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The Physics of Baking: An Experimental Investigation of Air Incorporation and Temperature on Cake Texture

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Abstract: ***This research paper delves into the physical principles at play in the art of baking, focusing on how air incorporation and baking temperature affect cake texture. on the texture of cakes. By systematically varying the amount of air introduced through the creaming process and altering baking temperatures, this study provides detailed insight into how these variables influence cake structure and overall texture. The optimal texture of the cake was attained when the batter was creamed 7–11 minutes (the control) and baked at 350°F for 25 minutes, allowing for the perfect amount of air going in and a controlled release of air and creation of air pockets. The implications of these findings extend to both amateur and professional baking practices, offering a scientific approach to perfecting the art of baking.***

Keywords: Baking physics, Cake texture, Air incorporation, Creaming method, Baking temperature.

1. Introduction

Baking, commonly celebrated as a culinary art, is also a complex science that integrates principles of chemistry, physics, and mathematics. This study explores the physics of baking, particularly examining the roles of air and temperature control in crafting the perfect cake texture. Traditional ingredients such as baking soda and baking powder are well-known for their chemical roles, but this research emphasizes the mechanical process of air incorporation through creaming and its thermal management during baking as pivotal factors that shapes the cakes structural integrity and textural experience. Previous studies have examined the effect of creaming—the process of adding air into the mixture—in biscuits. The results showed that the aeration of the dough significantly affected the final texture of the biscuit, with more air resulting in a softer and taller biscuit, much like the results of this study.

2. Materials and Methods

Experimental Design:

Ingredients and Equipment:

- 280g All purpose flour (Kirkland Signature)
- 2 ¼ tsp baking powder (Trader Joe's)
- ¾ tsp salt (Kirkland Signature sea salt)
- 1 ⅔ cups granulated sugar (Kirkland Signature organic cane sugar)
- ¾ cup unsalted butter (Kerrygold)
- 3 large eggs (Kirkland Signature organic brown eggs)
- 1 tbsp vanilla extract (Kirkland Signature)
- 1 cup milk (Kirkland Signature organic A2 whole milk)
- 2 tsp lemon juice
- 8 inch stainless steel baking pan
- Kitchen Aid 6 Quart Bowl lift Stand Mixer
- Kitchen Aid conventional oven
- Silicon spatula

Control Group (Standard Creaming and Baking):
Served as the baseline for comparison, incorporating air to an optimal level determined by traditional creaming times. The butter was kept out for a couple of hours to reach a softened room temperature and cut into large cubes before adding it to the stand mixer, then the granulated cane sugar was mixed into it at a slow speed, gradually increasing the mixer speed to 7, creamed for 7 minutes with brief pauses to scrape down the sides of the bowl. The final mixture looked nearly white and held on to the spatula when lifted; it also felt relatively lightweight. When the mixture was rubbed between the thumb and index finger, the grains felt minimal. The speed was then lowered to 4 and the eggs and vanilla extract were added, followed by increasing the speed to 7 for another minute. Then the dry mixture (flour, baking powder, and salt) were added in three intervals alternating with the buttermilk (milk + lemon juice) at a reduced speed for 4 until a homogeneous batter was created. The batter was poured into a 9-inch stainless steel baking tin lined with a snug-fitting circle of parchment paper on the bottom and sides. The cake was baked at 350°F for 25 minutes. When pricked in the center with a toothpick, the toothpick came out clean.

Variable Group 1 – Under-Creamed:
To test the effect of minimal air incorporation, creaming time was substantially reduced. For this case the sugar and butter were creamed for 3 minutes with 2 scrape-downs. The resulting mixture was thick with a yellowish tint from the butter. When rubbed between fingers it had big granules of sugar and felt dense when lifted with the spatula, sticking in big clumps. The rest of the ingredients were mixed in the same order and the cake was baked using the same method as the control cake, in the same tin and at the same temperature.

Variable Group 2 – Over-Creamed:
To examine the impact of excessive air, creaming time was significantly increased. For this case the butter and sugar were creamed for 12 minutes with 9 scrape-downs resulting in a pale white mixture that was very soft and almost slid off the spatula. The weight felt lighter than the under-creamed

mixture but still denser than the control group. The rest of the ingredients were mixed in the same order and the cake was baked with the same method as the control cake, in the same tin and at the same temperature.

Temperature Variations:
The same methodology was used as the control group to create two identical batters that were then baked in the same 9-inch tin at 300°F and 400°F to examine the effects of a lower and higher temperature respectively. They were baked until a toothpick inserted in the center came out clean.

Data Collection Methods:
Visual observations were made regarding the color, crust and height of the cake along with the crumb size when cut into. Three blindfolded panelists between 13 and 40 years of aged were asked to examine the mouthfeel and texture of the cake.

3. Results

Table 1: Effect of Creaming Time on Cake Outcomes

Creaming Time	Results/Observations	Crumb/Structure	Mouthfeel
3 minutes (Under-creamed)	Flat top, small air pockets on top; edges stuck to parchment	Finer crumb, weak structure	Dry, crumbs disperse; sticks to finger when pressed
7–10 minutes (Control)	Golden brown crust; even color; no visible cracks or holes	Soft, small crumbs mostly adhere; stable structure	Melts in mouth; moist; not sticky
12 minutes (Over-creamed)	Inward dome; yellow top; visible cracks and holes	Dense and sticky; large clumps break off	Sticks to roof of mouth; hard to swallow

Table 2: Effect of Baking Temperature on Cake Outcomes

Temperature	Time Baked	Results/Observations	Crumb/Structure	Mouthfeel
300°F	40 minutes	Even coloration; flatter top; softer edges	Smaller crumb; denser texture	Moisture similar to control; slightly stickier
350°F (Control)	25 minutes	Golden crust; soft, slightly flaky top; brown edge; even color	Most crumbs small; adhere rather than spill	Melts in mouth; moist; slides down easily
400°F	15 minutes	Much darker outer edge; more defined dome; slight surface cracking	Prominent crumbs; drier texture; thicker crust	Drier; rougher mouthfeel

Figure 1: Comparative images of creamed mixture: over-creamed, control, and under-creamed (left to right).

Figure 2: Comparative images of cakes: over-creamed, control, and under-creamed (left to right)

4. Discussion

Creaming time: The process of creaming allows the cake batter to form little pockets of air within the batter. When heated, the air pockets act like nuclei and expand, not only due to the heat but also due to other gases formed through leavening agents (like baking powder). The results indicate that creaming times generally affect the final texture and the rise of the cake as well. The under-creamed cake had a finer crumb with very little structure as we can see by the fact that it stuck to parchment paper. We can conclude that the air incorporated in that stage provides the cake with much needed structure, since the tiny air bubbles act as nuclei that expand with steam and leavening gases during baking, helping the cake set with a stable framework. With minimal air added, there are fewer and smaller air bubbles that expand, resulting in a looser texture that is more prone to falling apart. The flat top is because with less air incorporated, there are fewer bubbles to expand when heated, so the cake forms fewer and smaller air pockets, leading to less lift. For the over-creamed cake, the mixture was beaten to the point that the air bubbles formed in the creaming broke down, resulting in less air in the final product and a more flowy batter. With little stable air left to expand, the gases produced during baking built up pressure inside the dense batter. Since the structure could not distribute this pressure evenly, the surface cracked as the steam and CO_2 escaped. The stickiness of the cake came from the dense structure— with fewer air pockets separating starch and sugar, the crumb set more compactly and retained more surface moisture. The control cake had the ideal creaming time because it incorporated just enough air for just enough time to create evenly distributed air pockets, spaced so that starch gelatinized and protein coagulation could stabilize the structure, producing a soft, fluffy crumb.

Temperature: From the above results we see that the temperature, similar to the creaming process, also affects the crumb formation and the rise and also affects the outside coloration of the cake. At 300°F the gentler heat transfer causes air pockets to expand more slowly and evenly throughout the cake. The exterior of the cake is also not exposed to as extreme heat, resulting in an even coloration across the surface of the cake. Due to the lower baking temperature, the cake takes a longer time to set, and the air bubbles expand more slowly, resulting in less oven spring and a slightly denser texture. Even though the baking time is longer, the moisture content remains similar because the slower heat reduces evaporation, balancing out the extended bake time. The higher temperature on the other hand resulted in a dry crumbly cake caused by the rapid expansion of air cells and accelerated moisture loss. When the cake is put in, it is exposed to high temperature almost immediately and air bubbles start rising rapidly creating larger air pockets while the intense heat drives off more moisture, leading to a dry crumb. Due to the rapid expansion the cake also has a significantly larger dome. The extreme air expansion can also cause cracks on the surface, as the rapid rise puts stress on the setting crust. And while the inside continues to cook, the exterior, exposed to intense heat, undergoes faster browning and crust formation, resulting in a thicker, darker, and less even surface.

Comparison with Prior Studies

Creaming time — Under-creamed: finer but weaker crumb, sticks to parchment paper, fewer air pockets leading to weaker structure. A study looking at the evolution of cake batter structure also shows that insufficient batter aeration produces fewer, larger or fewer stable bubbles and lower leavening gas hold-up, producing a low-volume fragile cake.

Creaming time — Over-creamed: bubbles break down leading to flowy batter and fewer stable air cells, and cracked or sunken dome. The same study mentioned above also showed that aeration beyond optimal causes coalescence and collapse of gas cells within the batter. Batter rheology (study of flow under stress) shifts towards lower elasticity which reduces oven spring and results in defects like cracking and collapse. Other studies have also shown similar results.

Temperature — 300°F (lower temperature) leads to slower more even baking and bubble expansion, longer set time and a dense but still moist cake. A study looking at the influence of baking temperature on pogácsa cake showed that lower baking temperatures slow internal heating and evaporation, often reducing surface browning and producing a more even rise but less spring (more dense). It also mentioned that the cake is able to retain moisture despite the longer bake time.

Temperature — 400°F (higher temperature) leads to rapid bubble expansion with larger pockets, drier crumb, a big dome, cracking and a thicker, darker crust. The same study shows that evaporation rate depends on surface temperature and time; lower temperatures reduce the driving force for evaporation, which can offset longer bake time, leading to similar moisture in some cases.

5. Conclusion

This research underscored the importance of precise air incorporation and temperature in achieving the desirable cake texture. For instance, for a muffin with a high dome, a higher temperature is ideal to expand the air pockets fast, whereas for more even color and bake, like a cheesecake, one would choose baking it at a lower temperature also allowing it to retain moisture. Findings like these not only help home and professional bakers attain their desired texture but also help guide while developing new recipes.

6. Future Work

Future studies could investigate the effect of alternate mixing methods, such as high speed bursts of mixing rather than a constant speed, or the effect of changing the order ingredients are mixed— for instance adding wet to dry rather than the normal dry to wet methods. Both these studies can give further insight into the additional baking variables that influence the final texture.

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References

[1] Amani, H., Baranyai, L., Badak-Kerti, K., & Mousavi Khaneghah, A. (2022). Influence of baking temperature and formulation on physical, sensorial, and morphological properties of pogácsa cake: An image analysis study.
[2] https://pmc.ncbi.nlm.nih.gov/articles/PMC8834173/
[3] Anges de Sucre. (n.d.). Cake baking temperature guide: Tips for perfectly baked cakes every time. https://www.angesdesucre.com/blogs/anges-de-sucre/baking-temperatures-the-dos-donts
[4] Chesterton, A. K. S., Allais, I., & Alcoutlabi, M. (2012). Evolution of cake batter bubble structure and rheology during planetary mixing. https://www.sciencedirect.com/science/article/abs/pii/S0960308512000740
[5] Brijwani, K. (2017). Aeration of biscuit doughs during mixing. https://www.sciencedirect.com/science/article/abs/pii/B9781891127595500419
[6] Robbins, M. (2015). Creaming butter and sugar: How to get it right.
[7] https://www.kingarthurbaking.com/blog/2015/04/27/creaming-butter-sugar
[8] Dependahl, J. (2022). How creaming the butter will impact your cake. https://www.tastingtable.com/1146761/how-creaming-the-butter-will-impact-your-cake/
[9] Molina, M. T., Vaz, S. M., & Bouchon, P. (2021). The creaming of short doughs and its impact on the quality attributes of rotary-molded biscuits. https://pmc.ncbi.nlm.nih.gov/articles/PMC7999813/
[10] Parks, S. (2019). Cookie science: Why cream butter and sugar? https://www.seriouseats.com/cookie-science-creaming-butter-sugar
[11] Rampe, A. (2022). Here's how the temperature in your kitchen affects your baking. https://www.foodandwine.com/here-s-how-the-temperature-in-your-kitchen-affects-your-baking-6822478