Effect of rum amount and functional ingredients on physical properties and microwaveable reheatability of rum cake

by

Kyle Andrew Phalen

B.S., Kansas State University, 2015

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Food Science

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2024

Approved by:

Major Professor
Kelly J.K. Getty, Ph.D.

Copyright

Abstract

Rum cake remains a popular consumer good in the United States and Caribbean islands. A single-serving, frozen rum cake that is ready-to-eat after 1 min of microwaving was developed, however microwaving of cereal-based goods often leads to textural problems. To minimize textural defects (tough, rubbery, and gummy) caused during microwaving, functional ingredients such as modified starches, emulsifiers, and hydrocolloids are commonly added to cakes.

The two main objectives were: 1) to determine how rum amount affects texture and structure of fresh rum cake, and 2) to analyze two functional ingredients (modified starch and glycerol monostearate (GMS)) on final quality of fresh rum cake and frozen then microwave reheated rum cake.

To determine the effect of rum, four rum cake formulations were analyzed (0% (control), 7.6%, 10.1%, 12.6% rum w/w, true %). Water was added as needed to formulations to obtain the same moisture level and all other ingredients and processes were held constant. For the functional ingredients experiment, three levels of modified starch (0.21%, 0.42%, 0.63% w/w, true %) and two levels of GMS (0.11% and 0.17% w/w, true %) were analyzed using a 2x3 factorial design. Control samples contained no modified starch or GMS.

Specific gravity, consistency, and final temperature of the batters were measured along with final cake height to determine final cake volume. Physical properties of cakes were also analyzed through texture analysis (cake firmness and elasticity) using a TA-XT *Plus* Texture Analyzer.

For the alcohol study, rum presence showed an increase in elasticity and cake height ($p<0.05$). The actual amount of rum (7.6, 10.1%, and 12.6%) was not significant, but each

treatment that contained rum was significantly different from the control (0% rum). Rum presence of significantly reduced moisture loss of cakes ($p<0.05$), which could be a contributing factor to the increased elasticity and height of rum-containing formulas. The increase in elasticity and height are both seen as positive attributes from a consumer acceptance standpoint, as consumers are looking for high volume cakes that will not crumble under stress. These results suggest that the presence of rum in a cake creates a more elastic cake with greater volume and height, indicating a physiochemical effect of rum in the batter or through the prevention of moisture loss.

In the functional ingredient experiment, the addition of a pregelatinized waxy maize starch increased the batter consistency ($p<0.05$). In fresh cakes, the addition of starch and GMS at low levels resulted in decreased firmness. All three starch levels and both GMS levels tested significantly increased cake elasticity when compared to the control. For both firmness and elasticity, the presence of the ingredient was more impactful than percent added. Decreased firmness and increased elasticity are both seen as positive textural attributes by consumers.

In frozen and then microwave reheated cakes, no significant differences were observed in peak firmness or height. Elasticity significantly decreased ($p<0.05$) when comparing control versus high starch cakes and control versus low GMS cakes. These results indicate that the modified starch and GMS used in this experiment did not have the expected positive impact on physical properties of frozen, microwave reheated rum cakes. Procedural changes to the length of frozen storage or reheating method may provide some additional learnings on the freeze-thaw effectiveness of these ingredients.

Overall, the addition of rum to a cake batter creates an airier, more elastic cake, although the level of rum was insignificant. The addition of functional ingredients such as modified starch and GMS had a positive impact on physical properties of fresh cakes in the form of decreased firmness and increased elasticity, but this same impact was not observed in cakes that had been frozen and then microwave reheated.

Table of Contents

List of Figures viii
List of Tables ix
Acknowledgements x
Chapter 1 - Introduction 1
  References 3
Chapter 2 - Literature Review 4
  History of Rum Cake 4
  Chemical and Physical Reactions during Cake Baking 5
  Functionality of Major Ingredients in Cakes 9
    Flour 9
    Sugar 10
    Water 11
    Eggs 11
    Shortening 12
    Chemical Leaveners 12
  Effect of Alcohol on Cake Quality 13
  Use of Functional Ingredients in Cakes 14
    Modified Starches 14
    Emulsifiers 18
    Hydrocolloids 19
  Effects of Freezing on Quality of Baked Cakes 22
  Effects of Microwave Heating on Cake Quality 24
  Summary 26
  References 26
Chapter 3 - Effect of Rum Amount and Functional Ingredients on Physical Properties of Rum Cake 33
  Introduction 33
  Materials and Methods 38
    Experimental Design 38

Rum Experiment 38
Functional Ingredient Experiment 39
Formulation Development 40
Rum Experiment 40
Functional Ingredient Experiment 41
Cake Mixing and Baking Procedures 45
Pre-baking Batter Analyses 47
Final batter temperature 47
Specific gravity 47
Consistency 47
Post-baking Tests 48
Height 48
Texture analysis 48
Moisture loss 49
Data Analysis 49
Rum Experiment 49
Functional Ingredient Experiment 50
Results and Discussion 50
Rum Experiment 50
Functional Ingredient Experiment 56
Fresh rum cakes 59
Frozen then microwaved rum cakes 62
Conclusion 67
References 68
Chapter 4 - Conclusion 73
Appendix A - Initial Development of a Mango Rum Cake 74

List of Figures

Figure 2.1. Photomicrographs of cake batters prepared with (a) no emulsifier and (c) propylene glycol monostearate (Jyotsna and others 2004) 18

Figure 3.1. Comparison of fresh rum cakes from formulations with varying levels of rum 56

Figure 3.2. Comparison of fresh cakes from formulations containing varying levels of modified starch and GMS. Low starch = 0.21%, Mid starch = 0.42%, High starch = 0.63%. Low GMS = 0.11%, High GMS = 0.17% 65

Figure 3.3. Comparison of frozen cakes from formulations containing varying levels of modified starch and GMS. Low starch = 0.21%, Mid starch = 0.42%, High starch = 0.63%. Low GMS = 0.11%, High GMS = 0.17% 66

List of Tables

Table 3.1. Experimental order for mixing and baking 39
Table 3.2. Formulations for rum cakes with 0% (control), 7.6%, 10.1% and 12.6% rum amount in grams and percentages 42
Table 3.3. Formulations for testing the effect of modified starch and mono/diglyceride on crumb structure and freeze-thaw stability of rum cake 43
Table 3.4. Batter characteristics of rum cakes 51
Table 3.5. Physical characteristics of rum cakes 54
Table 3.6. Mean moisture loss of rum cakes 54
Table 3.7. Batter characteristics of rum cake.. 58
Table 3.8. Contrast comparison of batter characteristics (Pr > F) 58
Table 3.9. Physical characteristics of fresh rum cakes 60
Table 3.10. Contrast comparison of physical characteristics of fresh rum cakes (Pr > F) 61
Table 3.11. Mean moisture loss of rum cakes with different levels of starch and GMS............. 62
Table 3.12. Physical characteristics of frozen and then microwaved rum cakes.......................... 64
Table 3.13. Contrast comparison of physical characteristics of frozen and then microwaved rum cakes (Pr > F) 64
Table A.4.1. Initial development of a mango rum cake formulation.. 74

Acknowledgements

First and foremost, I would like to thank my beautiful wife Morgan for displaying constant love, support, encouragement, and patience throughout this journey. I would also like to thank my friends and family for encouraging me to continue my education and for all their everlasting support. To my parents – thank you for always being there for me whenever I needed help. Whether I needed help moving, needed a dog sitter, or simply needed some time with my family, you never hesitated to make the 10 hour drive out to Manhattan.

I would also like to give special thanks to Dr. Kelly Getty. I met Dr. Getty back in 2013 when transferring into Food Science as an undergraduate student, and she always embraced and encouraged growth as a student and as a person throughout the years. Dr. Getty immediately trusted me to work for her and provided me endless opportunities to make the most out of my time in Manhattan. When I was about to finish my undergraduate work and was not sure what to do next, Dr. Getty gave me the opportunity to stay and pursue another degree. I consider Dr. Getty more of a mentor and a friend than my advisor, and I have so much appreciation for everything she has done for me.

To my other committee members – Dr. Rebecca Miller and Dr. Umut Yucel, thank you for believing in me and helping me throughout the process of researching and writing my thesis. Your flexibility and encouragement were hugely important in my success. There are countless other professors that I got to know throughout my time at Kansas State, and all of them have helped me grow in some way. I would also like to thank Elsa Toburen, whose friendly smile and dependability did not go unnoticed.

Lastly, I would like to thank Yuda Ou, Austin Weber, Erin Manville, Kyle Johnson, Megan Steward, and Jia Liang for their help with my research, and Calvin Liu for his help with the data analysis.

Chapter 1 - Introduction

Rum cake in the United States is a delicacy that has remained a popular holiday treat since its introduction around prohibition in the early 1900s. Several variations of the cake exist, including Caribbean black cakes that contains fruit soaked in rum for months, and baba au rhum which is a yeast-leavened cake that is soaked in a syrup made with rum (Durrwachter 2017; Baba Au Rhum 2017). Rum cake remains very popular in the Caribbean islands, and the popular *Tortuga* brand of rum cake remains the number one export of the Cayman Islands (Tortuga 2017). Formulations and processing methods can vary widely among manufacturers, so making an acceptable rum cake can be difficult. Cake batters consist of a very complex matrix of water, lipids, proteins, and carbohydrates (namely starch and sugar). In the case of rum cake, the rum itself is another component that adds to the complexity of this matrix. To develop a high-quality rum cake, it is important to understand how the formulation and processing methods affect important physical and chemical reactions that take place during baking, including Maillard browning and starch gelatinization (Hesso and others 2015).

During initial development of a frozen, microwaveable mango rum cake (Appendix A), it was noted that the amount of research related to the impact of alcohol on the structure and quality of cake was limited. Additional research in this area would assist rum cake manufacturers in developing formulations that would result in a higher-quality product with lower costs. With retail feasibility in mind, it also was important to formulate a cake that was stable throughout freezing and remained high-quality after the microwaving process. Freezing of cakes can cause defects such as starch retrogradation and a fractured crumb structure, and microwaving of cereal-based products often leads to textural defects described as tough, rubbery, and gummy (Díaz-Ramírez and others 2016; Mizrahi 2012). Several studies have been done on the effectiveness of different functional ingredients (such as gums and modified starches) in reducing textural defects observed after microwaving cereal-based products. A study by Clarke and Farrell (2000) found that some combinations of functional ingredients improved the microwave reheatability of frozen pizza (e.g. the emulsifier, Panodan (DuPont) and oat fiber), whereas others either did not help or were disadvantageous (e.g. pea fiber). Due to the number of functional ingredients available and the possible interactions between functional ingredients when used in different applications, it can be difficult to predict how different functional ingredients will perform.

Two experiments were conducted to better understand how rum and two functional ingredients affect physical properties and microwave reheatability of rum cake. The first experiment involved rum cake treatments with four different levels of rum, and the second experiment involved a 2x3 factorial design using three levels of modified starch and two levels of glycerol monostearate (GMS). In both experiments, physical proprieties of cakes were analyzed through texture profile analysis (cake firmness and elasticity). Mango was removed from the initial formulation in Appendix A to focus on the effects of rum and functional ingredients on texture and structure of cakes. Therefore, the objectives of the study were 1) to determine the effect that rum amount has on the texture and structure of fresh rum cake and 2) to determine the effect of two different functional ingredients (modified starch and glycerol monostearate (GMS)) on the final quality of fresh rum cake and rum cake that had been frozen and then reheated in a microwave.

References

Baba Au Rhum Cake History. What's Cooking America. Available from https://whatscookingamerica.net/History/Cakes/BabaCake.htm. Accessed 2017 October 30.

Clarke CI, Farrell GM. 2000. The effects of recipe formulation on the textural characteristics of microwave-reheated pizza bases. J Sci Food Agric 80:1237–44.

Díaz-Ramírez M, Calderón-Domínguez G, Salgado-Cruz M, Chanona-Pérez J, Andraca-Adame JA, Ribotta P. 2016. Sponge cake microstructure, starch retrogradation, and quality changes during frozen storage. Int J Food Sci Tech 51(8):1744–53.

Durrwachter, W. 2017. Origin of a classic: Bermudian rum cake. Bake from Scratch Magazine. Available from https://www.bakefromscratch.com/bermudian-rum-cake/. Accessed 2017 October 30.

Hesso N, Loisel C, Chevallier S, Le-Bail A, Queveau D, Pontoire B, Le-Bail P. 2015. Monitoring cake baking by studying different ingredient interactions: From a model system to a real system. Food Hydrocolloid 51:7–15.

Mizrahi S. 2012. Mechanisms of objectionable textural changes by microwave reheating of foods: A review. J Food Sci 71(1): R57–62.

Tortuga. 2017. History. Available from https://www.tortugarumcakes.com/tortuga_history. Accessed 2017 November 12.

Chapter 2 - Literature Review

History of Rum Cake

The prohibition era in the United States (1920-1933) was largely responsible for the discovery and popularity of rum cake. During this time, the production, transport, importation, and sales of alcohol became illegal. Thousands of speakeasy clubs and bootlegging operations began popping up around the country as Americans looked for ways to quietly consume alcohol (Okrent 2011). Smuggling of rum from the Bahamas to Florida became a huge source of income for the islands and was so common that the British Empire had to expand the Prince George Wharf in Nassau just to accommodate the amount of alcohol that was being transported. This sudden source of income for the Islands also brought about a large increase in rum production, so Caribbean civilians started finding new ways to utilize the alcohol. Rum started to be included in local recipes, and the inclusion into fruit pudding recipes that were brought over by European colonists became popular. Caribbean chefs also started to realize that the addition of sugar and alcohol helped preserve foods in the warm, humid climate, further adding to the popularity of these rum-filled puddings. These rummy puddings were the precursor to the common day rum cake, although rum cake recipes themselves started using different ingredients and flavor profiles (Brathwaite 2017).

One example of a rum cake that was derived from rummy puddings are Caribbean black cakes. These dark, rich cakes are unique as they contain fruit (such as figs, dates, and cherries) that have been soaked in rum for months before adding to the recipe (Durrwachter 2017). Because of the costly ingredients and tedious preparation process, Caribbean black cakes are a popular gift in Jamaica around the holiday season that symbolizes a deep friendship with the recipient (The Jamaican Rum Cake 2017). Another type of rum cake that is popular throughout the world is rum baba. Rum baba (also known as baba au rhum, babka, or savarin) is a type of yeast-leavened cake that is usually filled with whipped or pastry cream and baked before being soaked in a syrup containing rum (Baba Au Rhum 2017). Although preparation methods differ between Caribbean black cakes and rum baba, both products typically contain both fruit and rum, resulting in a mouth-watering dessert.

The popularity of rum cake in the United States saw a sharp increase in the 1970s when rum cake recipes were featured in both the Bacardi Party Book and an issue of *Southern Living* (Baba Au Rhum 2017). In fact, *Southern Living* lists rum cake in 1977 as one of the most popular cakes in Southern history (Burch 2017). Rum cake remains a popular treat in the United States, especially during the holiday season. The popular rum cake brand *Tortuga* has said their rum cakes remain the number one export of the Cayman Islands and have been voted “Best Cruise Souvenir” for eight consecutive years, indicating that rum cake has both sentimental and economic importance (Tortuga 2017).

Chemical and Physical Reactions during Cake Baking

The production of cakes can be summarized in three stages: aeration of the batter, thermal stabilization of the batter, and thermal setting. The first two stages require soluble and foamable proteins to retain air and surface-active compounds to stabilize the oil/water emulsion, but the third stage involves more complex reactions (Karaoğlu and others 2001). As with all starch-based products, the baking process involves heat and mass transfer processes that are critical in establishing structural, textural, and physical properties of cakes. Through baking, increase in temperature and subsequent dehydration of the batter results in several important physical and chemical reactions, including starch gelatinization and an increase in volume, protein denaturation, and browning caused by the Maillard reaction. Understanding these reactions and how ingredient interactions may affect them is critical in producing a consistent, high-quality end product (Hesso and others 2015).

Starch gelatinization is one of the most important reactions that occurs during baking for its importance in setting the structure of the cake (Hesso and others 2015). Starch is stored in plants in the form of semi-crystalline granules with diameters ranging from 1-100 μm, and within these granules there is a mix of two polysaccharides – linear shaped amylose and highly branched amylopectin. Amylopectin has more stabilizing properties, whereas amylose has a tendency to form gels and other complexes with lipids and other batter components. Amylopectin-rich starches, called "waxy" starches, are commonly used in food processing for their stabilizing effect (Hermansson and Svegmark 1996). The functionality of starches can vary widely based on several factors, including botanical origin, amylose: amylopectin ratio, and chemical modifications such as cross-linking (Hesso and others 2015; Hermansson and Svegmark 1996). The functionality of starch in cake batters is also impacted by other batter components, including pH, amount of water present, and the types and amounts of salt, sugar, fat, and protein present (Hesso and others 2015). For these reasons, it is very difficult to predict the outcome of a cooked starch system based on the composition of the starch alone.

The reaction that occurs when starch granules are heated in excess water is called gelatinization, which can be described as a phase transition of starch granules from an ordered to an unordered state. This reaction usually occurs at a temperature between 60-70°C and is characterized by a swelling of starch granules causing hydration of the starch, loss of crystallinity, and loss of birefringence. During gelatinization, swollen granules consist mostly of amylopectin, as amylose solubilizes and diffuses out of the granules, creating a continuous gel phase. The swelling of granules in this gel phase causes an increase in viscosity, which is critical to the cake structure formation (Hermansson and Svegmark 1996). It has been noted by several authors that sugar increases gelatinization temperature, likely due to the decrease in water activity and interaction with starch in the amorphous areas (Perry and Donald 2002; Prokopowich and Biliaderis 1995; Torley and Van der Molen 2005). Although it can be detrimental if gelatinization is delayed too much, a slight delay in gelatinization caused by sugar can improve cake volume by allowing air bubbles to expand with the formation of CO_2 and water vapors before the cake structure is set (Yamazaki and Kissell 1978). Gelatinization temperature has been reported as being a critical point during cake baking that has a strong influence on final cake volume and quality (Kim and Walker 1992). It has also been emphasized by several authors that the presence of *intact* starch granules is necessary to set the structure of cakes (Howard and others 1968; Wilderjans and others 2010). Balancing formulations between gelatinization temperature and leavening rate is critical for the production of a consistent, high-quality product (Kim and Walker 1992).

In addition to starch gelatinization, another important reaction in the development of a cake structure has to do with protein denaturation and coagulation. As the temperature of cake batters increases during baking, proteins from gluten or egg are denatured and water that was bound to the proteins is released and available for starch gelatinization. This gelatinization and coagulation of flour and egg proteins causes a significant increase in batter viscosity. The rapid increase in viscosity at this point is also critical in providing sufficient leavening and volume increase, as it has been well documented that a viscous batter is needed to trap and retain air bubbles during mixing and baking (Wilderjans and others 2010).

Shepherd and Yoell (1976) described the interaction between starch and protein by using a brick-and-mortar model, concluding that intact starch granules serve as the bricks and strands of egg protein as the mortar. Studies by Donelson and Wilson (1960a; 1960b) described gluten in cake formulations as a binder that helps hold together the primary structure formed from starch. Because high levels of fat and sugar in cake batters often make up a majority of the formula, development of gluten is limited but still plays an important role. In cakes, where a gluten-starch blend was used and starch exceeded 92.5%, substantial collapsing was observed (Wilderjans and others 2008). Along with sugar and water, proteins are another component that can affect gelatinization temperature due to the competition for water between the two ingredients (Mohamed and Rayas-Duarte 2003; Ghiasi and others 1982). This relationship between protein and starch during cake baking cannot be overlooked, as studies have found that the combined effect of swollen starch granules and a continuous egg protein gel phase are responsible for making up the crumb cell walls and providing a firm structure (Wilderjans and others 2010; Guy and Pithawala 1981).

As the temperature of the cake batter continues to rise, the color and flavor profile of the cake begins to change due to Maillard browning. Maillard browning is a complex reaction that occurs in many food products under the presence of amino acids, reducing sugars, and heat (around 90°C), and is responsible for giving foods a desirable flavor and brown color. Low-temperature cooking methods, such as microwave irradiation, can result in a lack of browning and flavor development and a subsequent decrease in consumer acceptance (Yeo and Shibamoto 1991).

In conclusion, many important chemical and physical reactions take place during baking that are responsible for the development of the structure, flavor, and color of cakes. The difficulty in predicting final cake quality lies in the very complex nature of cake batters and the interactions between ingredients. Sugars, proteins, water, fats, and starch characteristics all play a role in at least one of the aforementioned reactions, and very slight changes to a formulation can completely change the final quality of the cake. Processing methods must also be considered, as a change in processing methods or baking temperature also may impact cake quality.

Functionality of Major Ingredients in Cakes

Cake batters are a complex matrix composed mainly of flour, eggs, lipids, sugar, and liquids (such as water or milk), as well as minor ingredients such as chemical leaveners and flavor additives (Hesso and others 2015). Functionalities of some of these main ingredients are summarized below.

Flour

As previously mentioned, flour is the main ingredient in establishing the structure of cakes. Wheat flour (often cake flour) is commonly used in cake baking as it contains starch and gluten to help set up the structure of the cake. During the baking process, the increase in temperature denatures the gluten and allows starch granules to absorb the water that was previously bound to gluten. Batter viscosity increases and creates a starch granule in the amylose-gel matrix that is largely responsible for setting the structure and preventing collapsing in cake (Wilderjans and others 2010; Hesso and others 2015).

Certain modifications to flour, such as chlorination or decreasing the particle size, can result in an even higher-quality cake product. As the particle size of flour decreases, the amount of water that can be absorbed increases, which as a result transforms the aqueous batter into a solid, porous structure (Wilderjans and others 2010). Another common modification is to treat flour with chlorine gas at a level up to 2 oz/cwt. The chlorination of flour decreases its pH to 4.5-4.9 and increases the rate and amount of water that the flour can absorb. This has been proven to increase cake volume, reduce crumb stickiness, and impart a finer texture in cakes (Kissell and

Yamazaki 1979; Kim and Walker 1992). A study by Telloke (1985) found that an increase in the degree of chlorination of flour also increased the degree of amylose leaching and subsequently increased gel strength, crumb firmness, and resistance to collapse in high-ratio cakes (cakes that contain more sugar than flour).

As one would expect, changing the origin or specifications of the flour impacts the final cake quality. Typical flour specifications for most cake products include protein level between 7-9%, ash level of 0.36 ± 0.04%, pH between 4.5-4.9 (for chlorinated flours), and particle size between 17-35 microns (Pyler and Gorton 2008). When compared to a typical all-purpose flour (10-12% protein), the decreased protein content and subsequent gluten formation from cake flour results in cakes with a lighter, more delicate crumb.

Sugar

In high-ratio cakes, sugar is the most abundant ingredient in terms of weight. Sugar has many functionalities in a cake formulation, including sweetness, tenderness, preservation, and retardation of starch gelatinization. Sucrose is the primary sugar used in most cakes, although dextrose and corn syrup are sometimes used as partial sucrose replacers. When replacing sucrose with other sweeteners, it is important to keep gelatinization temperature in mind.

As briefly mentioned before, sugar is an important ingredient in delaying starch gelatinization and balancing it with aeration and the setting of the cake structure. By increasing the gelatinization temperature of starch, sugar gives air bubbles in the batter more time to expand and coalesce before being locked in by the cake structure, giving the final cake an improved volume and texture (Yamazaki and Kissell 1978; Perry and Donald 2002; Prokopowich and Biliaderis 1995; Torley and Van der Molen 2005).

Water

Water is another batter component with multiple functionalities, including acting as a solvent, dispersing solids evenly throughout the batter, controlling batter viscosity, and tenderizing the final product. Moisture content for high-ratio cakes can range anywhere from 15-30% w/w.

Water is also a necessary component for gluten formation and starch gelatinization to occur, and therefore is needed to set the structure of cakes. Since cake batters are considered a limited water system, water is typically bound by proteins and sugar before starch. Because of this, the presence of these water-binding batter components delays starch gelatinization until the denaturation of proteins frees up water to be absorbed by starch (Hesso and others 2015).

Eggs

Generally, eggs are the most expensive ingredient in cake formulations and can be difficult to replace based on their functional properties. Industrial manufacturers often use dried, powdered eggs as they can be more cost-effective and an easier supply chain to manage than traditional fresh, whole eggs. Egg proteins have unique foaming, emulsifying, and heat coagulation properties that define volume and texture of cakes (Ashwini and others 2009). Egg replacement studies have been popular in recent years for both cost reduction and health reasons. However, the addition of several hydrocolloids and emulsifiers (such as guar gum, xanthan gum, glycerol monostearate, and sodium stearoyl-2-lactylate) have been unable to completely replace the functionality of eggs in a cake system (Ashwini and others 2009; Arozarena and others 2001).

As previously mentioned, egg proteins form a continuous gel around swollen starch granules during baking that assists in developing the crumb cell walls in cake (Wilderjans and others 2010; Guy and Pithawala 1981). In the brick-and-mortar analogy by Shepherd and Yoell (1976), strands of egg protein assist in serving as the mortar that supports starch granules. Foaming properties of egg whites also assist in leavening, while egg yolks aid in tenderization and provide lecithin for emulsification. The combination of all these functions, as well as providing flavor, make eggs an important functional ingredient in cake formulations.

Shortening

In addition to providing flavor, the main functionality of shortening in cakes is to tenderize the product by coating protein and starch to prevent gluten toughening, although shortening also provides several functionalities. Shortening (as opposed to liquid oil) is capable of trapping air during the creaming stages of mixing. When fat melts during baking, air cells that were previously trapped are released and provide important nucleation sights for chemical leavening to occur. If emulsifiers are not used, non-hydrogenated liquid oil is difficult to aerate and will result in a cake with poor volume. The amount of shortening in a typical high-ratio layer cake ranges from 50-60% (flour basis), although the amount of shortening can vary based on the addition of emulsifiers and other ingredients (Pyler and Gorton 2008).

Chemical Leaveners

Leavening of cakes can occur in three primary ways: mechanical (e.g. aeration during mixing), biological (e.g. yeast fermentation), or chemical. Chemical leaveners provide a source of CO_2 either through neutralization or decomposition reactions to improve volume, tenderness, and overall eating quality. An example of a decomposition reaction is the thermal breakdown of ammonium bicarbonate, whereas the pairing of sodium bicarbonate with a leavening acid is considered a neutralization reaction. Neutralization reactions are popular because sodium bicarbonate is cheap, safe, and produces tasteless end-products (Holmes and Hoseney 1987; Conn 1965).

When considering neutralization reactions, there are several leavening acids that are available, including both fast-acting acids such as monocalcium phosphate and slow-acting acids such as sodium aluminum phosphate. Leavening acids differ based on leavening rates, which is a product of solubility and activation time/temperatures. Fast-acting acids release as much as 80% of gas during mixing and holding, whereas slow-acting acids produce most of the gas during baking (Holmes and Hoseney 1987, Pyler and Gorton 2008). When leaveners are activated, CO_2 bubbles are released and migrate towards the nucleation sights that were formed during the creaming and subsequent melting of shortening, where they then expand due to a vapor pressure increase from steam (Pyler and Gorton 2008).

The reason for having multiple leavening acids with different leavening rates is because the timing of leavening has to align with the setting of the structure. If CO_2 production occurs before batter viscosity starts increasing and the structure starts to set, bubbles will migrate towards the outside of the batter and escape (Pyler and Gorton 2008). Another important consideration is neutralizing value of the acid when pairing sodium bicarbonate with leavening acids. Neutralizing value for leavening acids is defined as the amount in grams of sodium bicarbonate that will neutralize 100 grams of the acid to completely convert the bicarbonate to carbonate dioxide (Holmes and Hoseney 1987). Understanding neutralizing value allows a manufacturer to maximize the amount of gas produced by the leavening system.

Effect of Alcohol on Cake Quality

A thorough literature review resulted in no scientific peer-reviewed findings about the effect of alcohol or alcohol quantity on the microstructure or quality of cakes. Anecdotal evidence has claimed the addition of vodka will disrupt gluten formation in pie crusts leading to a more tender product compared to a control crust without vodka, but this has not been explored in a controlled research environment (Crosby 2012). The importance of gluten in helping to support the primary starch-based structure and prevent collapsing of cakes has been well documented, as is the fact that the gliadin portion of gluten is characterized by its solubility in high levels of ethanol (Wilderjans and others 2008; Wilderjans and others 2010; Donelson and Wilson 1960a; Donelson and Wilson 1960b; Malik 2009).

Use of Functional Ingredients in Cakes

Functional ingredients such as modified starches, emulsifiers, and hydrocolloids are commonly added to cake formulations to improve texture, structure, and stability of cakes, especially in cases where the product may go through intense processes such as freeze-thaw cycles or microwaving (Pyler and Gorton 2008; Mizrahi 2012).

Modified Starches

Native starch functionality varies widely based on botanical origin. Several modifications are available to improve starches for specific applications. Chemical modifications for starch include thin-boiling, crosslinking, substituting, and pregelatinizing. All these modifications change some aspects of starch functionality, including adhesion, binding, coating, emulsion stabilization, gel-forming capability and translucency of formed gels, moisture holding, and thickening properties in order to create more desirable starches for specific applications. Starches are also commonly used in cake mixes to increase viscosity and stability of cakes due to ingredient interactions in the mix (Karaoğlu and others 2001).

Thin-boiled starches are thinned using an acid treatment that increases gelatinization temperature range and achieves high gel strength at high solids level. Thin-boiled starches are useful in confections where gelling is required even at high sugar levels (Pyler and Gorton 2008).

Crosslinked starches form covalent crosslinks between starch molecules, increasing gelatinization temperature. This decreases the swelling of starch granules, which as a result increases gel clarity and lowers hot paste viscosity. They are useful in providing stability to acid, heat, and shear, and have improved freeze-thaw stability. If the degree of crosslinking is high enough, starch gelatinization will not occur at all (Pyler and Gorton 2008).

Substituted starches, such as acetylated and hydroxypropylated starches, add a charged group to the starch to lower gelatinization temperature and increase swelling. Starches can be substituted to the point where they gelatinize at room temperature. They also decrease retrogradation, which increases clarity, inhibits gel formation, and improves freeze-thaw stability. Substituted starches are commonly used to improve the stability of products such as instant pie fillings (Pyler and Gorton 2008).

Pregelatinized starches are precooked and dried, which allows them to dissolve in cold water but causes granules to lose their integrity. They are often used in puddings, soups, and salad dressings. Cold water swelling starches are like pregelatinized starches, but they are only pre-swelled, not precooked, allowing granules to maintain their integrity and improve freeze-thaw stability (Pyler and Gorton 2008).

It is obvious that the use of modified starches is highly dependent on processing conditions and the specific application they are used in. In a study by Karaoğlu and others (2001), effects of pregelatinized, acid-thinned, crosslinked, and dextrinized wheat and corn starches at various levels on cake quality were evaluated. It was observed that the variety of starch (wheat versus corn) had a significant effect on batter viscosity, cake volume, specific volume, and firmness of cakes on the first day of storage. However, the type of modification had a significant effect on batter viscosity, as well as volume, specific volume, volume index, and firmness on the first, third, and fifth day of storage. Acid-thinned and crosslinked starches decreased batter viscosity, which could be explained by their replacement of flour and inability to dissolve and absorb water at low temperatures. Pregelatinized starch, on the other hand, increased batter viscosity due to its ability to instantly hydrate. Pregelatinized starches improved cake volume the most of all the modified starches tested, likely due to the increase in batter viscosity. Dextrinized starch produces a low viscosity gel that is unable to trap and retain gas and yielded cakes with the lowest volume. While the addition of modified starches extended shelf-life and improved the softness of cakes by the seventh day of storage, not all starch modifications improved cake quality. The authors concluded that pregelatinized starch improved quality, but dextrinized starch decreased quality.

Another study by Wilderjans and others (2010) evaluated the effect of crosslinked and hydroxypropylated wheat starch on cake quality. The authors replaced 30% of the total starch in a gluten-wheat starch blend with the two types of modified starches mentioned and evaluated batter viscosity, cake height, and protein extractability. Replacement of 30% native starch with hydroxypropylated starch resulted in earlier swelling and viscosity increase due to the hydroxypropyl groups facilitating the penetration and absorption of water into starch granules. Cakes with hydroxypropylated starch reached their maximum height in the oven after the shortest time, likely due to the earlier swelling and viscosity increase when compared to the control ($p<0.05$). Authors noted that hydroxypropylated cakes had the greatest extractability of protein, and therefore a less efficient aggregation of proteins. They concluded that increased amylose leaching caused by hydroxypropylation as well as the excessively swollen granules may have created a barrier for protein aggregation, which also is supported by research from Goesaert and others (2008). Hydroxypropylated starch also had the lowest gel-forming capacity, and combined with poor protein aggregation, resulted in cakes with more collapsing than the control ($p<0.05$). When comparing HP40 (40.0 ml propylene oxide per 1200 g starch) to HP80 (80.0 ml propylene oxide per 1200 g starch), the higher degree of hydroxypropylation (HP80) showed a significantly higher percent collapse than HP40 ($p<0.05$).

The overall effects of crosslinked starch on batter viscosity, starch gelatinization, and final cake quality were less pronounced than with hydroxypropylated starch. Crosslinked starches reduced swelling and peak viscosity at the higher level of crosslinking (CL 150 [150.0 ml of 5% sodium trimetaphosphate per 1500 g starch]), and although their gel-forming capability is much better than hydroxypropylated starches, their degree of collapse was not significantly different from the control cakes due to the late formation of the gel. Crosslinked starch produced cakes with a significantly greater firmness than control cakes, which is likely related to the gel-strength of crosslinked starch. Hydroxypropylated starch, on the other hand, reduced firmness of cakes ($p<0.05$) (Wilderjans and others 2010).

When considering the addition of modified starches to cake formulations, it is important to consider how the modification may affect batter viscosity, gelatinization temperature, protein aggregation, and gel strength. Modified starches may improve cake quality in some aspects, such as decreasing firmness, but may have negative effects on other characteristics such as degree of collapsing. The use of starches with multiple modifications along with a comprehensive understanding of these modifications is necessary to select the best possible option for a cake formulation.

Emulsifiers

Emulsifiers act as surface active agents that create a membrane at oil-water interfaces to turn an otherwise immiscible mixture into a stable, miscible emulsion. The use of emulsifiers in cakes is important due to the batter matrix containing both lipids and water. By coating fat droplets throughout the batter, emulsifiers are very effective in increasing the number and distribution of air cells in cakes, subsequently increasing the number of nucleation sites for leavening and increasing volume (Pyler and Gorton 2008, Kim and Walker 1992; Jyotsna and others 2004; Ravi and others 2000; Richardson and others 2002). A reduction in batter density has been observed in cakes containing emulsifiers, further supporting the idea that emulsifiers improve aeration of cake batters (Jyotsna and others 2004). Microscopy has been utilized to observe the difference in batters that did and did not contain emulsifiers, and the difference is very clearly seen. The photo of the batter in Figure 2.1 that did not contain an emulsifier (a) shows larger air cells with a much less consistent dispersion than the batter with emulsifiers (c).

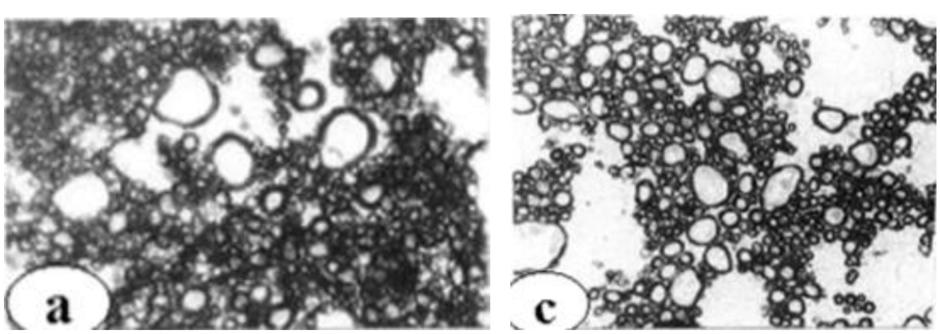

Figure 2.1. Photomicrographs of cake batters prepared with (a) no emulsifier and (c) propylene glycol monostearate (Jyotsna and others 2004)

In addition to improving air cell distribution, emulsifiers have been known to soften the crumb structure and retard staling of cakes due to reduced retrogradation (Ashwini and others 2009; Hesso and others 2015; Eliasson and Ljunger 1988). Monoglycerides have been reported to form helical inclusion complexes with amylose, which as a result prevents amylose and some amylopectin from recrystallizing during cooling and storage (Hesso and others 2015; Eliasson and Ljunger 1988).

When selecting an emulsifier for use in food applications, it is important to consider preparation methods for the emulsifier. According to Jyotsna and others (2004), hydration of powdered emulsifiers in hot water before use results in formation of a more flexible α crystalline form. The authors state that the most important factor affecting the functionality of emulsifiers is their physical state, and emulsifiers in the α-gel state are capable of creating a stabilizing film that covers the air cell surfaces. This film is largely responsible for the improvements to aeration, firmness, staling, and stability of foams and emulsions (Howard 1972; Krog 1997; Silva 2000).

The development of emulsifiers has resulted in major improvements to the baking industry's products and the way baked goods are processed. With the use of emulsifiers, sponge cake batters can be whipped in a 1-stage process rather than creaming the fat separately (Jyotsna and others 2004). Emulsifiers are also necessary for high-speed continuous mixing in commercial manufacturing. This reduced mixing time and improved processing speed greatly increases throughput for manufacturers. Emulsifiers are needed for the production of boxed cake mixes as well as giving bakers the ability to replace hydrogenated shortening with fluid shortening, resulting in improvements to both convenience and health (Pyler and Gorton 2008).

Hydrocolloids

Hydrocolloids consist of a wide range of products with either thickening or gel-forming capabilities and are typically used at a low level (0.1-0.6% flour basis). Whereas modified starches have thickening abilities when heated, hydrocolloids have better initial thickening ability of the batters before baking. Examples of commonly used hydrocolloids in the baking industry include guar gum, xanthan gum, gum Arabic, carrageenan, hydroxypropylmethylcellulose (HPMC), gelatin, and pectin. All hydrocolloids are capable of swelling and absorbing large amounts of water, and as a result they provide stability to products and are capable of modifying texture. Functionality of hydrocolloids are determined by several factors, including molecular size and orientation, concentration, and particle size (Pyler and Gorton 2008).

Hydrocolloids have a wide range of functionalities in baked goods, including water binding, thickening, foaming, emulsifying, gelling, retarding retrogradation and staling, improving freeze-thaw stability, providing dietary fiber, and improving volume and texture (Ashwini and others 2009; Gómez and others 2007). Similar to emulsifiers, hydrocolloids are also used when replacing hydrogenated fat in cake formulations with oil (Kumari and others 2011).

Several studies have been conducted to evaluate the effect of hydrocolloids on microstructure and quality of different starch-based products, and results from these studies have highlighted the importance of hydrocolloid selection depending on application. In a study by Mandala and Sotirakoglou (2005), xanthan and guar gum were used at levels of 0.16 and 0.65% (flour basis) to evaluate the effect on physical attributes (specific volume, porosity, firmness, and elasticity) of fresh bread and bread that had been frozen and microwave reheated. Results from this study indicated that guar gum resulted in a rubbery crust with lower specific volume and porosity in frozen samples, representing an overall less desirable product. The authors attributed these results to the gums water binding capability or inhibition of gluten-starch interactions. Xanthan gum, however, improved texture of fresh and microwaved bread when used at 0.16%. The authors found that the use of these gums at the higher level (0.65%) had a destabilizing effect on frozen bread, as larger ice crystals were observed with a scanning electron microscope and texture attributes were negatively affected.

Another study by Gómez and others (2007) looked at the functionality of several hydrocolloids (sodium alginate, carrageenan, pectin, HPMC, locust bean gum, guar gum, and xanthan gum) on quality of yellow cakes as well as retardation of staling. The staling retardation effect of hydrocolloids has been attributed to a combination of water holding capacity as well as a strong association of amylose with gums, resulting in a decrease of starch retrogradation (Ashwini and others 2009).Xanthan gum and locust bean gum both significantly increased the height and symmetry of the cakes, whereas all of the gums except sodium alginate significantly increased cake volume ($p<0.05$). . All the hydrocolloids except alginate, locust bean gum, and HPMC significantly increased crumb firmness of fresh cakes, with guar gum having the greatest firmness ($p<0.05$). After two days of storage, the effect of hydrocolloids on firmness was highly dependent on the type of hydrocolloid added. Carrageenan, pectin, and guar gum increased the hardness after two days of storage compared to control ($p<0.05$), but xanthan gum prevented firmness from increasing after two days and resulted in a firmness that was 40% lower than the control.

In a study by Ashwini and others (2009), the effect of several hydrocolloids (gum Arabic, guar gum, xanthan gum carrageenan, and HPMC) alone and in combination with emulsifiers on rheological, structural, and quality characteristics of eggless cakes was tested. Results showed that all hydrocolloids significantly increased batter viscosity and specific gravity ($p<0.05$), indicating a thicker batter but with less aeration capability. They also found that all hydrocolloids except gum Arabic significantly increased moisture content of cakes ($p<0.05$). Of all the hydrocolloids tested, xanthan gum increased batter viscosity the most while gum Arabic had the lowest batter specific gravity. The authors also noted that only HPMC improved specific volume, whereas gum Arabic and xanthan gum showed no improvements while guar gum and carrageenan decreased specific volume ($p<0.05$). The authors attributed this difference in volume to the different dielectric properties of the hydrocolloids as studied by Datta and others (2005). The addition of HPMC significantly decreased firmness, while all other hydrocolloids except gum Arabic increased firmness ($p<0.05$). HPMC also improved crust color, , crust shape, crumb grain size, thickness of cell walls, texture, mouthfeel, and overall quality of cakes as determined by sensory analysis ($p<0.05$). All other hydrocolloids either showed no improvement to those properties or had an adverse effect. Overall, HPMC showed the most improvement to eggless cakes when used by itself.

These studies highlight the importance of type and concentration of hydrocolloids when selecting for use in different applications. The functionalities of these ingredients are extensive but highly variable, and selection of the wrong hydrocolloid can result in adverse effects in starch-based goods.

Effects of Freezing on Quality of Baked Cakes

Freezing of part-baked cakes, fully-baked cakes, and cake batters is a common practice used to reduce staling rate and improve shelf-life (Díaz-Ramírez and others 2016). Freezing of cakes or cake batters does have a detrimental effect on cake quality, however, as several studies have reported an increase in firmness and decrease in specific volume and moisture content during frozen storage (Díaz-Ramírez and others 2016; Karaoğlu and others 2008; Gómez and others 2011; Jia and others 2014). All three attributes are related, as moisture migration influences both specific volume and firmness, while firmness is also affected due to starch retrogradation (Díaz-Ramírez and others 2016; He and Hoseney 1990).

There are conflicting reports about whether the freezing process or time of frozen storage has a greater impact on quality of cakes. In a study by Díaz-Ramírez and others (2016), the initial freezing process did not have an effect on any of the quality parameters that were evaluated, including moisture, specific volume, firmness, cohesiveness, resilience, cell area, and pore density. By two months of frozen storage, however, firmness of samples significantly increased while cohesiveness and resilience decreased ($p<0.05$). Starch retrogradation was also observed at this time. After four months of frozen storage, crystallinity increased and crumb fractures were observed. By six months of frozen storage, firmness value had approximately doubled from where it was initially, and starch granule shrinkage was observed. Starch circularity values significantly decreased after six months of storage ($p<0.05$).

In another study by Bárcenas and others (2003), an increase in frozen storage time of bread that was part-baked, frozen, and then rebaked resulted in a progressive increase in the temperature range of amylopectin retrogradation as well as a progressive increase in crumb hardness. These results indicate that frozen storage time has an effect on structural changes to amylopectin as well as the rate of hardening in bread. In a similar study, Fik and Surówka (2002) evaluated the effect of frozen storage on quality and texture characteristics of part-baked bread and found that the most pronounced changes in bread quality occurred at the beginning of the storage period (within the first week of frozen storage). Contrary to Bárcenas and others (2003), the authors concluded that the freezing process itself had a greater effect on the quality of frozen bread than the time of frozen storage.

Regardless of whether the freezing process or frozen storage time has more of an effect on the structure and quality of starch-based foods, manufacturers must deal with the adverse effects that freezing causes. The use of functional ingredients is an effective way to improve freeze-thaw stability. Modified starches that have been stabilized or crosslinked can improve freeze-thaw stability, as well as several hydrocolloids, including alginates, carboxy methylcellulose, and xanthan gum (Pyler and Gorton 2008; Mandala and Sotirakoglou 2005).

Effects of Microwave Heating on Cake Quality

Microwaves remain a popular way to heat foods due to their ease of use and convenience, which aligns with growing consumer demands for fast, ready-to-eat meals (Vadivambal and Jayas 2010). Conventional heating relies on conduction and convection where heat must diffuse through the surface of the material to heat the inside. Microwaves, however, use volumetric heat generation as a way to heat foods much faster. Volumetric heat generation is a process in which materials absorb microwave energy internally and convert it into heat by converting the energy from an alternating electromagnetic field into thermal energy (Vadivambal and Jayas 2010; Mullin 1995; Gowen and others 2006). Conventional heating experiences high surface temperatures, whereas microwave heating produces more non-uniform internal heat and is often colder at the surface. Uneven heating from microwaves can create hot and cold spots and superheating, and sometimes raises microbial concerns as a result (Mizrahi 2012; Vadivambal and Jayas 2010).

Although fast and convenient, the use of microwaves to heat starch-based foods can result in a lack of crust formation as well as several textural problems that are often described as tough, rubbery, or gummy. Surface boiling during conventional heating is responsible for forming a desirable crispy crust in products, however internal boiling during microwaving can cause undesirable changes such as toughening and collapsing of crumb structures. This internal generation of steam during microwaving is largely responsible for the toughening of products after they have been microwaved and cooled, as steam replaces the air within the crumb structure and then condenses upon cooling, forming a vacuum and subsequent collapse of the structure (Mizrahi 2012).

Another reason for the toughening of cake after microwaving comes from the redistribution of starch molecules and the depositing of amylose crystals onto the cell walls after internal boiling. During boiling, amylose leaches out of the starch granules and into the intergranular solution, where the steam then redistributes amylose back onto the surface of starch granules and crumb cell walls. During cooling, amylose quickly recrystallizes and causes severe toughening of the product (Mizrahi 2012). A study by Uzzan and others (2007) explored this amylose redistribution phenomenon and found that it only occurs in products with starch as the primary structural component and only when boiling occurs. Another study by Seyhun and others (2005) found that the degree of amylose leaching was greater in microwave baked cakes than conventionally baked cakes.

One method for controlling undesirable changes in microwave-reheated baked goods is using functional ingredients such as hydrocolloids and emulsifiers. A study by Clarke and Farrell (2000) explored the use of water-binding agents and emulsifiers (such as modified starches, fibers, and gums) on the microwavability of frozen pizza crust and found that certain combinations of these functional ingredients were able to improve textural characteristics of the pizza crust after microwave reheating. The use of the emulsifier Panodan paired with oat fiber produced the best results, however pea fiber seemed to have no real effect on many textural characteristics, including hardness, springiness, and cohesiveness ($p>0.05$). Another study by Miller and Hoseney (1997) found several emulsifiers (hydrated monoglyceride, ethoxylated monoglyceride, and monooleate) to be effective at 0.5% (flour basis) in reducing toughness of bread that had been reheated in a microwave. One explanation for this effect is due to the emulsifiers' ability to bind water to prevent rapid water loss and reduce boiling during microwaving, which as a result could reduce toughening of cereal-based products.

If the proper measures are taken, microwave heating can be an easy, convenient, and effective way to heat foods. Combinations of water-binding agents, emulsifiers, and special packaging that absorbs microwave energy at the surface are some of the ways that manufacturers reduce textural defects caused from microwave heating of starch-based products (Mizrahi 2012).

Summary

In summary, cake systems are very complex matrices, and a multitude of factors can significantly affect the end quality of the cake, including formulation, processing conditions, and storage conditions. Because of the lack of published research on the effect of alcohol on physiochemical properties in cake systems, it was determined that a study about the effect of alcohol on structure and texture characteristics of cake was necessary. It was also deemed necessary to study the effects of functional ingredients on finished cake quality, as a thorough literature review revealed a wide range of effectiveness of different functional ingredients on quality of both fresh and frozen cakes.

References

Arozarena I, Bertholo H, Empis J, Bunger A, de Sousa I. 2001. Study of the total replacement of egg by white lupine protein, emulsifiers and xanthan gum in yellow cakes. Eur Food Res Technol 213:312–6.

Ashwini A, Jyotsna R, Indrani D. 2009. Effect of hydrocolloids and emulsifiers on the rheological, microstructural, and quality characteristics of eggless cake. Food Hydrocolloid 23(3):700–7.

Baba Au Rhum Cake. 2017. History. What's Cooking America. Available from https://whatscookingamerica.net/History/Cakes/BabaCake.htm. Accessed 2017 November 24.

Bárcenas ME, Haros M, Benedito C, Rosell CM. 2003. Effect of freezing and frozen storage on the staling of part-baked bread. Food Res Int 36:863–9.

Brathwaite S. 2017. A Brief History of Carribbean Rum Cake. The Culture Trip. Available from https://theculturetrip.com/caribbean/articles/a-brief-history-of-caribbean-rum-cake/ Accessed 2017 November 24.

Burch M. 2017. The Most Popular Cakes in Southern History. Southern Living. Available from http://www.southernliving.com/desserts/cakes/popular-cakes-by-year#1948-orange-chiffon-cake. Accessed 2017 November 24.

Clarke CI, Farrell GM. 2000. The effects of recipe formulation on the textural characteristics of microwave-reheated pizza bases. J Sci Food Agric 80:1237–44.

Conn JF. 1965. Baking powders. Bakers Dig 39(2):66.

Crosby G. 2012. Vodka Makes Pie Dough Easy. In: J. Bishop, G. Crosby, M. Birnbaum, D. Souza, editors. *The science of good cooking*. 1st ed. Brookline, MA: America's Test Kitchen. p 378–87.

Datta AK, Sumnu G, Raghavan GSV. 2005. In: M. A. Rao, S. S. H. Rizvi, A. K. Datta, editors. *Engineering properties of foods*. 3rd ed. New York: CRC Press. p 501–65.

Díaz-Ramírez M, Calderón-Domínguez G, Salgado-Cruz M, Chanona-Pérez J, Andraca-Adame JA, Ribotta P. 2016. Sponge cake microstructure, starch retrogradation, and quality changes during frozen storage. Int J Food Sci Tech 51(8):1744–53.

Donelson DH, Wilson JT. 1960a. Effect of the relative quantity of flour fractions on cake quality. Cereal Chem 37:241–62.

Donelson DH, Wilson JT. 1960b. Studies on the effect of flour-fraction interchange upon cake quality. Cereal Chem 37:683–709.

Durrwachter W. 2017. Origin of a classic: Bermudian rum cake. Bake From Scratch Magazine. Available from https://www.bakefromscratch.com/bermudian-rum-cake/. Accessed 2017 November 24.

Eliasson AC, Ljunger G. 1988. Interactions between amylopectin and lipid additives during retrogradation in a model system. J Sci Food Agr 44:353–61.

Fik M, Surówka K. 2002. Effect of prebaking and frozen storage on the sensory quality and instrumental texture of bread. J Sci Food Agric 82:1268–75.

Ghiasi K, Hoseney RC, Varriano-Marston E. 1982. Effects of flour components and dough ingredients on starch gelatinization. Cereal Chem 60(1):5861.

Goesaert H, Leman P, Delcour JA. 2008. Model approach to starch functionality in bread making. J Agr Food Chem 65(15):6423–31.

Gómez M, Ronda F, Caballero PA, Blanco CA, Rosell CM. 2007. Functionality of different hydrocolloids on the quality and shelf-life of yellow layer cakes. Food Hydrocolloid 21:167–73.

Gómez M, Ruiz E, Oliete B. 2011. Effect of batter freezing conditions and resting time on cake quality. LWT-Food Sci Technol 44:911–6.

Gowen A, Abu-Ghannam N, Frias J, Oliveira J. 2006. Optimisation of dehydration and rehydration properties of cooked chickpeas (*Cicer arietinum* L.) undergoing microwave-hot air combination drying. Trends Food Sci Tech 17(4):177–83.

Guy RCE, Pithawala HR. 1981. Rheological studies of high ratio cake batters to investigate the mechanism of improvement of flours by chlorination or heat treatment. Food Tech 16(2):153–66.

He H, Hoseney RC. 1990. Changes in bread firmness and moisture during long-term storage. Cereal Chem 67:603-5.

Hermansson A, Svegmark K. 1996. Developments in the understanding of starch functionality. Trends Food Sci Tech 7(11):345–53.

Hesso N, Loisel C, Chevallier S, Le-Bail A, Queveau D, Pontoire B, Le-Bail P. 2015. Monitoring cake baking by studying different ingredient interactions: From a model system to a real system. Food Hydrocolloid 51:7–15.

Holmes JT, Hoseney RC. 1987. Chemical Leavening: Effect of pH and Certain Ions on Breadmaking Properties. Cereal Chem 64(4):343–8.

Howard NB. 1972. The role of some essential ingredients in the formation of layer cake structures. Bakers Dig 46:28–37.

Howard NB, Hughes DH, Strobel RGK. 1968. Function of the Starch Granule in the Formation of Layer Cake Structure. Cereal Chem 45:329–38.

Jia C, Huang W, Ji L, Zhang L, Li N, Li Y. 2014. Improvement of hydrocolloid characteristics added to angel food cake by modifying the thermal and physical properties of frozen batter. Food Hydrocolloid 41:227–32.

Jyotsna R, Prabhasankar P, Indrani D, Venkateswara Rao G. 2004. Improvement of rheological and baking properties of cake batters with emulsifier gels. J Food Sci 69(1):SNQ16–9.

Karaoğlu MM, Kotancilar HG, Çelik I. 2001. Effects of utilization of modified starches on the cake quality. Starch-Starke 53:162–9.

Karaoğlu MM, Kotancilar HG, Gerçekaslan KE. 2008. The effect of par-baking and frozen storage time on the quality of cup cake. Int J Food Sci Tech 43:1778–85.

Kim CS, Walker CE. 1992. Interactions between starches, sugars, and emulsifiers in high-ratio cake model systems. Cereal Chem 69(2):206–12.

Kissell LT, Yamazaki WT. 1979. Cake-baking dynamics: relation of flour-chlorination rate to batter expansion and layer volume. Cereal Chem 56(4):324–7.

Krog NJ. 1997. Food emulsifiers and their chemical and physical properties. In: S. E. Friberg, K. Larrson, editors. *Food emulsions*. 3rd ed. New York: Marcel Dekker. p 141–88.

Kumari R, Jeyarani T, Soumya C, Indrani D. 2011. Use of vegetable oils, emulsifiers, and hydrocolloids on rheological, fatty acid profile and quality characteristics of pound cake. J Texture Stud 42:377–86.

Malik AH. 2009. Nutrient uptake, transport and translocation in cereals: Influences of environment and farming conditions. Swedish University Agricultural Sciences. ISSN1654-3580. p 1–46.

Mandala IG, Sotirakoglou K. 2005. Effect of frozen storage and microwave reheating on some physical attributes of fresh bread containing hydrocolloids. Food Hydrocolloid 19:709–19.

Miller RA, Hoseney RC. 1997. Method to measure microwave-induced toughness of bread. J Food Sci 62(6):1202–4.

Mizrahi S. 2012. Mechanisms of objectionable textural changes by microwave reheating of foods: A review. J Food Sci 71(1):R57–61.

Mohamed AA, Rayas-Duarte P. 2003. The effect of mixing and wheat protein/gluten on the gelatinization of wheat starch. Food Chem 81(4):533–45.

Mullin J. 1995. Microwave processing. In: G. W. Gould, editor. *New methods of food preservation*. Bishopbriggs, UK: Blackie Academic and Professional. p 112–34.

Okrent D. 2011. Prohibition: Speakeasies, Loopholes, and Politics. National Public Radio. Available from: https://www.npr.org/2011/06/10/137077599/prohibition-speakeasies-loopholes-and-politics. Accessed 2017 November 24.

Perry PA, Donald AM. 2002. The effect of sugars on the gelatinisation of starch. Carbohyd Polym 49(2):155–65.

Prokopowich DJ, Biliaderis CG. 1995. A comparitive study of the effect of sugars on the thermal and mechanical properties of concentrated waxy maize, wheat, potato, and pea starch gels. Food Chem 52(3):255–62.

Pyler EJ, Gorton LA. 2008. *Baking science and technology: Fundamentals and ingredients*. 4th ed. Kansas City, MO, USA: Sosland Publishing Company.

Ravi R, Sai Manohar R, Haridas Rao P. 2000. Influence of additives on the rheological characteristics and baking quality of wheat flours. Eur Food Res Technol 210:202–8.

Richardson G, Langton M, Faldt P, Hermanson AM. 2002. Microstructure of α-crystalline emulsifiers and their influence on air incorporation on cake batter. Cereal Chem 79:546–52.

Seyhun N, Sumnu G, Sahin S. 2005. Effects of different starch types on retardation of staling of microwave-baked cakes. Food Bioprod Process 83:1–5.

Shepherd IS, Yoell RW. 1976. Cake Emulsions. In: S. Friberg, editor. *Food emulsions*. New York: Marcel Dekker. Chapter 5.

Silva RF. 2000. Uses of α-crystalline emulsifiers in the sweet goods industry. Cereal Foods World 45:405–11.

Telloke GW. 1985. Chlorination of cake flour and its effect on starch gelatinization. Starke 37(1):17–22.

The Jamaican Rum Cake. 2017. The Jamaican Rum Cake: History and Recipe. Jamaica Experience. Available from https://ajamaicaexperience.com/jamaican-rum-cake/. Accessed 2017 November 3.

Torley PJ, Van der Molen F. 2005. Gelatinization of starch in mixed sugar systems. LWT-Food Sci Technol 38(7):762-71. Accessed 2017 November 24.

Tortuga. 2017. History. Available from: https://www.tortugarumcakes.com/tortuga_history. Accessed 2017 November 12.

Uzzan M, Ramon O, Kopelman IJ, Kesselman E, Mizrahi S. 2007. Mechanism of crumb toughening in bread-like products by microwave reheating. J Agric Food Chem 55(16):6553–60.

Vadivambal R, Jayas DS. 2010. Non-uniform Temperature Distribution During Microwave Heating of Food Materials - A Review. Food Bioprocess Technol 3:161–71.

Wilderjans E, Luyts A, Goesaert H, Brijs K, Delcour JA. 2010. A model approach to starch and protein functionality in a pound cake system. Food Chem 120(1):44–51.

Wilderjans E, Pareyt B, Goesaert H, Brijs K, Delcour JA. 2008. The role of gluten in a pound cake system: A model approach based on gluten-starch blends. Food Chem 110(4):909–15.

Yamazaki WT, Kissell LT. 1978. Cake flour and baking research: A review. Cereal Food World 23:114.

Yeo H, Shibamoto T. 1991. Effects of moisture content on the Maillard browning model system upon microwave irradiation. J Agric Food Chem 39:1860–2.

Chapter 3 - Effect of Rum Amount and Functional Ingredients on Physical Properties of Rum Cake

Introduction

The history of rum cake in the United States can be tied back to the early 1900s when the United States passed the 18th Amendment, prohibiting the production, importation, and sale of alcohol. Because of this prohibition, rum smuggling from the Bahamas to the United States became commonplace. The sudden increase in rum production in the Bahamas forced people to find other ways to utilize the alcohol, such as incorporating it in food. Rum started to be incorporated into fruit puddings from recipes that European colonists had brought over (Brathwaite 2017). An early example of this is Caribbean black cakes, where dried fruit such as figs were soaked in rum for months before being added to the dough (Durrwachter 2017). These rum-soaked fruit puddings were the precursor to what would eventually become the modern-day rum cake (Brathwaite 2017). Around the same time, Caribbean chefs were discovering that the addition of sugar and alcohol helped preserve foods in the warm climate, which was a driving force behind the popularity of rum cakes on the Caribbean islands (The Jamaican Rum Cake 2017). A combination of food preservation techniques and finding creative ways to consume alcohol during prohibition were two important factors that led to the discovery and popularity of rum cakes in the United States.

The popularity of rum cakes in the United States saw another increase in the 1970s when Bacardi featured a recipe for rum cake in its Bacardi Party Book and a recipe for baba au rhum was featured in a January 1975 issue of *Southern Living*. This baba au rhum cake featured many of the same ingredients you would see in any cake, namely eggs, flour, sugar, and baking powder, but was unique in that it also featured a ½ cup of rum, 3 cups of brewed coffee, 1 tbsp of finely ground coffee, and 1 tsp of coffee extract. In this recipe, brown sugar and brewed coffee were brought to a boil before adding rum and reducing the mixture down to a sauce (Burch 2017). Baba au rhum, also known as rum baba, babka, or savarin in some parts of the world, is typically a yeast-leavened cake that is soaked in a syrup made with hard liquor (Baba Au Rhum 2017). It is different from the rum cakes in this study, as the rum cakes in this study were made by adding rum to the batter, whereas rum baba is baked and then soaked in a syrup containing rum.

In many areas of the United States and around the world, rum cake and black cakes remain a staple of the holiday season. Gifting a rum cake to someone in Jamaica holds symbolic significance, as the costly ingredients and tedious preparation assumes a deep friendship with the recipient. Since the fruit in these cakes is often soaked in rum for months before baking, it truly is a gift that must be well thought-out and prepared ahead of time (The Jamaican Rum Cake 2017).

In general, cakes are composed of a complex matrix of water, lipids, proteins, starch, and sugar that undergoes both heat and mass transfer processes during baking. As the temperature of a cake increases during baking, several physical and chemical reactions are taking place, including Maillard browning, starch gelatinization, and an increase in cake volume (Hesso and others 2015). The composition of the batter complex has a strong effect on these physical and chemical reactions, and ultimately affects the consistency and acceptability of the end baked product.

Although rum cakes have become a current trend in the market with several companies retailing various flavors of rum cake, there is limited research on the effect that alcohol such as rum has on the final quality of rum cake. It has been mentioned anecdotally in several places, such as cookbooks, that adding alcohol to baked goods can help limit gluten formation and lead to more tender products, but this has not been studied in a controlled experimental research setting (Crosby 2012). For this reason, the main objective of this first experiment was to explore how the presence and amount of rum (7.6, 10.1, and 12.6%) in a typical rum cake affects physiochemical properties of the batter and final product.

Freezing cakes can also have a significant effect on the structure and quality of the cake crumb. A study by Díaz-Ramírez and others (2016) found that after two months of frozen storage, starch retrogradation was observed and firmness significantly increased while cohesiveness and resilience significantly decreased. By four months of frozen storage, crystallinity increased, and a fractured crumb was observed. By the sixth month of storage, significant shrinkage of starch granules was observed. A similar study by Mandala and Sotirakoglou (2005) found significant shrinkage and porosity reduction in bread after freezing and thawing. For these reasons, it is not uncommon to see a loss of structural integrity when freezing cakes.

One method for reheating frozen cakes is the use of a microwave. Microwave heating relies on transforming energy from an alternating electromagnetic field into thermal energy by interacting with molecules within the product. An important distinction between microwave heating and conventional heating is that conventional heating relies on heat diffusing into the product through the surface, whereas microwave heating undergoes volumetric heat generation, meaning the product absorbs microwave energy internally and converts it to heat (Vadivambal and Jayas 2010; Mullin 1995; Gowen and others 2006). Conventional heating experiences higher surface temperatures, while microwave heating produces more non-uniform internal heat that is often colder at the surface. Microwaving also creates hot and cold spots, superheating, and internal boiling. Surface boiling during conventional heating is responsible for forming a desirable crispy crust, however internal boiling during microwaving can cause undesirable changes such as toughening and collapsing of the crumb structure (Mizrahi 2012). Another concern that arises from uneven internal heating during microwaving includes microbial concerns, as cold spots in the product may not reach temperatures high enough to kill dangerous pathogens (Vadivambal and Jayas 2010). This uneven heating can result in an unacceptable sensory experience for the consumer.

Although microwave reheating is faster and more convenient than conventional heating, there are several textural issues that arise when microwaving cereal-based products such as cakes. According to Mizrahi (2012), microwave heating is "notorious for lack of crust formation and severe toughening of flour and starch-based products." Mizrahi (2012) explains that while low surface temperature is responsible for the inability to form a crust, the internal generation of steam during microwaving is largely responsible for causing severe toughening. When a cake is microwaved, the air present within the crumb structure is replaced by steam. When the cake cools, the internal steam condenses and creates a vacuum within the cake, causing the collapse of cells and a denser, tougher structure.

Another reason for the toughening of cake after microwaving comes from the redistribution of starch molecules and the depositing of amylose crystals onto the walls of the crumb cells after internal boiling (Mizrahi 2012). A study by Uzzan and others (2007) explored this phenomenon, finding it to occur in products with starch as the primary structural component (above 37% for wheat starch, wet basis) and only when boiling occurs. During boiling, amylose leaches out of the starch granules and into the intergranular solution. The steam that is produced during boiling redistributes this amylose onto the surface of the granules and foam cells before quickly crystallizing during cooling. This crystallization is largely responsible for texture changes in reheated products that are described as tough, rubbery, and gummy. Food manufacturers often use special packaging materials to absorb microwave energy at the surface to combat some of these undesirable characteristics, but textural changes still remain a problem in many microwaved foods (Mizrahi 2012).

One method for controlling undesirable changes in microwave-reheated baked goods is using functional ingredients such as water-binding agents and emulsifiers. A study by Clarke and Farrell (2000) explored the use of water-binding agents and emulsifiers (such as modified starches, fibers, and gums) on the microwavability of frozen pizza crust and found that certain combinations of these functional ingredients were able to improve textural characteristics of the pizza crust after microwave reheating. The use of the emulsifier Panodan paired with oat fiber produced the best results, while pea fiber seemed to have no real effect on many textural characteristics, including hardness, springiness, and cohesiveness. Another study by Miller and Hoseney (1997) found emulsifiers to be effective in reducing the toughness of bread that had been reheated in a microwave. One explanation for this effect is due to the water-binding agents' ability to prevent rapid water loss and boiling during microwaving, which as a result could reduce toughening of cereal-based products.

A second experiment utilized a factorial design, where a modified starch was added to rum cake (7.6% rum) at three levels (0.21, 0.42, and 0.63% w/w, true percent) along with glycerol monostearate at two levels (0.11 and 0.17% w/w, true percent). A control also was evaluated that contained 0% starch and 0% GMS. The two objectives of this second experiment were: 1) to determine the effects of modified starch and GMS on the final physical characteristics of a fresh rum cake and 2) to determine how these functional ingredients affected freeze-thaw stability and textural attributes after microwaving frozen rum cakes.

Materials and Methods

Experimental Design

Rum Experiment

The four treatments consisted of a control with 0% rum and rum formulations (w/w basis, true percent) of 7.6, 10.1, and 12.6%. The 7.6% rum amount was chosen based on previous work (data not shown) with rum cake. The rum level was increased in even intervals of 2.5% to determine how an increased amount would affect the cakes. All formulations had the same amount of total liquids in the batter, as formulations with less rum had added water to equal the weight of the rum in the 12.6% formulation. The rest of the ingredients remained constant throughout the four treatments. Three separate batters of each treatment were mixed, baked, and placed in resealable plastic Ziploc® bags for analysis the following day. This same procedure was then repeated a second time on a different day for a total of six batches per formulation (n=6).

For this study, the experimental design was a randomized complete block design, with "day" as the blocking factor. Since baking occurred on two different days, the blocking factor explains changes that may have occurred due to the difference in day rather than differences in the formulations. Each day of baking involved three groups (six groups total), with groups containing one batch of each treatment, as shown in Table 3.1. Within each group, the order of mixing and baking was determined by randomization software (R version 3.2.4, Vienna, Austria). Each treatment was mixed and baked in triplicate (three separate batters/day for each treatment, hence the three groups of baking/day). All of Group 1 was completed before moving on to Group 2 and subsequently Group 3.

Table 3.1. Experimental order for mixing and baking

Order of mixing/baking	Day 1 Group 1	Day 1 Group 2	Day 1 Group 3	Day 2 Group 1	Day 2 Group 2	Day 2 Group 3
First	10.1%*	10.1%	10.1%	0%	7.6%	0%
Second	0%	7.6%	7.6%	10.1%	12.6%	12.6%
Third	7.6%	0%	12.6%	12.6%	0%	10.1%
Fourth	12.6%	12.6%	0%	7.6%	10.1%	7.6%

*Indicates percentage of rum in each batter (w/w, true percent).

The moisture loss experiment was carried out separately from the above experiment and only three batters per treatment were analyzed (n=3) for the Rum Experiment and two batters per treatment (n=2) for the Functional Ingredient Experiment. Randomization software (R version 3.2.4, Vienna, Austria) was used to randomize the order of mixing and baking different treatments, and all baking took place in one day. Batters were weighed in the pan prior to baking and then weighed again after baking and approximately 30 min of cooling. The amount of total liquids lost during baking was calculated. For the Rum Experiment, actual water (moisture) loss was calculated on the assumption that the alcohol in the rum cooked off before the water.

Functional Ingredient Experiment

A 2x3 factorial design was used to test three levels of starch (0.21, 0.42, and 0.63%, true percent) and two levels of GMS (0.11 and 0.17%, true percent), and a control was prepared without any modified starch or GMS. After baking, subsamples were randomly selected to be stored either fresh or frozen (two-week frozen storage time) before analyzing for texture properties. The two ingredients of interest in this experiment were C-PolarTex 12640 modified corn starch (Cargill, Plymouth, MN) and GMS90 monoglyceride (α-state, hydrated) (Cargill, Plymouth, MN). Both ingredients were of interest for their emulsification and freeze-thaw stability properties. The modified starch used in this experiment was a waxy maize starch (high amylopectin) that was also pregelatinized, stabilized, and crosslinked. All other ingredient weights and processes were held constant. Total batch weights for the six treatments differ minimally, as the weight of modified starch and the mono- and diglyceride blend vary slightly between treatments while all other ingredient weights stayed the same. Each of the six treatments were mixed and baked twice (total of 12 batters/day), using randomization software (R version 3.2.4, Vienna, Austria) to determine baking order. This experiment was then replicated on a second day (n=4).

Formulation Development

Rum Experiment

During preliminary research (Appendix A), various rum cake recipes from cookbooks and online recipes were baked and evaluated for consistency and overall acceptability. After several trials, a formulation with 7.6% alcohol was selected. The formulation in Appendix A was later modified to a slightly higher alcohol percent (7.92%), but 7.6% was chosen as a baseline for this study. To determine the effect of alcohol on the texture and structure of rum cakes, the amount of rum in the formulations increased by 2.5% and 5% (w/w, true percent) from the initial level of 7.6% to achieve treatments with 10.1% and 12.6% of rum. Water was added to the batters of the control, 7.6%, and 10.1% rum formulations to ensure all formulations had the same amount of liquids. All formulations can be seen below in Table 3.2.

Functional Ingredient Experiment

A microwave-reheatable rum cake with high sugar (27%, true percent) and fat content (8.2% combination of shortening and oil, true percent) was developed for this study through preliminary research (Appendix A). It was determined through this preliminary research that functional ingredients were needed to maintain the desirable texture and structure of the cake after microwaving. Several combinations of modified starch and glycerol monostearate (GMS) were tested to find an optimal combination that would improve the physical properties of the cake after microwaving. All formulations can be seen below in Table 3.3.

Table 3.2. Formulations for rum cakes with 0% (control), 7.6%, 10.1% and 12.6% rum amount in grams and percentages

	Treatment			
	Control	**7.6% Alcohol**	**10.1% Alcohol**	**12.6% Alcohol**
Ingredient and supplier	**Weight in grams and percent**	**Weight in grams and percent**	**Weight in gram and percent**	**Weight in grams and percent**
Dark rum (Bacardi Oakheart, Hamilton, Bermuda)	0 (0%)	80.5 (7.6%)	107.0 (10.1%)	133.5 (12.6%)
Water	133.5 (12.6%)	53.0 (5.0%)	26.5 (2.5%)	0 (0%)
Sugar (C&H pure granulated cane sugar, Pleasant Hill, CA)	273.0 (25.8%)	273.0 (25.8%)	273.0 (25.8%)	273.0 (25.8%)
All-purpose, enriched, bleached flour (Great Value, Bentonville, AK)	186.0 (17.6%)	186.0 (17.6%)	186.0 (17.6%)	186.0 (17.6%)
Whole eggs - large (Kroger, Cincinnati, OH)	109.0 (10.3%)	109.0 (10.3%)	109.0 (10.3%)	109.0 (10.3%)
Heavy whipping cream - Grade A pasteurized (Kroger, Cincinnati, OH)	88.8 (8.4%)	88.8 (8.4%)	88.8 (8.4%)	88.8 (8.4%)
Unsalted butter (Land O' Lakes, Arden Hills, MN)	85.0 (8.0%)	85.0 (8.0%)	85.0 (8.0%)	85.0 (8.0%)
Buttermilk -cultured lowfat (Kroger, Cincinnati, OH)	59.2 (5.6%)	59.2 (5.6%)	59.2 (5.6%)	59.2 (5.6%)
Vegetable shortening (Crisco, Orrville, OH)	47.5 (4.5%)	47.5 (4.5%)	47.5 (4.5%)	47.5 (4.5%)
Canola oil (Kroger, Cincinnati, OH)	35.5 (3.3%)	35.5 (3.3%)	35.5 (3.3%)	35.5 (3.3%
Egg yolk – large (Kroger, Cincinnati, OH)	35.0 (3.3%)	35.0 (3.3%)	35.0 (3.3%)	35.0 (3.3%)
Salt (Kroger, Cincinati, OH)	3.0 (0.3%)	3.0 (0.3%)	3.0 (0.3%)	3.0 (0.3%)
Baking powder – double acting (Clabber Girl, Terre Haute, IN)	2.5 (0.2%)	2.5 (0.2%)	2.5 (0.2%)	2.5 (0.2%)
Vanilla extract (Kroger, Cincinnati, OH)	1.75 (0.2%)	1.75 (0.2%)	1.75 (0.2%)	1.75 (0.2%)

Table 3.3. Formulations for testing the effect of modified starch and mono/diglyceride on crumb structure and freeze-thaw stability of rum cake

Ingredient	Low starch/ Low GMS	Low starch/ High GMS	Medium starch/ Low GMS	Medium starch/ High GMS	High starch/ Low GMS	High starch/ High GMS
	(Weight in g and percent)	(Weight in g and percent)	(Weight in g and percent)	(Weight in g and percent)	(Weight in g and percent)	(Weight in g and percent)
Modified starch, C-PolarTex 12640 (Cargill, Plymouth, MN)	2.6 (0.21%)	2.6 (0.21%)	5.3 (0.42%)	5.3 (0.42%)	7.9 (0.63%)	7.9 (0.63%)
Glycerol Monostearate, GMS90 (Cargill, Plymouth, MN)	1.4 (0.11%)	2.1 (0.17%)	1.4 (0.11%)	2.1 (0.17%)	1.4 (0.11%)	2.1 (0.17%)
Sugar (C&H pure granulated cane sugar, Pleasant Hill, CA)	338.8 (27%)	338.8 (27%)	338.8 (27%)	338.8 (27%)	338.8 (26.9%)	338.8 (26.9%)
All-purpose, enriched, bleached flour (Great Value, Bentonville, AK)	231 (18.4%)	231 (18.4%)	231 (18.4%)	231 (18.4%)	231 (18.4%)	231 (18.3%)
Whole eggs - large (Kroger, Cincinnati, OH)	135 (10.8%)	135 (10.8%)	135 (10.8%)	135 (10.7%)	135 (10.7%)	135 (10.7%)
Heavy whipping cream – Grade A pasteurized (Kroger, Cincinnati, OH)	110 (8.8%)	110 (8.8%)	110 (8.8%)	110 (8.8%)	110 (8.7%)	110 (8.7%)

Table 3.3. CONTINUED FROM PREVIOUS PAGE						
Unsalted butter (Land O' Lakes, Arden Hills, MN)	105.5 (8.4%)	105.5 (8.4%)	105.5 (8.4%)	105.5 (8.4%)	105.5 (8.4%)	105.5 (8.4%)
Dark rum (Bacardi Oakheart, Hamilton, Bermuda)	100 (8%)	100 (8%)	100 (8%)	100 (8%)	100 (7.9%)	100 (7.9%)
Buttermilk – cultured lowfat (Kroger, Cincinnati, OH)	73.5 (5.9%)	73.5 (5.9%)	73.5 (5.9%)	73.5 (5.9%)	73.5 (5.8%)	73.5 (5.8%)
Vegetable shortening (Crisco, Orrvile, OH)	58.8 (4.7%)	58.8 (4.7%)	58.8 (4.7%)	58.8 (4.7%)	58.8 (4.7%)	58.8 (4.7%)
Canola oil (Kroger, Cincinnati, OH)	43.8 (3.5%)	43.8 (3.5%)	43.8 (3.5%)	43.8 (3.5%)	43.8 (3.5%)	43.8 (3.5%)
Egg yolk – large (Kroger, Cincinnati, OH)	43.5 (3.5%)	43.5 (3.5%)	43.5 (3.5%)	43.5 (3.5%)	43.5 (3.5%)	43.5 (3.5%)
Salt (Kroger, Cincinnati, OH)	3.8 (0.3%)	3.8 (0.3%)	3.8 (0.3%)	3.8 (0.3%)	3.8 (0.3%)	3.8 (0.3%)
Baking powder – double acting (Clabber Girl, Terre Haute, IN)	3.1 (0.25%)	3.1 (0.25%)	3.1 (0.25%)	3.1 (0.25%)	3.1 (0.25%)	3.1 (0.25%)
Vanilla extract (Kroger, Cincinnati, OH)	2.1 (0.17%)	2.1 (0.17%)	2.1 (0.17%)	2.1 (0.17%)	2.1 (0.17%)	2.1 (0.17%)
Total batch weight	**1252.9**	**1253.6**	**1255.6**	**1256.3**	**1258.2**	**1255.9**

Cake Mixing and Baking Procedures

Batters were prepared by using a mixer with a paddle attachment (KitchenAid Artisan KSM150PS, St. Joseph, MI). The specific mixing procedure was as follows: butter was tempered at ambient temperature (23 ± 2°C) for 30 min prior to mixing. Butter was then creamed for 35 s on speed 4. Shortening was then added and mixed for 2 min at speed 4 before adding sugar and mixing for 2.5 min at speed 4. The sides of the bowl were scraped throughout this process to ensure even mixing. Once butter, shortening, and sugar were mixed, wet ingredients were added. Canola oil, vanilla, rum, and water were added slowly and mixed for 2 min at speed 4. Whole eggs and egg yolks were then added at speed 2 and mixed for 45 s. In a separate bowl, flour, baking powder, and salt were all combined and whisked together until an even dry-blend mixture was achieved. The next step was to alternate the addition of this flour mixture and buttermilk on the lowest speed and mix for 2 min. For the final step, heavy whipping cream was added and mixed for 30 s on speed 4. For the Functional Ingredient experiment, GMS was mixed in with shortening and modified starch was mixed in with the dry blend. Each cake batter was analyzed for final batter temperature, specific gravity, and consistency before adding batter to the cake pan.

Prior to filling the pan, each well was greased with vegetable shortening until there was a thin but consistent layer throughout the well. A 160 g portion of batter was placed in each well of a Wilton Excelle Elite 6-cup mini-fluted bundt pan (Wilton Enterprises, Naperville, IL). The pan had six separate wells (each well 10 cm in diameter, 4.4 cm deep) and batter produced six mini bundt cakes.

After filling the pan, cakes were placed in a standard conduction oven with an internal temperature of 325±3°F (161.1-164.4°C) as measured by an oven thermometer, and the pan was placed on the middle shelf to bake for 32 min. Each treatment was baked one at a time and all treatments were baked using the same oven. The final internal temperature of the cakes after baking was measured at 94 ± 3°C.

Upon removal from the oven, the pan was placed on a cooling rack and a moist towel was draped over the top of the pan for approximately 5 min to trap steam and aid in consistent removal of the whole cake from each well. After the towel was removed, cakes continued to cool for approximately 30 min until an ambient temperature (23 ± 2°C) was reached. For the Rum Experiment, cakes were removed from the pan, using a knife to gently scrape the sides if necessary, and stored in resealable Ziploc® bags at an ambient temperature (23 ± 2°C) until the next day. For the functional ingredient experiment, three cakes (out of the six produced from the bundt pan) were randomly selected to be frozen. These cakes were placed in a freezer-friendly resealable Ziploc® bags and were frozen at -15 ± 2°C in a normal consumer freezer (Frigidaire Model FRT22INLH, Charlotte, NC) for 14 days after the first round of baking and 15 days after the second round of baking due to time constraints. The other three cakes from each batch were placed in a resealable Ziploc® bag and stored at ambient temperature (23 ± 2°C) for testing the next day.

Fresh cakes were analyzed for texture (firmness and elasticity) and height the day after baking. Frozen cakes for the Functional Ingredient Experiment were analyzed two weeks after freezing. All the batter and finished product tests are explained in more detail below.

Pre-baking Batter Analyses

Final batter temperature, specific gravity, and consistency were measured after mixing and before baking to ensure control of temperatures and determine if formulation differences had an effect on batter aeration or viscosity. For the moisture loss study, batters were weighed in the pan prior to baking to determine the moisture loss during baking.

Final batter temperature

After mixing, final batter temperature was measured with a calibrated thermometer (Daigger Scientific Traceable Water Resistant Thermometer EF2430B, Vernon Hills, IL) and recorded. Measurements were taken in the center of the batter, away from the walls of the bowl.

Specific gravity

Specific gravity is a ratio of the batter density to that of pure water. To measure specific gravity, a ¼ cup measuring cup was filled with water and the weight of the water was recorded. The same measuring cup was then filled with batter, leveled off, and weighed. The ratio of batter weight to water weight was the calculated specific gravity by using the following equation:

$$\text{Specific gravity} = \frac{\text{Weight of batter}}{\text{Weight of equal volume of water}}$$

Consistency

Batter consistency was measured using a Bostwick Consistometer (CSC Scientific Company, Fairfax, VA). The Bostwick Consistometer is a slightly declined trough with 0.5 cm increments and a gate at the back end. The trough legs are adjusted until they are level, and the gate is closed so the area behind the gate can be filled completely with batter and leveled off. The gate is then opened, and the batter is allowed to run down the trough for 30 s. After 30 s had elapsed, the distance the batter traveled (in cm) was recorded. A longer travel distance or an increase in cm represents a thinner batter.

Post-baking Tests

Height

Three out of the six cakes per treatment were chosen at random to be measured for height. A calibrated 6” stainless steel digital caliper (Tool Shop, Eau Claire, WI) was used to measure the height in mm at a randomly selected location on the outside of the cake. Since all cakes were made using the same pan, a cake with more height would also have a greater cake volume, which is usually indicative of a higher-quality cake (Ashwini and others 2009; Díaz-Ramírez and others 2016).

Texture analysis

The same three randomly chosen samples that were used to measure height were also used to analyze firmness and elasticity using a TA.XTPlus Texture Analyzer (Texture Technologies Corp., Scarsdale, NY/Stable Micro Systems, Godalming, Surrey, UK). Firmness and elasticity of the crumb were measured using a modified version of AACCI Method 74-09.01 for use with the TA.XTPlus instrument rather than the Instron (AACCI 2010). A 25 mm diameter cylindrical probe was used to compress a cross-sectional area of the cakes at a speed of 1.7 mm/sec until a 7 mm compression was reached, where the compression was then held for 30 s. The instrument measured the peak force required for the 7 mm compression, as well as the force after 30 s of holding. Firmness is reported as the peak force at 7 mm compression, whereas elasticity was calculated as the force recorded after 30 s of holding divided by the peak force at 7 mm compression and multiplied by 100 to convert to percent. The elasticity calculation is shown in the following equation:

$$\%\ \text{Elasticity} = \frac{\text{Force after 30 s of holding}}{\text{Peak force}} \times 100$$

For the analysis of frozen, microwave reheated cakes, the tops of the cakes were sliced off and cross-sectional areas were placed on a 1000 watt microwave spinning plate (Hamilton Beach Model HB-P100N30AL-S3, Glen Allen, VA) and microwaved for 40 s. Approximately 10 to 15 s after microwaving, the warm cross-section was transported across the lab to the Texture Analyzer where the same texture analysis settings and procedure were used

Moisture loss

To determine moisture loss, 160 g of batter was deposited into each of the six wells and the batter and pan were weighed prior to baking. The filled pan was placed in the oven and baked. The cakes were allowed to cool in the pans for approximately 30 min and then the pan with baked cakes still in it was weighed. Three separate batters of each treatment were analyzed during the Rum Experiment (n=3), and two separate batters of each treatment were analyzed during the Functional Ingredient Experiment (n=2).

Data Analysis

Rum Experiment

Six separate batters of each treatment were tested for pre-baking batter characteristics (final batter temperature, specific gravity, and consistency) as well as post-baking physiochemical characteristics (height, firmness, and elasticity) (n=6). For the moisture loss experiment, three separate batters of each treatment were tested (n=3).

Since three subsamples were taken per batter to measure cake height, firmness, and elasticity, data from subsamples were averaged before calculating means of each treatment. SAS (Version 9.4, Cary, NC, USA) was used to run the analysis on each attribute. Degrees of freedom were adjusted using the Kenward-Roger method for missing experimental units (Kenward and

Roger 1997). Type 3 Tests of Fixed Effects were used to determine treatment effects ($p<0.05$), and pairwise comparisons were performed when significant treatment effects were present.

Functional Ingredient Experiment

Aside from the moisture loss experiment, four batters of each treatment were prepared and baked for analysis (n=4). For the moisture loss experiment, two batters of each treatment were analyzed (n=2). Since three subsamples were taken per batter for assessment of both fresh and frozen cakes, data from subsamples were averaged before calculating means of each treatment. SAS (Version 9.4, Cary, NC, USA) was used to run the analysis on each attribute. For each response, a means model was fitted through PROC MIXED. The combination of starch and GMS, control were fixed effects. Comparison of main effects and main effect against control were carried out via CONTRAST statement. Tukey's adjustment is applied to the pairwise comparisons at alpha level of 0.05.

Results and Discussion

Rum Experiment

Results from batter characteristic tests are shown in Table 3.4. The effect of formulation did not have any significant effects on specific gravity or consistency. However, final batter temperatures were lower in the 12.6% formulation than all other formulations, likely because this was the only formulation with no added water. If the water added was warmer than the rum (which was held at ambient temperature), it would cause a slight increase in the final batter temperature. Fluctuations in final batter temperature can have an effect on aeration and chemical leavening during baking, as a warmer batter will experience early activation of chemical leavening and produce a cake with less volume and a more fragile crumb (Weekley 2017). The difference between the warmest batter (7.6% rum) and coolest batter (12.6% rum) was only 1.45°C, and while statistically significant, this likely did not have much of an effect on the cakes from a practical standpoint. Insignificant differences in specific gravity suggests that rum did not have an effect on early batter aeration, as any differences in aeration would result in a different specific gravity (Weekley 2017).

Table 3.4. Batter characteristics of rum cakes

Percent rum in formulation	Specific gravity	Final batter temp (°C)	Bostwick (cm)
0%	0.94 ^{a} (0.012)[1]	18.58 ^{a} (0.24)	3.18 ^{a} (0.37)
7.60%	0.93 ^{a} (0.012)	18.80 ^{a} (0.24)	3.07 ^{a} (0.37)
10.10%	0.94 ^{a} (0.012)	18.18 ^{a} (0.24)	3.23 ^{a} (0.37)
12.60%	0.93 ^{a} (0.012)	17.45 ^{b} (0.24)	3.12 ^{a} (0.37)

^{ab}Different superscripts within columns represent differences at $p<0.05$ (n=6).
[1]Numbers in parenthesis are standard errors.

The rum in this study had a significant effect on elasticity and height ($p<0.05$) of cakes. No significant effects were observed for cake firmness. According to Carr and Tadini (2003), crumb firmness is described as the force necessary to attain a given deformation and is the texture property that gets the most attention when assessing bread quality because of its close association to freshness. Although cake and bread portray some different textural characteristics, having a soft crumb is still essential in cakes for the product to be perceived as fresh. Cake firmness tends to increase throughout the staling process, as other studies have found a negative correlation between firmness and moisture and a positive correlation between firmness and starch retrogradation – both of which are processes associated with staling (Díaz-Ramírez and others 2016).

As seen in Table 3.5, the presence of rum significantly increased the mean elasticity of cakes ($p<0.05$), but the amount of alcohol in the formulation did not have a significant effect. Elasticity (sometimes referred to as resilience or springiness), describes how well a product returns to its original position after a stress is applied. According to Díaz-Ramírez and others (2016), a lower elasticity signifies a more brittle crumb and affects cake functionality in several ways, including a reduction in the amount of water that can be held and a reduction in the volume of sponge cake. Both characteristics reduce acceptability by consumers. The significant increase in elasticity in cakes containing rum is a positive textural attribute that may be associated with increased consumer acceptance in sensory testing. A study by Wilderjans and others (2010) found that protein aggregation is positively correlated with elasticity. One theory is that the presence of rum in this study assisted in disrupting gluten formation and instead improved gluten's ability to aggregate during baking. A protein extractability test would be useful in determining whether the rum actually improved protein aggregation and was responsible for the increase in elasticity. All formulations with rum had higher elasticities than the control, but none of the rum-containing formulations were significantly different amongst each other. Therefore, it would be interesting to see if there is a threshold level below the 7.6% rum formulation that still causes a significant increase in elasticity. This could increase consumer acceptability of cakes without adding too much formulation cost.

The presence of rum had a significant effect on the height of cakes, as cakes that had alcohol in the formulation had a greater mean height than the control (Table 3.5). Since all cakes were baked in the same pan and had the same diameter, an increase in height also represents an increase in cake volume, which is a desirable quality in cakes. It should be noted, however, that an increase in elasticity is also associated with an increase in volume (Díaz-Ramírez and others

2016). The increase in elasticity in cakes containing rum may help to explain the increase in volume, as cakes with greater elasticity will have an improved ability to retain its shape.

These results indicate that the presence of rum in a cake formulation creates a springier cake with increased volume. The significant increase in elasticity for cakes containing rum should not be overlooked, as higher elasticity is associated with fresher, higher-quality products from a sensory standpoint (Díaz-Ramírez and others 2016). It is very important to note that in textural attributes that did show significant differences, the differences were only seen between the control and formulations containing rum (Table 3.5). None of these attributes showed significant differences between two formulations containing rum – for example the 7.6% and 12.6% formulations. This suggests that the presence of rum in a cake batter has significant effects on some physical characteristics, but there may be some diminishing returns as rum quantity (and subsequently formulation costs) continues to be increased.

Since none of the formulations containing rum had any significant differences amongst each other in any of the physical attributes measured, it would be interesting to test lower levels of alcohol to see if there is a lower threshold that still shows significant differences from the control. This would help manufacturers formulate their cakes with low levels of alcohol to achieve a more palatable cake while keeping costs down. However, sensory properties also need to be tested. It would also be interesting to run this experiment again but with a lower-protein flour, such as cake flour. This may have an effect on how alcohol interacts with the gluten matrix and affects crumb characteristics of the cake.

Table 3.5. Physical characteristics of rum cakes

Percent rum in formulation	Mean firmness (g)	Mean elasticity (%)	Mean height (mm)
0%	493.04 ^{a} (35.14)[1]	53.83 ^{a} (0.36)	40.45 ^{a} (0.50)
7.60%	506.81 ^{a} (35.14)	55.05 ^{b} (0.36)	42.79 ^{b} (0.50)
10.10%	469.77 ^{a} (35.14)	55.77 ^{b} (0.36)	43.38 ^{b} (0.50)
12.60%	529.90 ^{a} (35.14)	55.29 ^{b} (0.36)	43.97 ^{b} (0.50)

^{ab}Different superscripts within a column represent differences at $p<0.05$ (n=6).
[1]Numbers in parenthesis are standard errors.

Results from the moisture loss experiment revealed that the addition of rum significantly reduced moisture loss during baking. As the amount of rum in the formula increased, the moisture loss continued to decrease significantly (Table 3.6). Considering all formulas had the same amount of total liquids, this can be explained by the alcohol in the cakes cooking off before the water. As the amount of alcohol increased in the formulations, the amount of water that was cooked off decreased while under the same cooking time and temperature. It should be noted that moisture loss data in this experiment was collected for the entire batch, each batch consisting of six mini bundt cakes in one pan.

Table 3.6. Mean moisture loss of rum cakes

Percent of rum in formulation	Mean moisture loss (g)
0%	83.67^{a} (1.85)
7.60%	61.63^{b} (1.85)
10.10%	53.76^{c} (1.85)
12.60%	48.46^{d} (1.85)

^{abcd}Different superscripts within a column represent differences at $p<0.05$ (n=3).
[1]Numbers in parenthesis are standard errors.

These moisture loss results may have a connection to the increased height and elasticity of formulations containing rum, as cakes with more water after baking should be less crumbly and better able to retain their shape without seeing an increase in firmness. As mentioned by Díaz-Ramírez and others (2016), elasticity and moisture retention of cakes has a positive correlation which is supported by this data. Using this information, it would be interesting to conduct the same physiochemical experiment but with increased water in the control, 7.60% rum, and 10.10% rum formulations. This would help confirm whether the increase in elasticity and height is a function of the rum itself or a function of decreased water loss during baking. It also would be important to determine the amount of alcohol remaining in each rum treatment.

Cross-sectional pictures were taken of the four variations (Figure 3.1). As observed visually the overall structure of each treatment is very similar in regard to number of cells, cell size, and the area of the cell size.

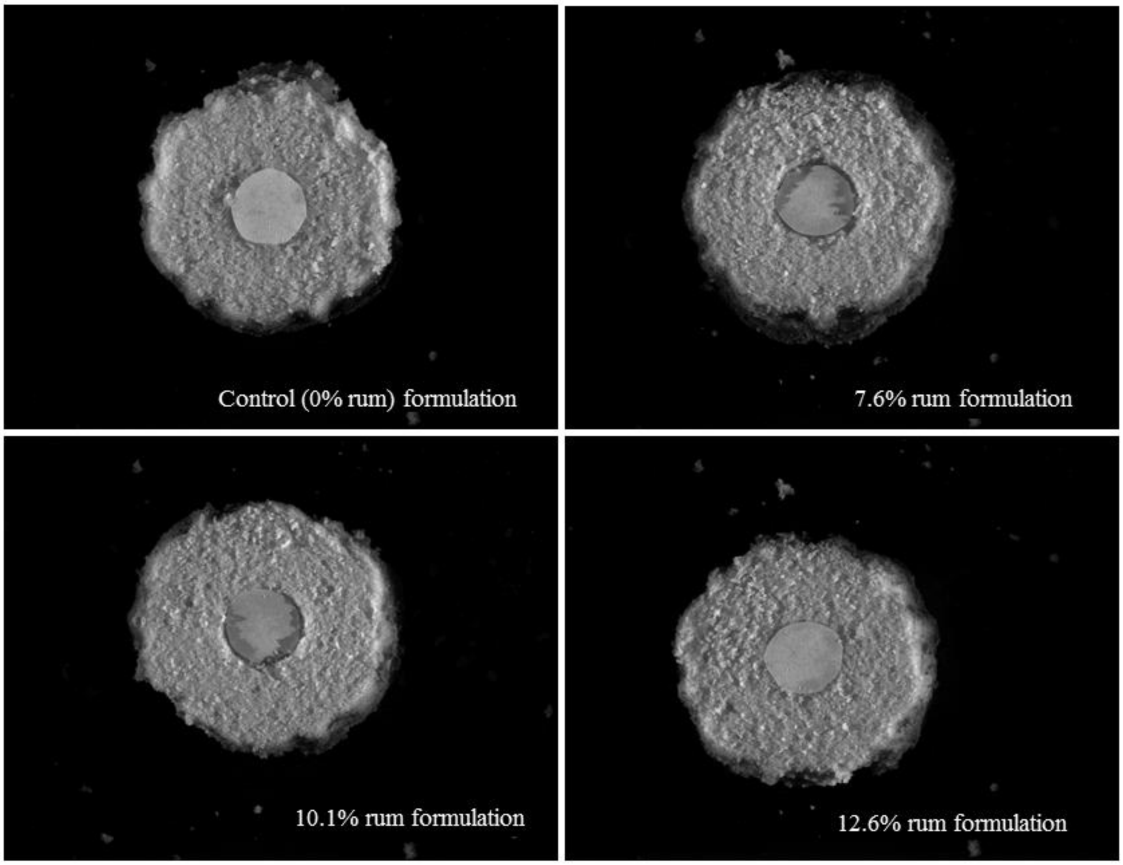

Figure 3.1. Comparison of fresh rum cakes from formulations with varying levels of rum

Functional Ingredient Experiment

Results from batter characteristic tests can be seen in Tables 3.7 and 3.8. Since subsamples were randomly selected to be stored either as fresh or frozen after baking, storage conditions had no effect on batter characteristics. Although no significant effects were observed regarding specific gravity in this experiment, others have reported conflicting results regarding the effect of emulsifiers on specific gravity. Jooste and Mackey (1951) described that when GMS was added to the batter, “air was immediately lost, and the mixture became pasty and compact,” indicating an increase in specific gravity. Another study, however, reported a significant decrease in batter density and improved aeration with the addition of emulsifier gels in the α-state, indicating a decrease in specific gravity (Jyotsna and others 2004). Although not explicitly stated, it is possible that the GMS used in the Jooste and Mackey (1951) study remained in the β-crystalline form and was responsible for the increase in specific gravity. These results indicate minimal differences in early batter aeration amongst formulas.

There was a significant difference ($p < 0.05$) in final batter temperature observed when contrasting the control with formulations containing 0.42% starch. Although the final batter temperature can impact aeration and chemical leavening during baking, the temperature difference between the warmest batter and coolest batters was less than 1°C; this difference is unlikely to have much impact on final cake quality.

Some of the more notable differences in batter characteristics are observed in the batter consistency (Bostwick) results. Significant differences ($p < 0.05$) can be seen in batter consistency when comparing the control formulation to formulations with either medium or high starch levels, as well as when comparing the control formulation to formulations with either low or high levels of GMS. There was also a significant difference noted when comparing formulations that contained a high level of starch with those that were low starch. Results from this analysis are expected as a thickening effect occurs when using a pregelatinized starch such as the one used in this experiment. If the starch was not pregelatinized in this experiment, the increase in batter consistency would likely have been less severe.

The thickening ability of the pregelatinized starch, along with the GMS' ability to emulsify and stabilize the air bubbles that are formed during creaming and mixing resulted in batters with increased consistency. In general, an increase in batter consistency is seen as a positive attribute, as thicker batters have an increased ability to retain air bubbles, leading to a final product with greater volume and elasticity (Tsatsaragkou and others 2015).

Table 3.7. Batter characteristics of rum cake

Formulation (starch/GMS)	Percent Starch	Percent GMS	Specific gravity	Final batter temp (°C)	Bostwick (cm)
Control	0	0	0.92 (0.02)[1]	17.65 (0.23)	1.85 (0.25)
Low/Low	0.21	0.11	0.85 (0.02)	18.16 (0.26)	1.65 (0.28)
Low/High	0.21	0.17	0.90 (0.02)	17.70 (0.23)	1.48 (0.25)
Mid/Low	0.42	0.11	0.89 (0.02)	18.17 (0.26)	1.10 (0.28)
Mid/High	0.42	0.17	0.87 (0.02)	18.36 (0.25)	1.10 (0.26)
High/Low	0.63	0.11	0.88 (0.03)	17.51 (0.30)	0.75 (0.32)
High/High	0.63	0.17	0.86 (0.02)	18.13 (0.23)	0.90 (0.25)

[1]Numbers in parenthesis are standard errors.

Table 3.8. Contrast comparison of batter characteristics (Pr > F)

Contrast	Specific gravity	Final batter temperature	Bostwick (Consistency)
Low Starch vs. Mid Starch	0.93	0.20	0.10
Mid Starch vs. High Starch	0.67	0.09	0.31
High Starch vs. Low Starch	0.76	0.70	0.02
Control vs. Low Starch	0.15	0.36	0.37
Control vs. Mid Starch	0.16	0.05	0.02
Control vs. High Starch	0.10	0.58	0.00
Low GMS vs. High GMS	0.86	0.58	0.97
Control vs. Low GMS	0.10	0.30	0.03
Control vs. High GMS	0.12	0.15	0.03

Fresh rum cakes

Results from the physical characteristics of fresh rum cake testing can be seen in Tables 3.9 and 3.10. Contrast statements were used to determine if any significant effects ($p < 0.05$) were caused from the modified starch or glycerol monostearate, and at which formulation levels significant differences were observed.

When looking at mean firmness, significant differences were observed when comparing control versus low starch and control versus low GMS. Out of all formulations, cakes that did not contain any modified starch or GMS (control) had the highest peak firmness. While these significant differences were seen when comparing the control to formulations with low starch or low GMS, it should be noted that minimal differences were observed when comparing formulations that contained at least some modified starch or GMS. It should also be noted that although differences in control versus mid/high starch and control versus high GMS were not significant ($p > 0.05$).

Several significant differences ($p < 0.05$) were observed when looking at elasticity. All three starch levels and both GMS levels tested had a significant increase to cake elasticity when compared to the control. Similar to firmness, significant differences were not observed in formulas comparing different levels of starch or GMS, suggesting that the presence of such ingredients will increase elasticity, but further increasing usage rates may increase formulation costs without much improvement to final cake quality.

The decrease in firmness and increase in elasticity are likely related; batters that contain these ingredients are better able to emulsify and stabilize air bubbles within the batter (as seen in Figure 2.1) and during the baking process. The improved distribution and stabilization of these air bubbles through improved batter consistency and emulsion stability results in a crumb that is airier and more elastic after a mechanical stress is applied. For high-ratio cakes such as this, decreasing firmness and increasing elasticity will help achieve the light, delicate texture that many consumers expect.

Table 3.9. Physical characteristics of fresh rum cakes

Formulation (starch/GMS)	Percent Starch	Percent GMS	Mean firmness (g)	Mean elasticity (%)	Mean height (mm)
Control	0	0	593.01 (60.32)[1]	46.63 (0.80)	45.28 (0.73)
Low/Low	0.21	0.11	422.21 (67.98)	52.48 (0.91)	44.61 (0.82)
Low/High	0.21	0.17	433.58 (60.32)	52.34 (0.81)	46.78 (0.73)
Mid/Low	0.42	0.11	433.15 (67.98)	51.23 (0.91)	45.19 (0.82)
Mid/High	0.42	0.17	468.51 (63.60)	52.01 (0.85)	44.32 (0.77)
High/Low	0.63	0.11	440.46 (77.65)	52.09 (1.04)	46.52 (0.94)
High/High	0.63	0.17	471.61 (60.32)	50.47 (0.81)	45.26 (0.73)

[1]Numbers in parenthesis are standard errors.

Table 3.10. Contrast comparison of physical characteristics of fresh rum cakes (Pr > F)

Contrast	Mean firmness	Mean elasticity	Mean height
Low Starch vs. Mid Starch	0.73	0.38	0.25
Mid Starch vs. High Starch	0.94	0.69	0.16
High Starch vs. Low Starch	0.70	0.25	0.82
Control vs. Low Starch	0.04	<0.0001	0.65
Control vs. Mid Starch	0.07	0.0001	0.57
Control vs. High Starch	0.09	0.0003	0.52
Low GMS vs. High GMS	0.63	0.65	0.98
Control vs. Low GMS	0.04	<0.0001	0.85
Control vs. High GMS	0.07	<0.0001	0.83

The moisture loss study revealed no significant differences amongst any of the treatments, including the control (Table 3.11). These results indicate that any of the significant physiochemical differences in fresh cakes were a result of ingredient functionality that is not related to moisture retention.

Table 3.11. Mean moisture loss of rum cakes with different levels of starch and GMS

Formulation (starch/GMS)	Percent Starch	Percent GMS	Mean moisture loss (g)
Control	0	0	106.63 [a] (2.08)[1]
Low/Low	0.21	0.11	100.75 [a] (2.94)[1]
Low/High	0.21	0.17	101.75 [a] (2.94)
Mid/Low	0.42	0.11	101.25 [a] (2.94)
Mid/High	0.42	0.17	105.75 [a] (2.94)
High/Low	0.63	0.11	104.25 [a] (2.94)
High/High	0.63	0.17	106.50 [a] (2.94)

[a]Different superscripts within columns represent differences at $p<0.05$ (n=2).
[1]Numbers in parenthesis are standard errors.

Frozen then microwaved rum cakes

Results from the physical characteristics of frozen then microwaved rum cake testing can be seen in Tables 3.12 and 3.13. Contrast statements were used to determine if any significant effects ($p < 0.05$) were caused from the modified starch or glycerol monostearate, and at which formulation levels significant differences were observed. There were no significant differences observed when testing mean firmness or mean height of frozen then microwaved cakes, but elasticity significantly decreased ($p < 0.05$) when comparing control versus high starch cakes and control versus low GMS cakes.

These results indicate that the addition of modified starch and GMS did not improve physical characteristics of rum cakes that had been frozen and then reheated in a microwave. It is possible that the short freezing time (2 weeks) in this study was at least partly responsible for a lack of significant differences in mean firmness and height among treatments. There are conflicting reports about the importance of frozen storage time on the quality of starch-based goods. According to a study by Fik and Surówka (2002), time of frozen storage (from 1 to 11 weeks) had little effect on several instrumental textural parameters of fully and part-baked frozen bread. Some of the textural parameters that had insignificant differences among storage times were hardness, cohesiveness, springiness, chewiness, and resilience. Fik and Surówka (2002) also mention that the most pronounced changes in bread quality were observed at the beginning of the storage period (after 1 week), and changes after that period were minimal, indicating that the freezing process itself has more of an effect on the quality of starch-based goods than frozen storage time.

Other studies, however, have found that frozen storage time does have a significant effect on the quality of bread. A study by Bárcenas and others (2003) found that time of frozen storage resulted in a progressive increase of retrogradation and hardness in frozen part-baked and rebaked bread. Another study found several textural and quality changes to occur in sponge cake only after a certain length of frozen storage, including a significant increase in firmness, decrease in cohesiveness and resilience and observed starch retrogradation after two months of storage, an increase in crystallinity and crumb fractures after four months, and shrinkage of starch granules after six months (Díaz-Ramírez and others 2016).

It would be interesting to see if an extended frozen storage time resulted in more pronounced differences among treatments. Both the modified starch and GMS were of interest for their emulsification properties, and the modified starch was also of interest for its freeze-thaw stability properties. If frozen storage time were longer, it is possible that the importance of these functional ingredients and their ability to prevent undesirable changes in frozen cakes would become more prevalent and more significant differences based on formulation would be observed.

Table 3.12. Physical characteristics of frozen and then microwaved rum cakes

Formulation (starch/GMS)	Percent Starch	Percent GMS	Mean firmness (g)	Mean elasticity (%)	Mean height (mm)
Control	0	0	129.88 (11.76)[1]	55.57 (0.78)	46.77 (0.84)
Low/Low	0.21	0.11	133.14 (13.02)	53.88 (0.87)	48.63 (0.92)
Low/High	0.21	0.17	139.72 (11.76)	53.96 (0.78)	48.27 (0.84)
Mid/Low	0.42	0.11	162.99 (14.91)	53.53 (0.99)	46.34 (0.92)
Mid/High	0.42	0.17	133.76 (12.37)	54.19 (0.82)	47.65 (0.88)
High/Low	0.63	0.11	131.39 (12.37)	52.67 (0.82)	47.26 (0.88)
High/High	0.63	0.17	138.01 (11.76)	53.65 (0.78)	47.31 (0.84)

[1]Numbers in parenthesis are standard errors.

Table 3.13. Contrast comparison of physical characteristics of frozen and then microwaved rum cakes (Pr > F)

Contrast	Mean firmness	Mean elasticity	Mean height
Low Starch vs. Mid Starch	0.37	0.95	0.12
Mid Starch vs. High Starch	0.28	0.41	0.74
High Starch vs. Low Starch	0.89	0.38	0.21
Control vs. Low Starch	0.66	0.11	0.12
Control vs. Mid Starch	0.23	0.10	0.83
Control vs. High Starch	0.74	0.02	0.62
Low GMS vs. High GMS	0.61	0.42	0.64
Control vs. Low GMS	0.38	0.03	0.52
Control vs. High GMS	0.60	0.09	0.33

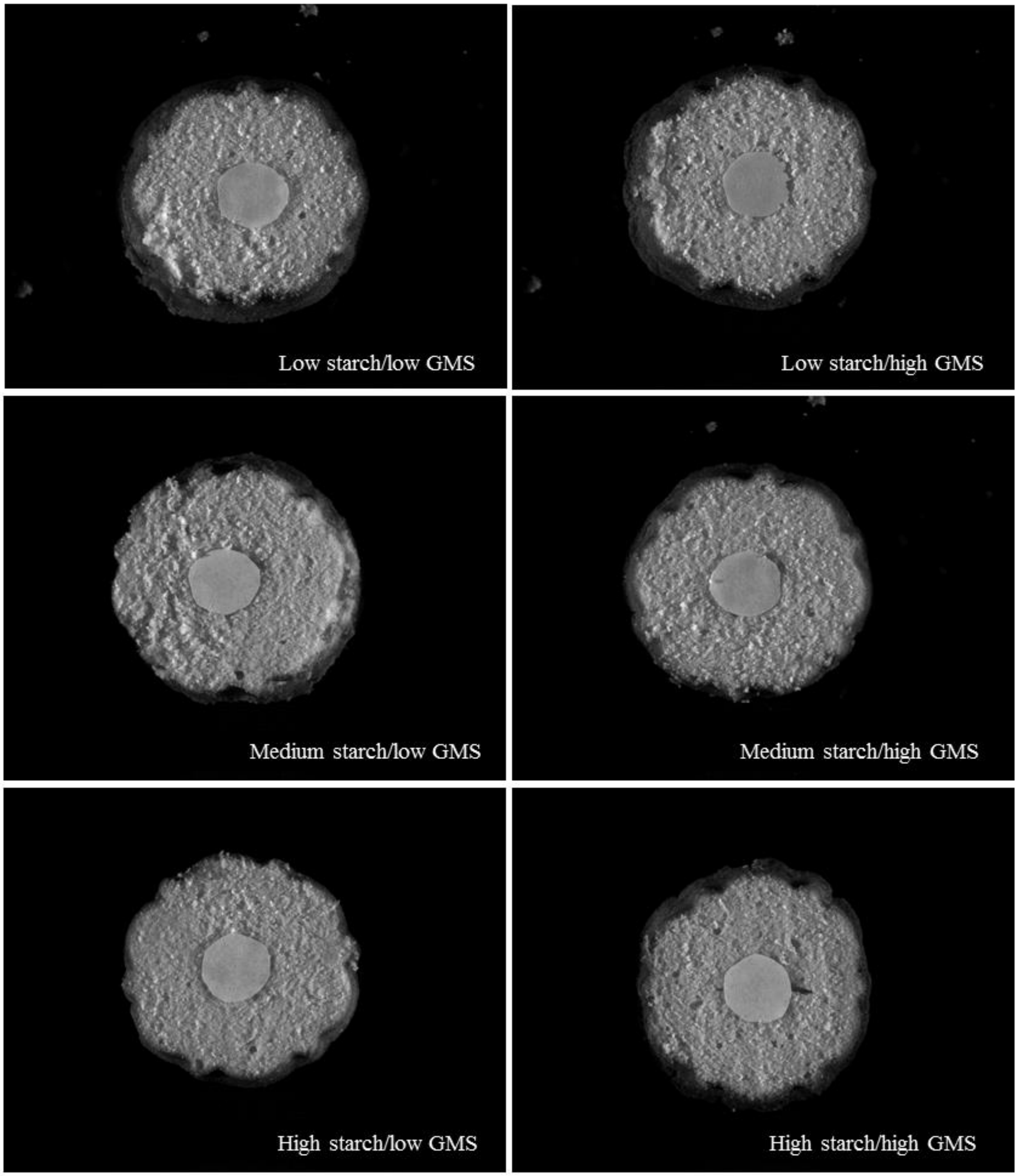

Figure 3.2. Comparison of fresh cakes from formulations containing varying levels of modified starch and GMS. Low starch = 0.21%, Mid starch = 0.42%, High starch = 0.63%. Low GMS = 0.11%, High GMS = 0.17%

Figure 3.3 shows the various treatments with starch and GMS. Overall, the cakes visually appeared to have more cells, large cells randomly throughout the cross-section, and a larger cell area for most cells than the cakes with only alcohol addition.

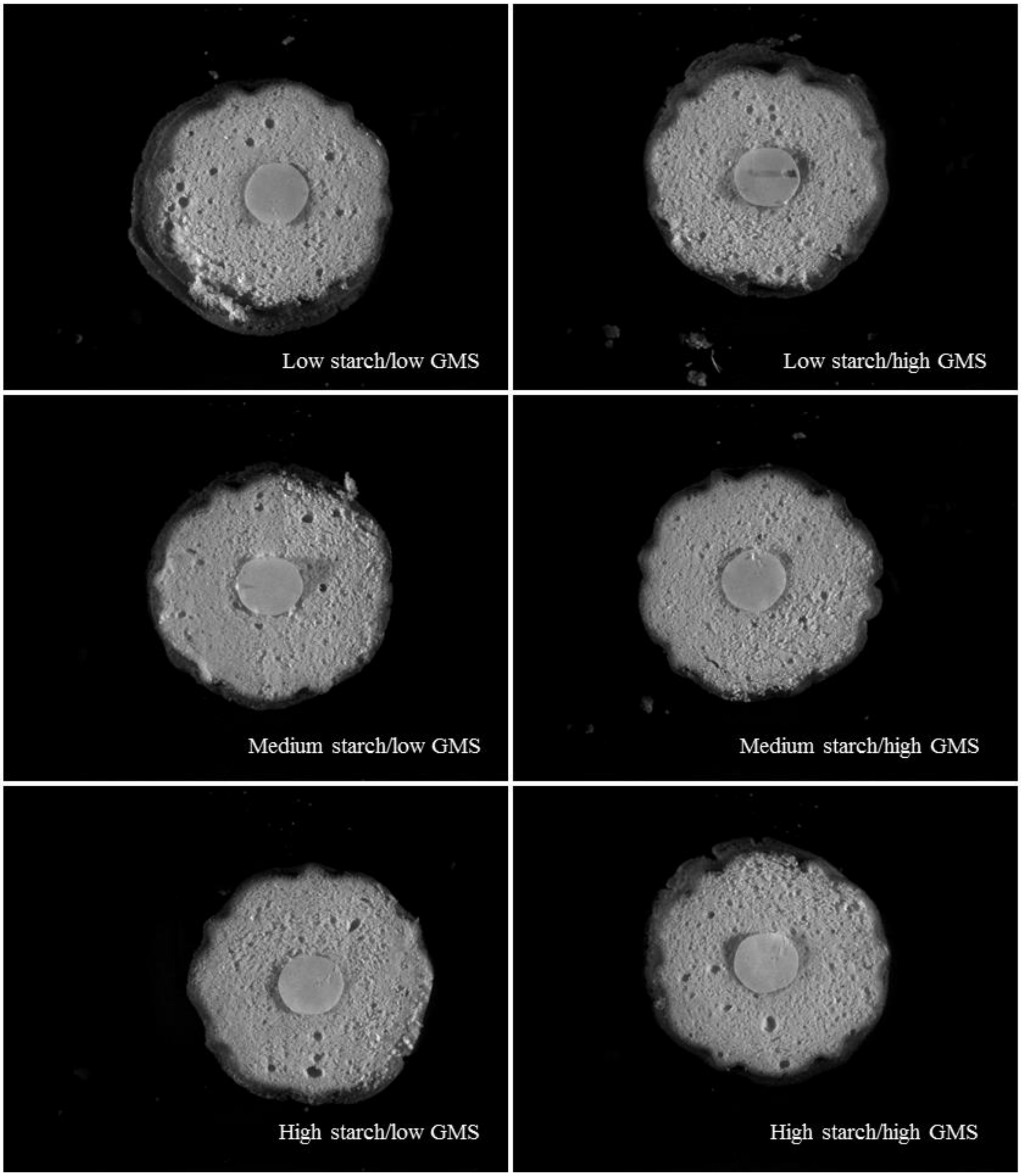

Figure 3.3. Comparison of frozen cakes from formulations containing varying levels of modified starch and GMS. Low starch = 0.21%, Mid starch = 0.42%, High starch = 0.63%. Low GMS = 0.11%, High GMS = 0.17%

Conclusion

The addition of rum to a cake batter at 7.6% or greater significantly increased cake elasticity and height. From this data alone, it cannot be determined whether the increase to elasticity and height were a function of the rum or a function of increased moisture retention in cakes containing higher levels of rum. The increase in elasticity and height are seen as positive attributes from a consumer acceptance standpoint. Therefore, the addition of rum to a cake improves the overall physical properties of cake while also providing a unique flavor profile that is desired by consumers.

Pregelatinized starch was found to have a significant effect on batter viscosity, as increasing the level of starch resulted in a progressively thicker batter. In fresh cakes, the addition of starch and GMS at low levels resulted in decreased firmness. All three starch levels and both GMS levels tested significantly increased cake elasticity when compared to the control. For both firmness and elasticity, the presence of the ingredient was more impactful than the usage rate.

In frozen and then microwave reheated cakes, no significant differences were observed in peak firmness or height. Elasticity significantly decreased when comparing control versus high starch cakes and control versus low GMS cakes. These results indicate that the modified starch and GMS used in this experiment did not have the expected positive textural impact on frozen, microwave reheated rum cakes.

Perhaps the brief frozen storage time in this experiment played a role, and increasing the frozen storage time up to six months may result in more pronounced differences among treatments. It would also be interesting to repeat the experiment but with a few procedural changes, including assessing texture of microwaved cakes after they had cooled.

Results from the rum experiment showed the presence of rum at 7.6% or greater significantly increased elasticity and height. The presence of rum in all six formulations may have affected how the functional ingredients affected structure and texture, but since no studies are currently available that evaluated the effectiveness of functional ingredients in formulations that contain alcohol, it is difficult to make predictions about a possible interaction between alcohol and modified starch or GMS.

References

AACC International 2010. Approved Methods of Analysis, 11th Ed. Method 74-09.0. AACC International: St. Paul, MN.

Ashwini A, Jyotsna R, Indrani D. 2009. Effect of hydrocolloids and emulsifiers on rheological, microstructural, and quality characteristics of eggless cake. Food Hydrocolloid 23(3):700–7.

Baba Au Rhum Cake. 2017. History. What's Cooking America. Available from https://whatscookingamerica.net/History/Cakes/BabaCake.htm. Accessed 2017 October 30.

Bárcenas ME, Haros M, Benedito C, Rosell CM. 2003. Effect of freezing and frozen storage on the staling of part-baked bread. Food Res Int 36(8):863–9.

Brathwaite, S. 2017. A Brief History of Caribbean Rum Cake. The Culture Trip; 2017. Available from https://theculturetrip.com/caribbean/articles/a-brief-history-of-caribbean-rum-cake/. Accessed 2017 October 30.

Burch, M. 2017. The Most Popular Cakes in Southern History. Southern Living. Available from http://www.southernliving.com/desserts/cakes/popular-cakes-by-year#1948-orange-chiffon-cake. Accessed 2017 October 30.

Carr LG, Tadini CC. 2003. Influence of yeast and vegetable shortening on physical and textural prameters of frozen part baked French bread. Lebensm.-Wiss. u.-Technol. 36(6):609–14.

Clarke CI, Farrell GM. 2000. The effects of recipe formulation on the textural characteristics of microwave-reheated pizza bases. J Sci Food Agric 80:1237–44.

Crosby G. 2012. Vodka Makes Pie Dough Easy. In: J. Bishop, G. Crosby, M. Birnbaum, D. Souza, editors. *The science of good cooking*. 1st ed. Brookline, MA: America's Test Kitchen. p 378–87.

Díaz-Ramírez M, Calderón-Domínguez G, Salgado-Cruz M, Chanona-Pérez J, Andraca-Adame JA, Ribotta P. 2016. Sponge cake microstructure, starch retrogradation, and quality changes during frozen storage. Int J Food Sci Tech 51(8):1744–53.

Durrwachter, W. 2017. Origin of a classic: Bermudian rum cake. Bake from Scratch Magazine. Available from https://www.bakefromscratch.com/bermudian-rum-cake/. Accessed 2017 October 30.

Ferreira, PBM. Watanabe, E. 1998. Estudo da formulação na produção de pão francês pré-assado. XVI Brazilian Congress of Food Science and Technology, CD-ROM, Paper no. 72.

Fik M, Surówka K. 2002. Effect of prebaking and frozen storage on the sensory quality and instrumental texture of bread. J Sci Food Agric 82:1268–75.

Gallagher E, Gormley TR, Arendt EK. 2004. Recent advances in the formulation of gluten-free cereal-based products. Food Sci Technol Trends 15:143–52.

Gowen A, Abu-Ghannam N, Frias J, Oliveira J. 2006. Optimisation of dehydration and rehydration properties of cooked chickpeas (*Cicer arietinum* L.) undergoing microwave-hot air combination drying. Trends Food Sci Tech 17(4):177–83.

Hesso N, Loisel C, Chevallier S, Le-Bail A, Queveau D, Pontoire B, Le-Bail P. 2015. Monitoring cake baking by sutdying different ingredient interactions: From a model system to a real system. Food Hydrocolloid 51:7–15.

Howard NB. 1972. The role of some essential ingredients in the formation of layer cake structures. Bakers Dig 46:28–37.

Jooste M, Mackey A. 1951. Cake Structure and Palatability as Affected by Emulsifying Agents and Baking Temperatures. J Food Sci 17:185–96.

Jyotsna R, Prabhasankar P, Indrani D, Venkateswara Rao G. 2004. Improvement of rheological and baking properties of cake batters with emulsifier gels. J Food Sci 69(1): SNQ16–9.

Kenward M, Roger J. 1997. Small sample inference for fixed effects from restricted maximum likelihood. Biometrics 53(3):983–97.

Krog NJ, Sparsø FV. 2003. Food emulsifiers: Their chemical and physical properties. In: S. Friberg, K. Larrson, J. Sjoblom, editors. *Food emulsions*. Boca Raton, FL: CRC Press. p 45.

Malik AH. 2009. Nutrient uptake, transport and translocation in cereals: Influences of environment and farming conditions. Swedish University Agricultural Sciences. ISSN1654-3580. p 1–46.

Mandala IG, Sotirakoglou K. 2005. Effect of frozen storage and microwave reheating on some physical attributes of fresh bread containing hydrocolloids. Food Hydrocolloid 19:709–19.

Miller RA, Hoseney RC. 1997. Method to measure microwave-induced toughness of bread. J Food Sci 62(6):1202–4.

Mizrahi S. 2012. Mechanisms of objectionable textural changes by microwave reheating of foods: A review. J Food Sci 71(1): R57–62.

Mullin J. 1995. Microwave Processing. In: G. W. Gould, editor. *New methods of food preservation*. Springer Science+Business Media. p 112–34.

The Jamaican Rum Cake. 2017. History and Recipe. Jamaica Experience. Available from https://ajamaicaexperience.com/jamaican-rum-cake/. Accessed 2017 October 30

Silva R. 2000. Uses of α-crystalline emulsifiers in the sweet goods industry. Cereal Foods World 45:405–11.

Tsatsaragkou K, Papantoniou M, Mandala I. 2015. Rheological, physical, and sensory attributes of gluten-free rice cakes containing resistant starch. J Food Sci 80(2):E341–8.

Uzzan M, Ramon O, Kopelman IJ, Kesselman E, Mizrahi S. 2007. Mechanism of crumb toughening in bread-like products by microwave reheating. J Agric Food Chem 55(16):6553–60.

Vadivambal R, Jayas DS. 2010. Non-uniform temperature distribution during microwave heating of food materials - A Review. Food Bioprocess Tech 3(2):161–71.

Weekley B. 2017. Quality cake production guide. General Mills. Available from https://www.generalmillscf.com/industries/bakery/support-tool-categories/technical-support/cake-troubleshooting-tips/quality-cake-production-guide. Accessed 2017 November 20.

Wilderjans E, Luyts A, Goesaert H, Brijs K, Delcour JA. 2010. A model approach to starch and protein functionality in a pound cake system. Food Chem 120:44–51.

Wilderjans E, Pareyt B, Goesaert H, Brijs K, Delcour JA. 2008. The role of gluten in a pound cake system: A model approach based on gluten-starch blends. Food Chem 110:909–915.

Chapter 4 - Conclusion

- The addition of rum to cake batter at 7.6%, 10.1%, and 12.6% increased cake elasticity and height when compared to a control. Overall, the addition of rum improved texture of cakes while also providing a unique flavor profile.
- Although significant differences were seen among formulations containing rum and the control (0% rum), no differences were seen among formulations containing different levels of rum. This suggests that the presence of rum had more of an effect on texture and structure of cakes than the amount of rum.
- Testing rum levels below 7.6% may result in a lower threshold that still imparts desirable effects on texture and structure of cake. This would give manufacturers an option for improving palatability of cakes while keeping formulation costs down.
- Sensory testing may be useful in determining consumer preferences for rum amount added to cakes.
- The addition of a pregelatinized waxy maize starch to cake batter increased batter viscosity. Higher batter viscosity is desirable in cakes because of an improved ability to trap and retain air bubbles during mixing and baking.
- The addition of both modified starch and GMS had positive textural impacts in fresh cakes in the form of decreased firmness and elasticity. While the presence of these ingredients was significant, differences were not seen amongst the various usage rates.
- The addition of both modified starch and GMS did not have the expected positive textural impact on cakes that had been frozen and then microwave reheated. No differences were observed in firmness or height, and a decrease in elasticity was observed when comparing the control to cakes with a high starch level or low GMS level.

Appendix A - Initial Development of a Mango Rum Cake

A frozen, microwaveable mango rum cake was initially developed for a product development competition. The following formulation was used for the development of this cake.

Table A.4.1. Initial development of a mango rum cake formulation

Ingredient	Percent (True %)
Sugar	24.43
All Purpose Flour	13.96
Mango	12.75
Whole Egg	9.75
Heavy Whipping Cream	7.94
Dark Rum	7.92
Unsalted Butter	7.60
Buttermilk	5.30
Vegetable Shortening	4.25
Canola Oil	3.18
Egg Yolk	1.74
Modified Starch	0.42
Salt	0.27
Baking Powder	0.22
Vanilla Extract	0.16
Glycerol Monostearate	0.11

Mixing and baking procedures for this cake were as follows: Pre-heat oven to 350ºF/177ºC. Generously spray a six 4” × 1-3/4” cavity fluted Bundt pan with nonstick cooking spray, set aside for later use. Using a KitchenAid mixer, beat the butter to soften on medium speed. Add shortening and GMS and beat mixture for about 3 min or until mixture is pale in color. Add sugar and then cream sugar until light. Before proceeding check if all ingredients are incorporated by scraping the sides and the bottom of the bowl at least once. Beat in the canola oil, the vanilla, and the rum. On low speed, blend the egg yolks and then blend whole eggs one at a time. In a medium sized bowl, with a fork or hand mixer, combine flour, baking powder, modified starch, and salt. On the lowest speed, blend one-third of the flour mixture into the butter batter. Alternate adding buttermilk and flour until both are fully incorporated. Once fully incorporated scrape down the sides and across the bottom at least once. Then on low speed, slowly add in the heavy whipping cream, mix until well blended. Remove bowl from mixer and gently fold in the mango chunks with a spatula.

Pour 185 grams of batter into the already greased pan. Place the filled pan into the preheated oven and bake for approximately 32 min or until a toothpick inserted in the middle comes out clean, but moist. Remove from oven and place pan on rack to cool. Let cakes stand for approximately 32 min, then shake pan to loosen cakes.