispersed in fats, which increased the system fluidity.

Table 2. Compliance of the Maxwell dashpot (J_{∞}), Kelvin-Voigt element (J_{KV}), and parameter B fitted to Equation (3) with $C=1$.^a

T (°C)	J_{MAX} (MPa ⁻¹)	J_{SM} (MPa ⁻¹)	J_{KV} (MPa ⁻¹)	J_{∞} (MPa ⁻¹)	B (s)	R ²
5	9.43 ^a	0.269 ^a	6.54 ^a	2.63 ^a	0.303 ^a	0.967
20	11.11 ^b	0.095 ^a	7.77 ^b	3.24 ^b	0.201 ^a	0.986

^a In the columns, mean values with the same lowercase letters in the superscript are not significantly different ($P \leq 0.05$).

Proteins as biopolymers have the ability to increase the viscosity of food products (Yada, 2004). As a result of a change in the protein content in a product are changes in its textural and rheological properties (Yada, 2004; Picout *et al.*, 2003; Sams, 2001). Torres *et al.* (2013) showed a statistically significant effect of temperature on the mechanical properties of the membranes formed from biopolymers originating from *Gallus gallus*. Biopolymer membranes were tested in the temperature range from 10 to 70°C. In this case, Young's modulus showed a linear inverse dependence with regard to the temperature of the sample. Other authors (Watts *et al.*, 1987; Bonser *et al.*, 1995; Chae *et al.*, 2003) also observed the effects of temperature on mechanical properties of protein structures. In view of the above, the significant differences in compliance between sausages tested at room and refrigeration temperatures could be attributed to changes in the rheological properties of the fat and proteins contained within the sausages.

Recovery

Maximum deformation values (J_{MAX}), were observed after 60 seconds of exposure to stress, after which the recovery phase of the compression creep-recovery test began (Figure 3). Parameter C equal to unity was used in Equation (3) to produce the compliance values for the Maxwell dashpot and Kelvin-Voigt elements (J_{∞} and J_{KV}), respectively. The results, parameters B and determination coefficients R^2 , are shown in Table 2. The values of J_{∞} , J_{MAX} and J_{KV} tended to increase with temperature. A

reverse trend showing the effect of temperature on J_{SM} and B was also observed.

In the recovery phase, the decrease in material deformation is measured after the discontinuation of stress. The mechanical properties of a sample are determined by analyzing the contribution of each element in Burgers Model to maximum deformation (J_{MAX}). The following formula can be used to calculate the percentage deformation caused by each element of Burgers Model (Dolz *et al.*, 2008; Yilmaz *et al.*, 2012a):

$$\%J_{element} = \frac{J_{element}}{J_{MAX}} \times 100 \quad (6)$$

Where, $J_{element}$ is the corresponding compliance parameter: J_{SM} , J_{KV} , or J_{∞} . The following formula can be used to calculate the final percentage recovery of the entire system (Dolz *et al.*, 2008; Yilmaz *et al.*, 2012a):

$$\%R = \frac{J_{MAX} - J_{\infty}}{J_{MAX}} \times 100 \quad (7)$$

The contribution of the two components, namely, Maxwell and global Kelvin–Voigt elements, to overall deformation is presented in Table 3. A comparison of samples stored at two temperatures revealed that temperature influenced the contribution of every modeled element to total deformation. The contribution of the Maxwell spring (J_{SM}), to total deformation of the sample was relatively small in comparison with the Maxwell dashpot, J_{∞} , and the Kelvin–Voigt element (J_{KV}), and it decreased with the temperature of the sample. The contribution of J_{∞} and J_{KV} to deformation increased with temperature, indicating that heating lowered the sample's resistance to deformation. In the

above samples, the percentage contribution of the Maxwell dashpot to deformation was greater, reflecting the fact that this gel system was characterized by the most solid behavior. It should also be noted that in the analyzed gel systems, the total contribution of both Maxwell elements [spring (J_{SM}) and dashpot (J_{∞})] to unit deformation was ca. 2.5 times higher than the contribution of the Kelvin–Voigt element (J_{KV}), indicating that the Kelvin–Voigt element contributed less to the deformation of emulsion samples. Similar results were reported by Yilmaz *et al.* (2012a) for an O/W Model of meat emulsions.

The final percentage recovery ($\%R$), values of frankfurter samples are presented in Table 3. The percentage recovery of samples analyzed at 5°C was higher than that of samples stored at 20 °C because lower-temperature samples were characterized by more solid behavior than the samples tested at 20°C. A similar drop in final percentage recovery values with an increase in temperature was observed by Yilmaz *et al.* (2012a) in an O/W Model of meat emulsions with different oil concentrations.

CONCLUSIONS

This study analyzed the influence of temperature on the rheological properties of chicken meat sausages. Burgers Model was used to simulate the viscoelastic behavior of frankfurter samples as a function of temperature. Storage temperature significantly influenced the rheological properties of chicken frankfurters. The lower creep compliance of sausages stored under refrigeration conditions in comparison with the samples analyzed at room temperature indicated that even a small increase in sausage temperature could significantly raise creep compliance. The lower creep compliance of samples stored at 5°C demonstrated that sausages should be mechanically processed at refrigeration temperatures. The rheological properties of

Table 3. Percentage contribution of each element of Burgers Model to maximum system compliance.

T (°C)	% J_{SM} (%)	% J_{KV} (%)	% J_{∞} (%)	%R (%)
5	2.85	27.7	69.3	72.1
20	0.86	29.2	70.0	70.8



sausages determined in this study can be used to optimize manufacturing processes such as crushing, packaging, storage, and transport. Further research is needed to investigate the impact of temperature and composition on the viscoelastic-plastic properties of other processed meat products.

ACKNOWLEDGEMENTS

This study was supported by grant N N313 789140 from the Polish Ministry of Science and Higher Education. We would like to thank Wojciech Regin, PhD student at the Faculty of Technical Sciences at the University of Warmia and Mazury in Olsztyn, Poland, for his help with the measurements.

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ویژگی های خزشی و بازیابی سوسیس فرانکفورتر از گوشت مرغ

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چکیده

در این پژوهش، اثر درجه حرارت روی رفتار گرانیروی برگشت پذیر (ویسکوالستیسیته) سوسیس فرانکفورتر از گوشت مرغ با آزمون بازیابی خزشی بررسی شد. به این منظور، آزمون های فشردگی خزش-بازیافت در درجه حرارت اطاق (۲۰ درجه سلسیوس) و یخچال (۵ درجه سلسیوس) روی نمونه های استوانه ای شکل انجام شد. رفتار گرانیروی برگشت پذیر نمونه ها بر مبنای پارامترهای چهار-عنصری مدل برگرز (Burgers Model) مشخص شد. در طی فاز فشردگی، در نمونه هایی که در حرارت بالاتری مطالعه شده بودند، تغییر شکل بیشتری مشاهده شد و این مطلب با کم شدن مودول الاستیسیته و گرانیروی درونی عناصر کلونین-ویگت (Kelvin-Voigt elements) در پی افزایش درجه حرارت نشان داده می شد. با افزایش حرارت، درصد نهایی باز یافت نمونه های فرانکفورتر کم شد. تفاوت در compliance بین نمونه های آزمون شده در حرارت های مختلف را می توان به تغییرات ناشی از حرارت در خواص چربی سوسیس ها در هنگام آماده سازی نمونه ها نسبت داد.