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Impact of Aeration Time on the Density and Rheological Properties of Batter

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ABSTRACT

The impact of aeration time on the density and rheological properties of a batter was determined. The batter was made by mixing sugar, margarine, eggs, and flour. While the sugar and margarine was creamed together, the eggs were whisked into foam and was added to the creamed sugar and margarine. Flour was added and the mixture mixed at 1 to 5 min for aeration control. Samples were collected at 1 min interval and labelled A, B, C, D, and E. The result of the batter density at different aeration time showed a decrease from 0.98 to 0.83 g/cm^3 with a corresponding increase in the aeration time from sample A, 1 min to sample E, 5 min. The viscosity result increased from 1465 to 1681 cP as the aeration time increases from sample A, 1 min to sample E, 5 min. The flow index increased from 0.14 to 0.15 with a corresponding increase in the aeration time from sample A,1 min to sample E, 5 min respectively. This study reveals that aeration time did not have effect on the flow index (0.14 to 0.15) indicating a shear-thinning fluid behaviour which can easily flow and good for smooth spreading in pans. These findings have important implications for the food industry for good batter preparation that will produce consistent quality cake.

Keywords: Impact, aeration time, density, rheological properties, batter

1.0 Introduction

Aerated food products such as cake batters, are a complex systems where the incorporation and retention of air significantly influence their physical, sensory and functional properties. The quality of cakes characterized by a light, fluffy texture and uniform crumb structure- depends heavily on the rheological properties of the batter which are governed by factors such as ingredient composition, mixing techniques, and processing conditions. The process of mixing turns batter into a complex emulsion that, increases its viscosity, and enhances its ability to hold onto air bubbles when baking (Hesso *et al*., 2015). One crucial element affecting the final cake volume is the integration and mobility of air bubbles in the batter. The ability of the batter to hold onto air before the cake sets is reflected in the rate at which air bubbles rise due to buoyancy. Consequently, a lesser cake volume is produced by a faster rate of air bubbles in a low viscosity batter (Baixauli *et al*., 2008).

Rheology, the study of flow and deformation, is critical in understanding how batters behave during mixing, pumping, and baking, ultimately affecting the final product’s volume, texture, and consumer acceptability. Density control, achieved through aeration during mixing, is a key parameter that modulates these properties by altering the incorporation of air bubbles, which affects bulk density, viscosity, consistency, and flow behavior. Several research has been done on batter. Yee *et al*., (2018), studied the effect of partial sugar replacement with ultrasonically treated citrus pectin on aeration and rheological properties of batter, while, Mahsa *et al*., (2010), studied the simultaneous reduction of fat and sugar in cake production; effects of changing sucrose, oil, water, inulin, and Rebaudioside: A on cake batter properties. Also, a study was done on the effect of shortening with oatrim on the physical and rheological properties of cakes by Lee, *et al*., (2005). Despite these researches carried out on batter, there is little or no information on the effect of aeration time on the density and rheological properties of batter. Hence, the objective of this study is to understand the effect of vary aeration time on the density and rheological properties of batter.

2.0 Materials and methods

The wheat flour, sugar, margarine and eggs used were bought from Ekenonwa market in Owerri, Imo State while the preparation and analysis were carried out in the quality control laboratory at Federal Polytechnic Nekede, Owerri. Equipment used were Hubert B-20F mixer, Brookfield viscometer DV II+ Pro, and weighing balance.

2.1 Preparation of cake batter

The formulation of the batter was prepared according to Kim et al. (2012) with modification. Sugar (180 g) and shortening (160 g) were creamed for 5 min at 173 rpm in a Hubert B-20F mixer, China. Liquid whole eggs (160 g) were whipped with Hubert B-20F mixer, China for 5 min at 173 rpm. The whipped eggs were added to the creamed sugar and shortening and mixed for 3 min at 58 rpm for homogeneity. Finally, the flour (100 g) and baking powder (1.7 g) were added and mixed for 1 to 5 min at 58 rpm for aeration of the batter. Samples were collected at each min interval and labelled A, B, C, D and E respectively.

2.2 Determination of batter density

The method as described by Gomez *et al*., 2010 was used. The batter density was calculated by dividing the mass of the batter with the volume of the container. 5g of the batter was weighed into a 250 mL measuring cylinder, filled with water up to 100 mL, and the difference in volume was noted and recorded. The measurement was done in duplicate

$$Density = \frac{Mass}{Volume} \qquad (1)$$

2.3 Determination of batter rheology

A Brookfield DV II+ Pro viscometer was used for the rheological determination of the batter according to Gomez *et al*., 2010 with modification. 100g of the batter was placed inside a 250 mL beaker, and an RV cylindrical spindle no 5 attached to the viscometer was continuously stirred to obtain the data for, viscosity, η, shear stress, τ (Pa) and shear rate, γ (s^{-1}) at 50 s^{-1} for 2 min and the log data of the shear stress and shear rate fitted into the power law model in equation 2 to calculate the consistency index, K ($Pa.s^{-1}$) and flow index, n was from 3 to 50 s^{-1}. The measurement was done in duplicate.

Power law equation

$$\tau = k\gamma n \qquad (11)$$

Where:

τ = shear stress (Pa)

γ = shear rate (s^{-1})

k = consistency index ($Pa.s^{-1}$)

n = Flow behavior index (Dimensionless)

3.0 Results and Discussion

Batter density and viscosity

The density of batter is closely associated with its aeration level and ability to hold air bubbles during the mixing process, which is notably affected by viscosity and the composition of the batter (Gomez *et al*., 2007). A well-aerated batter, attained through proper mixing techniques, usually results in cakes that have a light and porous texture, serving as a clear sign of decreased density (Christaki *et al*., 2017). The data shown in Table 1 illustrates a distinct trend, with the density of the batter decreasing from 0.98 g/cm³ in sample A (aerated for 1 minute) to 0.83 g/cm³ in sample E (aerated for 5 minutes) as the aeration time increased. This gradual decline implies that sample E, exhibiting the lowest density of 0.83 g/cm³, is likely to produce a cake with an ideally airy and light texture, marginally better than samples A through D, due to improved incorporation of air bubbles. Thus, extending the mixing time to capture a larger volume of air bubbles proves beneficial for baking cakes with a premium texture, highlighting the essential role of aeration time in batter optimization.

Viscosity is a significant measure of how effectively air bubbles are integrated and retained within the batter, a crucial element that greatly influence the quality of the final product. Elevated viscosity levels can hinder air bubble incorporation during mixing, which may adversely affect the cake's structure and texture (Matsakidou *et al*., 2010; Kim *et al*., 2012). On the other hand, moderately low viscosity promotes the inclusion and stabilization of air bubbles, encouraging the formation of a desirable cake texture. The research findings show that viscosity rose from 1465 cP in sample A (1 minute) to 1681 cP in sample E (5 minutes) with longer aeration. These viscosity readings indicate a strong ability to capture and hold air bubbles within the batter, reducing their escape during baking, which is vital for preserving the structural integrity and lightness of the finished cake product. This interplay between viscosity and aeration time emphasizes its significance in achieving a high-quality baked cake, warranting additional exploration into optimal mixing parameters to improve consistency across various formulations

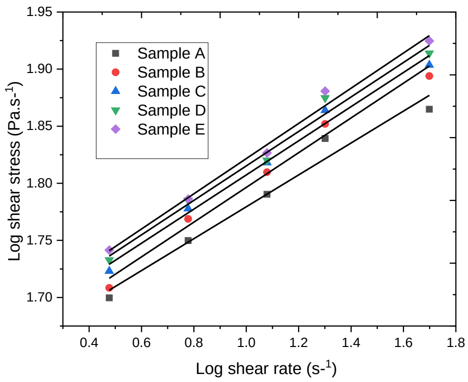
Table 1. Result of aeration time on density and rheological properties of batter

Sample	Aeration time (min)	Density (g/cm^3)	Viscosity (cP)	Consistency index ($Pa.s^{-1}$)	Flow behaviour index
A	1	0.98±0.04	1465±0.02	5.15±0.01	0.14±0.01
B	2	0.95±0.02	1567±0.01	5.18±0.03	0.15±0.02
C	3	0.92±0.01	1602±0.05	5.25±0.05	0.15±0.04
D	4	0.89±0.02	1640±0.03	5.28±0.04	0.15±0.02
E	5	0.83±0.03	1681±0.01	5.29±0.02	0.15±0.02

Batter consistency and flow behavior index

The consistency index (K) and flow behaviour index (n) are essential factors in evaluating the rheological characteristics of cake batter, specifically its ability to hold air bubbles and its flow properties, both of which are crucial for the final texture and volume of the cake. The results from the power law model curve fitting, illustrated in Figure 4.1, reveal a strong goodness of fit, with the consistency index rising from 5.15 $Pa.s^{-1}$ to 5.29 $Pa.s^{-1}$ and the flow behaviour index increasing from 0.14 to 0.15, along with an improvement in the R^2 value from 0.97 to 0.99 as aeration time progressed from sample A (1 minute) to sample E (5 minutes). This gradual increase in the consistency index indicates enhanced interactions among air bubbles, egg foam proteins, and emulsified fats from the margarine, implying a more fortified network within the batter structure. Such advancements suggest that the batter is better equipped to retain air bubbles during baking, which is a critical aspect for achieving an ideal cake texture defined by greater volume and a light, porous structure. The elevated R^2 values (0.97–0.99) further confirm the dependability of the power law model in illustrating these rheological shifts, emphasizing that extended aeration time optimizes air bubble stability, a crucial element in producing high-quality cakes.

The flow behavior index (n), remaining relatively unchanged at values between 0.14 (sample A) and 0.15 (sample E), both below 1, indicates a consistent shear-thinning behavior across different aeration durations. This consistency is a significant finding, as it shows that the added air bubbles remain whole and undamaged despite longer mixing times, thus maintaining the batter's structural integrity. The shear-thinning characteristic, where viscosity decreases under applied shear stress, ensures that the batter flows smoothly and can be handled accurately when poured into baking pans, aiding in even distribution and minimizing the risk of air bubble collapse during processing. This rheological stability is particularly beneficial in both industrial and artisanal baking, where consistent flow properties improve operational efficiency and product uniformity. The slight change in n (0.01 increase) indicates that aeration time does not considerably affect the batter's fundamental flow dynamics, providing a stable basis for scaling up production while preserving quality. These findings collectively highlight the significance of optimizing aeration time to achieve a balance between air retention and flow properties, potentially warranting further investigation into the interactions of ingredient ratios and mixing methodologies to enhance these results across various cake recipes.



Sample A ($y = 0.1397x+1.6398$, $R^2 = 0.9712$)

Sample B ($y = 0.1495x+1.6443$, $R^2 = 0.9864$)

Sample C ($y = 0.1509x+1.6578$, $R^2 = 0.9874$)

Sample D ($y = 0.1531x+1.6643$, $R^2 = 0.9884$)

Sample E ($y = 0.1541x+1.6678$, $R^2 = 0.9889$)

Figure 1. Linear fitting of power law model for the batter

4.0 Conclusion

This research provided important insights into how aeration time influences batter quality in cake making. The findings showed that adjusting aeration time effectively reduced the batter's density while increasing its viscosity, which aids in better air bubble incorporation—an essential factor for achieving a lighter and more consistent cake texture. Consistency values showed minimal variation across different aeration times, indicating a stable thickness of the batter, thus maintaining its structural integrity during processing. Additionally, the flow behaviour index was consistent, demonstrating the batter's natural shear-thinning characteristics, which is a favourable attribute that allows for smooth spreading and even distribution in baking pans, enhancing overall baking performance. These results highlight the significance of managing aeration time as a crucial element in batter formulation, providing a practical method to enhance cake quality by balancing air incorporation with structural stability. Nevertheless, the study could be broadened to investigate the effects of aeration time on the final volume of the cake and its crumb structure, along with interactions with other variables like flour type or sugar content, to gain a more comprehensive understanding of batter optimization in both industrial and artisanal baking settings.

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