Effect of concentration of porang flour and temperature on rheological properties of tomato ketchup

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Abstract. The rheological properties of fluid and semisolid foodstuffs is important in the design of flow processes in the quality control, storage stability, and in understanding and designing texture of the product. The viscosity of tomato ketchup is one of the major quality components for consumer acceptance. The tomato ketchup is a semisolid material, which obtain its viscosity from naturally occurring pectic substances in fruits. Enzymatic degradation, pectic/protein interaction, pulp content, and homogenization process may affect the consistency of tomato product. These inconsistencies may be diminished by the addition of hydrocolloids. In this study, the flow properties of tomato ketchup were evaluated upon addition of different concentrations of porang flour (0.25%, 0.50% and 0.75%) and in various temperatures (25, 35, 45 and 55 °C). The flow behaviour was characterized by fitting the experimental data of each formulations to the power-law and Herschel-Bulkley model. The Arrhenius equation was used to describe the effects of temperature on the apparent viscosity of the tomato ketchup formulations. The temperature dependency was assessed to evaluate the stabilizing effect of different concentrations of porang flour on tomato ketchup. Increasing porang flour concentration in tomato ketchup resulted in a decline of the activation energy.

1. Introduction

Tomato ketchup is a vegetable sauce made from either cold or hot extracted tomatoes or directly concentrates, purees or tomato paste mixed with sugar, salt, and different spices. One of the major quality attributes of tomato concentrate products is their viscosity. Reliable and accurate rheological data are required for the design evaluation of food processing equipment such as pumps, piping, filters, mixers, and heat exchangers. The viscosity of tomato ketchup affected by naturally occurring pectic substances in fruits. Ketchup produced from tomato varieties with less pectin may result in reduced consistency and other factors such as enzymatic degradations and pectin/protein interaction may also affect the consistency of tomato ketchup [1]. However, the consistency of ketchup can be maintained by addition of different hydrocolloids [2].

Hydrocolloids are hydrophilic molecules with a high molecular weight that serve a variety of functions in food systems including enhancing viscosity, creating gel structure, film formation, inhibition of syneresis, improving texture, and lengthening the physical stability [3]. Porang flour or yellow konjac flour is produced from the tubers of Amorphophallus muelleri, which have yellow natural color and contains a high level of water-soluble glucomannan [4]. Glucomannan is a hydrocolloidal polysaccharide and highly viscous dietary fiber, with frequent application in food industry as a food
Konjac glucomannan was used as a stabilizing agent and gelling or viscosifying agent because of its excellent thickening and water binding properties. Glucomannan hydrate rapidly and absorbing up to 200 times their weight in water (depending on purity) to forms viscous, pseudoplastic dispersions.

The long-term stability of tomato ketchup is very important for consumer’s acceptability. Temperature variation in distribution and storage of tomato product may affect its rheological properties. Hydrocolloids can be added to improve consistency and decrease the effect of temperature on the viscosity of ketchup. Thus, the purpose of this study was to investigate the flow behavior and to determine the temperature dependency of tomato ketchup as affected by the addition of different concentration of porang flour.

2. Materials and Method
2.1. Materials
Commercial tomato paste and other ingredients were purchased from a local market in Malang, Indonesia. Porang flour was produced at our pilot plant facilities, Faculty of Agricultural Technology, Brawijaya University.

2.2. Preparation of tomato ketchup
40 g of tomato paste was diluted with 70 mL of water. This mixture was placed into an open pan and heated at 60°C for 7 min. Subsequently, sugar (13 g), salt (4 g), water (10 mL), and porang flour with different concentrations (0.25%, 0.50%, or 0.75%) were added and the mixture was mixed and heated at 80°C for 7 min. Then, vinegar (2 mL) was added to the mixture and the ketchup was continuously heated at 80°C for 1 min. Ketchup samples were poured into glass jars, sealed with rubber seal screw caps, and then stored in a refrigerator prior to be analysed.

2.3. Rheological measurements
Rheological evaluations were carried out on the tomato ketchup samples using the TA Instruments Discovery Hybrid Rheometer DHR-1. The 25 mm parallel plate geometry was used with a gap of 500 μm and standard Peltier plate as the temperature module. The samples were subjected to a programmed shear rate ramp at different temperatures (25, 35, 45 or 55°C). Shear stress and apparent viscosity as a function of increasing shear rate from 0 to 50 s⁻¹ were recorded. Flow behaviour was described by the fitting of power law (Eq. 1) and Herschel-Bulkley (Eq. 2) model to experimental data:

\[ \tau = k\dot{\gamma}^n \]  
\[ \tau = \tau_0 + k\dot{\gamma}^n \]  

where \( \tau \) is shear stress (Pa), \( \tau_0 \) is yield stress (Pa), \( \dot{\gamma} \) is shear rate (s⁻¹), \( k \) is consistency coefficient (Pa sⁿ) and \( n \) is flow behaviour index (dimensionless).

The temperature dependency of tomato ketchup with different concentration of porang flour was evaluated by fitting the Arrhenius equation (Eq. 3) to experimental data using the consistency coefficient as an indication of the viscous nature of food:

\[ k = k_0 e^{E_a/RT} \]  

where \( k_0 \) is the proportionality constant (or consistency coefficient at a reference temperature, Pa sⁿ), \( E_a \) is the activation energy (J mol⁻¹), \( R \) is the universal gas constant (J mol⁻¹ K⁻¹), and \( T \) is the absolute temperature (K).
3. Results and Discussion

3.1. Flow behaviour

Flow curves of tomato ketchup with the addition of different concentrations of porang flour (PF) observed at different temperatures are shown in Figure 1. The consistency coefficient ($k$), flow behaviour index ($n$), and yield stress ($\tau_0$) obtained by fitting of the power law and Herschel-Bulkley models to the experimental shear stress-shear rate data. Values of rheological models parameters used to describe the experimental flow curves are summarized in Table 1. Values of determination coefficients ($R^2$) show that the power law model was better fitted to the flow curves.

Viscosity function data showed that all tomato ketchups under investigation were non-Newtonian fluid, pseudoplastic (shear thinning) behaviour, as the values for flow behaviour index ($n$) were below 1. The $n$ values of the power law model ranged between 0.19 and 0.36. Therefore, the apparent viscosities decreased with increasing shear rate. Shear thinning flow behaviour of tomato ketchups were reported previously by many authors [2, 8]. Shear thinning behaviour may be induced by orientation of solid particles of tomato paste along the flow lines. The other factor affecting the viscosity of tomato ketchup is the presence of swollen and partially gelatinized starch granules or their fragments, which individual starch granules can be deformed at higher shear rates [11].

| Sample     | Temperature (°C) | Power law | Herschel-Bulkley |
|------------|------------------|-----------|------------------|
|            |                  | $k$ (Pa s$^n$) | $n$ | $R^2$ | $\tau_0$ (Pa) | $k$ (Pa s$^n$) | $n$ | $R^2$ |
| PF 0.25%   | 25               | 108.26    | 0.19 | 0.89 | 70.96 | 18.23 | 0.75 | 0.54 |
|           | 35               | 57.61     | 0.32 | 0.97 | 29.42 | 13.58 | 0.86 | 0.64 |
|           | 45               | 47.36     | 0.32 | 0.97 | 26.36 | 8.86  | 0.95 | 0.71 |
|           | 55               | 30.12     | 0.33 | 0.97 | 17.53 | 5.69  | 0.93 | 0.77 |
| PF 0.50%   | 25               | 95.99     | 0.22 | 0.82 | 58.27 | 12.75 | 0.96 | 0.63 |
|           | 35               | 61.03     | 0.31 | 0.96 | 32.94 | 10.76 | 0.98 | 0.66 |
|           | 45               | 43.26     | 0.36 | 0.97 | 21.20 | 7.83  | 1.05 | 0.64 |
|           | 55               | 45.49     | 0.36 | 0.99 | 20.31 | 12.07 | 0.89 | 0.58 |
| PF 0.75%   | 25               | 80.44     | 0.23 | 0.83 | 38.92 | 19.57 | 0.76 | 0.41 |
|           | 35               | 65.05     | 0.23 | 0.97 | 36.67 | 10.75 | 0.91 | 0.41 |
|           | 45               | 54.67     | 0.32 | 0.98 | 23.94 | 16.00 | 0.80 | 0.55 |
|           | 55               | 46.45     | 0.31 | 0.98 | 21.43 | 12.01 | 0.84 | 0.47 |

3.2. Effect of temperature

Viscosity of fluids significantly influenced by temperature. Energy is supplied to the sample when temperature increase, resulted in the decrease of intermolecular interactions and internal friction during flow, therefore viscosity of the system decreases. For non-Newtonian fluid, the effect of temperature on rheological properties of fluid is described by the value of consistency coefficient ($k$) or apparent viscosity at a given shear rate [11]. The results showed that $k$ values decrease with increasing temperature, which indicate a decrease in apparent viscosity at higher temperatures. Similar results for the effect of temperature on consistency coefficient or apparent viscosity have been reported previously [9, 12, 13].
Figure 1. Changes in shear stress and apparent viscosity with shear rate in tomato ketchup added with porang flour (PF) at three different concentrations (0.25%, 0.50%, and 0.75%) at different temperatures: 25 °C (A), 35 °C (B), 45 °C (C), and 55 °C (D)

The temperature dependence of the viscosity of tomato ketchup was evaluated by using the Arrhenius model. The consistency index, an indication of the viscous nature of food, used to describe the variation in viscosity with temperature. The values of proportionality constant ($k_0$) and activation
energy ($E_a$) obtained by fitting the consistency coefficient data as a function of temperature are presented in Table 2. The changes in viscosity of the fluid with increasing temperature measured by flow activation energy. In general, the higher activation energy resulted in the greater the effect of temperature on the viscosity [14]. The results showed that the $E_a$ values decrease with the increase of porang flour concentrations. Therefore, the addition of 0.25% porang flour had the greatest temperature dependency and the addition of 0.75% porang flour, the least. These results are confirmed by the observation obtained by Koocheki et al. [8], who reported that increasing hydrocolloid concentration in ketchup resulted in a decline of the activation energy. This study indicated that the addition of 0.75% porang flour had the highest stabilizing effect on tomato ketchup.

| Table 2. Parameters of Arrhenius model describing dependence of consistency coefficient on temperature for tomato ketchup thickened with porang flour |
|---------------------------------------------------------------|
| Sample            | $k_0$ (Pa s$^n$) | $E_a$ (kJ mol$^{-1}$) |
| PF 0.25%          | 0.0002           | 32.86               |
| PF 0.50%          | 0.0164           | 21.25               |
| PF 0.75%          | 0.2019           | 14.82               |

4. Conclusions
The results of this study indicated that tomato ketchup supplemented with porang flour behave as non-Newtonian, shear thinning fluid in temperature range of 25 – 55 ºC. Fitting of the power law model to the experimental data was more reliable estimation of the rheological behaviour of the tomato ketchup than the Herschel-Bulkley model. The addition of 0.75% porang flour had the lowest temperature dependency meaning that had the highest stabilizing effect on tomato ketchup.

References
[1] Vercet A, Sánchez C, Burgos J, Montañés L, Buesa P L 2002 The effects of manothermosonication on tomato pectic enzymes and tomato paste rheological properties J. Food Eng. 53 273-278.
[2] Sahin H, Ozdemir F 2004 Effect of some hydrocolloids on the rheological properties of different formulated ketchups Food Hydrocoll. 18 1015-1022.
[3] Dickinson E 2003 Hydrocolloids at interfaces and the influence on the properties of dispersed systems Food Hydrocoll. 17 25-39.
[4] Widjanarko S B, Amalia Q, Hermanto M B, Mubarok A Z 2018 Evaluation of the effect of yellow konjac flour-κ-carrageenan mixed gels and red koji rice extracts on the properties of restructured meat using response surface methodology J. Food Sci. Tech. 55 1781-1788.
[5] Faridah A, Widjanarko S B 2013 Optimization of multilevel ethanol leaching process of porang flour (Amorphophallus muelleri) using response surface methodology Int. J. Adv. Sci. Eng. Inf. Technol. 3 172-178.
[6] Philp K 2018 Polysaccharide ingredients in Reference Module in Food Science Elsevier.
[7] Nishinari K, Kim K, Kohyama K 1987 Solution properties of konjac mannan In 2nd International Workshop on Plant Polysaccharides, Grenoble
[8] Koocheki A, Ghandi A, Razavi S M, Mortazavi S A, Vasiljevic T 2009 The rheological properties of ketchup as a function of different hydrocolloids and temperature Int. J. Food Sci. Technol. 44 596-602.
[9] Sharoba A, Senge B, El-Mansy H, Bahlol H E, Blochwitz R 2005 Chemical, sensory and rheological properties of some commercial German and Egyptian tomato ketchups Eur. Food Res. Technol. 220 142-151.
[10] Sengül M, Ertugay M F, Sengül M 2005 Rheological, physical and chemical characteristics of mulberry pekmez Food Cont. 16 73-76.
[11] Juszczyk L, Oczadły Z, Galkowska D 2013 Effect of modified starches on rheological properties of ketchup Food Bioprocess Technol. 6 1251-1260.

[12] Ibarz A, Garvin A, Costa J 1996 Rheological behaviour of sloe (Prunus spinosa) fruit juices J. Food Eng. 27 423-430.

[13] Alvarez E, Cancela M, Maceiras R 2004 Comparison of rheological behavior of sweet and salad sauces Int. J. Food Prop. 7 511-518.

[14] Nurul M, Azemi B M, Manan D 1999 Rheological behaviour of sago (Metroxylon sagu) starch paste Food Chem. 64 501-505.