Jurnal
Teknologi

Full Paper

EFFECTS OF XANTHAN GUM AND HPMC ON THE STRUCTURE OF SPONGE CAKES

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Article history
Received
15 June 2015
Received in revised form
16 November 2015
Accepted
11 January 2016

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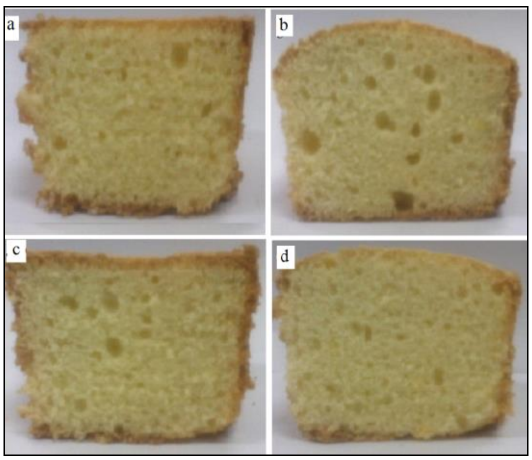
Graphical abstract



Abstract

The effect of xanthan gum and HPMC in foam stability of egg white protein is studied. Due to different functionality of xanthan gum (XG) and Hydroxypropylmethylcellulose (HPMC), there is significant change in foam stability of liquid egg white. Addition of xanthan gum enhanced the foam stability over the storage time compared to addition of HPMC. The viscoelastic properties of sponge cake batters are studied from 25˚C to 95˚C. The early onset temperature for starch gelatinization and denaturation of protein is related with the addition of xanthan gum and HPMC. The physical structure showed that xanthan gum and HPMC affected the structure of sponge cake differently. Xanthan-cake results in more dense structure compared to HPMC-cake.

Keywords: Sponge cake, HPMC, xanthan gum, foam stability, viscoelastic, structure

1.0 INTRODUCTION

In bakery products, the demands for quality and longer shelf life always being study and lead to applications of various kind of additives with the aim to reduce staling [1]. Many studies have related the association of starch molecules and water with the additives as a possible condition to slow the rate of staling which retain the moistness of cakes [2,3]. The additives used are usually focusing on improving dough or batters, volume and crumb texture, while some additives are used to extend the shelf life of baked product during storage [4].

Xanthan gum and HPMC in baked products have been studied due to their ability to form interaction with water and starch. They found that these substitutions increased cake softness and extended the shelf-life, with the disadvantage of lowering its volume [5,6]. However, there is lack of information based on the relationship between batter properties and physical structure of cake especially the significant change in their structure during thermal process.

During heating, it is generally involve the starch gelatinization, denaturation and coagulation of protein. This process also determines the ability of batter to retain the pressure produced by gas formation and their expansion during heating which contribute to the cell structure and volume of the cakes [7,8]. The addition of additives eventually change the ability of batter to develop and reform stable aerated structure during heating and these changes can be observed through the viscoelastic study.

Therefore, the aims of this study are to determine the effect of different hydrocolloids on the foam stability, viscoelastic properties and microstructure of sponge cakes after baking.

2.0 MATERIAL AND METHODS

2.1 Material

Xanthan gum and HPMC were supplied by Sigma Aldrich (USA). Wheat flour, eggs, buttercup and sugar were obtained from the local market (GIANT) in Section 7, Shah Alam, Selangor.

2.2 Preparation of Sponge Cake

Sponge cake was prepared based on Table 1. Egg white was beaten using mixer (Panasonic MK-GH1) at high speed and followed by addition of sugar and continuously beaten for 3 minutes. Next, hydrated hydrocolloid was mixed into yolk mixture and beaten for 1 minute. Finally, yolk mixture, dry ingredients and butter were folded into the creamy mixture. Batter was baked in the oven (Revent International) for 30 minutes at 175˚C and cooled. Cake was stored in zip plastic bag after cooling for 1 hour at room temperature for further analysis.

Table 1 Ingredients of Sponge Cake with and without Addition of Hydrocolloids

Ingredients	Weight (g)			
	Control	1%XG	1%HPMC	1%XG-HPMC*
Wheat flour	23.8	23.8	23.8	23.8
Corn starch	13.8	13.8	13.8	13.8
Sugar	47.5	47.5	47.5	47.5
Egg	55	55	55	55
Buttercup	11	11	11	11
Water	11	11	11	11
Xanthan Gum	-	0.38	-	0.09
HPMC	-	-	0.38	0.28

*The ratio of xanthan gum to HPMC was 0.25:0.75.

2.3 Foam Stability of Egg White

Foam stability of egg white was evaluated based on [9]. 100g of liquid egg white was mixed using a hand mixer (Panasonic MK-GH1) at high speed for 3 minutes. The foam was transferred into 1000 ml graduated volumetric cylinder (Bomex). The volume of emulsified foam was measured and recorded at room temperature until 3 hours. The foam stability was reported as foam volume multiply by 100 and divide by the initial foam volume.

2.4 Rheological Properties of Batter

Effect of hydrocolloids on rheological characteristics of batter was studied in duplicate using Rheometer Physica Antor Par MCR 300 based on [10]. Batters were kept at room temperature for 1 hour after preparation prior to rheological test. For flow properties. A 40-mm diameter plate sensor geometry with a serrated surface and 1-mm gap was employed. A continuous ramp was applied and apparent viscosity was measured as a function of shear rate over the 0.1-100 s^{-1} range at 25˚C for 5 min. Two replicates of each flow curve were run. All curves were adjusted to Ostwald model following power-law equation: $\eta = k\acute{y}^{n-1}$, where η =apparent viscosity, k= consistency index, ý=shear rates and n= flow behavior index. Viscoelastic properties of batter were performed at temperature sweeps from 25˚C to 95˚C, heating rate of 1.0˚C/minute and strain amplitude of 0.0005.

2.5 Microstructure Analysis

The method was based on [9]. Microstructure of cake crumb was determined using Carl Zeiss Subra 40VP (German), scanning electron microscope. The cake was cut into a size of 0.8 x 0.8 x 0.3 cm and freeze-dried for two days. Next, sample was sputter-coated with gold and observed in the microscope at 100x magnification.

2.6 Statistical Analysis

Analysis of variance using SAS 9.1.3 (USA) was performed to determine significant differences between samples.

3.0 RESULT AND DISCUSSION

3.1 Effects of Xanthan Gum and HPMC on Protein Strength of Liquid Egg White

The foam stability of liquid egg white with the addition of hydrocolloids (1% XG, 1% HPMC and 1% XG-HPMC) was shown in Figure 1 and Figure 2.

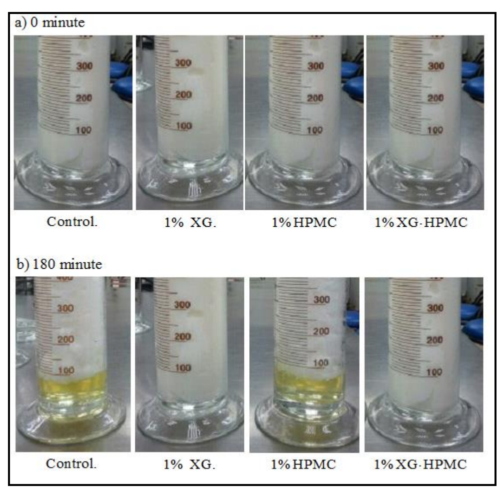


Figure 1 Foam stability and drainage of liquid egg white with and without hydrocolloids at (a) 0 minute and (b)180 minute

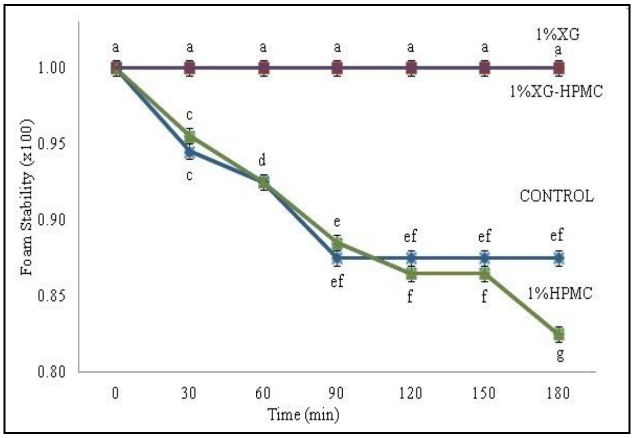


Figure 2 Foam stability of liquid egg white with and without hydrocolloids.Two way ANOVA

In control, the drainage of liquid occurred after 30 minutes until 90 minutes of storage. Then, the drainage remained constant until 180 minutes. However, in 1%HPMC, the drainage of liquid was continuously occurred from 30 minutes until 120 minutes storage and slowly drained at 180 minutes. The foam stability was observed in 1%XG and 1%XG-HPMC since no drainage of the liquid occurred during storage time (0-180 minutes).

Over the storage time, volume of foam reduced and caused drainage of liquid in Control and 1% HPMC. This could be due to the instability of the films where it became progressively thinner and ruptured with storage time. The fluid was lost by lamellar water drainage, at which the van der Waals forces increased between films in adjacent bubbles, thus, resulting in a foam collapse [11].

High foaming stability of 1% XG and 1% XG-HPMC could be related to their high viscosity compared to 1%HPMC and Control. Xanthan gum solution can exhibit high viscosity at low concentration and even at the same concentration as compared to HPMC in egg white protein solution [12].

This was due to the differences in molecular weight and structures of the hydrocolloids. Due to its molecular properties, xanthan gum could adopt helical conformation and bind water molecules in large quantities. At high viscosity, air bubble was highly immobilized due to the considerable motion resistance in the continuous phase. Thus, it maintained the foam stability and reduced the drainage of liquid [13, 14]. Hence, xanthan gum became a support system for the foam structure within continuous phase [15]. On the other hand, the instability of the foam in the presence of HPMC was due to competitive adsorption at the interface between egg white protein and HPMC molecules which weaken the protein strength [16].

3.2 Viscoelastic properties of the batters during heating at 25-95°C

The linear viscoelastic properties were studied during temperature sweep from 25°C to 95°C to observe the structural changes that took place in batter as a substituted of oven heating. G' is the parameter to describe the elastic characteristic (solid-like), while G'' is the parameter that describes the viscous behavior (liquid-like) of a material [17]. The viscoelastic modulus was shown in Figure 3.

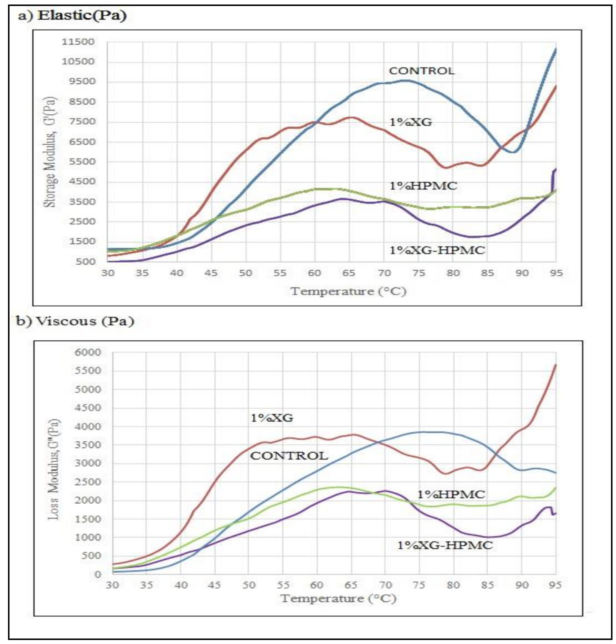


Figure 3 Viscoelastic modulus as a function of increasing temperature (25-95°C)

At the temperature of 45°C, gradual increased in elastic modulus was observed in Control (2521Pa) until it achieved high elasticity at 75°C (9424Pa). Further heating after that temperature caused the elastic modulus to rapidly decline at 85°C (6952Pa), and then increased rapidly at the end of heating with the highest elastic modulus (11180Pa).

According to [18], high elastic modulus during heating of batter is due to the presence of egg white proteins that have high elastic value between 60-85°C and thus able to form network which is stabilized by sucrose as thickening agent in continuous phase of batter [10]. As temperature increased, elastic modulus (G') of Control batter became increased due to protein association resulted from protein aggregation through SH/SS interchange, oxidation and hydrophobic interaction [10, 19].

The elastic modulus of hydrocolloid batters had the same heating pattern as in Control. However, the main difference was the early changes in batter which occurred at lower temperature (65°C). The presence of hydrocolloids in batter might lead to the additional interaction for water molecules apart from the interaction with polymer within the batters which increased its gelation strength [20]. Consequently, it lowered the temperature for starch gelatinization and protein denaturation as the availability of free water molecules was reduced during thermal process, thus accelerated the heating effect on batter structure.

At the end of heating range (85-95°C), there was a progressive increased of elastic values for Control, 1%XG and 1%XG-HPMC but only minor and steady increased in 1%HPMC batter was observed. From this result, it could be assumed that acceleration of protein aggregation had occurred rapidly without HPMC molecules compared to addition of xanthan gum and their mixture [21]. However, elastic modulus of Control still the highest compared to 1%XG and 1%XG-HPMC, indicating that there was physical differences in the heat-set protein foam networks associated with the addition of Xanthan gum and HPMC. High elastic modulus (G') in a cake batter was related with stabilized foam and cake expansion during baking [18].

The viscous modulus during heating was shown in Figure 3b. Viscous moduli of Control and 1%XG were significantly higher than 1%HPMC and 1%XG-HPMC at temperatures 65, 75 and 85°C. However, at the end of heating (95°C), only 1%XG batter showed high viscous modulus (5671Pa) compared to Control (2751Pa), 1%HPMC (2351Pa) and 1%XG-HPMC(1658 Pa). The high values of viscous modulus of 1%XG might be due to its properties which resistance toward high temperature, thus it did not lose their properties as thickening agent [22]. Therefore, it could support the emulsion structure by accelerating the protein aggregation thus increase the strength of polymer network inside the cake. Besides, it did not interfere with the aggregation of protein-protein interaction, but only interpenetrating with the emulsified structure [13]. Therefore, the internal structure of batter could retain the pressure during heating and rapidly increased the viscous values of 1%XG. As reported by [23], an increase in viscous moduli led to the increase of the rigidity of aerated cake structure. In contrast, Control and 1%HPMC batter showed steady and minor increase of viscous moduli, showing that the protein aggregation rate at liquid phase was slower than 1%XG.

The result from Table 2 had supported the presence of strong interaction within the batters between 1%XG, water and starch before heating as it had significant high apparent viscosity (72.57Pa.s) compared to 1%XG-HPMC(31.63Pa.s), 1%HPMC (25.23Pa.s) and Control (22.33Pa.s). These might contribute to the increase in viscoelastic values during initial heating of 1%XG batter. Besides, the protein-protein interactions in batter emulsion also increased the elastic values [8]. This could be observed in 1%XG batter that had maximum value of elastic modulus (4096 and 7048 Pa) within the early onset temperature of elastic modulus (45 and 55°C) compared to Control (2521 and 5947 Pa), 1%HPMC (2611 and 3715 Pa) and 1%XG-HPMC(1667 and 2780 Pa), respectively.

Table 2 Apparent viscosity (Pa.s) of batters at 0.05s^{-1}

	Apparent Viscosity(Pa.s)
CONTROL	22.33 ^{d}±1.51
1% HPMC	25.23 ^{c}±2.85
1% XG	72.57 ^{a}±0.74
1% XG-HPMC	31.63 ^{b}±1.65

Values followed by different letter within the same column were significantly different ($p< 0.05$)

3.3 Effects of Hydrocolloids on Structural Changes in Sponge Cakes

In sponge cake, the effect of hydrocolloids in foam stability (protein network) in batter emulsion could be observed when they were incorporated into the cake formulation (Figure 4). In Control, the crust surfaces of sponge cake tend to collapsed in shape as compared to 1%XG and 1% XG-HPMC cakes. While in 1%HPMC cake, the crust surface was observed in negative curvature (inward). Both 1%XG and 1%XG-HPMC exhibited positive curvature (outward) which reflected a stable protein network in the sponge cake.

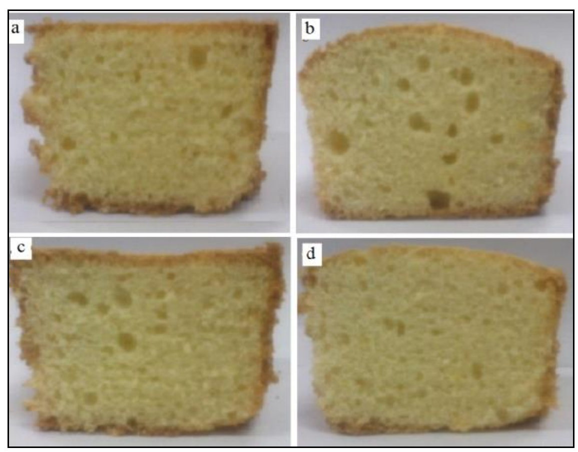


Figure 4 Sponge cake structure and coalesced bubble formation; a (Control), b(1%XG), c(1%HPMC), d(1% XG-HPMC)

In control batter, the dispersion of fat in batter emulsion might cause the thinning of the lamella between bubbles, which might lead to film destabilization and air bubbles collapse [13]. The presence of lipid at interface had disrupted the interfacial film of protein, thus caused air to escape during heating and cooling [24].

The negative curvature in 1% HPMC cakes was similar to observation of [25] in rice cake formulation at high concentration of HPMC. The air bubbles entrapped into the batter during mixing could not remain in the cake during baking period because of high surface activity of HPMC at interface [16]. Finally, it affected the interfacial film by interrupting protein-protein network through its competitive binding at interface of oil phase. This result supported the behavior of HPMC as a surface active molecules in batter emulsion which had have competed with protein, thus interrupted the protein network in sponge cake. More air was escaped during cooling.

The physical structures of 1%XG-HPMC and 1% XG were improved as both cakes maintained the positive curvature shape (inward) of crust. However more coalesced bubbles were observed in the crumb due to high concentration of xanthan gum (1%). This also supported the behavior of xanthan gum as thickening agent in batter emulsion which caused rapid coalescence of air bubbles due to its high viscosity [12]. In 1%XG-HPMC, the stable crust structure was observed even after the heat treatment.

This proposed that the addition of low concentration of xanthan gum and HPMC resulted in good emulsion stability. This was supported by [26] where low concentration of xanthan gum (maximum 0.2%) in continuous phase resulted in decrease in oil droplet diameter and enhanced the water phase viscosity and created a network which slowed down the movement of oil droplets and their collisions.

3.4 Microstructure Analysis

The micrographs in Figure 5 showed the inner surface structure of the sponge cake using a scanning electron microscope (SEM) analysis with 100x magnification.

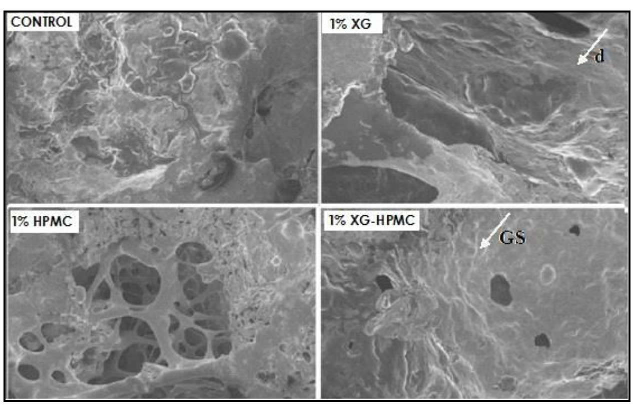


Figure 5 SEM micrograph for sponge cakes (100x magnification). Arrows indicate d (deformed starch structure); GS (granular starch residues)

Generally, more uniform structure was obtained when hydrocolloids were added into the cake formulations. From the observation, Control cake had both small and large pores and the distribution of the pores was not homogenous. Protein matrix was also visible in the microstructure of Control-cake. However, starch granules were not clearly visible as shown in 1% XG cake. In 1% XG cake, xanthan gum thickens the crumb air cell walls. Due to its high concentration (1%), it enhanced the compact structure. Starch granules residue was wrapped by xanthan gum. [27] also observed the same pattern in bread containing xanthan gum. Micrograph of crumb of cake containing 0.5% xanthan gum and emulsifiers wherein only few starch granules with distorted outlines embedded in thick protein matrix can be seen. Some of the starch granules are completely wrapped with xanthan gum.

In 1% HPMC cake, protein matrix and a few partial outlines of starch granules were visible in the microstructure of the cake. A smooth texture of crumb cake could be observed and the gas cells showed more continuous surface with a thicker appearance compared to control cake, similar to [28] in their work in eggless cake containing HPMC. In comparison with the Control cake, the hydrocolloid-cakes had void spaces and also showed a condensed arrangement of smaller holes. In 1% XG-HPMC, combination of xanthan gum and HPMC created smooth, compact and also void spaces within the crumb.

4.0 CONCLUSION

The addition of xanthan gum and HPMC at 1% level in foam stability and viscoelastic properties of batter exhibited different effects on protein network. In foam stability, xanthan gum was able to maintain its structure over the storage time compared to HPMC due to its thickening properties which hindered the drainage of liquid.

Low viscoelastic moduli in batter were related with the inappropriate bubble expansion due to their interaction with starch and water and also because of the instability of aerated structure itself which could not retain the gas formation.

High viscous modulus at the end of heating was related with the dense structure of cake. This result could be observed in microstructure studies at which xanthan-cake exhibited thick wall and compact structure compared to HPMC-cake. The effect of HPMC on protein network was more preferred compare to effect of xanthan gum as the crumb structure of HPMC-cake was less dense compared to xanthan-cake.

Acknowledgement

The authors thank Faculty of Applied Sciences and MITRANS UiTM Shah Alam, Selangor, Malaysia and gratefully acknowledge the financial assistance from Research Management Institute (RMI), Universiti Teknologi MARA. The Fundamental Research Grants (600-RMI/FRGS 5/3 (148/2013)) is acknowledged.

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