Comparing Butter and Oil in Yellow Butter Cake: Impact on Crumb Structure and Flavor

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Abstract

Cakes are complex systems where the interactions between ingredients determine the final product's texture, flavor, and overall structure. Among these ingredients, fat plays a crucial role in shaping the cake's characteristics. This study specifically investigates how varying the ratio of saturated to unsaturated fats in a yellow butter cake recipe affects several key attributes: color, texture, moisture, flavor, and crumb structure. The experiment involved baking cakes with different butter-to-oil ratios, each based off of a modified version of Rose Levy Beranbaum's All-Occasion Downy Yellow Butter Cake recipe. To evaluate the cakes, a combination of quantitative measurements and visual analysis was conducted, including assessments of height, density, color, and air bubble distribution. Additionally, sensory evaluations were performed to examine flavor and texture.

The results revealed distinct differences based on fat proportions. Cakes made with higher oil content were moister, slightly shorter and denser, and had a subtler flavor. In contrast, cakes with a higher butter content had a more delicate, crumbly texture and a richer, more pronounced flavor. Despite these variations in texture and flavor, color differences among the cakes were minimal. Cakes with more oil also exhibited less uniform air bubbles, likely due to the thinner consistency of the batter, which caused air to be less evenly distributed throughout the cake. These findings highlight the significant role that fat composition plays in determining a cake's moisture, texture, and flavor profile. This study can provide useful insights for both home bakers and industrial cake production, where texture and flavor consistency is crucial.

Introduction

Cake is a complex system that relies on the interactions of several ingredients to achieve its desired characteristics. At its core, a cake is made up of four base ingredients: lipids, egg, sugar, and flour. Baking a cake involves a simultaneous heat and moisture transfer process in which the crumb sets as proteins form a network and starches gel (Hesso et al. 2015). For the purposes of this study, "cake" is defined as a yellow butter cake, known by its tender crumb and rich flavor (Beranbaum 25). The name "butter" cake typically refers to the flavor and texture of the cake, but similar results can be achieved without butter. It contains a one-to-one ratio of flour to sugar and butter as its primary source of fat. The cake's batter is made by combining the dry ingredients with the butter first, and then gradually adding the eggs and liquid in parts (Beranbaum 25), rather than by a traditional creaming method.

A cake's structure, or crumb, is a sponge-like matrix made up of starch and proteins, filled with air pockets (McGee 520). The crumb forms when the batter is heated, as a result of protein coagulation, starch gelatinization, and air bubble expansion and stabilization (Wilderjans et al. 2013; Hesso et al. 2015; McGee 525).

This structure is formed through many physical and chemical processes, as well as many textural and flavor transitions. Each of these changes collectively contribute to a cake's final form. The cake recipe used for this study was based off of a modified version of Rose Levy Beranbaum's All-Occasion Downy Yellow Butter Cake Recipe, using the whole egg variation and halved for convenience sake. Firstly, aeration occurs during the process of incorporating a mixture of eggs, vanilla extract, and milk in three increments into the dry ingredients and butter, mixing in between each addition (see methods for more details). Then, as the cake is being baked in the oven, five processes occur: gas expansion from the leavening agent (McGee 526), starch gelatinization from the flour and liquid (McGee 525), protein coagulation from the egg proteins (Wilderjans et al. 2013), evaporation from steam escaping from air bubbles (McGee 525), and finally caramelization from the sugar (Wilderjans et al 2013). Having discussed how these ingredients come together to form the cake's final structure, it is also important to understand the primary ingredients and their roles.

Flour, specifically its starch, makes up most of the final cake structure. During baking, starch granules absorb water, swell, and gelatinize, giving the cake its shape and structure. Then, as the starch granules stop the air bubbles from growing, steam forces itself outside of the bubbles, leading to the formation of a cake's sponge-like network (McGee 525). This process is influenced by temperature, moisture, sugar content, and fat content, which can change the point at which gelatinization occurs (Hesso et al. 2015; Kadam, 2016). Flour also contributes gluten, but excess gluten formation is unfavorable for cakes, since it often leads to toughness.

A cake's liquid ingredients work together with flour, affecting the setting and texture of a cake, as water hydrates the starch and protein. The proportion of sugar and fat modifies the water content, which shifts gelatinization and protein coagulation (Hesso et al. 2015).

Eggs contribute to the cake's air incorporation, which in turn affects the cake's overall structure. Egg proteins coagulate to support the cake's structure during baking (Wilderjans et al. 2013). Additionally, egg yolks also contain emulsifiers, which work to distribute air bubbles (Vissers et al. 2020).

Sugar provides much more to a cake than just its sweetness. It delays the setting of a cake's structure by increasing the temperature at which starch gelatinizes, decreasing water activity, and stabilizing proteins, which allows the cake batter to stay liquid for longer, allowing for more gas expansion to take place (Hesso et al. 2015). Sugar also retains moisture and contributes to a cake's browning via caramelization (Wilderjans et al. 2013).

Leavening agents and batter aeration are the key to a cake's final texture. Initial aeration occurs during the mixing process, specifically when creaming together butter and sugar or whipping eggs. A smaller and tenderer crumb results from many early air bubbles being formed in a cake's initial aeration (McGee 526). Chemical leavening contributes to a cake's secondary aeration, which occurs in the oven. Common chemical leavening agents include baking soda, which requires an acid in order to react, and baking powder, which does not require any other ingredient besides heat. Some leavening agents are double-acting powders, which release carbon dioxide twice. Adding an excess of leavening, however, does not always mean the cake will rise more (Book & Brill 2015), as leavening agents do not *create* any new air bubbles; rather, they expand the existing bubbles from initial aeration (McGee 526). In fact, too much leavening can lead to cake collapse. Leavening agents also contribute in part to cake softness (Book & Brill 2015).

Fat contributes in three primary ways to a cake. Firstly, it coats protein and starch granules, effectively stopping unfavored gluten formation, improving mouth-feel by softening the cake. Additionally, saturated fats, which are typically solid at room temperature, entrap air during the aeration process and emulsify the liquid within a cake, leading to a tender finished product (Zhou et al. 1). On the other hand, unsaturated fats, which are typically liquid at room temperature, are not able to incorporate air by themselves (Zhou et al. 47).

This study focuses on the effects of using different proportions of butter and oil in a set recipe, taking into account the changes in the cake's color, height, density, crumb structure, and flavor in order to explore how cakes can be optimized for specific ends by varying fat ratios.

Methods

First, the eggs, butter (if needed), and whole milk were set out to warm to room temperature (about 65 degrees Fahrenheit). Then, the oven was preheated to 350 degrees Fahrenheit. Sifted flour, sugar, and salt were mixed using the paddle attachment on a stand mixer for 30 seconds on low speed (2). Then, the butter and/or oil and ⅔ of the whole milk was added into the stand mixer. These ingredients were mixed for 15 seconds on low speed (2) until the dry ingredients were moistened. Then, a mixture of the eggs, vanilla extract, and the remaining milk were incorporated into the stand mixer in thirds, stirring on low (2) for 5 seconds and then on medium speed (4) for 20 seconds in between each addition. Additionally, to account for the water content found in butter that is not present in oil, the appropriate amount of water was added in each of the trials that contained oil to compensate during this time. Finally, the batter was scraped into a 9-inch round pan lined with parchment paper and baked for 38 minutes.

Cake #	Butter-to-Oil Ratio
Cake 1 (Control)	100%/0%
Cake 2	75%/25%
Cake 3	50%/50%
Cake 4	25%/75%
Cake 5	0%/100%

Figure 1

Each of the 5 cake trials were made using a different ratio of butter to oil, as seen in Figure 1.

In order to determine the differences between each cake with different fat contents, both pictures and quantitative measurements were taken. For color, a top-down picture of each cake was taken in the exact same lighting. To account for differences in the cake's air bubbles, pictures were also taken of the cross-section. For the cake's height, a measurement (cm) was taken from the bottom to the tallest point. Finally, for the cake's density (g/cm^3), three portions of every cake were measured to determine its volume (cm^3) and weighed (g). An average of each portion of the cakes were taken to determine the cake's density.

Materials

Sifted cake flour, eggs, whole milk, baking powder, vanilla extract, white granulated sugar, salt, butter and/or vegetable oil, water, standmixer, paddle attachment, 9-inch round pan, spatula, parchment paper, 0.1g precision digital food scale.

Results

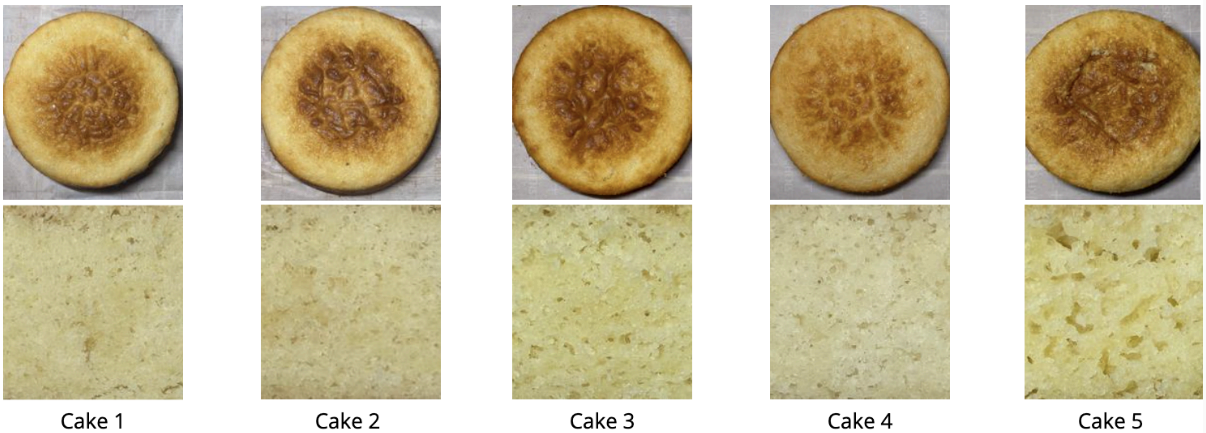

Figure 2

Each cake's color had very minimal changes overall. The air bubbles in Cakes 1-4 looked largely the same with fairly uniform, medium-sized bubbles. However, Cake 5 has visibly less uniform air bubbles, with some bubbles being similar in size to the bubbles in Cakes 1-4, while several bubbles were about double or even triple that, as can be seen in Figure 2.

Cake #	Height (cm)	Density (g/cm³)
Cake 1	5.7cm	0.44g/cm³
Cake 2	5.5cm	0.45g/cm³
Cake 3	5.2cm	0.46g/cm³
Cake 4	4.9cm	0.47g/cm³
Cake 5	4.5cm	0.45g/cm³

Figure 3

As less butter and more oil was used, the cakes became shorter by about 0.2-0.4 cm as a higher proportion of oil was used, which in turn resulted in overall denser cakes (see details in Figure 3).

In terms of flavor and texture, the cakes with more oil, beginning noticeably in Cake 3, were more moist but also more bland. The cakes with more butter, especially Cakes 1-2, felt much more delicate and crumbled easily.

Discussion

It seemed, at first, unexpected that Cake 5 had the largest air bubbles of all of the samples, particularly because air can be whipped into a saturated fat like butter, but not into oil (Brooker 285). However, unsaturated fats do not have a crystal structure and therefore cannot control bubble formation as well as the cakes with butter (Zhou et al. 47). Similarly, Cake 5 also had a less even distribution of air bubbles. This is because Cake 5 had a significantly thinner batter than any other trial, and cakes with a lower viscosity batter have a less even distribution of air bubbles (Vissers et al. 2020). Finally, Cake 5 also did not follow the upward trend of density as more oil was used due to the many large air bubbles, which drove down the cake's average weight per centimeter.

The cakes decreased in height and increased in density as a higher ratio of oil was used also as a result of liquid oil's inability to contain air with its non-crystal structure (Zhou et al. 43). The cakes with butter were taller and less dense because butter is an emulsion, which can trap air into the batter (Zhou et al. 43).

Cakes 1-2 had the richest flavor out of all the cakes, with Cakes 3-5 tasting more bland. However, if tasted in isolation, none of the cakes seemed deficient in flavor. The vanilla aroma from the vanilla extract used was likely enough to compensate for the lost flavor when using butter. Cakes 3-5, however, did feel significantly more moist than Cakes 1-2, due to oil being liquid at room temperature and butter being solid.

Conclusion

This study highlights the critical role that fat composition plays in shaping a cake's texture, moisture, flavor, and overall structure. By altering the ratio of butter to oil, significant differences were observed in each cake's height, air bubble distribution, mouthfeel, and flavor. While the cakes made with a higher oil ratio were denser and moister with a subtler flavor, the cakes with more butter were lighter, more crumbly, and richer in flavor. Despite these differences in both texture and flavor, the color of the cakes remained fairly consistent throughout each trial. The cakes became shorter and denser as a higher ratio of oil was used. The cake with the only oil (Cake 5) had the least uniform air bubbles out of all the cakes.

These findings can be valuable for both amateur bakers and mass cake production, providing insights into how fat proportions affect key cake attributes. By fine-tuning fat ratios and mixing techniques, bakers can target their desired cake texture and flavor balance. Using a higher ratio of butter-to-oil will lead to a more delicate, crumbly, and rich cake, while the opposite will yield a much more moist and dense cake.

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