ASM Sc. J., 13, Special Issue 4, 2020 for NCAFM2018, 45-52

The Effect of Mixing on the Aeration Structure of *Kuih Bahulu*

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Aerated food is appreciated mainly due to its structure that able to produce different sensory characteristics. *Kuih Bahulu* can be classified as an aerated baked product in which the aeration is achieved by mechanical whipping. The aeration method was differentiated to explore the impact of mixing towards the aeration structure of *Kuih Bahulu*. In the manual process, a spring whisk that is bounced up and down was used, while in the automated process, a planetary mixer, with wire whip attachment was used. The highest 171% overrun was achieved from a foam of 15 minutes of automated mixing. Rheologically, both *Kuih Bahulu* batter showed a shear thinning behaviour, (n < 1) in a range of 0.7 to 0.8. The cake produced from the automatically mixed batter had lower cake volume 563 cm^3 than the manually mixed batter, the air bubbles in the batter were more compact with an average air bubbles distance 227.0 ± 62.0 µm and smaller in size with an average diameter of 140.6 ± 42.5 µm.

Keywords aeration; aerated food; Kuih Bahulu; mixing

I. INTRODUCTION

Foods with bubble formations are regarded as aerated foods. The bubbles are considered as one of the food ingredient (Campbell & Mougeot, 1999; Germain & Aguilera, 2014). Bubbles are exploited to give versatility and novel properties to the final food products especially to the texture, appearance and shelf life (Campbell & Mougeot, 1999; Germain & Aguilera, 2014; Jang *et al.*, 2005; Lau & Dickinson, 2004). Aerating food can result in a reduced in the product density, change in the texture and rheology, increased surface area, modification of digestibility, a decrease of flavour intensity and shorter shelf life (Campbell & Mougeot, 1999; Germain & Aguilera, 2014).

Generally all bubbles or foams initially in liquid form (Germain & Aguilera, 2014). Foam is a colloid system, with water as the continuous phase and the gas bubbles (or air) as the dispersed phase. The presence of interfacial surface tension interconnecting these two phases and lead to its stability. However, thermodynamically, the foam is considered unstable (Campbell & Mougeot, 1999). Bubbles may coalescence, coarsening and disproportioning (Jang *et al.*, 2006; Lazidis *et al.*, 2017)

It is known that properties of foam differ based on the method and equipment used to achieve foaming (Phillips *et al.*, 1987) and the methods to achieve aeration can also be used to categorize aerated commonly used food (Campbell & Mougeot, 1999). The simplest and most useful aeration method for quantifying the foam properties (Phillips *et al.*, 1990; Phillips *et al.*, 1987) is via mechanical action or mixing. Mixing of cake batter is required for combining all ingredients into a homogeneous batter and stable emulsion (Wilderjans *et al.*, 2013). Air bubbles incorporation is also believed initiated at the stage of batter preparation (Brooker, 1993). The properties of the foam are primarily affected by the stirring parameters during mixing, for instance, impeller type, mixing speed and time (Jang *et al.*, 2005; Lomakina & Mikova, 2006; Spencer *et al.*, 2008) and other intrinsic

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properties such as viscosity, surface tension and the continuous media (Jang *et al*., 2005).

Kuih Bahulu can be classified as an aerated baked product in which the aeration is achieved by mechanical whipping. It is also a foam cake type similar to sponge cake, in which the fat content is contributed by the composition of egg yolk (Miller, 2016). The process of making Kuih Bahulu begins with the creaming of egg and sugar and then followed by folding of flour into the mixture. These processes are described as two steps, single mixing in the foam type cakes batter processing (Wilderjans *et al*., 2013)

Kuih Bahulu is listed as one of Malaysia intangible heritage food by the National Heritage Department (Negara, 2019). *Kuih Bahulu* is one of the many usually snacks that are served during festive occasions and still popularly eaten as everyday afternoon tea snacks to the locals (Raji *et al*., 2017). Abdul Wahid (2015) also mentioned that the effort to introduce *Kuih Bahulu* as one of the tourism's food is hindered by the food quality. To date, there are no studies on the food quality aspects of this cake, except on the proximate analysis by Rosniyana *et al.* (2003) and the gap perceptions analysis between producer and consumer of the cakes by Abdul Wahid (2015); Abdul Wahid and Mudor (2016); (Mudor, 2010); Wahid (2009).

Therefore, this study aims to compare the aeration structure includes foam characterization, batter density, batter rheology and images, alongside the characteristics of *Kuih Bahulu* such as cake volumes produced from the automatic and manual mixing process.

II. MATERIALS AND METHODS

All materials were sourced from the local hypermarket (Tesco Sg Dua, Penang). *Kuih Bahulu* batter was prepared by mixing the L size eggs (38 % w/w) and granulated sugar (30 % w/w). Wheat flour (32 % w/w) was then folded in the mixture. The batter was then filled in the mould (flower shaped, about 40mm diameter) and baked in the convection oven (Bakbar Turbofan 32, New South Wales, Australia) at 180°C for 20 minutes.

A. Mixing Parameters

In the automated process, wire whisk beater was attached to a heavy duty stand mixer (Kitchen Aid Model 5K5SS, USA). The mixer speed was adjusted to speed 5, and the mixing process was continued for 15 minutes**.** While in the manual process, the spring whisk beater was used, and the mixing process also continued for 15 minutes. In every fifteen minutes of manual mixing, an average of 400 strokes of beating process occurred**.**

B. Foam Characterization

Overrun measurements of the batter were done according to the methods of Lau and Dickinson (2004); Phillips *et al.* (1990); Phillips *et al.* (1987); M. C. Tan *et al.* (2011) with a slight modification to prevent entrapped air pocket in the foam. The eggs were stirred with sugar in 1:1 ratio for 15 minutes in the pre weighted stainless steel container. At every 5 minutes interval, the foam was scooped out, filled in a cup and levelled. The mixing process was paused briefly, and the egg-whipped was then weighed. The period of pausing and resuming was minimized to 2 minutes. The same procedures were also implemented in the manual process. The overrun is calculated based on Equation 1. Experiments were carried out in triplicates.

$$\text{Overrun} = \left(\frac{\rho \text{ of unaerated batter}}{\rho \text{ of aerated batter}} - 1\right) \times 100 \qquad (1)$$

C. Batter Density

Batter density was measured following the methods described by Mei C Tan *et al.* (2010); M. C. Tan *et al.* (2011). A cup with a volume of 83 cm^3 was used and measured at room temperature. The batter was then filled in the cup, leveled of the top surface with cautious using a spatula to prevent large air pocket trapped in the batter. It was then weighted in the weighing balance. The batter density, ρ_{batter} is measured as:

$$\rho_{\text{batter}} = \frac{\text{mass of batter (g)}}{\text{Volume of cup (cm3)}} \qquad (2)$$

All experiments were carried out in triplicates in both automated and manual mixing process.

D. Batter Rheology

The rheology measurements were carried out using Rheometer (AR1000-N, TA Instrument, New Castle, USA). A cone and plate, 40 mm, 2° geometry was used to characterize the steady-state flow behaviour. The shear rate ramp (10 to 10^3 Pa) was set in the rheometer. The excess batter was removed, and silicone oil was applied to each sample prior to rheology measurements to prevent drying. Data of shear rate-shear stress was plotted and then fitted to the Power Law model in Equation 3.

$$\tau = K\gamma^n \tag{3}$$

where τ is shear stress (Pa); γ is shear rate (1/s); K is consistency index (Pa.s^n) and n is the flow behaviour index. K and n value were obtained from the Power Law model linearized graph plot.

E. Batter Images

Samples were freeze-dried for 48 hours at 25 °C in a freeze dryer (LD53, Millrock Technology, New York, USA) and then followed in oven drying (ED 23, Binder, Germany). Batter samples in 1x1 cm cube sizes were prepared and coated with gold/palladium before subjected to electron scanning. A Scanning Electron Microscopy (EVO I MA 10, Carl Zeiss, Germany) with magnification of 20x and 25x were used accordingly for the bubble's images acquisition. Image J software was used to measure the distance and the air bubbles population of the images.

F. Cake Volume

Cake Volume is measured using coriander seed displacement method as described by Tan, *et al.* [31]. The bulk density of the coriander seed is measured in a 1440 cm^3 rectangle container by filling in full with seed. The surface was levelled using a ruler and the weight of the seed is weighted until a constant weight is achieved for three consecutive reading. A value of 0.253 g/cm^3 was then used as the seed density, ρ_{seed} for the cake density measurement. For the cake density measurement, 1000 cm^3 coriander seed was first poured in the rectangle container. A cake was then placed inside the container, and the remaining space was then again filled with coriander seeds. The surface of the container is levelled to remove excess seed and the container is then weighted, obtaining the W_{seed}. V_{seed} which is the volume of seeds occupying the space within the cake is calculated by dividing the W_{seed} with its density, ρ_{seed}. The formula is given as in Equation 4 below. In order to get the cake volume, V_{cake}, the volume of the empty container, $V_{container}$ (1440 cm^3) is then subtracted with the volume of occupied seed, V_{seed}. The calculation is simplified as in Equation 5.

$$V_{seed} = \frac{W_{seed}}{\rho_{seed}} \tag{4}$$

$$V_{seed} = \frac{W_{seed}}{\rho_{seed}} \tag{5}$$

III. RESULTS AND DISCUSSION

A. Overrun

In this experiment, the overrun was measured during the creaming of egg products and sugar. Before mixing, the mixture was only whole eggs and sugar. After 15 minutes of mixing, the foam was created. From the visual observation, the mixture was turned lighter in colour as well as changed in viscosity.

Overrun for both types of *Kuih Bahulu* foam studied were depicted as in Figure 1. Overrun which is also foam expansion or foaming capacity is the air content of an aerated food (Lau & Dickinson, 2004). The graph shows that the highest overrun after 15 minutes of mixing was achieved from automated processing with a final value of 171 % while the manual processing showed a lower overrun of 120 %. Both foams showed an increment in overrun value during the mixing process. It is a typical foam phase indicating that rapid air incorporation occurred in the mixture (Jang *et al.*, 2005; Lau & Dickinson, 2004).

The highest overrun from automated processed foam is contributed by the design of the planetary mixer, which has a dual motion that gives maximum contact area to the entire container *(Delaplace et al., 2007)*. In the manual processing, the pattern of beating poses a tendency to follow the viscosity of the mixture, therefore there is a possibility of work input is varying at each time due to the change of viscosity and making it harder to incorporate more air *(Lau & Dickinson, 2004)*. In the manual mixing, the horizontal action gives a longitudinal velocity to the component mixture in which the velocities are parallel to the mixer, while in the automated process the component mixture received rotational velocities that are tangential to the mixer shaft *(Fellows, 2009)*.

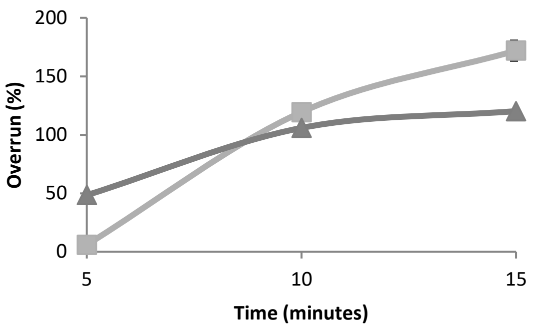


Figure 1. The overrun achieved after 15 minutes of mixing for both type of processes, □ showed automatically processed batter, while ∆ represented the manually processed batter

B. Batter Density

The density of the batter indicates the amount of air content in the batter. In this experiment, the density of the batter is calculated after the aeration process and addition of flour. The batter density for both batter types was illustrated in Figure 2.

The manually processed batter showed a lower batter density (0.65 g/cm^3) than the automatically processed batter (0.84 g/cm^3). The incorporation of air decreases density and modifies batter viscosity (Edoura-Gaena *et al.*, 2007). In this study, the correlation was not found as the automatically processed batter that had the higher batter density also showed the higher foam overrun. This might be contributed by the mode of incorporation of the batter. In this study, the density was measured after the flour was added to the foam and folded until well-mixed. The incorporation process was monitored visually, without a quantification of the degree of mixing. Allais *et al.* (2006) found that the aeration effect is affected by the incorporation mode, and 'two-stage" incorporation increased the batter density. A paired-samples t-test was conducted to compare the batter density for both types of mixing methods. There was a significant difference in the scores for the manually processed batter (M=0.654, SD=0.02) and the automatically processed batter (M=0.841, SD=0.04) conditions; t (3) =-8.19, p = 0.003. The observed difference between the sample means (0.654 - 0.84) is convincing enough to say that the average number of batter density between the manually processed batter and the automatically processed batter differ significantly.

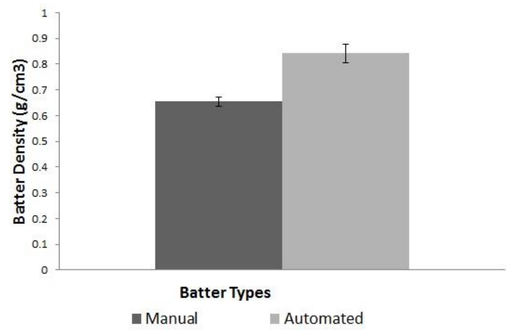


Figure 2. The batter density achieved after 15 minutes of mixing for both type of processes

C. Flow Behaviour

The apparent viscosity curves for the *Kuih Bahulu* batters were shown in Figure 3. The apparent viscosity was decreasing at the increasing shear rates for the batter irrespective the processing they underwent. This indicated that both batters followed the shear thinning behaviour. The same flow characteristic was also found by Ronda *et al.* (2011) in layer cakes batter, Chesterton *et al.* (2011), Busarawan and Pongsawatmanit (2011) for sponge cake batter and Allais *et al.* (2006) in lady finger's batter.

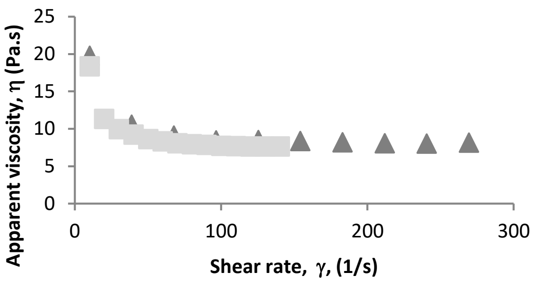


Figure 3. The flow behaviour of *Kuih Bahulu* batter, □ showed the automatically processed batter, while Δ represented the manually processed batter

The wall slip occurred at different shear rates, with the manually processed batter able to resist higher shear rates than the automated mixing. Lau and Dickinson (2004) correlated wall slip as foam structure breakdown in the high sugar system. It was suggested that roughening the contact surface may prevent the wall slip occurrence (Germain & Aguilera, 2014)

Table 1. The flow behaviour index, n and consistency index, K of the Kuih Bahulu batter

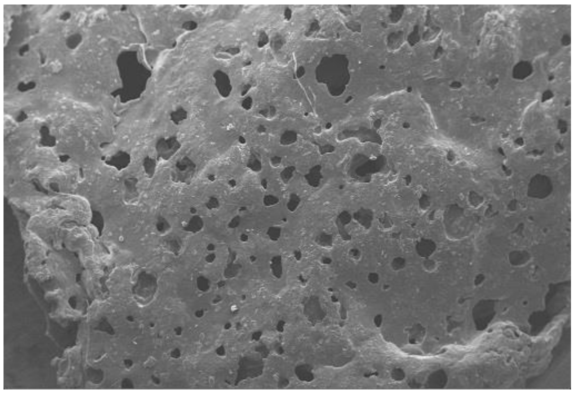
Processing Condition	*n*	*K*	R^2
Automated	0.76 ± 0.02	25.81 ± 2.32	0.985
Manual	0.68 ± 0.02	46.61 ± 0.18	0.974

The shear rate-shear stress data were then fitted to the Power Law model, giving a good fit with R^2 value > 0.97. Data of *K* (consistency index) and flow behaviour index (*n*) were shown in Table 1. Both batters showed a flow behaviour index, $n < 1$, agreeing a shear thinning behaviour in which the flow index was around 0.7. The inverse relation of *K* value and *n* value found in this study is similar to the previous study on sponge cake (M. C. Tan *et al.*, 2011).

D. Image Analysis

The images of the bubbles are an indication of air distribution in the batter. Both batter types were then subjected to electron scanning to capture the images of the dehydrated batters. Figure 4 showed the aeration structures of the *Kuih Bahulu* batter.

a)



b)

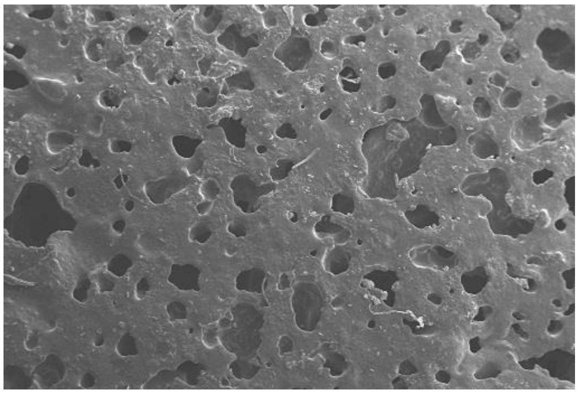


Figure 4(a) and (b). Air bubbles of the batter captured by SEM for a) automatically processed batter b) manually processed batter

From the SEM images of the batter, it showed that a compact air bubbles were found in the automatically processed batter. From the Image J software, the average distance between bubbles in the automatically processed batter obtained was 227.0 ± 62.0 µm while the average distance in manually processed batter was 289.9 ± 78.0 µm. The bubbles population from the Image J showed that automatically processed batter was around 797 and the population in the manually processed batter was around 1387 bubbles. The SEM images captured that the smaller bubbles with an average of bubbles diameter size 140.6 ± 42.5 µm existed in the automated process. Larger bubbles were found in the manually processed, with an average of bubbles diameter size 155.8 ± 21.4 µm. These results might be contributed to the better air incorporation and dispersion achieved by using the automated planetary mixer.

E. Cake Volume

The cake volumes of *Kuih Bahulu* were shown in Table 2. The highest cake volume was achieved from the manually processed batter, 607 cm^3 compared to automatically processed batter that had a volume of 563 cm^3.

Table 2. The relation between K value for Kuih Bahulu batter and final cake volume of the Kuih Bahulu

Processing Condition	*K*	Cake Volume (cm^3)
Automated	25.81 ± 2.32	563 ± 5.33
Manual	46.61 ± 0.18	607 ± 19.12

A linear correlation between cake volume and *K* value was obtained from this study. The higher *K* value was also the higher volume of cake, which is from the manually processed batter while the lower *K* value and lower cake volume were from the automatically processed batter. Edoura-Gaena *et al.* (2007) speculated that this is due to the capacity for air retention in the batter. The specific volume of the cake indicated the remaining air in the cake (Busarawan & Pongsawatmanit, 2011). The ability of the batter to retain the air resulted in volume expansion and higher specific volume of the cake.

IV. CONCLUSION

The study was intended to investigate the aeration structure of *Kuih Bahul*u produced by two different processing techniques. *Kuih Bahulu* was made from eggs, sugar and flour. There was no leavening agent used, and aeration was primarily achieved from the mixing process. In terms of overrun, automatically processed foam showed higher overrun than manually processed. In the automated process, *Kuih Bahulu* foam had a final overrun of 171 % higher than the manually processed batter, which was 120%. The two stages mixing in the incorporation of flour affected the batter density and consequently put the automatically processed batter had higher batter density. *Kuih Bahulu* batter displayed shear thinning behaviour as it showed *n* value < 1, when fitted to Power law Model. The *K* and *n* were inversely related, with a value range from 26 to 47. The lower *K* value was related to lower cake volumes were observed in this experiment. The automatically processed batter had higher viscosity and lower cake volume. While manually processed batter had vice-versa properties; lower viscosity and higher cake volume. In the air bubbles images, the manually processed batter had larger air bubbles than the automatically processed batter. This study had proven that the selection of the mixing process could affect the quality of the *Kuih Bahulu* batter, both in the macro and micro scales. Therefore, it is suggested that to study the microscopic scale structure to have an in-depth understanding of the bubble's formation and interaction.

V. ACKNOWLEDGMENT

The authors would like to express their appreciations and gratitude to all staff of the Food Technology Division, School of Industrial Technology, USM especially, En. Mohamad Firdaus Mohd Adnan, En. Abd Rahim Md Sari and En. Shamsul Zoolkifli for their help in the experimental work.

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