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RESEARCH NOTE

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Time-dependent Flow Properties of Commercial Kochujang (Hot Pepper-Soybean Paste)

Su-Jin Choi and Byoungseung Yoo*

Department of Food Science and Technology, Dongguk University Seoul 100-715, Korea

Abstract Time-dependent flow properties of commercial kochujang (hot pepper-soybean paste) were evaluated at various shear rates (5, 15, 25, and 35 $\sec^{-1}$) and temperatures (5, 15, and 25°C). Flow properties of all samples showed thixotropic behaviors, which were qualitatively evaluated and quantitatively described by the Weltman, Hahn, and Figoni and Shoemaker models. Time-dependent flow properties of kochujang were found to vary over the range of the shear rate and temperature investigated. Time-dependent models of Weltman and Hahn were suitable (R^2=0.923-0.987) for commercial kochujang.

Key words: flow property, kochujang, hot pepper-soybean paste, thixotropy, time-dependent model

Introduction

Kochujang, a hot pepper-soybean paste, is a typical Korean fermented suspension food that is composed of solid particles dispersed in a continuous medium (1, 2). There are two different types of kochujang referred to as traditional and commercial products. The traditional kochujang is prepared from a mixture of glutinous rice, red pepper, malt flour, *Meju* flour, salt, and water (1). *Meju*, cooked soybean with *Aspergillus oryzae,* is used for enzymatic reaction with proteins in soybean and carbohydrates in glutinous rice. In the preparation of commercial product, koji, which is glutinous rice inoculated with *Aspergillus oryzae*, is used instead of *Meju* (2).

Time-dependency of food suspensions is an important property used when establishing the relationships between structure and flow (3, 4). Therefore, shear stress-time curves recorded at a constant shear rate can provide a means of evaluating structural changes in food suspensions. In general, the time-dependent flow properties in food suspensions have been described by the Weltman (5), Hahn *et al.* (6), and Figoni and Shoemaker (7) models. Yoo (2) found that traditional kochujang exhibited a time-dependent flow behavior at a constant shear rate (0.6 $\sec^{-1}$) and temperature (20°C), and also that Weltman model was more applicable than both the Hahn model and the Figoni and Shoemaker model. Choi and Yoo (8) also recommended the application of time-dependent model of Weltman for food suspensions, such as mustard, tomato ketchup, and bay food, which were measured at different shear rates and temperatures. However, little information is available on the applicability of these time-dependent flow models to commercial kochujang, although many food suspensions, such as salad dressing (9), infant foods (8, 10), fruit concentrate and pulp (4, 11), tomato ketchup (8), and mustard (8), including traditional kochujang (2), have been reported to exhibit time-dependent flow behaviors. In particular, no attempt has been made to examine the time-dependent flow properties of commercial kochujang at various shear rates and temperatures.

The overall objective of this study was to investigate the effects of shear rate and temperature on the time dependency of commercial kochujang under constant shear, and examine the suitability of time-dependent flow models (Weltman, Hahn, and Figoni and Shoemaker).

Materials and Methods

Materials Experimental studies on time-dependent flow properties were conducted with a commercial kochujang (Taeyangcho, Haechandle Co., Ltd., Korea) purchased at a local supermarket. The total solid content (%) of kochujang was 63.2%, which was determined by drying in a dry oven at 105°C to a constant weight.

Measurements of time-dependent flow The time-dependent flow properties of kochujang samples were obtained with a TA AR1000 rheometer (TA Instruments Inc., New Castle, DE, USA) using a parallel plate system (4 dia.) at gap 1000 μm. To quantify the time dependency of kochujang samples at various shear rates (5, 15, 25, and 35 $\sec^{-1}$) and temperatures (5, 15, and 25°C), shear stress-time of shearing data were fitted to the Weltman (5), Hahn *et al.* (6), and Figoni and Shoemaker (7) models:

Weltman model: $\sigma = A - B \ln t$ (1)

Hahn model: $\log (\sigma - \sigma_e) = P - at$ (2)

Figoni and Shoemaker model:

$$\sigma = \sigma_e + (\sigma_{max} - \sigma_e) \exp (-kt) \quad (3)$$

Where, σ is the shear stress at time of shearing (t), σ_e is the equilibrium stress value, σ_{max} is the maximum shear stress, and A, B, P, a, and k are constants. Each sample was transferred to the rheometer plate at a set temperature, and the excess material was wiped off with a spatula. The exposed sample edge was covered with a thin layer of light paraffin oil to prevent evaporation during measurements. Each measurement was taken after a five-minute rest after loading, which also allowed for temperature

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*Corresponding author: Tel: 82-2-2260-3368; Fax: 82-2-2264-3368
E-mail: bsyoo@dongguk.edu

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equilibrium. The samples were sheared at a constant shear rate for 1000 sec^{-1}. All measurements were performed in triplicates. Results reported are an average of three measurements.

Results and Discussion

Typical time-dependent curves of kochujang samples at various shear rates under constant temperature (5°C) (Fig. 1) and various temperatures under constant shear rate (5 sec^{-1}) (Fig. 2) exhibited a characteristic viscoelastic behaviour with a maximum shear stress (σ_{max}) and an equilibrium stress value (σ_e), as reported by Yoo (2) and Choi and Yoo (8). Time-dependent curves in the stress decay region showed that the extent of stress decay depended on the shear rate and temperature. The stress decay with increasing time of shear is a characteristic of time-dependent suspensions and could be explained by two mechanisms: the disintegration of flocculated suspension, and the orientation or deformation of structure of suspended solids caused by the shearing action (12). Table 1 also shows the effect of shear rate and temperature on the time-dependent flow properties of all samples using three time-dependent models (Weltman, Hahn, and Figoni and Shoemaker). Parameters A and P (Eq. 1 and 2) represent the shear stress needed for the structure to start degrading. Parameter B (Eq. 1), a (Eq. 2), and k (Eq. 3) indicate the rate of structure breakdown during shearing. All parameter (A. P, B, a, and k) values increased with the increase in shear rate. Parameter (σ_{max} - σ_e) (Eq. 3), which represents the quantity of breakdown structure for shearing, also increased with the increase in shear rate.

As temperature increases, thixotropy is reduced, as reported by Ramos and Ibarz (12) and Yoo (8) for food suspensions. The parameters σ_{max} - σ_e, A, B, and P of kochujang samples also decreased with the increase in temperature. The decrease in these parameter values with temperature was more pronounced at higher shear rates.

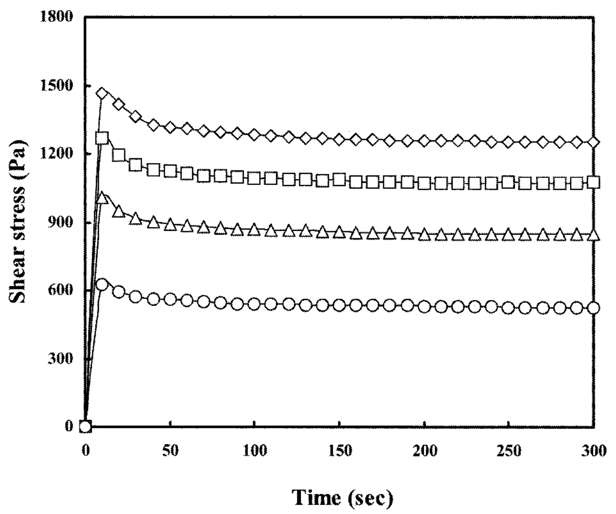

Fig. 1. Time-dependent curves for kochujang samples with different shear rates at a constant temperature of 5°C. 5 sec^{-1} (○), 15 sec^{-1} (△), 25 sec^{-1} (□), 35 sec^{-1} (◇).

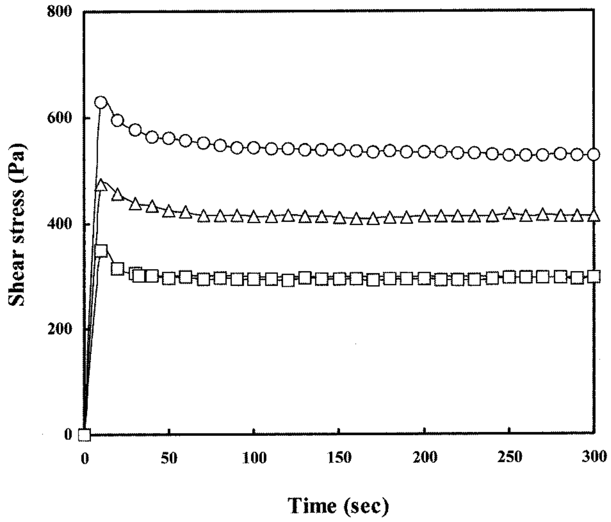

Fig. 2. Time-dependent curves for commercial kochujang with different temperatures at a constant shear-rate of 5 sec^{-1}. 5°C (○), 15°C (△), 25°C (□).

Table 1. Parameters from the Weltman, Hahn, and Figoni and Shoemaker models for commercial kochujang samples at various temperature and shear rates

Temperature (°C)	Shear rate (sec^{-1})	Weltman model			Hahn model			Figoni and Shoemaker model		
		A	B	R^2	a (×10^2)	P	R^2	σ_{max} - σ_e	k (×10^2)	R^2
5	5	713 ± 3.7	39.6 ± 1.8	0.976	1.64 ± 0.16	2.05 ± 0.03	0.970	87.6 ± 0.2	3.23 ± 0.26	0.938
	15	1141 ± 4.4	63.1 ± 0.1	0.968	1.90 ± 0.14	2.26 ± 0.01	0.965	144 ± 4.1	3.76 ± 0.41	0.949
	25	1428 ± 5.7	77.2 ± 2.2	0.960	2.04 ± 0.01	2.33 ± 0.02	0.956	168 ± 0.7	4.21 ± 0.05	0.947
	35	1613 ± 28.5	80.3 ± 3.4	0.951	2.30 ± 0.08	2.43 ± 0.01	0.960	173 ± 7.7	4.41 ± 0.18	0.948
15	5	530 ± 2.4	29.0 ± 0.4	0.979	1.65 ± 0.16	1.90 ± 0.00	0.973	60.6 ± 0.9	3.73 ± 0.16	0.949
	15	794 ± 3.3	41.5 ± 0.4	0.974	1.89 ± 0.18	2.12 ± 0.06	0.971	88.2 ± 0.5	3.89 ± 0.72	0.928
	25	954 ± 2.5	45.1 ± 0.2	0.978	2.22 ± 0.11	2.16 ± 0.03	0.986	91.1 ± 0.9	4.13 ± 0.37	0.923
	35	1103 ± 1.6	47.5 ± 0.5	0.985	2.72 ± 0.04	2.31 ± 0.08	0.974	93.6 ± 0.2	4.16 ± 0.64	0.930
25	5	334 ± 2.4	9.6 ± 0.7	0.958	1.64 ± 0.14	1.40 ± 0.06	0.923	22.1 ± 0.3	3.56 ± 0.10	0.920
	15	501 ± 1.5	11.9 ± 0.6	0.959	1.84 ± 0.10	1.54 ± 0.01	0.981	25.6 ± 0.8	3.74 ± 0.41	0.946
	25	600 ± 1.4	13.6 ± 0.3	0.987	1.94 ± 0.17	1.64 ± 0.00	0.986	28.0 ± 0.9	4.13 ± 0.19	0.941
	35	727 ± 5.1	18.4 ± 0.4	0.966	2.73 ± 0.12	1.85 ± 0.05	0.970	33.8 ± 1.1	4.71 ± 0.54	0.915

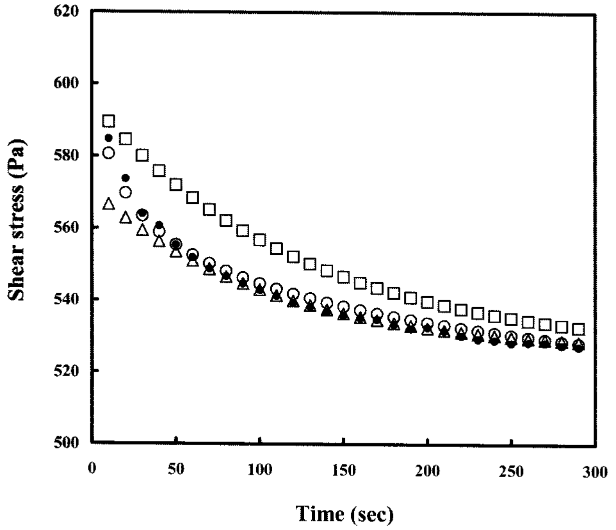

Fig. 3. Shear stress-time plots for predictions of experimental shear stress of a kochujang sample at a constant shear rate of 5 sec^{-1} at 5°C. Dotted lines are predictions by Weltman model (○), Hahn model (△), and Figoni and Shoemaker model (□).

However, in general, there were large variations in the values of parameters a and k. The parameter values obtained from the three models at various shear rates and temperatures revealed that the time-dependent flow properties of commercial kochujang samples depended on shear rate and temperature.

Experimental values in the stress decay region at various shear rates and temperatures were fitted to three time-dependent models (Weltman, Hahn, and Figoni and Shoemaker) (Eq. 1-3) (Table 1). Both the Weltman model (R^2=0.951-0.987) and the Hahn model (R^2=0.923-0.986) fitted the time-dependency data better than the Figoni and Shoemaker model (R^2=0.915-0.949). In a comparison of the experimental and predicted shear stresses (Fig. 3), the Weltman and Hahn models gave better overall predictions of the experimentally measured shear stresses, suggesting that the time-dependent models of both Weltman and Hahn could be recommended for commercial kochujang.

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