Short communication

Stress Growth Behavior of Commercial Mayonnaise under Constant Shear Flow

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The non-linear rheological properties of commercial mayonnaise were studied. The stress growth behavior under constant shear flow was observed using a strain control-type rheometer. As the stress-strain curves of commercial mayonnaise showed non-linear behavior, the curves were analyzed with a polynomial model that is a power series of strain. Two types of commercial mayonnaise were investigated in this study; traditional and low-fat mayonnaise. The second order coefficient of the polynomial model revealed that the structure fracture behavior of these types of mayonnaise was very different. Because the fracture behavior of semisolid foodstuffs is considered to be an important mechanical property, the present approach may be useful for quantitative estimation of the texture of such foods.

Keywords: mayonnaise, rheology, viscosity growth, texture

Introduction

Traditional mayonnaise is an oil-in-water emulsion containing 70-80% oil (Depree and Savage, 2001). Recently, mayonnaise having a reduced oil content has become more common, as excess fat consumption may cause dyslipidemia or diabetes. Such a low inner phase volume fraction emulsion does not show elasticity. Therefore, it is necessary to modify the rheological properties of such foodstuffs. In many cases, texture modifiers are applied in the continuous phase of low-fat emulsion foodstuffs (Trueck, 1997; Wendin *et al.*, 1997; James, 1998; Murphy, 1999). Although the apparent consistency of low-fat mayonnaise can be adjusted similarly to that traditional mayonnaise, the texture of these two types of mayonnaise feel very different to consumers. The steady-state viscosity is generally measured to evaluate the consistency of such semisolid foodstuffs, but it is difficult to evaluate texture from steady-state viscosity.

Many attempts have been made to estimate the deformation behavior of mayonnaise in recent decades. Empirical models have been employed for this purpose, for example, the Casson model (Batista *et al.*, 2006; Guilmineau and Kulozik, 2007), the Herschel Burkley model (Liu *et al.*, 2007; Maruyama *et al.*, 2007) and others (Abu-Jdayil, 2003). Although such empirical equations are useful for estimating

deformation behavior, there are serious problems. Because the deformation behavior under shear stress in semisolid foodstuffs such as mayonnaise strongly depend on time (deformation speed or duration), it is difficult to unequivocally determine the parameters that denote deformation behavior.

We therefore attempted a novel approach to study the deformation behavior of semisolid foodstuffs. Recently, the fracture behavior of agar gels was investigated using a simple power expansion of the Hookean law (Barrangou *et al.*, 2006). Although this attempt was applied to uni-axial compression deformation, it can also be applied to the shear deformation. When compulsory strain is applied to the sample, we can obtain a stress growth curve at a certain shear rate, and the stress-strain curves are obtained from these measurements. The stress-strain curves of actual foodstuffs generally show non-linear behavior; thus, it is necessary to have quantitative estimations for such non-linearity.

The purpose of this study was to estimate the shear deformation behavior (non-linear stress-strain curve) of two types of commercial mayonnaise using the polynomial model, and to suggest a novel method for investigating the rheological properties of semisolid foodstuffs.

Materials and Methods

Materials Traditional mayonnaise and low-fat mayonnaise were purchased from a local store. Both types of mayonnaise are produced by Kewpie Co., Ltd. (Tokyo, Japan).

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Fig. 1. Viscosity growth curves of commercial mayonnaise, for which the shear rate is 0.1 s^{-1} . Open circles and closed circles denote the results for traditional (FM) and low-fat (QM) mayonnaise, respectively.

The traditional mayonnaise, “Kewpie mayonnaise©” and the low-fat mayonnaise “Kewpie quarter©” are hereinafter referred to as FM (full mayonnaise) and QM (quarter mayonnaise), respectively.

Rheological Measurement A strain controlled rheometer, RDA II (Rheometrics, USA), was employed for rheological study. A parallel plate-type fixture (50 mm, gap = 0.2 mm) was used. All measurements were performed at room temperature ($23 \pm 1^\circ\text{C}$)

Data Analysis Stress growth behavior under constant shear flow was measured for each sample. Measurement was performed six times for each sample. As shear deformation was at a constant speed, the strain that was applied to the sample can be described as (1)

$$\gamma = \frac{d\gamma}{dt} t \quad (1)$$

where, γ and t are the strain and time during shear deformation, respectively. Because the value of strain is obtained, we can determine the stress-strain curve (S-S curve) from the experimental results.

The shear modulus can be obtained using the Hookean equation (2), if the S-S curve agrees with the following equation:

$$\sigma = G\gamma \quad (2)$$

where, σ and G are the shear stress and shear modulus, respectively. However, it is expected that the S-S curves for semisolid foodstuffs would deviate from (2). If we are able to estimate the curvature of the experimental S-S curves, the non-linear behavior can be quantitatively estimated.

We attempted a simple power expansion of the Hookean

Fig. 2. Viscosity growth curves of commercial mayonnaise, for which the shear rate is 1.0 s^{-1} . Open circles and closed circles denote the results for traditional (FM) and low-fat (QM) mayonnaise, respectively.

equation (3), as follows:

$$\sigma = P_1\gamma + P_2\gamma^2 + \dots \quad (3)$$

where, P_1 and P_2 are the first order and second order coefficient, respectively. P_1 shows the shear modulus in a very small deformation region. Although the precise physical meaning of P_2 is unknown, the coefficient shows the curvature of the S-S curves. If the sample shows strain hardening behavior, P_2 will be positive, but if the sample shows strain softening behavior, the coefficient will be negative. Moreover, the absolute value of P_2 is related to the intensity of such trends.

Results and Discussion

Typical results for the viscosity growth behavior of FM and QM are shown in Figures 1 and 2 at 0.1 s^{-1} and 1.0 s^{-1} , respectively. The viscosity growth curves were different from one another, particularly at 0.1 s^{-1} (Fig. 1). The curve for FM shows stress overshoot before reaching steady-state flow. On the other hand, the curve for QM only slightly shows this trend. This trend disappeared with increased shear rate; the curves show a similar shape in Figure 2. This suggests that differences in structure fracture behavior in semisolid foodstuffs can be detected by analysis of data at 0.1 s^{-1} .

As mayonnaise is not a true viscous material (it is considered to be a viscoelastic body), the viscosity growth curve may be described as follows (4):

$$\eta^+(t) = \eta_s \cdot h(t) \quad (4)$$

where, $h(t)$ is an unknown damping function based on time

Fig. 3. Stress-strain curve of traditional mayonnaise (FM), for which the shear rate is 0.1 s^{-1} . Circles denote measurement results. Dotted line and solid line denote the first and second order estimation, respectively.

Fig. 4. Stress-strain curve of low-fat mayonnaise (QM), for which the shear rate is 0.1 s^{-1} . Circles denote measurement results. Dotted line and solid line denote the first and second order estimation, respectively.

and η_s is steady-state viscosity. Of particular interest is how the viscosity growth slows during shear deformation. As shown Figure 1, the viscosity growth behavior was very different in these samples. If it were possible to perform quantitative estimation of the stress damping behavior, such information would be more useful than the steady-state viscosity for considering the texture of semisolid foodstuffs. As mayonnaise is too complex a system to determine $h(t)$, we considered another parameter showing the deformation behavior of the sample. The S-S curves can be obtained from these stress growth curves, as noted in the experimental section. Figures 3 and 4 show the S-S curves and the fitting results using (3) for FM and QM at 0.1 s^{-1} , respectively. We were able to obtain useful parameters, P_1 and P_2 , for each sample as a result of analysis. The dotted lines in Figures 3 and 4 show the linear relationship between the stress and strain for each sample using P_1 obtained by fitting. It is clear that both samples show strain softening behavior at the shear rate deformation, and the fitting results agree with the experimental results. Parameters obtained after fitting are listed in Table 1. P_2 describes the intensity of shear softening. As shown in Table 1, the value for FM was larger than that for QM. This means that FM is more fragile than QM, although

its shear modulus was larger than QM. This phenomenon is easily recognized when considering the composition or structure of these semisolid foodstuffs. Although the precise contents of these mayonnaises are unknown, it is clear that the oil content of QM is lower than that of FM; QM is a low inner phase volume emulsion. Such a low inner phase volume emulsion must be treated with viscosity thickeners in order to make its consistency similar to the traditional mayonnaise. However, such modified mayonnaise-like foodstuffs may vary in texture from traditional mayonnaise. The present attempt to use S-S curves produced from shear deformation can detect differences among these commercial mayonnaises.

The relationship between these parameters and sensory test evaluation is quite interesting. One of authors (IK) successfully performed quantitative sensory evaluation of cosmetics using rheological parameters (Nakamura *et al.*, 2009). Further studies are underway and novel findings will be presented in forthcoming papers.

References

- Abu-Jdayil, B. (2003). Modelling the time-dependent rheological behavior of semisolid foodstuffs. *Journal of Food Engineering*, **57**, 97-102.
- Batista, A.P., Raymundo, A., Sousa, I. and Empis, J. (2006). Rheological characterization of coloured oil-in-water food emulsion with lutein and phycocyanin added to the oil and aqueous phase. *Food Hydrocolloids*, **20**, 44-52.
- Barrangou, L.M., Daubert, C.R. and Foegeding, E.A. (2006). Texture properties of agarose gels. I. Rheological and fracture properties. *Food Hydrocolloids*, **20**, 184-195.
- Depree, J.A. and Savage, G.P. (2001). Physical and flavour stability

Table 1. Fitting parameters for commercial mayonnaise.

	P_1 [Pa]	P_2
FM	562 ± 4.74	-1160 ± 66.5
QM	290 ± 18.1	-450 ± 109

- of mayonnaise. *Trends in Food Science and Technology*, **12**, 157-163.
- Guilmineau, F. and Kulozik, U. (2007). Influence of a thermal treatment on the functionality of hens egg yolk in mayonnaise. *Journal of Food Engineering*, **78**, 648-654.
- Liu, H., Xu, X.M. and Guo, S.D. (2007). Rheological, texture and sensory properties of low-fat mayonnaise with different fat mimetics. *LWT*, **40**, 946-954.
- Maruyama, K., *et al.* (2007). Relationship between Rheology, Particle Size and Texture of Mayonnaise. *Food Sci. Technol. Res.*, **13** (1), 1-6.
- Murphy, P. (1999). Low fat developments with specialty starches. *Food Technology International*, **22**, 24.
- Nakamura, A., *et al.* (2009). Novel attempt for quantitative sensory evaluation of cosmetics using the Nutting parameters. *Nihon Reorogi Gakkaishi*, **37** (5), 247-251.