

A food science and foodservice interdisciplinary framework for the development of sorghum and wheat products

by

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Abstract

Interdisciplinary Course Framework

A framework for two undergraduate food product development courses involving interdisciplinary work between food science and foodservice (university dining center) was implemented. Former students were surveyed to determine framework impact. Students agreed that the framework gave them experience with larger-scale food production equipment, and taught about foodservice perspectives (feasibility requirements, how dining centers operate) and the scale-up process. Students also developed research/laboratory skills, soft skills, and food production knowledge. In return, new recipes were developed for the dining center. This framework could be implemented at other universities to develop interdisciplinary relationships between dining centers and food science programs.

Development and Scale-Up of Gluten-Free Sorghum-Based Bakery Goods for Kansas State Dining Services

To create new product opportunities for sorghum in the state of Kansas, the FarmUs project had three primary pillars: Innovate, Scale, and Connect. The project aims to close the gap between industry and consumers by peaking interest in sorghum, its nutritional and sustainable benefits, and consumption of sorghum-based products. The primary focus of this study was to develop and scale-up three gluten-free sorghum-based products for Kansas State Dining Services. The secondary objective was to evaluate the sensory and physical properties of these products to provide developmental and research experience for students. Preliminary testing involved identifying optimum ratios of sorghum flour, xanthan gum, starch, and eggs for proper binding. Whipped egg whites were tested at different levels for product volume and texture. Repetition and reformulation of the products provided various renditions of each product. Quantity equipment needs; staffing feasibility, ingredient availability, and cost were determined.

Dining staff evaluated each product and once recipes were finalized, parameters (color, specific gravity, internal temperature, moisture loss, height/width, water activity) were evaluated. Dining center customers provided acceptability feedback for the three gluten-free products using the 9-point Hedonic scale. The first product, a savory waffle, can be stacked with turkey sausage and cheddar cheese for a breakfast sandwich. It utilizes sorghum flour, egg whites, xanthan gum, starch, and flaxseed for structure. This product received a range of 7.03–7.63 ($n = 43$) for all sensory attributes (acceptability, flavor, mouthfeel, texture, and aftertaste). The lemon blueberry muffin contains sorghum flour, eggs, buttermilk, xanthan gum, potato starch, and egg whites. Sensory data ($n = 49$) measured at acceptability (7.4), flavor (7.6), mouthfeel (6.4), texture (6.6), and aftertaste (7.6). The third product, a sweet potato muffin top, contains sorghum flour, xanthan gum, eggs, egg whites, and sweet potatoes. All three recipes were formatted via Computrition Menu Management system to provide methodology, nutritional analysis, costing, and labeling for university dining use. These recipes, along with sorghum-based educational materials, were shared with higher learning facilities across Kansas.

The Impact of Rum on Physicochemical Properties of Sorghum and Wheat Pound Cakes

Sorghum, a sustainable flour for gluten-free baked-products, typically results in products with decreased volume, less flexible crumb, and gritty mouthfeel. Ethanol can affect starch properties by increasing gelatinization, swelling, and surface wrinkling, but these effects have not been tested in a cake system. One previous study evaluated rum in wheat cakes and observed increased elasticity and volume. The objective of this study was to evaluate the impact of rum on sorghum and wheat-based pound cakes.

A 2x2 factorial design ($n=3$) was used to compare pound-cake formulations: sorghum with rum (SR), sorghum without rum (SN), wheat with rum (WR), and wheat without rum (WN). White pearled sorghum flour or soft wheat flour was used with rum (7.58%), xanthan

gum (0.25%) and potato starch (4.9%) by weight. Water was used instead of rum in the control formulations (SN and WN). Specific gravity (SG) of the batters was determined immediately after mixing. Cakes were baked in pup-loaf pans and cooled for 1h prior to testing. Finished products were evaluated for weight, volume (using laser topography), internal structure (using the C-Cell imaging system), and texture (hardness and cohesiveness, using a texture analyzer fitted with a 2.5cm probe). Data was analyzed using SAS Proc Mixed and Tukey's test ($p < 0.05$).

Sorghum-based batters had lower SG than their wheat counterparts, indicating higher air entrapment during mixing. Rum significantly decreased the SG for both grains. Final volume for wheat-based cakes was higher than sorghum, indicating better air retention, despite formulation with xanthan gum and potato starch for structure-creation. In contrast with SG data, rum significantly decreased cake volume. It also increased top concavity for SR and WR, indicating structural collapse. Regarding internal structure, rum led to an increased number of air cells in SR, and decreased cell wall thickness for both SR and WR. SR had lower hardness compared with WR, while WR presented increased cohesiveness. No differences for bake loss (5.9-6.6%) were noted.

Aeration, collapse, and gluten structures play important roles in cake quality. Sorghum and rum contributed to more batter aeration; however, cakes containing sorghum and/or rum had lower volumes. The increased top concavity suggests delay or inadequate structure setting.

With the current trend for alcohol-flavored baked goods, understanding the ingredient functionality of alcohol in baked goods can improve future products. This work indicates product structure is of primary concern in both wheat and gluten-free flours.

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Chapter 1 - Introduction

Interdisciplinary Course Framework

Despite being similar fields, interdisciplinary research between food science and foodservice has been limited, especially at the university level. Food science is focused on the chemical, microbiological, sensory, safety, regulatory, and quality assurance aspects of food, as well as the processing and engineering principles required to produce food on a large scale (IFT, 2018). Meanwhile, the field of foodservice focuses on the preparation and serving/distribution of food products for consumers to consume outside their homes (Edwards, 2013; USDA ERS - Food Service Industry, n.d.). Many university academic programs such as Hospitality Management, Dietetics, Culinary, and Business focus on foodservice systems as part of their curriculum and often their areas of research. Interdisciplinary collaboration brings diverse perspectives, which can improve not only the product being developed, but also the research process (Reinventing Undergraduate Education, 1998; Specht & Crowston, 2022; Struijk et al., 2022). Undergraduate research has been shown to be beneficial to students, providing them with scientific skills, soft skills, and experience (Adebisi, 2022; Linn et al., 2015; Petrella & Jung, 2008; Reinventing Undergraduate Education, 1998; Russell et al., 2007). A collaborative approach to food science, culinary, and foodservice management could also provide students with an interdisciplinary experience. Providing students with interdisciplinary research experience could better prepare them for a career in food science.

Objectives

A food science/foodservice interdisciplinary product development and undergraduate research experience framework was developed, where food product formulations were developed and scaled up into quantity recipes to be served in the dining centers. The primary objectives of

these two courses were to provide students with career-applicable experiences and to provide the Dining Center with new menu items. The secondary objective was to determine the framework's impact on students who participated in these courses. The project was funded by the Kansas Department of Agriculture United States Department of Agriculture's (USDA)/Agricultural Marketing Service (AMS). The purpose of the project (FarmUs) was to promote the consumption of two Kansas grains (sorghum and wheat) to university students through new recipes served in Dining Centers.

Development and Scale-up of Gluten-Free Sorghum-based Bakery Goods for K-State Dining Services

Sorghum is a mild-flavored gluten-free grain that is drought-resistant and heat tolerant (Ratnavathi & Komala, 2016). Sorghum is “the greatest drought tolerant among the world's top five carbohydrate-rich crops,” is tolerant to high temperatures, and needs only minimum care (Hossain et al., 2022). Sorghum also has a lower cost of production than wheat, maize, and rice (Hossain et al., 2022). Because of these resilient qualities, sorghum is already grown as a staple crop in some regions and could play an important role in feeding more regions of the world as climate change progresses (Hossain et al., 2022; Morris et al., 2013). For sorghum to fulfill that role, the development of consumer-accepted products made from sorghum will be vital.

Sorghum is a gluten-free grain. Gluten-free products are in high demand due to both health and trend-related consumer desires (Adiamo et al., 2018). Sorghum's sustainability and mild flavor make it a good alternative to wheat when developing products for people with gluten intolerances. However, like most gluten-free flours, sorghum products can have some less desirable traits. Sorghum products have been shown to have characteristics such as sandy, dense, mealy, and gritty (Badi & Hosney, 1976; Cayres et al., 2020; Glover et al., 1986; Marston et al.,

2016). Cakes containing sorghum can experience decreased volume (Glover et al., 1986; Marston et al., 2016).

In general, gluten-free products can fail to meet consumers' expectations of baked goods. They may have less desirable mouth feel and flavor in addition to inferior crust and crumb characteristics. (Naqash et al., 2017). Gluten-free bread products make a liquid batter instead of a dough and may have lower volume and a harder crumb (Naqash et al., 2017). Gluten-free baked products are also often “denser, shorter in height, have a larger spread, have a different color, and be harder in texture than traditional wheat-based baked goods” depending on the gluten-free flour used (Gustafson, 2016).

Adding ingredients to improve the nutritional, sensory, and physiochemical properties of food can aid in the development of gluten-free products. In a study that worked on the development of steamed cold noodles, it was found that the lack of gluten lead to a more fragile product with lower elasticity that could break easily (Bai et al., 2022). They then found that adding egg whites improved the water holding capacity, hardness, and gel strength of the noodles (Bai et al., 2022). They also added protein to the product. Hydrocolloids, enzymes, and starches can improve crumb porosity and increase gas cell size (Naqash et al., 2017). Orange flesh sweet potatoes can be added for flavor/texture and can also improve the nutritional value of a baked good because they contain “high levels of beta-carotene (5091-16,456 ug/100g), a precursor of vitamin A” and “high polyphenolics and antioxidant contents” (Kolawole et al., 2021).

Objectives

FarmUs, a farm to campus collaborative aimed at accessing consumer markets on college campuses, leveraging workforce development and student innovation to create new product opportunities for sorghum, had three primary pillars: Innovate, Scale, and Connect. The primary

focus on this study was to develop and scale-up three gluten-free sorghum-based bakery goods (lemon blueberry muffins, sweet potato muffin tops, and savory breakfast waffle sandwich) for Kansas State University Dining Services. Acceptable product development is vital to this process. Thus, the secondary objective was to evaluate the sensory and physical properties of these newly developed products.

The Effect of Ethanol on Sorghum and Wheat Pound Cake

Sorghum starch has a higher gelatinization temperature (67.5-79°C) than wheat starch (54.5-60°C) (Glover et al., 1986). This higher gelatinization temperature could be one explanation for the quality differences between wheat and sorghum. Delayed gelatinization can cause collapse in cakes (Curti et al., 2022). Previous studies have successfully improved sorghum products by modifying the starch. This can be done by using heat treatments to pregelatinize sorghum starch (Cayres et al., 2020; Marston et al., 2016). Physically damaging the starch can increase gelatinization (Curti et al., 2022; Glover et al., 1986). Ozone treatment can increase starch swelling (Marston, 2009). Replacing ingredients that delay gelatinization (sucrose) with ones that do not delay gelatinization as much (dextrose) can also increase gelatinization (Glover et al., 1986; Kim & Walker, 1992).

Ethanol could possibly be used to affect the starch in baked goods. Ethanol has also been shown to cause a variety of starch surface changes (depending on starch type and amylose/amylopectin ratio and structure) such as swelling, surface wrinkling, and opening-up (Zhang et al., 2012). The impact of ethanol (in the form of rum) has been studied in wheat cakes. It was found to significantly increase cake elasticity, volume, and height, while decreasing moisture loss (Phalen, 2024). If rum has the same impact on sorghum cake, these benefits could potentially assist in improving sorghum products, as some of the main difficulties with sorghum

products are the loss of volume and subpar texture. Zhu (2014) observed sorghum's "amylose content ranges from 0% to 55%...due to genetics and environmental factors." (Zhu, 2014). Because of this range, it is difficult to predict how ethanol might interact with the starch in sorghum.

Starches and hydrocolloids are commonly used to improve gluten-free products by imitating "the viscoelastic properties of gluten" (Salehi, 2019). Gluten is the primary structure former in cakes, but in its absence, starch functions as the "primary texture and structure forming agent in gluten-free systems" (Naqash et al., 2017). Using potato starch in gluten-free cupcakes led to increased batter viscosity, specific volume, and springiness, while decreasing hardness and chewiness (Aleman et al., 2021). Hydrocolloids impact gluten-free baked goods in many ways. Hydrocolloids can improve water holding capacity, texture and increase batter viscosity, volume, and porosity of cakes (Salehi, 2019). They can also delay staling (Salehi, 2019). Using xanthan (as 0.2% inclusion in formulation) in gluten-free cakes increases specific volume and improves texture by decreasing firmness and delaying staling (Preichardt et al., 2011).

Objectives

The objective of this study was to evaluate the impact of rum on sorghum and wheat-based pound cakes.

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Chapter 2 - Literature Review

Interdisciplinary Course Framework

Benefits of Interdisciplinary Research

Interdisciplinary collaboration brings diverse perspectives which can improve the research and the product being developed (Reinventing Undergraduate Education, 1998; Specht & Crowston, 2022; Struijk et al., 2022). Modern research has benefitted from and become more focused on work using expertise from multiple disciplines. Because of this, several terms have been created to describe this type of work such as interdisciplinary, multidisciplinary, and transdisciplinary. Unfortunately, the terms “are ambiguously defined and interchangeably used” (Choi & Pak, 2006). As observed in this literature review, different sources have used different terms. The university course framework suggested by our study uses interdisciplinary research defined as: interactive work between multiple disciplines to create integrated knowledge that impacts all disciplines involved (Choi & Pak, 2006; Frodeman et al., 2010; Morton et al., 2015; National Academy of Sciences et al., 2005). The use of interdisciplinary research in this course framework serves multiple purposes. It provides diverse perspectives that lead to a more functional product, develops important workplace skills, and gives students experience with an increasingly common aspect of work and research.

Despite being similar fields, interdisciplinary research between food science and foodservice has been limited, especially at the university level. Food science is focused on the chemical, microbiological, sensory, safety, regulatory, and quality assurance aspects of food, as well as the processing and engineering principles required to produce food on a large scale (IFT, 2018). Meanwhile, the field of foodservice focuses on the preparation and serving/distribution of food products for consumers to consume outside their homes (Edwards, 2013; USDA ERS -

Food Service Industry, n.d.). Many university academic programs such as Hospitality Management, Dietetics, Culinary, and Business focus on foodservice systems as part of their curriculum and often their areas of research. Interdisciplinary collaboration brings diverse perspectives, which can improve not only the product being developed, but also the research process (Reinventing Undergraduate Education, 1998; Specht & Crowston, 2022; Struijk et al., 2022). Research in the foodservice industry has previously been less common than in other food related areas but has been increasing over the years (Edwards & Causa, 2009). These are inherently interconnected fields, yet at many universities, there are little to no interactions between food science and foodservice. The increasing popularity of foodservice research and interdisciplinary research suggests the opportunity for interdisciplinary research between food science and foodservice.

Providing an interdisciplinary course experience for undergraduate students can assist in developing important workplace skills. Interdisciplinary work is becoming the new normal with many fields of study observing the positive impact it has (Cooper et al., 2001; Costa et al., 2019; D'Elia et al., 2015; Liguori et al., 2024; Omodei et al., 2017; Steele & Stier, 2000). It requires skills such as communication, coordination, organization, and planning across various disciplines (Cooper et al., 2001; Costa et al., 2019; Struijk et al., 2022). Having these useful skills can provide more opportunities for students as they continue through their academic and professional careers. Students can further develop these skills by participating in undergraduate research.

Benefits of Undergraduate Research

Undergraduate research has been shown to be beneficial to students. The experience can encourage students to more actively learn and give them the flexibility to focus the learning on their own interests (Adebisi, 2022; Petrella & Jung, 2008; Reinventing Undergraduate Education,

1998). Conducting research can also develop their scientific skills such as critical and independent thinking, scientific writing, scientific techniques, data analysis, and scientific conceptual understanding (Adebisi, 2022; Linn et al., 2015; Petrella & Jung, 2008; Reinventing Undergraduate Education, 1998; Russell et al., 2007). Undergraduate research builds soft skills such as communication, teamwork, presentation skills, self-confidence, patience, and perseverance (Adebisi, 2022; Linn et al., 2015; Reinventing Undergraduate Education, 1998; Russell et al., 2007). Undergraduate research can provide students with some more tangible benefits such as networking, being published, and having an experience to add to their resume (Adebisi, 2022). A collaborative approach to food science, culinary, and foodservice management could also provide students with an interdisciplinary experience.

Sorghum

Benefits of Using Sorghum

Sorghum is a mild-flavored gluten-free grain that is drought-resistant and heat tolerant (Ratnavathi & Komala, 2016). Sorghum also has a lower cost of production than wheat, maize, and rice (Hossain et al., 2022). Because sorghum is drought and heat tolerant, it can be grown in many places with little water input. Sorghum can also be grown in no-till or minimum-till conditions (Mitchell et al., 2022). These attributes demonstrate sorghum's sustainability. Sorghum's sustainability and mild flavor make it a good alternative to wheat when developing baked goods, such as cakes, for people with gluten intolerances or for creating more sustainable products.

Sorghum has been used to create baked goods that were acceptable to those sampling them. A panel evaluated cookies made from 100% sorghum flour for acceptability and found no difference in acceptability (appearance, aroma, color, texture, taste, aftertaste, and overall

acceptability) between the wheat and sorghum cookies (Aljobair, 2022). Another panel evaluated a different sorghum cookie formulation and found no significant difference in acceptability of appearance, aroma, taste, and overall liking between a red condensed tannin-free sorghum and the wheat control cookies (Chiremba et al., 2009). The sorghum cookie did however have a lower acceptability score for texture.

Challenges of Sorghum Baked Goods

Sorghum, like most gluten-free grains, present some challenges in baked goods. Sorghum products can have lower volumes, undesirable textures, less flexible crumb, decreased shelf life, and altered coloration.

Sorghum baked goods often have a lower volume than their wheat counterparts. In a study on cakes, wheat flour (commercial all-purpose) was partially substituted (5, 10, 15, 20, 30, and 50%) with non pinmilled sorghum flour of several varieties (bronze sorghum, white sorghum, and yellow sorghum). As the percentage of sorghum flour increased (regardless of variety), cake volume decreased (Glover et al., 1986). Cakes made completely of wheat flour had volumes of approximately 1050 cc, whereas cakes made with 50% bronze sorghum flour had volumes of approximately 600 cc (Glover et al., 1986). At lower inclusion rates (5-15%), the volume difference would not appear until “the last 2 to 3 minutes of baking”, suggesting collapse (Glover et al., 1986). Replacing wheat starch with sorghum starch in a wheat high ratio cake led to decreased volume due to decreased gelatinization (Glover et al., 1986). Cookies made from sorghum did not spread when baked (Badi & Hosney, 1976). However, a more recent study on sorghum flour cookies found no significant differences in diameter or spread ratio between wheat and sorghum cookies (Aljobair, 2022). This improvement in sorghum cookies is likely due to the use of guar gum and dextrose. One study evaluated the replacement of wheat flour with

sorghum flour in a bread product at varying levels (0, 10, 20, and 30%). As the level of sorghum increased, bread's specific volume decreased (Gigliotti et al., 2025).

Sorghum baked goods can suffer from undesirable textures. Sponge cakes made with sorghum had a sandy, gritty texture (Curti et al., 2022). High ratio sorghum cakes made from a premix had a sandy texture (Cayres et al., 2020). Sorghum cakes can also be dense (Glover et al., 1986; Marston et al., 2016). Cookies made with 100% sorghum flour had a mealy and gritty texture (Badi & Hosney, 1976). Increasing sorghum's replacement (0, 10, 20, and 30%) of wheat flour significantly increases the hardness of bread (Gigliotti et al., 2025). Significantly decreased springiness in bread was observed at the 20% and 30% replacement levels of wheat with sorghum (Gigliotti et al., 2025).

Sorghum can also have an in-flexible and fragile crumb structure. In a study of partial replacement of wheat with sorghum in high ratio cakes, the crumb of the cakes with higher replacement levels (30% and 50%) "had little flexibility, and would break or crack even when handled gently, indicating that the normal starch gel structure had not been established" (Glover et al., 1986). Replacing wheat flour with sorghum flour decreased cohesiveness of bread (Gigliotti et al., 2025). Sorghum cookies are more fragile than wheat cookies (Badi & Hosney, 1976). Whole meal flour sorghum cookies were fragile and difficult to handle (Chiremba et al., 2009). Baked goods that are fragile and prone to crumbling may not meet consumer expectations and are not ideal for transportation.

Sorghum products have a relatively short shelf life and quickly stale due to starch retrogradation (Matalanis et al., 2009). Amylopectin retrogradation is the cause of staling. The long B chains of amylopectin that are present in sorghum starch "have an increased tendency to retrograde" (Matalanis et al., 2009). One study evaluated the impact of partially replacing wheat

with sorghum flour in bread to evaluate sorghum's impact on staling (Gigliotti et al., 2025).

Samples containing sorghum exhibited increased hardness during storage (Gigliotti et al., 2025).

Sorghum can also impact the color of baked goods. As the percentage of sorghum replacing wheat flour increased, the color of both the crust and crumb of bread became darker (Gigliotti et al., 2025). The presence of sorghum decreased the yellowness of bread crust, although it did not differ between the three inclusion levels (10%, 20%, and 30%) (Gigliotti et al., 2025). The presence of sorghum also decreased yellowness in bread crumb. The presence of sorghum decreased the redness of bread crust but increased the redness of the crumb (Gigliotti et al., 2025). Sorghum cookies are darker than wheat cookies (Aljobair, 2022; Badi & Hosney, 1976). Sorghum cookies were also more red and less yellow compared to wheat cookies (Aljobair, 2022).

There are differences between the kernel structures of sorghum and wheat (Figures 2-1 and 2-2). In wheat flour, the main protein is gluten, but in sorghum flour, the main storage protein is kafirin. Kafirins are prolamins, which are soluble in alcohol-water solutions (Belton et al., 2006). Kafirins are encapsulated in protein bodies (Hamaker & Bugusu, n.d.). There are four types of kafirin proteins: α , β , γ , and δ (Belton et al., 2006). In sorghum, protein has been shown to form cross-links and 3D structures and compete with starch for water absorption which can inhibit starch swelling (Yang et al., 2025). Kafirins are more hydrophobic than wheat prolamins (Belton et al., 2006). This higher hydrophobicity increases the difficulty of extracting kafirins with ethanol (Belton et al., 2006). For kafirin extraction, 60% (v/v) aqueous tertiary butanol (2-methyl-2-propanol) is more effective than ethanol.

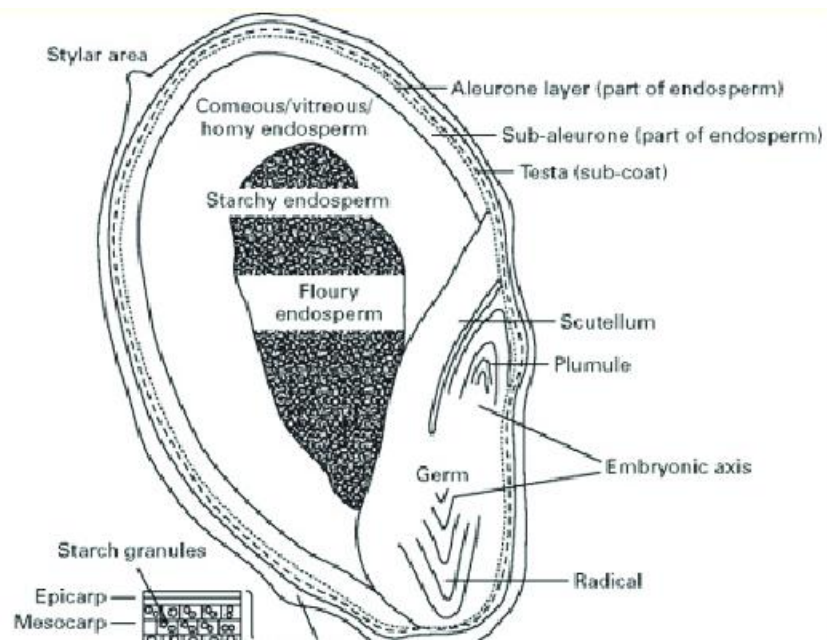


Figure 2-1. Structure of sorghum kernel (Sewak et al., 2023)

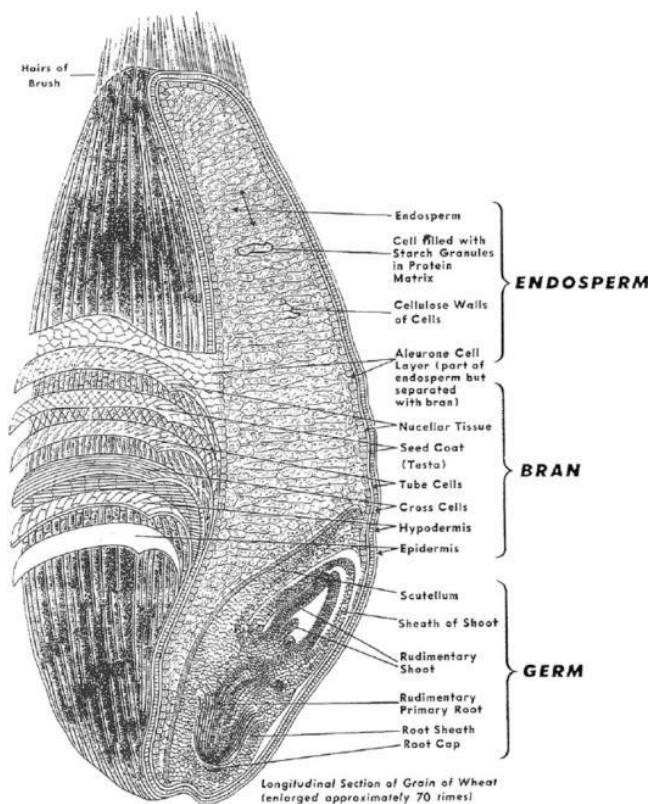


Figure 2-2. Structure of wheat kernel (Marchini et al., 2016)

The lipids in sorghum flour may be lacking an attribute that is present in wheat flour. A study that replaced wheat lipids with sorghum lipids (using defatted cake flour and sorghum lipids) found that the cakes “did not rise as high” and collapsed near the end of baking (Glover et al., 1986). They also observed that adding sorghum lipids to wheat lipids did not have a negative impact on the wheat flour cake (Glover et al., 1986). This suggests that sorghum lipids do not have detrimental characteristics but are missing an important trait. One study investigating sorghum cookies found that using defatted flour (sorghum or wheat) made cookies that “had less spread, no top cracks, and a pale color” (Badi & Hosney, 1976). Using sorghum lipids with defatted wheat flour resulted in poor quality cookies (Badi & Hosney, 1976). Using wheat lipids with defatted sorghum flour “improved top grain and spread” but still did not match the quality of the control cookies (Badi & Hosney, 1976).

Improvements to Gluten-Free and Sorghum Baked Goods

Additives

Starches and hydrocolloids are commonly used to improve gluten-free products by imitating “the viscoelastic properties of gluten” (Salehi, 2019). Gluten serves as a structure former but in its absence, starch functions as the “primary texture and structure forming agent in gluten-free systems” (Naqash et al., 2017). One study found that the addition of resistant starch to gluten-free cake decreased batter elasticity and viscosity, but increased cake specific volume and time the cake remained soft during storage, as well as improved sensory acceptability (Tsatsaragkou et al., 2015). They determined that replacing 20% of the flour with resistant starch created the most preferred cake (Tsatsaragkou et al., 2015). Using potato starch (9.29%) in gluten-free brown rice flour (60%) and tapioca starch (30.71%) cupcakes led to increased batter viscosity, specific volume, and springiness, while decreasing hardness and chewiness (Aleman et

al., 2021). Chemically modified starches can increase the volume and crumb structure elasticity of gluten-free baked goods (Naqash et al., 2017). Hydrocolloids impact gluten-free baked goods in many ways. Hydrocolloids can improve water holding capacity, texture and increase batter viscosity, volume, and porosity of gluten-free cakes (Salehi, 2019). They can also delay staling (Salehi, 2019). Carboxymethyl cellulose (as 1% inclusion in formulation) increased gas cell size and crumb porosity of gluten-free flat bread (Naqash et al., 2017). Using xanthan (as 0.2% inclusion in formulation) in gluten-free cakes increases specific volume and improves texture by decreasing firmness and delaying staling (Preichardt et al., 2011).

Sorghum Starch Modifications

Several studies have modified the starch in sorghum flour to improve sorghum baked goods. There are three main ways sorghum starch is modified: heat treatment, physical damage, and chemical interactions. Sorghum starch has a higher gelatinization temperature (67.5-79°C) compared to wheat starch (54.5-60°C) (Glover et al., 1986). This difference in gelatinization temperature could contribute to quality differences between wheat and sorghum. In wheat cakes, volume increases when starch gelatinization increased (Derby et al., 1975). Delayed gelatinization in gluten-free sponge cakes was shown to cause decreased viscosity and a system which could not support its own weight and collapsed during baking (Curti et al., 2022).

Heat can be used to modify sorghum flour's starch prior to use in baked goods. Heat treating sorghum flour (125°C for 30 minutes) prior to use in cake results in a higher batter viscosity (entrapped more air), higher volume cake, decreased firmness, and improved crumb structure compared to untreated sorghum (Marston et al., 2016). The cakes made from heat treated flour also had higher consumer acceptability scores (6.65 for treated versus 5.98 for control) (Marston et al., 2016). One study pregelatinized the starch in whole grain sorghum by

single-screw extruding a powdered mixture of 87.8% sorghum, 7.2% orange pomace flour, 5% whey powder, and water. Cakes made with pregelatinized sorghum did not have a sandy texture according to consumer sensory attribute testing (Cayres et al., 2020).

Physically damaging the starch in sorghum can increase gelatinization. One study found that decreasing particle size (increasing starch damage) of sorghum flour used in sponge cakes led to lowered gelatinization temperature, higher batter viscosities, decreased air bubble size, and increased air bubble distribution (Curti et al., 2022). Cakes made with flours of the smallest particle size (80 μm) also had higher volume, decreased hardness, and increased springiness (Curti et al., 2022). Another study also found that decreased particle size (24.2-26.5 μm) /increased sorghum starch damage (12.3-14.4%) led to increased volume and improved texture in cake (Glover et al., 1986).

Chemical treatments and interactions can impact starch in sorghum. One study found that using ozone-treated sorghum flour (15, 30, and 45 min) increased batter viscosity, decreased batter specific gravity (30 and 45 min), increased final volume (all times), gave structure to prevent collapse, and increased the number (30 and 45 min) in whole grain sorghum cakes (Marston, 2009). They suggested that this could have been the result of oxidation increasing the hydrophobicity on the surface of starch, which would improve bubble stability and allow for increased starch swelling and increased batter viscosity (Marston, 2009). Other ingredients within a formulation can also impact starch behavior. A sucrose starch and water solution has a higher gelatinization temperature than a dextrose starch and water solution (Kim & Walker, 1992). Increased gelatinization and swelling of sorghum starch granules was observed when sucrose was replaced with dextrose (25, 50, 75, and 100%) in a high ratio sorghum cake. This may have improved “symmetry, grain and texture” as well as “stabilized the gas cells” (Glover et

al., 1986). This is likely because dextrose does not delay gelatinization as much as sucrose does (Kim & Walker, 1992).

Rum Cakes

Rum

There is a possibility that rum could be used to modify sorghum starch to help improve sorghum baked goods. Rum “is distilled from the fermented juice of sugar cane, sugar cane syrup, sugar cane molasses, or other sugar cane by-products at less than 95 percent alcohol by volume...but not less than 40 percent alcohol by volume” (Alcohol and Tobacco Tax and Trade Bureau, Department of the Treasury, 2025). The sugar content in rum can vary, but a Bacardi spiced rum has only 1 gram of sugar per 1.5 oz serving (Bacardi Limited, n.d.). Any sugar present in the finished product was added post fermentation for flavor. The conversion factor for pure alcohol is 0.6 fl. oz/14 g (US Government, 2024). A formulation containing 61.79 g of rum would be at most 2.65 oz of liquid, which would mean only 1.77 g of added sugar from rum. This would be unlikely to affect a formulation that also contains 200 g of pure sugar.

Alcohol Remaining in Food Products

There are many reasons (for example: health, pregnancy, or driving) why a consumer would need to know the alcohol content of a food product. The alcohol remaining in a product also impacts the caloric content of the food. The content of ethanol remaining in a product is dependent on cook time (Ryapushkina et al., 2016). The loss of ethanol during cooking is greater than the loss of water (Ryapushkina et al., 2016). One study evaluated ethanol remaining in products (including: vinaigrette, pancakes, steamed fish, braised beef, spareribs, carrot soup, and rye bread porridge) made with beer. The carrot soup was found to have the highest remaining ethanol content per 250 ml serving at 1.28 g (0.512% g/ml) “which would be of little concern to

most people” (Ryapushkina et al., 2016). The study noted that, while the remaining ethanol content is low, it is possible that people would have multiple servings or eat several foods containing alcohol in a meal. The USDA found that percent of alcohol retained for alcoholic beverages cooked with different methods ranged from 5%-85% (U.S. Department of Agriculture, 2007). Another study measured the ethanol content of food products in the categories of nonalcoholic beer, nonalcoholic wine, soft drinks, vinegar, fruit juices, vegetable juices, instant meals, baby food, baked goods, bananas, jams, sauerkraut, sweets, meat, honey, and kefir (Reimann et al., 2023). Most products evaluated did not exceed the health-based guidance values for their primary consumer-type. There were two products that did exceed the health-based guidance values for their consumer age group in each of the following categories: baby food (no ethanol intentionally added, blood ethanol concentration: 0.02 and 0.04 g/l), baked goods (no ethanol intentionally added, blood ethanol concentration: 0.14 g/l), and sweets (ethanol intentionally added, blood ethanol concentration: 0.15 and 0.16 g/l) (Reimann et al., 2023).

Flavor Trends

Consumers are looking for cocktail flavors but with low- or no- alcohol (Cvetan, 2024). There has been an increased demand for mocktails and “boozy-inspired desserts” (Berry, 2024). There has been limited research on the impact of alcohol on food products and the final alcohol content after baking/cooking. People working to develop new products in response to this trend would benefit from knowing how using alcohol (as opposed to alcohol flavoring) might impact their products.

Previous Use of Ethanol in Cakes

A study on the impact of including rum in wheat cake suggested that rum increases cake volume and height and improves the texture, “indicating a physiochemical effect of rum in the

batter or through the prevention of moisture loss” (Phalen, 2024). These benefits could assist in improving sorghum products, as some of the main difficulties with sorghum products are the loss of volume and subpar texture. The prevention of moisture loss could also possibly aid in shelf-life and delay staling. Phalen (2024) saw significant differences between cakes with no rum and cakes with rum but found no significant differences between the three levels of rum inclusion tested (7.6%, 10.1%, and 12.6% true percent) (Phalen, 2024). There is also anecdotal evidence that brandy improves the texture of pound cakes (Patent, 2009).

Ethanol and Starch Interactions

Ethanol could possibly be used to affect the starch in baked goods. While there is limited existing research on ethanol and starch interactions within baked goods, there has been research on technical and direct impact of ethanol on starch in a lab setting. Ethanol changes the surface characteristics of starch, and its impact varies greatly depending on starch type (Zhang et al., 2012). For example, an aqueous ethanol treatment caused, “swelling and disintegration in waxy maize, surface wrinkling in normal maize and tapioca, swelling and opening-up in potato starches, and swelling and bursting in high amylose maize” (Zhang et al., 2012). For starch, an increased surface porosity (open structure) allows it to bind more water and oil which allows for more swelling (Marston, 2009). Ethanol is also used to inhibit granule swelling and create less crystalline starch with more granular integrity in granular cold water-soluble starches (Zhang et al., 2012). This variation of impact could be due to differences in ratios of amylose to amylopectin and the structure/packing of amylose and amylopectin across different starch types (Zhang et al., 2012).

Due to genetic diversity and environmental factors, the ratio of amylose to amylopectin in sorghum starch varies greatly with the amylose content ranging from 0% to 55% (Zhu, 2014). Gelatinization properties also vary greatly amongst sorghum varieties (Zhu, 2014). This variation makes it difficult to predict sorghum's interactions with ethanol. The amylose content is correlated with amount of the recessive gene wx (Sang et al., 2006). Waxy sorghum has three recessive waxy genes, heterowaxy sorghum has at least one, and normal sorghum has none. One study measured the amylose content of three sorghum hybrids and found that their waxy hybrid had 0% amylose, the heterowaxy had 14%, and the normal hybrid had 23.7%. The normal sorghum starch tested had a gelatinization temperature 2°C lower than the waxy and heterowaxy starches (Sang et al., 2006).

Wheat Cake

Gluten

Gluten, the main storage protein in wheat, is comprised of glutenin and gliadin which are classified as prolamins (Biesiekierski, 2017). Prolamins “represent seed proteins insoluble in water, but extractable in aqueous ethanol and are characterized by high levels of glutamine (38%) and proline residues (20%)” (Biesiekierski, 2017). The ratio of glutenin:gliadin can impact viscoelastic properties, “for example, purified hydrated gliadins contribute more to the viscosity and extensibility of the dough, whereas hydrated glutenins are cohesive and contribute to dough strength and elasticity” (Biesiekierski, 2017).

Gluten and ethanol interactions have not been directly studied within baked goods. However, one study evaluated the impact of ethanol on gluten hydrolysate solutions. Ethanol increased the foaming capacity, but decreased the foam stability, film strength, and surface tension of gluten hydrolysate solutions (Wouters et al., 2017).

Pound Cake

The original basic pound cake recipe, from 19th century American cookbooks, consisted of one pound each of flour, sugar, butter, and eggs each (Patent, 2009). Chemical leaveners were not typically used and leavening was dependent on eggs. Bakers would add their flavorings of choice to the recipe. One popular flavoring was brandy which impacts flavor and texture (Patent, 2009). Pound cakes originally became popular due to their large size (due to whipping of the egg whites) and ability to retain quality when stored at room temperature for several days (Patent, 2009). Pound cakes have a “fine, compact, moist crumb” and are firm enough to “be topped with fruit without disintegrating” (Patent, 2009). Over time, the term “pound cake” has been used more loosely. The ratio is often altered to contain more sugar (to increase moistness and tenderness) (Patent, 2009). The use of chemical leaveners is common as it allows the cake to rise without special treatment and separate beating of the eggs (Patent, 2009).

A study analyzed the impact of gluten on pound cakes by creating blends with differing gluten-starch ratios (Wilderjans et al., 2008). As the gluten content increased, batter viscosity increased. This higher batter viscosity allowed for greater retention of air throughout baking, resulting in increased final volume. Higher gluten content also resulted in “optimal grain structure with uniform cell distribution” (Wilderjans et al., 2008). Alternatively, cakes with lower gluten content collapsed during cooling, and “had a coarse crumb with a solid gummy layer at the bottom” (Wilderjans et al., 2008). They concluded that “protein gives the cakes resistance to collapse, resulting in desirable volumes and an optimal grain structure with uniform cell distribution” (Wilderjans et al., 2008).

Summary

The importance of interdisciplinary research has been increasing. Giving university food science students an opportunity for interdisciplinary work can better prepare them for a career in food science. Research is also a valuable experience for undergraduate students. Food science and foodservice are connected, yet separate fields that would benefit from interdisciplinary research. Analyzing the impact of an undergraduate interdisciplinary food science/foodservice course could give useful insight into the benefits in terms of students' impact and research results.

Sorghum is a sustainable, mild flavored grain that can be used in gluten-free baked goods. Using sorghum has challenges but added ingredients and starch modifications may improve products. The use of egg yolks and whipped egg whites may improve the volume and texture of chemically leavened baked goods (muffins and waffles). Furthermore, it is possible that using ethanol (in the form of rum) could improve sorghum baked goods. Because little research has been done on the impact of baking with ethanol, it was determined that it would be beneficial to investigate the impact of rum on pound cakes made from sorghum or wheat.

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Chapter 3 - Interdisciplinary Product Development Framework for Food Science Capstone Course and Undergraduate Research in Collaboration with a University Dining Center

Abstract

A framework for two undergraduate food product development courses involving interdisciplinary work between food science and foodservice (university dining center) was implemented. Former students were surveyed to determine framework impact. Students agreed the framework gave them experience with larger-scale food production equipment, and taught them about foodservice perspectives (feasibility requirements, how dining centers operate) and the scale-up process. Students also developed research/laboratory skills, soft skills, and food production knowledge. In return, new recipes were developed for the dining center. This framework could be implemented at other universities to develop interdisciplinary relationships between dining centers and food science programs.

Introduction

Despite being similar fields, interdisciplinary research between food science and foodservice has been limited, especially at the university level. Food science is focused on the chemical, microbiological, sensory, safety, regulatory, and quality assurance aspects of food, as well as the processing and engineering principles required to produce food on a large scale (IFT, 2018). Meanwhile, foodservice focuses on the preparation and serving/distribution of food products for consumers to consume outside their homes (Edwards, 2013; USDA ERS - Food Service Industry, n.d.). Many university academic programs such as Hospitality Management, Dietetics, Culinary, and Business focus on foodservice systems as part of their curriculum and

often their areas of research. Interdisciplinary collaboration brings diverse perspectives, which can improve not only the product being developed, but also the research process (Reinventing Undergraduate Education, 1998; Specht & Crowston, 2022; Struijk et al., 2022). Undergraduate research has been shown to be beneficial to students, providing them with scientific skills, soft skills, and experience (Adebisi, 2022; Linn et al., 2015; Petrella & Jung, 2008; Reinventing Undergraduate Education, 1998; Russell et al., 2007). A collaborative approach to food science, culinary, and foodservice management could also provide students an interdisciplinary experience. Our study defines interdisciplinary research as: interactive work between multiple disciplines to create integrated knowledge that impacts all disciplines involved (Choi & Pak, 2006; Frodeman et al., 2010; Morton et al., 2015; National Academy of Sciences et al., 2005).

Learning Outcomes

Our study assessed the impact of a food science/foodservice interdisciplinary product development/undergraduate research experience framework, where food product formulations are created, scaled up, and developed into quantity recipes to be served in the dining centers. The framework impact was assessed by interviewing and/or surveying students about their experiences while working on this project.

Methods and Applications

Subject of this Case Study

The Kansas Department of Agriculture (KDA) and the Center for Sorghum Improvement (CSI) sought to increase the consumption of Kansas sorghum and wheat in college students' diets by developing products to be served in campus dining centers. The goal of this project was to increase students' knowledge of whole grain and gluten-free food product options. To carry out this project, we decided to have Kansas State University (K-State) food science students in a

research and development of food products capstone course and/or undergraduate research credits develop food products while collaborating with K-State Housing and Dining Services for scaling up those food products.

The initial project took place over three years. Each year had a different category of sorghum and wheat products, determined by Center for Sorghum Improvement (CSI), the Kansas Department of Agriculture (KDA), and Dining Center representatives. The three categories were entrées, snacks, and baked goods. For each of these categories, Dining Services was specifically looking for items that could be sold at the recreational complex, on-the-go baked products, par-baked/frozen buns, and “on trend” baked items. As an enhancement of this framework, the 2024 food science capstone course students worked directly with Dining Services to experience the process of developing products from an initial concept to a finished scaled-up quantity recipe and conducting a consumer acceptability study within one semester.

Framework of Case Study

The goal of the framework was to give undergraduate students an experience similar to product development in industry. Throughout product development, students interacted with the clients and an advisory board to ensure they met the client’s needs. They also communicated and collaborated to use additional resources on campus such as dining center production facilities. The framework (Figure 3-1) includes two parts: an undergraduate capstone course (FDSCI 740: Research and Development of Food Products) and an undergraduate research course (FDSCI 530: Undergraduate Research in Food Science & Industry).

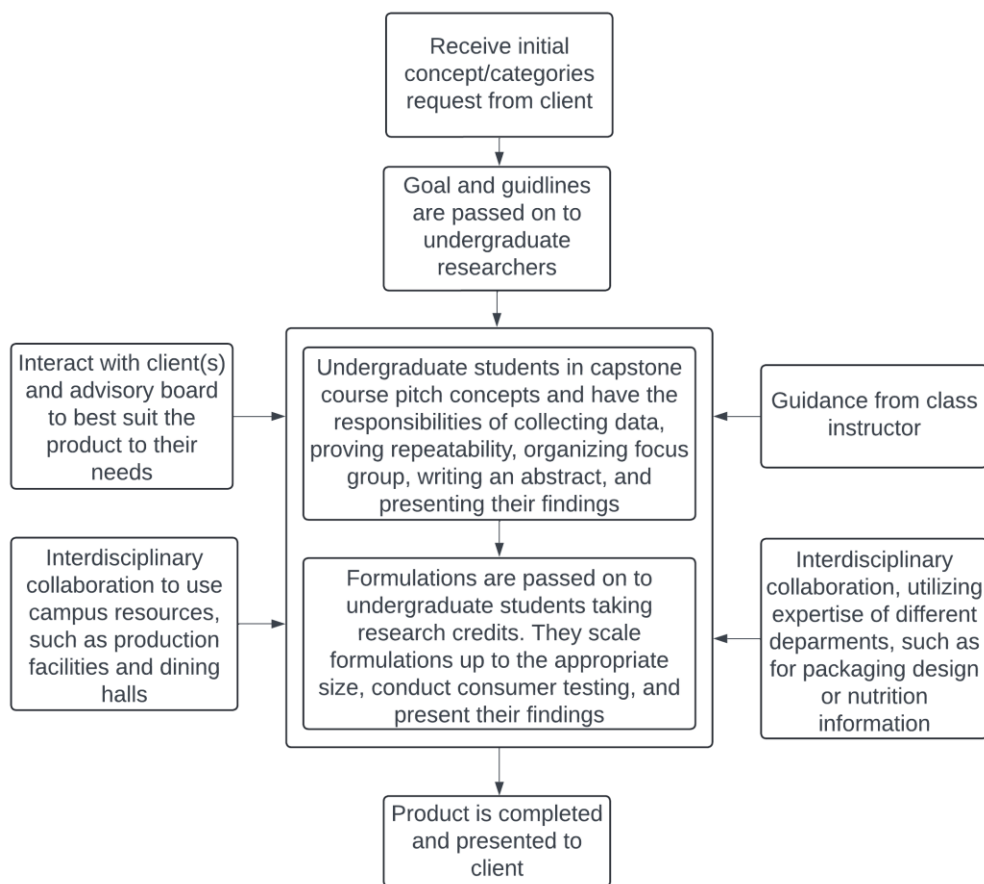


Figure 3-1. Course Framework

Capstone Course Previous Years (PY)

In the capstone course FDSCI 740, students were given basic guidelines in the form of categories or concepts from the dining center staff. Students then conducted market screenings and pitched product concepts that fit within those guidelines. The best concepts (determined by feasibility, creativity, and market potential) were selected to move forward to development. Students began to develop formulations during the lab section of the course [either alone or in groups, and either at home (due to COVID) or in a food science lab on campus] and collected

data throughout development. The course instructor(s) guided students during the lab period and provided feedback.

There was an additional interdisciplinary opportunity for students to collaborate with undergraduate agricultural and natural resources communications students in a layout and design course. Food science students provided content (product name, photos, net content, nutritional facts panel, ingredient statement and a company name/address) for a packaging label.

Undergraduate agricultural communications students enrolled in a layout and design course (AGCOM 345) submitted draft packaging designs that were reviewed by the course instructor and edited. The labels were then provided to the food science students to respond with additional feedback and suggested revisions for students in the layout and design course. This allowed food science students to learn about the creative process and agricultural communications students to learn about labeling requirements while gaining experience in making an appealing packaging design.

Food science students then organized and conducted a focus group to sample their products. Sensory aspects of products were also evaluated by the KDA, CSI consortium, and dining center student and management staff. Once all data was collected, students prepared a final report and presentation in an industry-style format. The final report was written using work from the entire semester and included an executive summary, market screening, project description, a formulation in percentages, description of each ingredient's function, process description (including a process flow diagram and specific equipment to be used), quality and safety parameters, package prototype, regulatory requirements, and a production cost analysis. They also gave a final presentation on their findings.

FDSCI 740 functions as a capstone course as it requires skills and knowledge students have accumulated throughout their degree program. Students used good manufacturing practices and food safety principles as they prepared product prototypes in the laboratory. Students also used their knowledge of physical, chemical, and sensory properties of ingredients to guide them on how to adjust formulations to create a better product. When writing the process flow diagram and calculating the scaled-up formulation, students used the skills they learned in their food processing and process calculations courses. Their knowledge of regulations was used when writing the quality and safety section of the report, which includes creating critical control points. The capstone course gives students the opportunity to combine and apply skills and knowledge learned throughout their degree, which further prepares them for careers in food science. The experience of interdisciplinary work and research in this course prepares them for a typical collaborative industry experience.

Undergraduate Research Credits (UR)

At the end of the capstone course, formulations were passed on to undergraduate students taking food science research credits (FDSCI 530) or work experience as a summer internship. In foodservice the term “recipe” is used instead of “formulation” as in food science. A formulation only lists ingredients and percentages. A recipe includes production details, cooking equipment, garnishing tips, serving sizes, and consumption quality standards. These students then began to scale up the product using larger scale equipment in the dining center. They also collaborated with and received feedback from dining center staff. Throughout the development process, they collected data in the form of pictures, processing steps, yields, and descriptions of the formulations they tested. Once they had satisfactorily achieved the desired flavor profile and scale, they conducted consumer testing (university students and staff) in the form of convenience

sampling. For example, they offered samples and a consumer acceptability questionnaire to patrons at the entrance of the dining center during mealtimes. FDSCI 530 students then analyzed the data collected from consumer testing. Students also input their recipe(s) into the dining center recipe system (Computrition). This system allows for accurate recipe formatting, costing, and nutritional/allergy labeling. Once all data was collected and analyzed, students prepared a 400-word abstract and presented a poster (3-5 minute oral presentation) at an undergraduate research symposium. A mentor survey was used to evaluate student performance.

2024 Capstone Course with Scale-up (TF)

The 2024 FDSCI 740 capstone course was unique from previous semesters due to students' increased interactions with the dining center. Students toured the dining center. The Registered Dietitian (RDN) who led the recipe development and menu writing process provided students with product concepts (such as a unique meatball product, vegan burger patty, and plant-based breakfast item). Students conducted market screenings based on concepts provided and presented their product pitches to another RDN. The two RDNs selected five products for benchtop development. Students were divided into groups (2-3 students) to develop these products. Midway through the semester, the RDNs selected two products for scale-up in the dining center using their large-scale equipment. Students were re-divided into two groups to scale up the two products so that all students had the opportunity to use the large-scale equipment. Consumer acceptability testing was conducted in the dining center for all products developed. The 2024 capstone course students also had the opportunity to interact with agricultural communications students to develop labels. They also prepared and presented final reports similar to previous years, but with the addition of quantity-formatted production recipes.

Assessment of Framework

The proposed framework was assessed using two main metrics: tangible results and student learning outcomes and impact. The tangible results include the products developed, the publications, and the symposium posters and presentations that came from this framework. The student learning outcomes and impact were evaluated using reflective surveys and interviews.

Assessment of Student Learning Outcomes and Impact

Two surveys and one interview were used to evaluate the framework. The study was reviewed and approved by the Kansas State University Institutional Review Board under IRB number 12516 (Appendix A1). Informed consent was obtained (Appendix A2, A3, and A4) from each subject prior to completing the reflective survey or interview. After taking the survey or being interviewed, participants were sent a debriefing statement (Appendix A5 and A6).

A Qualtrics (Provo, UT) survey (Appendix A7) using a 5-point Likert scale (where 1=strongly disagree and 5=strongly agree) and open-ended questions asking about their overall experience and suggestions for course improvement was developed and distributed to FDSCI 740 students. Responses were collected anonymously. The question categories were “Research and Laboratory Skills,” (RL) “Food Production Knowledge,” (FP) “Interdisciplinary Aspects,” (IA) “Soft Skills,” (S) and “Career Preparedness and Course Experience/Personal Impact” (CP).

FDSCI 530 students who took part in the scale-up research course or work experience were interviewed over a recorded Zoom meeting by a third-party interviewer or were offered to type out their responses to the interview questions over email if they preferred not to meet over Zoom. For each of the 33 questions (Appendix A8), interviewees were asked to respond on the 5-point Likert scale and then elaborate on why they selected that rating. There were also open-ended questions that did not feature a scale.

Students of the 2024 fall FDSCI 740 class were given a separate survey (Appendix A9) because they were the only capstone class that worked directly with the dining center. This was also an anonymous Qualtrics survey with the same categories as the other survey featuring 5-point Likert scale and open-ended questions. Because extra credit was offered for survey completion, some bias may have been present.

Results

Tangible Benefits

The project led to the successful development of 14 formulations/quantity production recipes (Table 3-1) that are now available in the K-State Dining Services recipe database (Computrition). Many continue to be served in the dining center on a regular basis.

Table 3-1. Recipes developed

Sorghum	Wheat	Other
Savory Sorghum Waffles	Tomato Basil Parmesan Sub Buns	Pizza Taquitos
Chocolate Sorghum Cookies	Peanut Butter Apple Muffin	Vegan Breakfast Bowl
Sorghum Lemon Blueberry Muffin	Japanese Curry Buns	Tofu Pho Bowl
Sorghum Energy Bites	Multigrain Sub Bun	Vegetarian Texturized Soy Lasagna
Sweet Potato Breakfast Cookies	Chocolate Chip Cookies with a Kick	Buffalo Chicken Meatballs

This work also led to several publications and presentations.

Publications:

1. FarmUs Recipe Book (was distributed to 40 university and community college dining centers and shared digitally with IFT Conference attendees and dozens of K-12 school foodservice organizations across the state) (example of recipe in figure 3-2) https://drive.google.com/file/d/1Ilqf0C-RQ3htNh_97-G3Hroez3dGx_W9/view?usp=sharing (Getty & Whitehair, 2022)

2. Development and scale-up of gluten-free sorghum-based bakery goods for K-State Dining Services (Cairns et al., 2023)

Tomato Basil Parmesan Sub Bun Wheat-based Yield: 48 each		
Ingredient	Amount	Method
Tomatoes, Sun Dried	0.045 lb.	1. Coarsley chop tomatoes with knife or robot coupe. Hold for step 2.2.
Water	0.444 lb.	2.1. Combine in mixer bowl on low.
Oil, Canola	0.090 lb.	2.2. Add chopped tomatoes from step 1 and mix with dough hook to 65 Deg. F on low speed.
Tomato Paste	0.076 lb.	
Sugar, Granulated	0.030 lb.	
Salt	0.015 lb.	
Cheese, Parmesan, Shredded	0.123 lb.	
Basil, Dried	0.009 lb.	
Flour, Bread	0.787 lb.	
Yeast, Instant	0.012 lb.	3.1. Add to mixer bowl, run on medium speed until internal temperature of 78-82 Deg. F. Note: the dough may take some time to reach the desired dough temperature. 3.2. Cover, let rest for 20 minutes. 3.3. Scale into 1.3 lb. rounds. Place 3x4 on greased 18x26x1 inch bun sheets. 3.4. Utilizing sheeter (settings may vary by model) process each 1.3 lb. lump into a 26-inch long loaf. 3.5. Place 3 loaves onto greased 18x26x1 inch bun pan. 3.6. Spray tops with non-stick spray. (You may cover and refrigerate overnight if prepping for a later use). 3.7. Proof until double in bulk. 3.8. Bake at 350 Deg. F (Conventional) for 15-20 minutes or until 200 Deg. F internal temperature.
		
Margarine, Melted	0.040 lb.	4.1. Brush over hot loaves 4.2. Cut each loaf lengthwise down center leaving hinged on one side. Then cut into six equal lengths.

Figure 3-2. Tomato basil parmesan sub bun recipe from FarmUs recipe book

National Conference Presentations:

1. Formatting a product development capstone course for development of grain-based baked items for use in Kansas State University dining services (Getty et al., 2021)
2. Development and scale-up of the gluten-free sorghum-based bakery goods for K-State dining services (Getty, Whitehair, Brazington, et al., 2022)

3. Creating undergraduate research experiences in product development of grain-based food products for KSU dining halls (Getty, Whitehair, & Jones, 2022)

FDSCI 530 Presentations:

1. Scale-up of Japanese curry buns for K-State dining services (Cairns et al., 2021)
2. Development gluten-free blueberry muffin for K-State dining services (Holmes et al., 2021)
3. Development and scale-up of peanut butter apple muffin (Martin et al., 2021)
4. Development and scale-up of the gluten-free savory breakfast waffle sandwich for K-State dining services (Vavra et al., 2021)
5. Development and scale-up of a gluten-free sorghum sweet potato muffin top for K-State dining services (Brazington et al., 2022)
6. Scale-up of sorghum energy bites for K-State dining services (Salmen et al., 2022)
7. Development and scale-up of a vegetarian lasagna using texturized soy protein for K-State dining services (Honor's Project) (Bhatt et al., 2024).

Summer Internship

Three undergraduate students participated in developing products. Formulations tested from FDSCI740 included a breakfast casserole with wheat, an oat milk shake, vegetable-based crackers, and breakfast biscuit bar but were not scaled up. The chocolate sorghum cookies, tomato basil parmesan bun, multi-grain bun, and whole grain chocolate chip cookie with a kick were all successfully scaled up as dining center recipes.

Product Consumer Acceptability and Physiochemical Properties

Examples of data from the project included consumer acceptability scores using a 9-point hedonic scale (1=extremely dislike and 9=extremely like). Physiochemical properties collected included color, volume, moisture loss, water activity, holding time-qualities, and reheat-ability. One goal of K-State Dining Services was to determine if a product could be frozen/refrigerated and reheated while maintaining its qualities to decrease waste and allow for advance food preparation, and on-demand heating. This concept provided another learning opportunity for students in FDSCI 530 as they were encouraged to experiment with freezing and reheating processes.

Using a 9-point hedonic scale, the sorghum waffle sandwich received scores of 7 and above for all attributes evaluated (acceptance, flavor, texture, aftertaste, and mouthfeel) (Cairns et al., 2023). The gluten-free muffins received scores of 7 and above in all categories except for texture (6.58) and mouthfeel (6.42) (Cairns et al., 2023). Figure 4-1 shows the volume of a gluten-free muffin during development (Cairns et al., 2023). Figure 4-8 was developed to have a color scale for dining staff to use to determine if color was too light or dark (Cairns et al., 2023). The data collected showed that students were able to develop acceptable, desirable gluten-free products while using analytical methods during their participation in this undergraduate interdisciplinary research framework.

Student Learning Outcomes and Impact

Survey of Previous Capstone Course Years

Forty-one students took the capstone course with this interdisciplinary framework before the 2024 class. Survey links were sent to each of these past students with a 24.4% (n=10) response rate.

Responses for the previous years survey were less positive than the 2024 survey and undergraduate research interviews. The average response percentages of strongly agree and agree for each category were 66% (research and laboratory skills), 73% (food production knowledge), 45% (interdisciplinary aspects), 68% (soft skills), and 67% (career preparedness and course experience/personal impact) (Figures 3-3 through 3-7). The previous years survey was a survey of people who saw this framework in its earlier stages, and the framework's effectiveness has increased over time, as evidenced by the more positive responses to the undergraduate research and 2024 surveys. Interdisciplinary aspects having the lowest average shows that earlier in the development of the framework, students weren't given equal opportunities to interact with dining center staff and packaging design students. This was improved in the 2024 class which observed a response of 84% for interdisciplinary aspects.

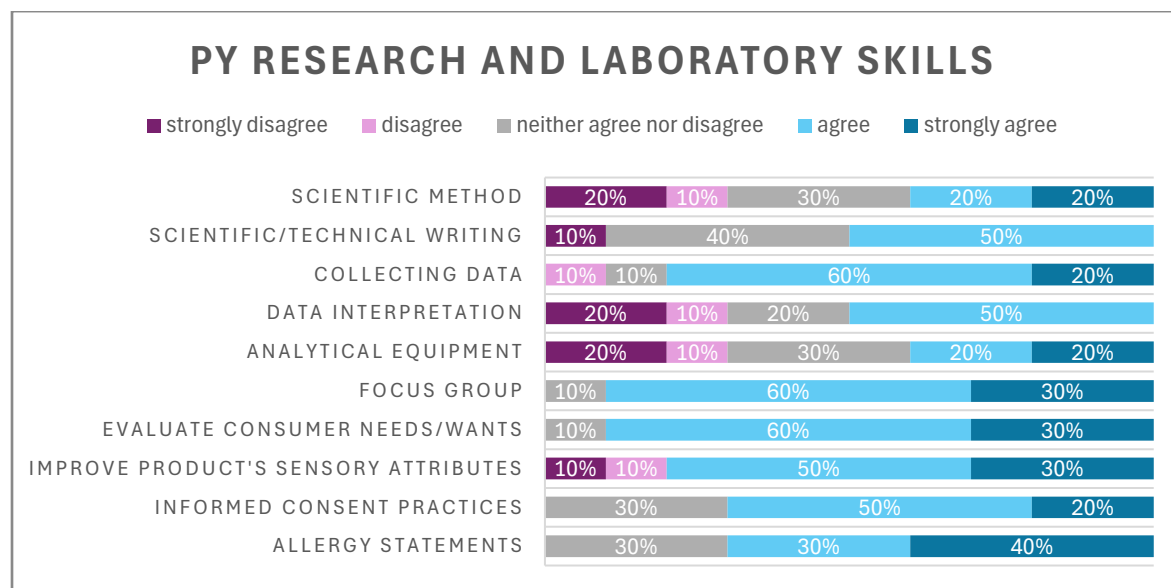


Figure 3-3. Previous Years (PY) Research and Laboratory Skills, for Full Statements (Appendix A7).

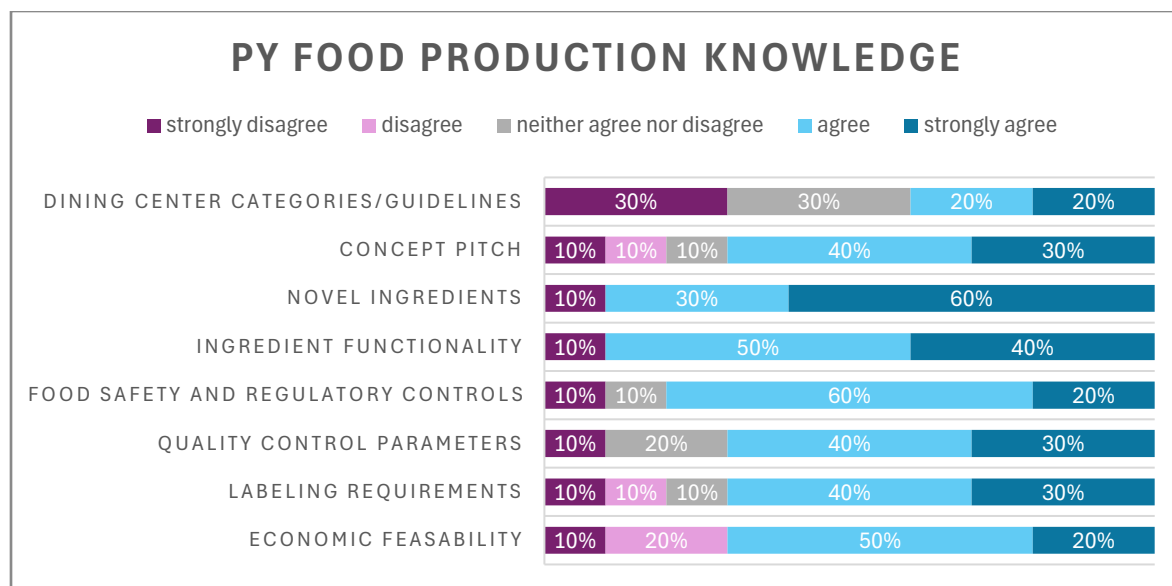


Figure 3-4. Previous Years (PY) Food Production Knowledge, for Full Statements (Appendix A7).

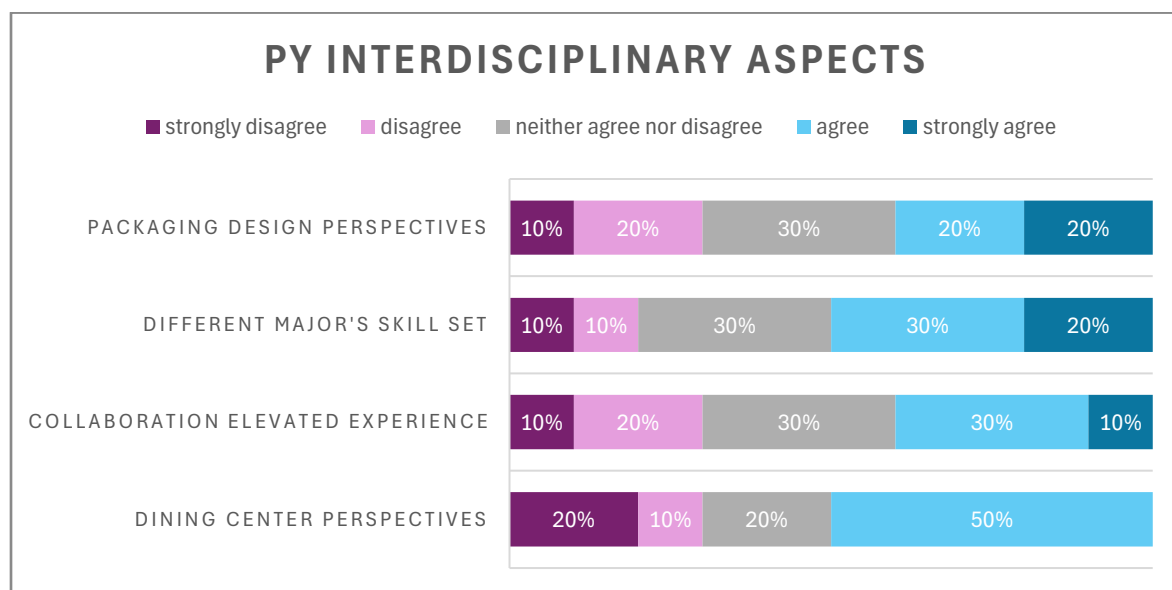


Figure 3-5. Previous Years (PY) Interdisciplinary Aspects, For Full Statements (Appendix A7).

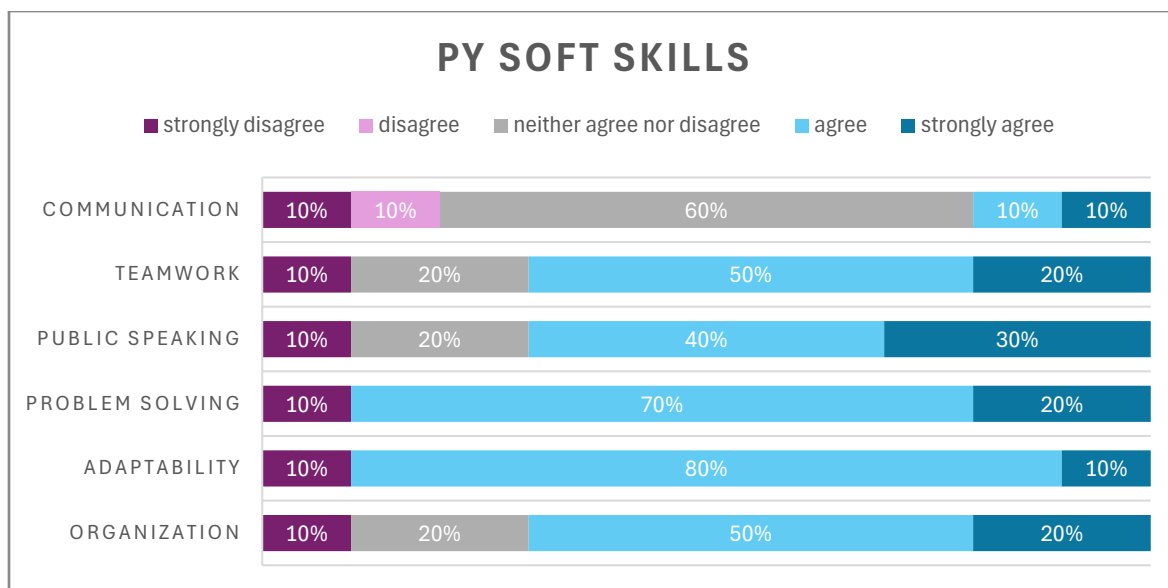


Figure 3-6. Previous Years (PY) Soft Skills, for Full Statements (Appendix A7).



Figure 3-7. Previous Years (PY) Career Preparedness and Course Experience, for Full Statements (Appendix A7).

Some suggestions that were provided by respondents were to increase communication with the packaging design class, to have shorter homework assignments (and to focus more on product development than homework), and to increase the organization and guidance in the course. One respondent also mentioned that COVID-19 policies that were in place at the time

impacted their course experience. There was also a respondent who credited their experiences in this course for helping them to get an internship at Kellogg's.

Interview of Undergraduate Research Course Participants

Of nine undergraduate research participants, seven agreed to be interviewed. The average response percentages of strongly agree and agree responses for each category were 79% (research and laboratory skills), 77% (food production knowledge), 76% (soft skills), and 71% (career preparedness and course experience/personal impact) (Figures 3-8 through 3-11). All averages were higher than those from the previous years survey. The undergraduate research interview having a higher soft skill average could be due to the more independent and self-led structure of the undergraduate research class that requires students to develop skills such as time management, organization, and problem solving. This is supported by other feedback undergraduate research students gave. Multiple interviewees also brought up that this project was a great resume-builder that helped them to get their current job and improved their independent time-management and self-discipline.

Notable Quotes:

Aspects that were liked:

- “This class and the skills I learned from it were...a really great resume builder...I think this is part of the reason why I got my current job...Anything with R&D on it and showing that you almost led a project really looks really good...it shows you have those soft skills: time management, communication, you're able to adapt.” - Interviewee 2
- “The time management...that really is something I was able to carry into my current job” -Interviewee 4

Suggestions for Improvement:

- “I would like to have been more organized from the beginning and have been able to have more time to run more trials and have had more time to collect more data.” - Interviewee 1
- “I wish I had more opportunities for consumer feedback” – Interviewee 7

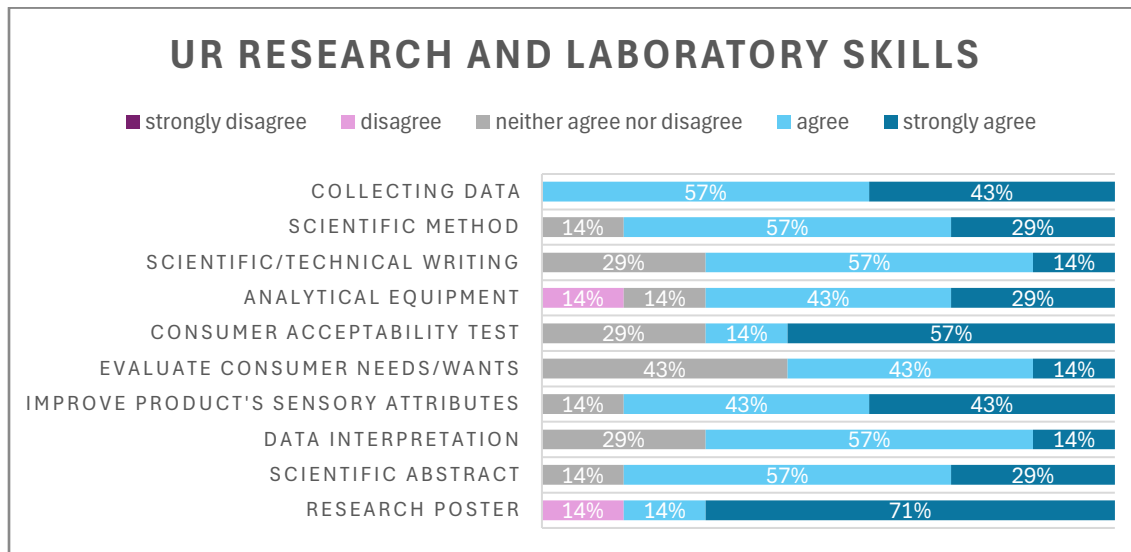


Figure 3-8. Undergraduate Research Experience (UR) Research and Laboratory Skills, for full statements (Appendix A8).

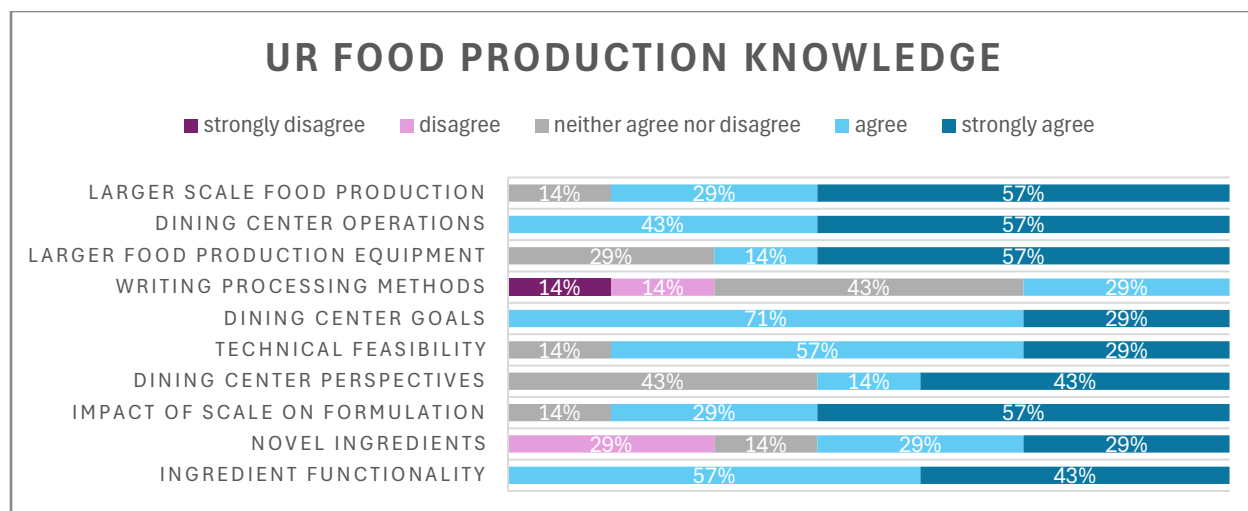


Figure 3-9. Undergraduate Research Experience (UR) Food Production Knowledge, for Full Statements (Appendix A8).

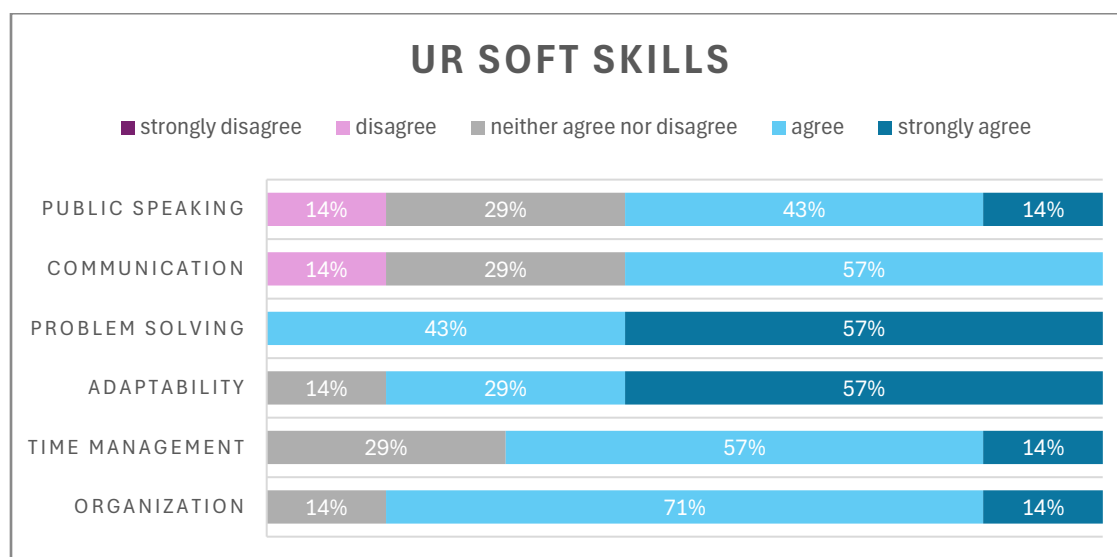


Figure 3-10. Undergraduate Research Experience (UR) Soft Skills, for Full Statements (Appendix A8).

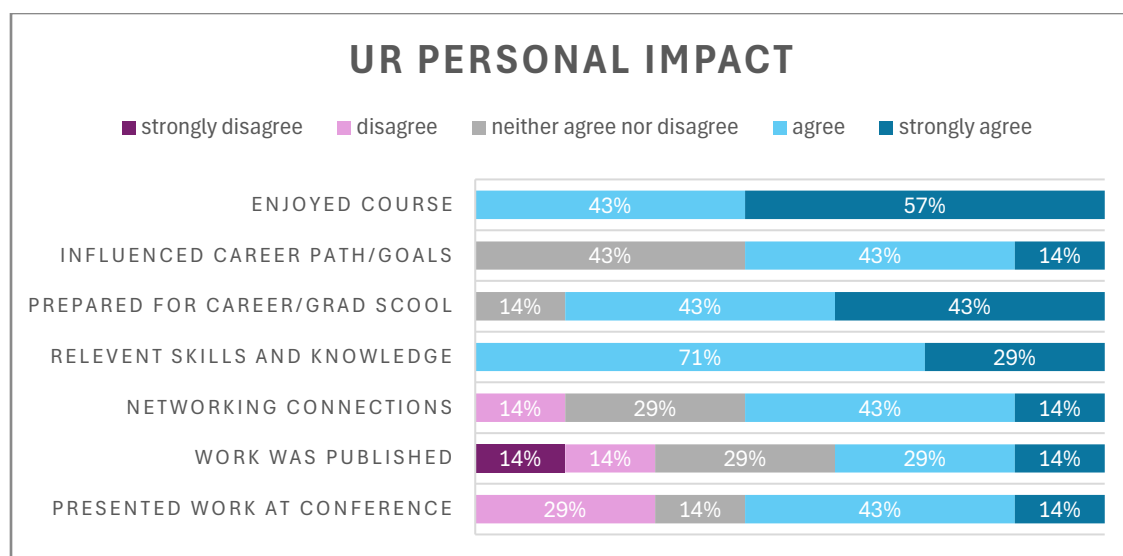


Figure 3-11. Undergraduate Research Experience (UR) Personal Impact, for Full Statements (Appendix A8).

Survey of Fall 2024 Class

Eleven students took FDSCI 740 in fall 2024 with a 100% (n=11) response rate. The average response percentages of strongly agree and agree responses for each category were 83% (research and laboratory skills), 85% (food production knowledge), 84% (interdisciplinary aspects), 73% (soft skills), and 77% (career preparedness and course experience/personal impact) (Figures 3-12 through 3-16). The averages for this survey were higher than the undergraduate research interview responses in every category except for soft skills. These higher averages correlate to the framework's improvement over time as it was developed.

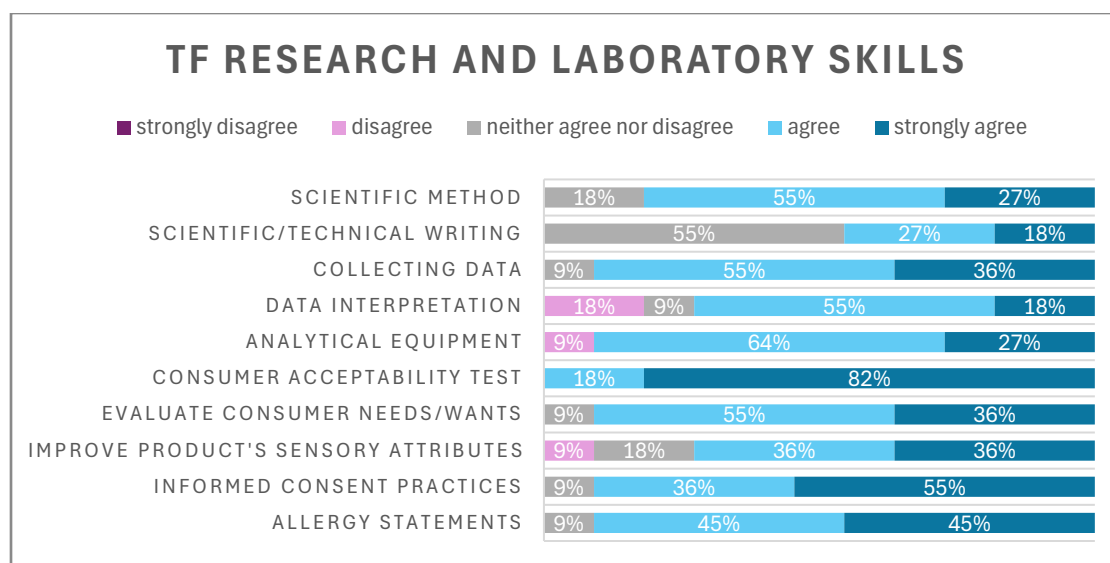


Figure 3-12. 2024 Capstone Course (TF) Research and Laboratory Skills, for Full Statements (Appendix A9).

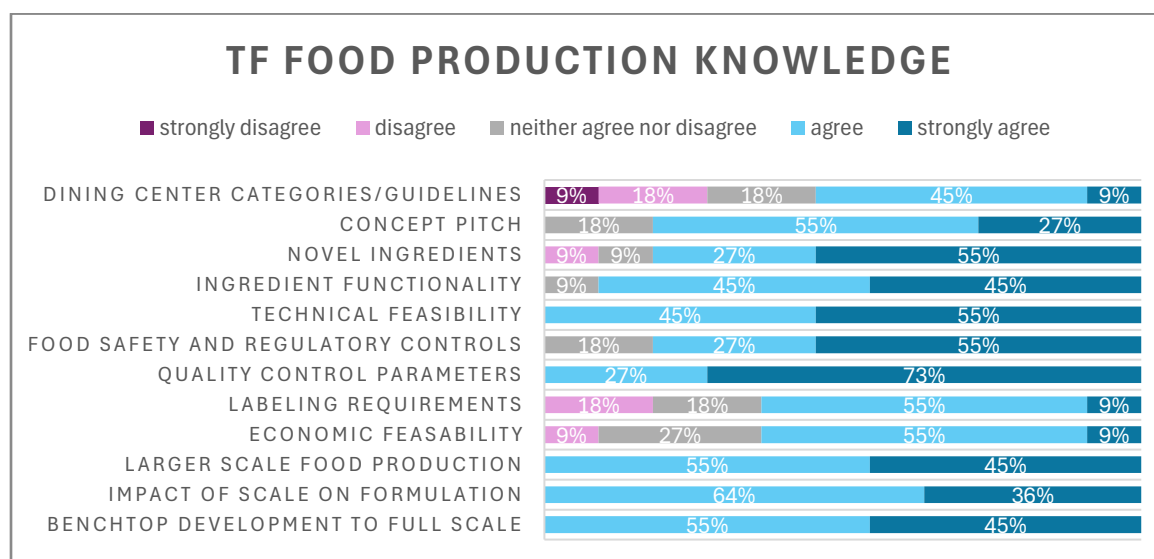


Figure 3-13. 2024 Capstone Course (TF) Food Production Knowledge, for Full Statements (Appendix A9).

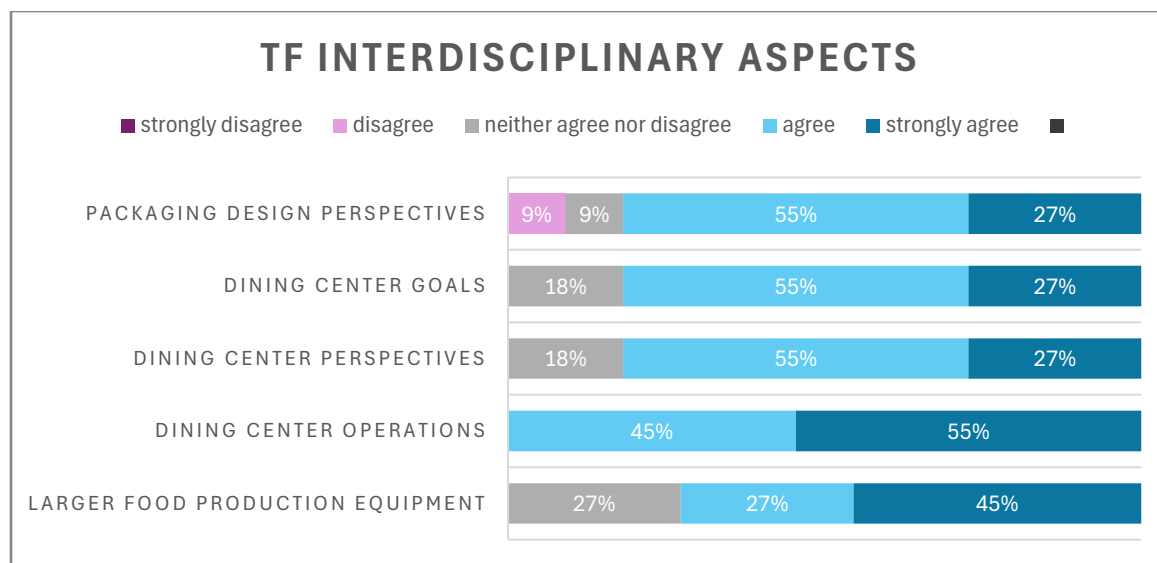


Figure 3-14. 2024 Capstone Course (TF) Interdisciplinary Aspects, for Full Statements (Appendix A9).

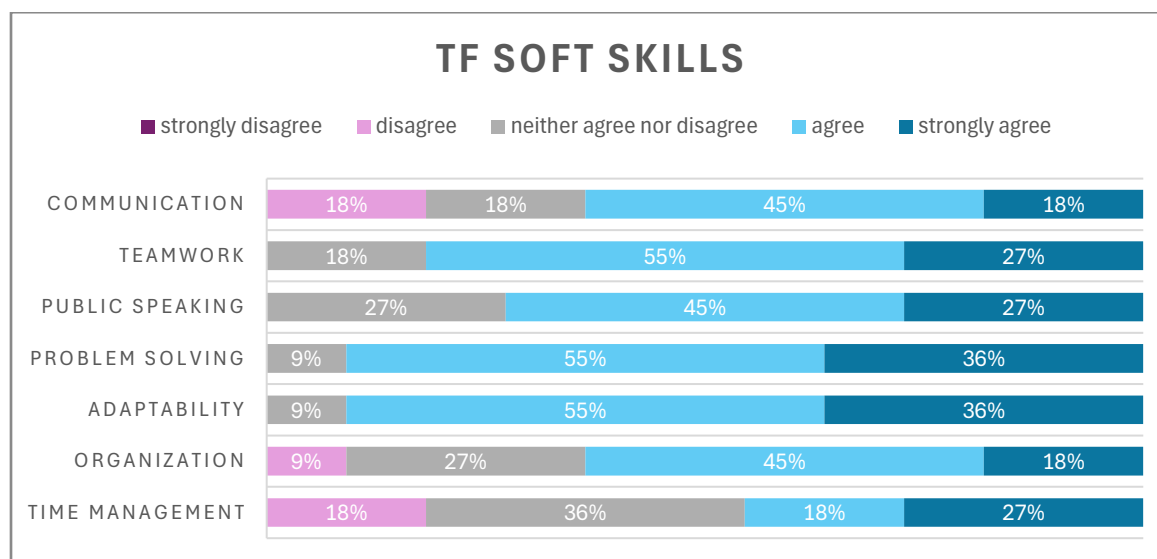


Figure 3-15. 2024 Capstone Course (TF) Soft Skills, for Full Statements (Appendix A9).

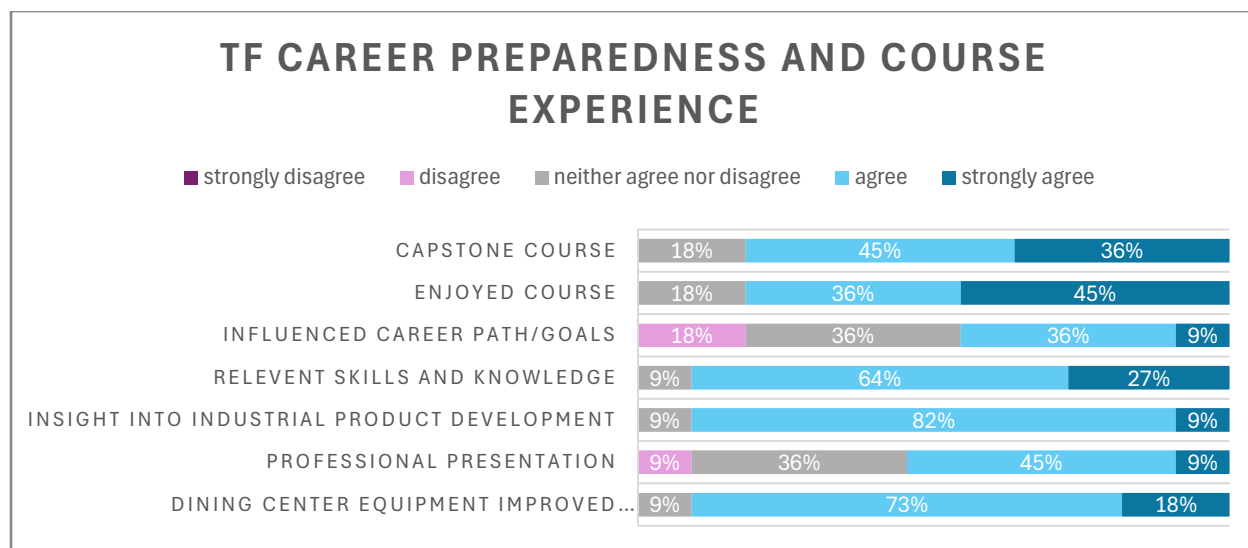


Figure 3-16. Capstone Course (TF) Career Preparedness and Course Experience, for Full Statements (Appendix A9).

Packaging design interactions improved for the 2024 capstone course in comparison to previous years. Examples of packaging designs can be found in Figure 3-17.



Figure 3-17. Packaging Designs from Fall 2024 Capstone Course (from left to right, designed by: Emerson Tarr, Kassidy Schuman, Kinsley Jordan, and Emma Sutherly)

Suggestions from respondents included requests for more structure/guidelines and interactions with dining center staff. This is likely because structure/guidelines were still being developed as 2024 was the first capstone class that worked to scale up their products in the dining center.

Applications:

Future Use of Course Framework

The course framework has evolved over the years since initially implemented. The feedback we received from students throughout each version of the course development has helped to identify best methods and recommendations for future implementation. Consistent benefits identified included improved student problem solving and adaptability skills, experience with data collection and ingredient functionality, hands-on consumer acceptability testing, and student enjoyment (figure 3-18). Dining Services consistently received formulations/quantity recipes throughout the program, providing them with new products without increased labor needs.

Students gained more experience and benefited most from iterations of the program where they worked more closely with the dining center staff (FDSCI 530: undergraduate research course and the 2024 FDSCI 740: capstone course). Students of the 2024 capstone course, who took the product from an initial concept to full scale, received the most hands-on experience (figure 3-18).

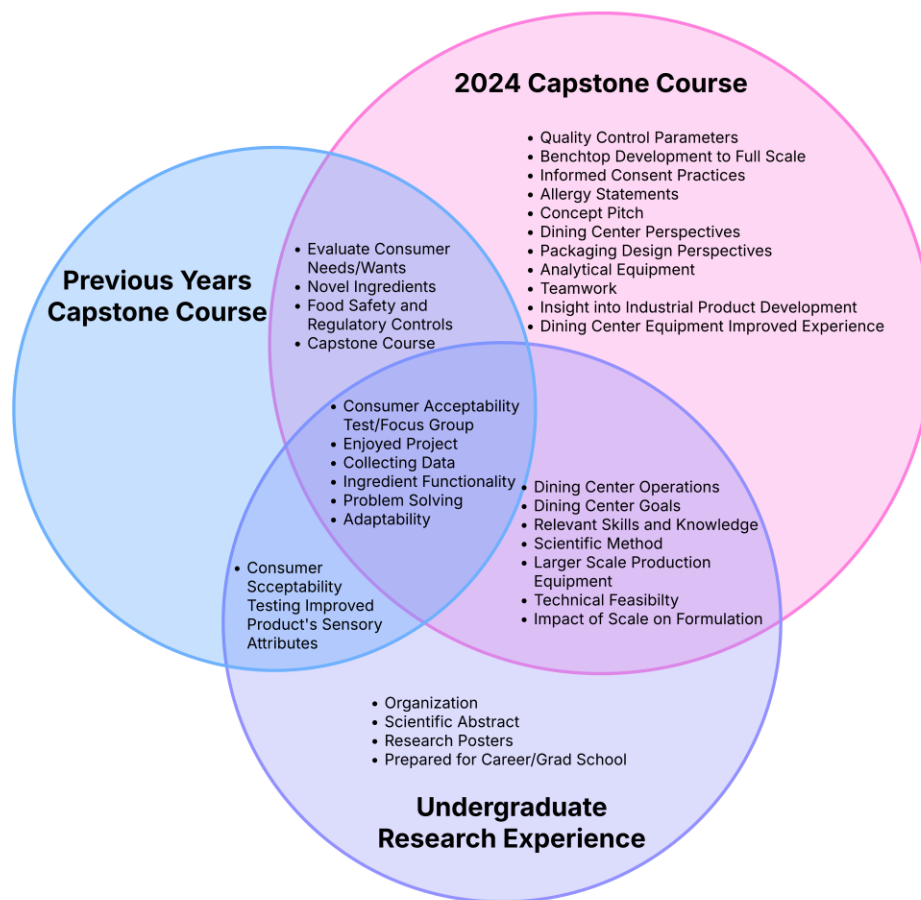


Figure 3-18. Benefits that 80% or More Participants Agreed or Strongly Agreed With

Moving forward this program would continue to benefit from including both the capstone course and undergraduate research course component. The capstone course would involve students meeting with dining center representatives, touring facilities, learning about available production equipment, and identifying menu goals and expectations. Students would individually conduct market screening research and present product concepts. Based on enrollment and dining center needs, appropriate concepts would be selected to move forward into development. Students would work in groups of 2-3 to develop initial product prototypes. Initial product prototypes would be reviewed by dining center staff and products would be selected for scale-up

and recipe formulation in the dining center. Students would be regrouped allowing everyone to be involved in the scale-up of one of the selected formulations. Scaled-up products would be put forth for consumer acceptability testing in the dining center. Once all data is collected, students will compose industrial-style reports and quantity recipes.

Product concepts that were presented but not selected for further development can be put to use by an undergraduate research course, dietetic interns, or other courses needing applied recipe development experiences in partnership with the dining center.

Each student would be assigned a product, allowing them to be responsible for the time management, project planning, and organization required for scale-up of the product. Guidance would still be provided by the instructor, preceptor, internship director, or mentor, but the project would be more independently run by the student. Dining center staff would still actively engage and provide feedback. These students would have access to large-scale equipment for scale-up and access to run consumer acceptability tests in the dining center. The data and experience could then be utilized for an abstract, poster presentation, or internship competency report. This framework allows for interdisciplinary connections between courses, academic programs, and departments across campus. It benefits both the students and the dining center. It would allow students to see a product from conception, through scale-up and into dining center distribution. The continuation of both an undergraduate research course and the capstone course allows interested students to gain more experience working independently, scaling-up products, and scientific writing/presentations. This course framework can be used to foster interdisciplinary relationships between food scientists, hospitality and dietetics management, and foodservice staff while giving students valuable experience and knowledge and providing campus dining centers with new and exciting menu items.

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Chapter 4 - Development and scale-up of gluten-free sorghum-based bakery goods for K-State Dining Services^{1,2}

Abstract

To create new product opportunities for sorghum in the state of Kansas, the FarmUs project had three primary pillars: Innovate, Scale, and Connect. The project aims to close the gap between industry and consumers by peaking interest in sorghum, its nutritional and sustainable benefits, and consumption of sorghum-based products. The primary focus of this study was to develop and scale-up three gluten-free sorghum-based products for Kansas State Dining Services. The secondary objective was to evaluate the sensory and physical properties of these products to provide developmental and research experience for students. Preliminary testing involved identifying optimum ratios of sorghum flour, xanthan gum, starch, and eggs for proper binding. Whipped egg whites were tested at different levels for product volume and texture. Repetition and reformulation of the products provided various renditions of each product. Quantity equipment needs, staffing feasibility, ingredient availability, and cost were determined. Dining staff evaluated each product and once recipes were finalized, parameters (color, specific gravity, internal temperature, moisture loss, height/width, water activity) were evaluated. Dining center customers provided acceptability feedback for the three gluten-free products using the 9-point Hedonic scale. The first product, a savory waffle, can be stacked with turkey sausage and cheddar cheese for a breakfast sandwich. It utilizes sorghum flour, egg whites, xanthan gum,

¹ Cairns, A., Brazington, S., Gragg, E., Holmes, A., Vavra, C., Whitehair, K., & Getty, K. (2023). Development and scale-up of gluten-free sorghum-based bakery goods for K-State Dining Services. *Journal of Agriculture and Food Research*, 100840. <https://doi.org/10.1016/j.jafr.2023.100840>

²Abstract presented Cereal and Grains Association 2022

starch, and flaxseed for structure. This product received a range of 7.03-7.63 (n=43) for all sensory attributes (acceptability, flavor, mouthfeel, texture, and aftertaste). The lemon blueberry muffin contains sorghum flour, eggs, buttermilk, xanthan gum, potato starch, and egg whites. Sensory data (n=49) measured at acceptability (7.4), flavor (7.6), mouthfeel (6.4), texture (6.6), and aftertaste (7.6). The third product, a sweet potato muffin top, contains sorghum flour, xanthan gum, eggs, egg whites, and sweet potatoes. All three recipes were formatted via Computrition Menu Management system to provide methodology, nutritional analysis, costing, and labeling for university dining use. These recipes, along with sorghum-based educational materials will be shared with higher learning facilities across Kansas.

Keywords: sorghum, sustainability, bakery goods, gluten-free, whole-grain

Abbreviations:

KSU or K-State	Kansas State University
KS	Kansas
QR	Quick Response
USDA	United States Department of Agriculture

Introduction

Sorghum is “the greatest drought tolerant among the world’s top five carbohydrate-rich crops” [1] and is tolerant to high temperatures while “consuming minimum input and care” [1]. It is also a highly efficient crop in respects to solar energy conversion and water usage [2]. Sorghum is specifically “well suited for Kansas agriculture,” as “Kansas leads the nation in sorghum production” [2]. Sorghum also presents financial advantages as the cost of production for sorghum is less than that of rice, wheat, or corn [1]. Because of these resilient qualities, sorghum has already been “a key staple food crop for millions of semi-arid tropic residents” and

could play a vital role in sustainably addressing food insecurity [1]. Another potential benefit of using sorghum in human food products is that it is a gluten-free grain.

Gluten-free products are in high demand due to both health and trend-related consumer desires [3]. Oftentimes, gluten-free products can fail to meet consumers' sensory or nutritional expectations of a baked good. They may have "poor crumb and crust characteristics as well as poor mouthfeel and flavor" [4]. Gluten-free bread product make a liquid batter instead of a dough and may have "reduced volume bread with low crumb softness" [4]. Gluten-free baked products are often "denser, shorter in height, have a larger spread, have a different color, and can be harder in texture than traditional wheat-based baked goods" depending on the gluten-free flour used [5]. Products that contain no gluten can also often have nutritional differences from products that contain gluten, such as having a lower protein content and a higher fat content [6]. Because of this, it can be beneficial to add ingredients, such as egg whites, sweet potatoes, or other functional ingredients to gluten-free products to improve nutritional, sensory, and physiochemical properties of the food product. In a study that worked on the development of steamed cold noodles, it was found that the lack of gluten caused "easy breakage, lack of toughness and elasticity" [7]. They then found that adding egg whites improved the water holding capacity, hardness, and gel strength of the noodles [7]. This also added protein to the product. Orange flesh sweet potatoes can be added for flavor and texture while also improving the nutritional value of a baked good because they contain "high levels of beta-carotene (5091-16,456 µg/100g), a precursor of vitamin A" and "high polyphenolics and antioxidant contents" [8]. Hydrocolloids, enzymes, and starches can be added to improve crumb porosity and increase gas cell size [4]. There are many ways to improve the sensory and nutritional characteristics of gluten-free products. Even so, gluten-free products cannot be expected to work exactly like

wheat-based products. Focus should be put on creating acceptable and desirable gluten-free products rather than making products that have the same exact characteristics as wheat-based products.

Sorghum is not the only gluten-free flour available. Other options include rice flour, oat flour, soy flour, and chickpea flour. Rice flour has a bland taste (a desirable trait in flour), a less dry texture, is hypoallergenic, and is often mixed with starch to aid in volume [9]. Rice flour can be available at a lower cost and more sustainable option than some flours because it is often made from broken grains that are a byproduct of rice factories [9]. However, rice flour has the disadvantage of not being homogenous due to differences in milling, particle size, and origin, which can cause varying quality of volume and texture of the products made with rice flour [9]. Oat flour has not been tested in as many gluten-free products because they were once believed to not be tolerated by celiacs, but it was more recently discovered that the intolerance was due to contamination of oat products with wheat products [9]. Oat flour has a pleasant taste as well as nutritional benefits, such as “a large amount of beta-glucans, which have been linked to important nutritional benefits, such as the prevention, treatment, and control of diabetes and cardiovascular diseases” [9]. Unfortunately, oat flour also has a high lipid content, and the grain must be thermally treated before milling to prevent rancidity caused by enzymes [9]. Soy provides a complete source of protein and can therefore be a nutritious replacement for wheat flour, although it can also result in a strong and undesirable “beany” flavor at higher levels of inclusion, so it must be used in combination with another flour to prevent this [10]. Chickpeas provide protein, fiber, folate, and trace minerals [11]. Chickpea flour has made successful baked products, even while sometimes imparting a “chickpea” taste [11,12]. This off flavor can also

lead to it being advantageous to mix chickpea with other flours to reduce this undesirable trait [13].

Compared to other gluten-free grains, sorghum's health benefits include having "slowly digestible starch, exclusive bioactive flavonoids, and action against irritation, oxidative pressure, and heart disease" [1]. Sorghum also contains bioactive phenolic compounds, such as caffeic acid, ferulic acid, gallic acid, 3-deoxyanthocyanins, luteolin, and apigenin, which can provide "antioxidant activity, anti-inflammatory effect, anti-proliferative effect, anti-diabetic, and anti-atherogenic effects" [14]. Sorghum has a lower protein content (8.3g/100g) than soy (51.1g/100g), wheat (10.6g/100g) or maize (9.8g/100g), but higher than rice (7.3g/100g) [15] [1]. It has an iron content (4 mg/100g) greater than that of maize (3 mg/100g) or rice (3 mg/100g) and equal to that of wheat (4 mg/100g) and lower than soybeans (7.34 mg/100g) along with a fiber content (13.8g/100g) higher than wheat (10.5g/100g), maize (9g/100g), rice (3.3g/100g), or soy (3g/100g) [15] [16] [1].

FarmUs, a farm to campus collaborative aimed at accessing consumer markets on college campuses, leveraging workforce development and student innovation to create new product opportunities for sorghum, had three primary pillars: Innovate, Scale, and Connect. The primary focus on this study was to develop and scale-up three gluten free sorghum-based bakery goods (lemon blueberry muffins, sweet potato muffin tops, and savory breakfast waffle sandwich) for Kansas State University (K-State) Dining Services. While farmers and agriculturists are aware of the sustainable benefits of growing sorghum, the average consumer is not. A market screening showed that there are limited baked goods made from sorghum available to consumers, the most readily available to an average consumer being muffins made with zucchini, sorghum flour and brown rice flour produced by Veggies Made Great™.

This study aims to close the gap in that communication by peaking consumer interest in sorghum, its nutritional and sustainable benefits, and consumption of sorghum-based products. Acceptable product development is vital to this process. Thus, the secondary objective was to evaluate the sensory and physical properties of these newly developed products.

Materials and methods

Basic experimental design

The initial gluten-free sorghum recipes used in this experimental study were created by graduate and senior undergraduate food science students at Kansas State University in the “Research & Development of Food Products” capstone class. Over this semester-long class, students developed their recipes on a small scale and presented them to a focus group for further feedback.

Three of these recipes were then scaled up for quantity production (dining center serving approximately 1,200 students) by undergraduate students enrolled in an undergraduate research course or gaining research experience by working with Dining Services staff. Modifications were made to better align with industrial size kitchen equipment and ingredients. Finalized recipes with production procedures for each product are shared in the results section. Nutrition and allergy facts for each recipe, along with consumer acceptance results are also shared. Once final recipes were formulated, each product was evaluated for color, water activity, height, width, and consumer acceptability. These products were not tested against a wheat flour control, as the goal of this study was not to create exact replicas of wheat products, but instead to determine the consumer acceptance of the sorghum products created. Then, each recipe was input into Computrition (a food service management system, Canoga Park, CA, USA). Computrition formats recipes for quantity use, procurement, pricing, and nutritional content.

Ingredients, preparations, and formulations

For the development of these products, whole grain white sorghum (NuLife™ Market, Scott City, KS, USA) was used. This local whole grain sorghum was selected for several reasons. Utilizing a grain produced in Kansas forges a partnership with local commodities, reduces transportation costs and decreases environmental impact. Using whole grain sorghum decreases waste which also makes these products more sustainable. Using whole grains can also increase nutrition. According to the United States Department of Agriculture (USDA), whole grain products provide magnesium and selenium to the diet, as well as dietary fiber which can aid in bowel movements and in preventing high cholesterol levels and heart disease [17].

To assist with the nutrition and acceptability of sorghum products, functional ingredients were added. Potato starch (Swan, MFG for Noon Products, Inc. Chicago, IL, USA) was used as a thickener and binder. Xanthan gum (Bob's Red Mill Natural Foods, Milwaukie, OR, USA) and liquid whole eggs with citric acid (Wholesome Farms, Sysco Brand, Houston, TX, USA) or sugar egg yolks (Sysco Brand, Huston, TX, USA) were used as binders. Whipped egg whites with guar gum and triethyl citrate (Glenview Farms, US Foods, Rosemont, IL, USA) were used to manage density, improve structure, and maintain volume after baking. Different ratios of these functional ingredients were tested to produce acceptable products. Suppliers for the other ingredients were liquid buttermilk (Hiland Dairy Foods, Springfield, MO, USA), granulated sugar (Western Sugar Cooperative, Denver, CO, USA), salt (Sysco Brand, Huston, TX, USA), baking powder (Clabber Girl, B&G Foods, Parsippany, NJ, USA), baking soda (Monarch, US Foods, Rosemont, IL, USA), and flaxseeds and flaxseed meal (Bob's Red Mill Natural Foods, Milwaukie, OR USA).

It was decided to further formulate and scale-up three baked breakfast goods using whole grain white sorghum as the only gluten-free grain. A sorghum-based lemon cake donut was initially developed in the capstone course. Due to unsuccessful scale-up of the donut, it was decided to change to a lemon blueberry muffin for a healthier option. The sweet potato muffin was initially developed as a low sugar muffin using 30% mashed sweet potatoes, Truvia® (Stacy, MN USA), and all-purpose flour. The concept was changed to be a sorghum-based sweet potato muffin top that utilized baked sweet potatoes (32%) from the Dining Center's potato bar.

The gluten-free savory sorghum waffle sandwich was developed in the capstone course starting with a sorghum waffle recipe (NuLife™ Market, Scott City, KS USA). The recipe was tested on and intended for Belgian style waffle irons. The waffle can either be served alone or as a breakfast sandwich containing turkey sausage and cheddar cheese, topped with maple syrup.

Physicochemical properties

Color, water activity, and the width and height of all three products were measured. A portable HunterLab MiniScan EZ colorimeter (Model No. 4500L, Reston, VA, USA) was used to measure L*, a*, and b* values for each product's color. For all three products the color was measured on the top surface. Color readings were measured in duplicate and averaged for each replication (n = 3).

Water activity was measured using a Rotronic water activity meter (HC2-AW-USB, Rotronic Instrument Corp., Huntington, NY, USA). Approximately two grams of each product was placed in 14 mm Rotronic plastic sample containers and water activity measured with a dwell time of 2 min at 24.5°C. Water activity measurements were performed in duplicate and averaged for each replication (n = 3). The height and width of each of the products was measured

with digital calipers (Tool Shop, Eau Claire WI). Each was measured from the bottom to the highest peak. For each product, this was measured in triplicate for each replication ($n = 3$).

Data collected for color, water activity, and width and height were analyzed to determine means and standard deviations by Excel (Microsoft Corporation, Redmond, WA, USA).

Consumer acceptability

Dining center students, faculty, and staff then provided sensory feedback by rating acceptance, flavor, texture, aftertaste, and mouthfeel on the 9-point Hedonic Scale (1 = dislike extremely, 9 = like extremely). This method was conducted for the Lemon Blueberry Muffin and the Savory Waffles. A tasting station was set up near the entrance to the dining center to attract students to evaluate products. Approval for consumer testing was approved by Kansas State University Institutional Review Board #08790. Data was analyzed using Excel (Microsoft Corporation, Redmond, WA, USA).

Consumer data for the Sweet Potato Muffin Tops was collected utilizing a Quick Response (QR) code and survey rating for appearance, texture, and flavor with response options of “very good, good, fair, poor, very poor.” Individuals participating in Konza Student Table, a free meal provided to the K-State and Manhattan community, received a muffin in their breakfast sacks that were labeled with the QR Code for feedback. Approximately 500 muffins were distributed and 49 people completed the QR survey.

Results and discussion

Lemon blueberry muffin

The effect of whipped egg whites on muffins can be seen in Fig. 4-1. In food service, a #12 disher was used to measure out batter portion for all treatments. For treatment a and b only sorghum flour, potato starch, xanthan gum and liquid eggs were used resulting in a muffin with a

low volume. For treatment c, whipped egg whites were added. The addition of whipped egg whites to the muffins improved the muffins' ability to maintain their volume after baking. In a previous study, Bravo-Núñez et al. (2019) observed that the addition of egg whites to a gluten-free layer cake improved the final volume of the cake and was similar to the control. It was also noted that batter with egg whites had improved foaming capacity as the density decreased allowing for more air entrapment [18]. As noted in Fig. 4-1 treatment d and Fig. 4-2 the inclusion of raw whipped egg whites at 7.51% yields a muffin with an acceptable volume. Table 4-1 shows the ingredient weights and processing steps for the lemon blueberry muffin. Whole grain white sorghum and xanthan gum were used at a ratio of 1.87:1. Fig. 4-3 indicates that each lemon blueberry muffin contains 3 g of protein and 190 calories in addition the formulation provides 2% iron, calcium, and potassium and contains real blueberries. The overall cost in a quantity production is \$0.28 per muffin (see Table 4-2).



Figure 4-1. Lemon blueberry muffins without whipped egg whites (a and b) and with whipped egg whites (c and d).



Figure 4-2. Lemon blueberry muffin final product.

Table 4-1. Lemon blueberry muffin recipe.

FarmUs Gluten Free Lemon Blueberry Muffins		
Category: Qk Bread:Muffins	Yield: 144	
Master Ref: 0.16 lb	Portion: 1 muffin	
Ingredients	Amount	Method
Sugar,Granulated.....	3.9 lb	1 1. Blend with French whip in bakers bowl. Set aside for step 2.3.
Flour,Sorghum,White,Whole Grain, NuLife.....	3.84 lb	
Flour,Potato Starch,Swan's.....	2.052 lb	
Xanthan Gum.....	0.024 lb	
Salt.....	0.12 lb	
Baking Powder.....	0.09 lb	
Baking Soda.....	0.09 lb	2 2. Combine with a flat paddle in mixer bowl until well blended. 3. On speed #1 slowly add dry ingredients from step 1.1 into bowl. 4. Scrape sides of bowl and mix for two minutes. Do not overmix.
Milk,Buttermilk,Fresh,DD.....	5.49 lb	
Egg,Whole,Liquid,Refrigerated.....	2.4 lb	
Oil,Salad,GAL.....	1.848 lb	
Extract,Lemon.....	0.24 lb	3 5. Place egg whites into clean mixing bowl, using whisk attachment, whip on high speed for 1 minute and 20 seconds, until stiff peaks form. Hand fold egg whites into batter with a spatula.
Egg,Whites,FZ,5LB.....	1.088 lb	
Flour,Sorghum,White,Whole Grain, NuLife.....	0.084 lb	4 6. In small bowl gently toss blueberries to coat with sorghum flour. 7. Gently fold into batter.
Blueberries,Cultivated,FZ.....	3.348 lb	
ZZ,Baking/Muffin Cups,Paper,4.5".....	144 each	5 8. Place in muffin tins. 9. Portion a #12 disher (approximately 0.16 lb.) of batter into each paper liner. 10. Bake at 350 Deg. F. (Conventional) for 22-26 minutes or to 208-210 Deg. F 11. Cool slightly before removing from pans. 6 12. Quality Standard: Muffins should be golden brown in color, slightly rounded with pebbly top, well-proportioned shapes; tender crust, even grain with no tunnels; moist crumb; breaks easily without crumbling; light and tender; good flavor. 7 13. Store leftovers in tightly sealed container.
		8 Equipment: Bakers Bowl - French Whip Mixer Bowl / Flat Paddle Rubber Scraper Muffin Tins / Paper Liners #12 Disher Conventional Oven 350 Deg. F Tongs 9 Date Entered in Computriton: 11/19/2021 - New (FarmUs / Food Science Student Project).

Nutrition Facts			
Serving Size		1 muffin (78g)	
Amount per serving			
Calories		190	
		% Daily Value*	
Total Fat	7g		9%
	Saturated Fat	1g	4%
	Trans Fat	0g	
Cholesterol	30mg		10%
Sodium	310mg		13%
Total Carbohydrate	29g		11%
	Dietary Fiber	<1g	3%
	Total Sugars	2g	
Includes 12g Added Sugars			25%
Protein	3g		
- Vitamin D	0%	- Calcium	2%
- Iron	2%	- Potassium	2%
*The % Daily Value (DV) tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.			

INGREDIENTS: Buttermilk (CULTURED GRADE A LOWFAT MILK, NONFAT DRY MILK, SALT, MODIFIED CORN STARCH, MONO AND DIGLYCERIDES, CARRAGEENAN, LOCUST BEAN GUM, NATURAL FLAVOR, VITAMIN A PALMITATE AND VITAMIN D3), White Whole Grain Sorghum Flour, Granulated Cane Sugar, Blueberries, Eggs (WHOLE EGGS, CITRIC ACID, 0.15% WATER ADDED AS CARRIER FOR CITRIC ACID), Potato Starch Flour, Canola Oil, Egg Whites (EGG WHITES, GUAR GUM, AND TRIETHYL CITRATE), Lemon Extract (ALCOHOL, WATER, AND OIL OF LEMON), Salt (SALT, SODIUM SILICOALUMINATE, DEXTROSE, POTASSIUM IODIDE), Baking Powder (CORN STARCH, SODIUM BICARBONATE, SODIUM ALUMINIUM SULFATE, MONOCALCIUM PHOSPHATE), Baking Soda (SODIUM BICARBONATE), Xanthan Gum

CONTAINS: Egg, Milk

Figure 4-3. Lemon blueberry muffin nutrition facts and ingredient statement.

Table 4-2. Lemon blueberry muffin cost.

Recipe Food Cost Report		Copyright© 1091–2023 Cumputrition, Inc. (v. 19.40.225/36)		
FarmUs Gluten Free Lemon Blueberry Muffins				
Category: Qk Bread:Muffins				Yield: 24
				Portion: 1 muffin
Ingredients	Amount (AP)	Cost Per Portion	Cost Per Recipe	Percent
Sugar, Granulated	0.65 lb	\$ 0.02	\$ 0.46	7%
Flour, Sorghum, White, Whole Grain	0.64 lb	\$ 0.04	\$ 0.93	14%
Flour, Potato Starch	0.34 lb	\$ 0.06	\$ 1.36	20%
Xanthan Gum	0.02 lb	\$ 0.00	\$ 0.09	1%
Salt	0.02 lb	\$ 0.00	\$ 0.00	0%
Baking Powder	0.02 lb	\$ 0.00	\$ 0.04	1%
Baking Soda	0.02 lb	\$ 0.00	\$ 0.01	0%
Milk, Buttermilk, Fresh	0.92 lb	\$ 0.02	\$ 0.54	8%
Egg, Whole, Liquid, Refrigerated	0.4 lb	\$ 0.02	\$ 0.59	9%
Oil, Canola	0.31 lb	\$ 0.02	\$ 0.55	8%
Extract, Lemon	0.04 lb	\$ 0.02	\$ 0.47	7%
Egg, Whites, FZ	0.18 lb	\$ 0.02	\$ 0.41	6%
Flour, Sorghum, White, Whole Grain	0.01 lb	\$ 0.00	\$ 0.02	0%
Blueberries, Cultivated, FZ	0.56 lb	\$ 0.04	\$ 1.04	16%
Muffin Cups, Paper, 4.5"	24 Each	\$ 0.01	\$ 0.15	2%
Total Costs:	\$ 0.28	\$ 6.68		

Sweet potato muffin top

In initial tests of replacing the original recipe's wheat flour with sorghum flour, it was found that the product had an exceedingly grainy mouthfeel and that the bottom of the muffin was too moist. To reduce those attributes, the batter was scooped onto a cookie sheet, to allow it to spread out. This resulted in a more even moisture content and a more subtle graininess in the mouthfeel. The product name then became muffin tops (Fig. 4-4). The sweet potatoes used in this recipe were varied to find the most effective way to cook them before adding them to the muffin tops. Boiled and cubed sweet potatoes made the batter too wet and dense. Frozen baked sweet potatoes were too dry. The leftover baked sweet potatoes from the dining center's potato bar were most acceptable. This is also beneficial in that it helps to reduce food waste.



Figure 4-4. Sweet potato muffin tops final product.

The sweet potato muffin tops contained 32% baked sweet potatoes, 25.32% whole grain white sorghum, and 8.02% whipped egg whites (Table 4-3). The egg white amount was similar to the lemon blueberry muffin amount of 7.51%. It has been noted that sweet potatoes may have a positive effect on texture properties of gluten-free baked goods. Sweet potatoes are a healthy food crop that is rich in beta-carotene, potassium, dietary fiber that can be processed into flour. Shih et al. (2005) determined the impact of sweet potato flour on gluten-free pancakes made with rice flour and 10, 20, and 40% sweet potato flour. The addition of sweet potato flour increased the water holding capacity of the pancakes. With the addition of 40% sweet potato flour, hardness and chewiness were decreased and cohesiveness was decreased [19]. Therefore, sweet potatoes are healthy addition that provides desirable texture attributes to gluten-free baked goods.

Table 4-3. Sweet potato muffin top recipe

Category: Qk Bread:Muffins		Yield: 144 each
		Portion: 1 each (0.13 lb batter)
Ingredient	Amount	Method
Baked Sweet Potato	6.15 lb	1 1. Remove peel from baked sweet potatoes. Set aside for step 3.4.
Egg, Whites, FZ	1.519 lb	2 2. Place egg whites into mixing bowl and whip with whisk until stiff peaks form. Set aside for step 6.8.
Egg, Yoks, Sugared, Refrig/ FZ	0.611 lb	3 3. Combine yolks, oil, and molasses in a baker's bowl.
Oil, Canola	1.427 lb	4 4. Fold in the sweet potatoes from step 1. Set aside for step 4.6.
Molasses	0.816 lb	
Baking Powder	0.111 lb	4 5. Combine in a separate bakers bowl.
Baking Soda	0.111 lb	6 6. Fold dry ingredients into wet ingredients from step 3.4. Mix until combined.
Spices, Cloves, Ground	0.01 lb	
Spice, Cinnamon, Ground	0.02 lb	
Sugar, Granulated	3.319 lb	
Salt	0.017 lb	
Xanthan Gum	0.036 lb	
Flour, Sorghum, White, Whole Grain	4.797 lb	5 7. Gradually (1/3 of the amount at a time) add the sorghum flour to the mixture, stirring gently after each addition just until combined. 6 8. Gently fold in the whipped egg whites from step 2.2 7 9. Portion #20 disher (0.13 lb) of batter 3 × 4 on a parchment lined bun sheet. 10. Bake at 375 Deg. F in conventional oven for 25 min, until springy to the touch and an internal temperature of 200 Deg. F. 11. Allow to cool slightly before removing from baking pans.

For example, the sweet potato muffin top contains 2 g of dietary fiber and 2 g of protein with the addition of 4% daily value of iron and potassium (Fig. 4-5). The cost per muffin is \$0.17 (Table 4-4).

Nutrition Facts		
Serving Size 1 each(60g)		
Amount per serving		
Calories 180		
% Daily Value*		
Total Fat	7g	9%
Saturated Fat	0g	2%
Trans Fat	0g	
Cholesterol	15mg	6%
Sodium	170mg	7%
Total Carbohydrate	29g	11%
Dietary Fiber	2g	5%
Total Sugars	2g	
Includes 13g Added Sugars		25%
Protein	2g	
- Vitamin D	0%	- Calcium 0%
- Iron 4%		- Potassium 4%
<i>*The % Daily Value (DV) tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.</i>		

INGREDIENTS: Sweet Potato, White Whole Grain Sorghum Flour, Granulated Cane Sugar, Egg Whites (EGG WHITES, GUAR GUM, AND TRIETHYL CITRATE), Canola Oil, Molasses, Sugared Egg Yolks (EGG YOLKS, SUGAR), Baking Powder (CORN STARCH, SODIUM BICARBONATE, SODIUM ALUMINIUM SULFATE, MONOCALCIUM PHOSPHATE), Baking Soda (SODIUM BICARBONATE), Xanthan Gum, Ground Cinnamon, Salt (SALT, SODIUM SILICOALUMINATE, DEXTROSE, POTASSIUM IODIDE), Ground Cloves

CONTAINS: Egg

Figure 4-5. Sweet potato muffin top nutrition facts

Table 4-4. Sweet potato muffin top cost

Recipe Food Cost Report		Copyright© 1091–2023 Cumpnutrition, Inc. (v. 19.40.225/36)		
FarmUs Gluten Free Sweet Potato Muffin Top				
Category: Qk Bread:Muffins				Yield: 520
				Portion: 1 each
Ingredients	Amount (AP)	Cost Per Portion	Cost Per Recipe	Percent
Baked Sweet Potato	22.21 lb	\$ 0.03	\$ 17.97	21%
Egg, Whites FZ	5.49 lb	\$ 0.02	\$ 12.45	14%
Egg, Yolks, Sugared, Refrig/FZ	2.21 lb	\$ 0.28	\$ 4.86	6%
Oil, Salad, GAL	5.15 lb	\$ 0.25	\$ 9.14	10%
Molasses	2.95 lb	\$ 0.01	\$ 3.99	5%
Baking Powder	0.4 lb	\$ 0.00	\$ 1.00	1%
Baking Soda	0.4 lb	\$ 0.00	\$ 0.40	0%
Spice, Cloves, Ground	0.04 lb	\$ 0.00	\$ 0.75	0%
Spice, Cinnamon, Ground	0.07 lb	\$ 0.00	\$ 0.39	1%
Sugar, Granulated	11.98 lb	\$ 0.02	\$ 8.39	10%
Xanthan Gum	0.13 lb	\$ 0.01	\$ 2.86	3%
Flour, Sorghum, White, Whole Grain	17.32 lb	\$ 0.05	\$ 25.30	29%
Total Costs:		\$ 0.17	\$ 87.43	

Savory waffle

According to a market screening completed by students in the capstone course, there are limited gluten-free hearty breakfast options on the market. The concept of a savory waffle sandwich with a turkey sausage patty and cheese was further developed (Fig. 4-6). For the final waffle batter, 8.71% whipped egg whites were needed to maintain structure during the griddle cooking process (see Table 4-5). Egg yolks were also added to assist with binding. Flaxseeds and flaxseed meal were added to provide texture and nutritional value. Flaxseed flour contains fiber, protein, omega 3,6, and 9 fatty acids [20]. In a study of gluten-free cinnamon rolls, a formula containing 65% resistant starch and 25% lupine flour with 10% flaxseed flour and 1% xanthan gum had optimal quality and sensory characteristics. One Belgium style waffle contains 10 g of protein and 3 g of fiber (see Fig. 4-7). The amount of flaxseed and flaxseed meal was 2.4% and 0.4% of xanthan gum (see Table 4-5). Potato starch (6.11%) and whole grain sorghum (17%) were incorporated into the formula. Aleman et al. (2021) noted that the addition of potato starch

to a gluten-free cupcake with high protein brown rice flour improved the texture by decreasing hardness and improving the volume of the cupcakes [21]. Ozkoc and Seyhun (2015) further demonstrated that less than 10% of potato starch improves the volume of bakery products [22].



Figure 4-6. Savory waffles and waffle sandwich with maple syrup.

Table 4-5. Savory waffle and savory waffle sausage sandwich recipe.

Savory Gluten Free Waffle – M		
Category: Bkst Entre:Panc/Waffl		Yield: 50 each
		Portion: 1 each
Ingredient	Amount	Method
Flour, Sorghum, White, Whole Grain	3.73 lb	1 1. Combine all dry ingredients. 2. Set aside for step #3.6.
Sugar, Granulated	0.741 lb	
Xanthan, Gum	0.087 lb	
Flour, Potato Starch	1.331 lb	
Baking Powder	0.589 lb	
Salt	0.109 lb	
Flax Seed, Golden	0.305 lb	
Flax Seed, Meal, Whole	0.218 lb	
Seasoning, Italian	0.091 lb	
Onions, Dried, Chopped	0.262 lb	
Milk, 2%	9.859 lb	2.3. Place milk, oil, and yolks into mixer bowl.
Oil, Canola	1.527 lb	4. Using a flat paddle mix on setting #1 for 1 min.
Egg, Yolks, Sugared, Refrig/FZ	1.025 lb	5. Scrape bowl.
		3 6. Add dry ingredients from step 1.1 to mixer bowl with milk and egg mixture.
		7. Using a flat paddle mix on setting #1 for 30 s. Scrape bowl.
		8. Mix on setting #2 for 1 min.
		Scrape bowl. Batter should be fairly thick.
		9. Allow this batter to rest for step 4.11, while you prep the egg whites.
Egg, Whites, FZ	1.897 lb	4 10. Place egg whites into clean mixing bowl, using whisk attachment, whip on high
		Speed for 1 min and 20 s, until stiff peaks form.
		11. Hand fold egg whites into batter with a spatula.
		5 12. Heat up waffle irons with top plates closed.
		13. Spray hot waffle irons with 4-5 squirts of waffle spray.
		14. Us 2 #8 (0.18 lbs per scoop) disher of batter and deposit in center of iron. Let cook for 2 min and 30 s.
		16. Remove baked waffle with large spatula.
		17. Cool waffles on cooling rack.
		18. Individually freeze before packaging waffles.
		Note: This recipe is formatted for waffles that will be frozen, then reheated for use. If wanting to serve immediately or make-to-order bake for 3 min and 15 s on the waffle iron. Internal temperature should reach 200 Deg. F.
		Equipment:
		Mixer Bowl – Flat Paddle
		Mixer Bowl – Whisk
		Belgian Waffle Iron

Savory Gluten Free Waffle – M		
Category: Bkst Entre:Panc/Waffl		Yield: 50 each
		Portion: 1 each
Ingredient	Amount	Method
		#8 Scoop
		Plastic Spatula
Savory Gluten-Free Waffle Sausage Sandwich		
Category: Bkst Entre: Sand/Wrap		Yield: 100 each
		Portion: 1 sandwich
Ingredient	Amount	Method
Turkey Sausage Patty	100 each	1 1. Prepare from recipe.
		2. Place in 12 x 10 x 4 inch pans fitted with perforated liners.
		3. Do not cover. Hold for service/use at or above 140 Deg. F.
Savory Gluten Free Waffle (from recipe)	50 each	2 4. Prepare from recipe.
		5. Drive each waffle into 4 sections.
		6. Place in 12 x 20 x 2 inch pans and hold at or above 140 Deg. F for service/use.
Syrup, Maple	12.5 lb	3 7. Prepare from recipe or use purchased product.
		8. Hold for service/use at or above 140 Deg. F.
Cheese, Cheddar, Sharp, Slices	100 each	4 9. Server will place 1 waffle section (triangle) on serving plate.
		10. Place sausage patty and a piece of cheese on waffle section.
		11. Place second waffle section on top.
		Note: May place back in warm oven to melt cheese if serving immediately. Cheese will melt in warmer or on serving line if preparing in batches for line.
		12. Portion 2 oz. Of syrup into bowl and hand to costumer. One portion is one sandwich with syrup.
		5 Cover, label, and date leftover sausage.
		Refrigerate at or below 40 Deg. F. Reheat to a minimum of 165 Deg. F. Cover, label, and date syrup. Store at room temperature.
		6 Equipment:
		12 x 10 x 4 Inch Pans – Perforated Liner Bun Sheets
		Oven 250 Deg F OR Toaster
		12 x 20 x 2 Inch Pans
		12 x 10 x 2 Inch Pans
		Tongs
		2 oz ladle

Nutrition Facts		
Serving Size	1 waffle(198g)	
Amount per serving		
Calories	420	
% Daily Value*		
Total Fat	21g	27%
Saturated Fat	2g	11%
Trans Fat	0g	
Cholesterol	90mg	30%
Sodium	1080mg	47%
Total Carbohydrate	52g	19%
Dietary Fiber	3g	11%
Total Sugars	6g	
Includes 8g Added Sugars		15%
Protein	10g	
- Vitamin D	6%	- Calcium 10%
- Iron	10%	- Potassium 6%
*The % Daily Value (DV) tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.		
INGREDIENTS: 2% Milk, White Whole Grain Sorghum Flour, Egg Whites (EGG WHITES, GUAR GUM, AND TRIETHYL CITRATE), Canola Oil, Potato Starch Flour, Sugared Egg Yolks (EGG YOLKS, SUGAR), Granulated Cane Sugar, Baking Powder (CORN STARCH, SODIUM BICARBONATE, SODIUM ALUMINUM SULFATE, MONOCALCIUM PHOSPHATE), Brown Flax Seed, Chopped Dried Onions, Ground Whole Flax Seed, Salt (SALT, SODIUM SILICOALUMINATE, DEXTROSE, POTASSIUM IODIDE), Italian Seasoning (MARJORAM, THYME, ROSEMARY, SAVORY, SAGE, OREGANO, AND BASIL), Xanthan Gum		
CONTAINS: Egg, Milk		

Figure 4-7. Savory Waffle Sandwich Nutrition Facts.

The waffle sandwich with a turkey sausage patty and slice of cheddar cheese contains 17 g of protein and 4, 20, 10, and 6% of the daily value of vitamin D, calcium, iron, and potassium. The cost per sandwich is \$1.23 (see Table 4-6).

Table 4-6. Savory waffle sandwich cost.

Recipe Food Cost Report		Copyright© 1091–2023 Cumputrition, Inc. (v. 19.40.225/36)		
FarmUs Gluten Free Savory Waffle Sausage Sandwich				
Category: Bkst Entre:Sand/Wrap				Yield: 100
				Portion: 1 sandwich
Ingredients	Amount (AP)	Cost Per Portion	Cost Per Recipe	Percent
Turkey Sausage Patty	100 Each	\$ 0.37	\$ 36.87	30%
Savory Gluten Free Waffle -M	50 Each	\$ 0.33	\$ 33.38	27%
Syrup, Log Cabin, Bottle	12.5 lb	\$ 0.28	\$ 28.02	23%
Cheese, Cheddar, Sharp, Slices	100 Each	\$ 0.25	\$ 25.00	20%
	Total Costs:	\$ 1.23	\$ 123.27	

Physiochemical properties

Overall, the lemon blueberry muffins had the highest L* value and the lowest a* value indicating they had more white color and less red color on the top crust (see Table 4-7). This is expected along with the sweet potato muffin tops having the lowest L* value as the color was a brown hue. For the savory waffle, researchers determined a proper time for waffles that would be cooked and reheated or cooked immediately and reach an internal temperature of 200 °F. To assist the Dining Centers staff, a visual color chart for the waffles was developed (Fig. 4-8). For the water activity values, the sweet potato muffin tops had a lower water activity of 0.89 likely due to the sweet potato fiber that would assist with binding free water. The waffle and muffin water activities were 0.92 and 0.93, respectively.

Table 4-7. Physical parameters means and standard deviations.

Product	Color			Water Activity	Height (mm)	Width (mm)
	L*	a*	b*			
Lemon Blueberry Muffin	50.54 ± 5.07	0.94 ± 3.40	25.65 ± 5.55	0.923 ± 0.002	41.43 ± 4.03	NA
Sweet Potato Muffin Tops	35.42 ± 1.59	14.12 ± 1.87	21.46 ± 1.84	0.8876 ± 0.0086	28.23 ± 0.25	79.62 ± 1.60
Savory Waffle	40.61 ± 5.56	12.74 ± 1.88	27.98 ± 2.02	0.9199 ± 0.012	NA	NA

**Figure 4-8. Color Sequence, light to dark, with optimal being between waffles 3 & 4.**

Consumer acceptance

On the hedonic scale “A mean liking score of 7 or higher on a nine-point scale is usually indicative of highly acceptable sensory quality” [23]. Most scores for the lemon blueberry muffin and all for the savory waffle sandwich were above 7 (Table 4-8). The only scores for the lemon blueberry muffin that were below a 7 were texture and mouthfeel and these values were still both above 6.4. Considering these are both gluten-free products (which often have undesirable texture and mouthfeel) [4], these scores show that these products were successful and acceptable for serving in dining centers or other locations.

Table 4-8. Hedonic scale consumer response for lemon blueberry muffins and savory waffles.

Product	Acceptance	Flavor	Texture	Aftertaste	Mouthfeel
Lemon Blueberry Muffin (n = 49)	7.04 ± 2.12	7.60 ± 1.41	6.58 ± 4.24	7.56 ± 2.21	6.42 ± 4.24
Savory Breakfast Waffle (n = 43)	7.47 ± 1.25	7.34 ± 1.69	7.52 ± 1.36	7.03 ± 1.39	7.63 ± 1.27

The sweet potato muffin tops also did well in consumer testing (Fig. 4-9). More respondents rated appearance, texture, and flavor as very good and good as opposed to fair or poor. No respondents rated any attribute as very poor. This shows that the sweet potato muffin tops were an acceptable product as well.

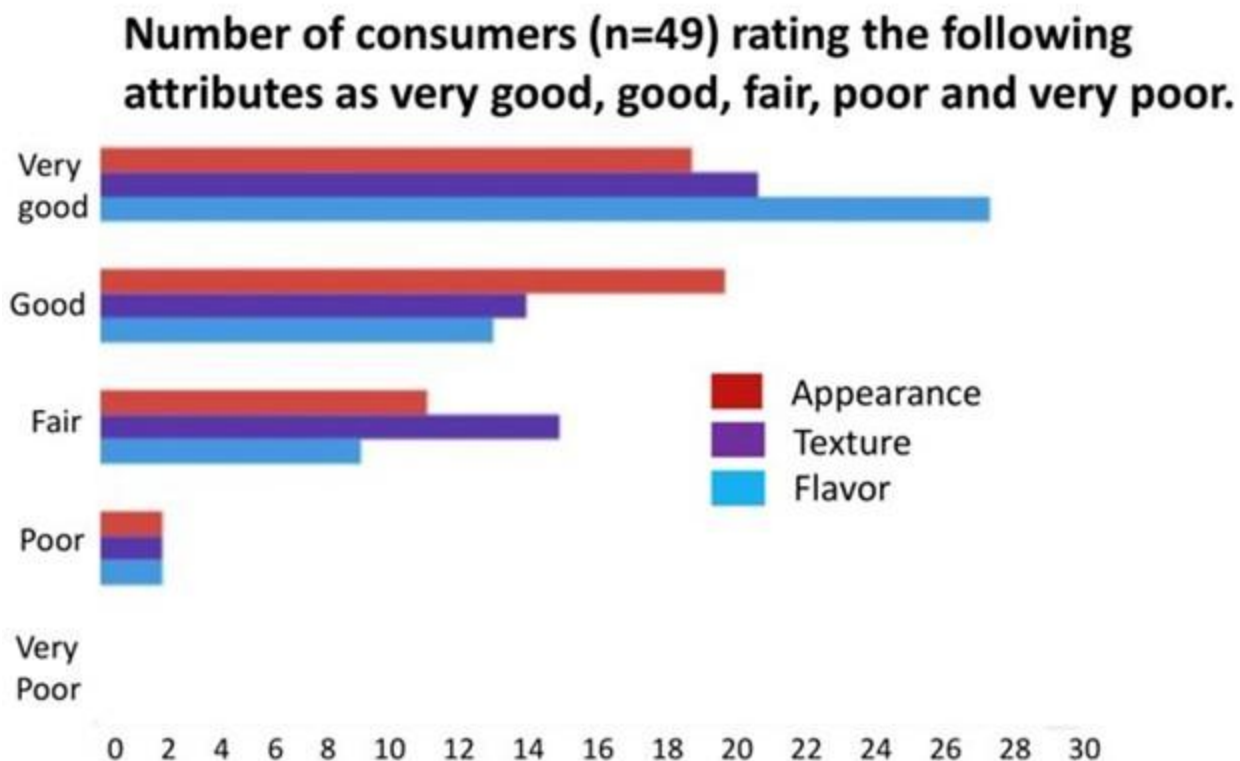


Figure 4-9. Sweet potato muffin top consumer acceptance.

Conclusions

To promote consumption of Kansan sorghum, increase sustainability, and provide more gluten-free options, three recipes for baked goods made from whole grain white sorghum flour were successfully scaled-up for quantity production to be served in college dining centers. These recipes were developed by varying the ratios of sorghum flour, sweet potatoes, starch, xanthan gum, whipped egg whites, and egg yolks used. The use of whipped egg whites significantly improved the structure of all products by improving final baking height and maintaining foam capacity after baking. Konza Student Table participants and dining hall consumers rated all products as very acceptable, showing that consumer acceptable products can be made with sorghum flour. Future studies could investigate the use of a combination of gluten-free flours or the use of millet to obtain the same physiochemical and consumer acceptance results.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Kelly Getty reports financial support was provided by US Department of Agriculture Agricultural Marketing Service.

Data availability

Data will be made available on request.

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Chapter 5 - The Impact of Rum on Physicochemical Properties of Sorghum and Wheat Pound Cakes

Abstract

Sorghum, a sustainable, gluten-free flour, typically results in baked goods with decreased volume, decreased crumb flexibility, and undesirable textures. One previous study evaluated rum in wheat cakes and observed increased elasticity and volume. This study's objective was to evaluate the impact of rum on sorghum and wheat-based pound cakes. A 2x2 factorial design (n=3) was used to compare pound-cake formulations: sorghum with rum (SR), sorghum without rum (SN), wheat with rum (WR), and wheat without rum (WN). Data was collected on batter specific gravity (SG), batter temperature, and baked product weight, volume, internal structure, and texture. Replacing wheat with sorghum and/or including rum in a formulation contributed to increased batter aeration. However, cakes containing sorghum and/or rum had lower final volumes, indicating decreased air retention. The presence of rum increased top concavity, indicating structural collapse, which suggests delayed or inadequate structure setting. Regarding internal structure, rum increased the air cells count in SR, and decreased cell wall thickness for SR and WR. Rum increased hardness and had no effect on cohesiveness. With the current trend for alcohol-flavored baked goods and the need for sustainable and gluten-free products, understanding the ingredient functionality of alcohol in baked goods can improve future products.

Introduction

Sorghum is a mild-flavored gluten-free grain that is drought-resistant and heat tolerant (Ratnavathi & Komala, 2016). Sorghum also has a lower cost of production than wheat, maize,

and rice (Hossain et al., 2022). These traits make it a good alternative to wheat when developing products for people with gluten intolerance. However, like most gluten-free flours, sorghum products can have some less than desirable traits. Cakes containing sorghum can experience decreased volume, a greasy and pitted crust from leavening gases escaping, and decreased crumb flexibility “and would break or crack even when handled gently, indicating that the normal starch gel structure had not been established” (Glover et al., 1986). Other sorghum products have been shown to have characteristics such as dense, mealy, and gritty (Badi & Hoseney, 1976; Cayres et al., 2020; Curti et al., 2022; Glover et al., 1986; Marston et al., 2016)

Some studies have created improved sorghum products by modifying the sorghum starch. Sorghum starch has a higher gelatinization temperature (67.5-79°C) compared to wheat starch (54.5-60°C) (Glover et al., 1986). Using pregelatinized sorghum starch was shown to prevent the sandy texture in high ratio cakes (Cayres et al., 2020). Using sorghum that had been pin milled (and therefore had a smaller particle size of 24.2-26.5 µm and increased damage to the starch of 12.3-14.4%) lead to a high ratio cake with better texture and volume than non-pin milled (>50 µm) sorghum flour (when used in 5%, 10%, and 15% replacement of wheat flour) (Glover et al., 1986). Replacing sucrose with dextrose in cakes containing sorghum starch led to improved grain structure, symmetry, texture, and volume, which was attributed to increased starch gelatinization which may have stabilized the gas cells (Glover et al., 1986). Therefore, Glover et al. (1986) suggested that decreasing the gelatinization temperature of sorghum to be more similar to wheat could improve products by increasing batter viscosity.

Ethanol could possibly be used to affect the starch in baked goods. Ethanol has also been shown to cause a variety of starch surface changes (depending on starch type and amylose/amylopectin ratio and structure) such as swelling, surface wrinkling, and opening-up

(Zhang et al., 2012). Sorghum's "amylose content ranges from 0% to 55%" (Zhu, 2014).

Because of this range, it is difficult to predict how ethanol might interact with the starch in sorghum.

There has been limited research on the impact of ethanol on baked goods and other food products. However, one study observed the impact of including rum in a wheat cake. Phalen (2024) saw significant differences between cakes with no rum and cakes with rum but found no significant differences between the three levels of rum inclusion tested (7.6%, 10.1%, and 12.6% true percent) (Phalen, 2024). The study found 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" (Phalen, 2024). These benefits could assist in improving sorghum products, as some of the main difficulties with sorghum products are the loss of volume and lower elasticity.

In addition to potential starch modification and gluten-free product improvements, alcohol has flavor applications. Cocktail/alcohol flavors are trending with the condition that the products contain little to no alcohol (Berry, 2024; Cvetan, 2024). There has been limited research on alcohol's impact on food products. People working to develop new products in response to this trend would benefit from knowing how using alcohol (as opposed to alcohol flavoring) might impact their products.

Objectives

Therefore, the objectives of this study were to investigate the impact of alcohol, in the form of rum, on pound cakes made with sorghum or wheat flour.

Materials and Methods

Experimental Design

A 2x2 factorial design (n=3) was used to compare pound-cake formulations: sorghum with rum (SR), sorghum without rum (SN), wheat with rum (WR), and wheat without rum (WN). There were three bake days. On each bake day, one batch of each formulation (Table 5-1) was baked. Formulations were baked in a randomized order. Each batch resulted in three cakes.

Materials

Cake formulations and procedures were based on the methods in a previous study (Wilderjans et al., 2010). Formulations were enhanced with xanthan gum (0.25% total) and potato starch (4.9% total) due to their ability to improve gluten-free products. Xanthan gum has been shown to improve gluten-free cakes by increasing specific volume, decreasing firmness, and delaying staling (Preichardt et al., 2011). In gluten-free products, starch becomes the main structure-former and contributor to texture (Witczak et al., 2016). In gluten-free cupcakes, potato starch led to increased batter viscosity, specific volume, and springiness, while decreasing hardness and chewiness (Aleman et al., 2021). The level of rum used in the rum treatments was selected based on the 7.6% (total percent) used in a previous study (Phalen, 2024).

Table 5-1. Cake formulations

	Sorghum Rum (SR)	Wheat Rum (WR)	Sorghum No Rum (SN)	Wheat No Rum (WN)
Ingredient	(Weight in g and on flour basis)	(Weight in g and on flour basis)	(Weight in g and on flour basis)	(Weight in g and on flour basis)
Unsalted Butter (Kroger, Cincinnati, OH)	200 100%	200 100%	200 100%	200 100%
Sugar (Pure Cane Fine Granulated Sugar, Imperial Sugar, Minneapolis, MN)	200 100%	200 100%	200 100%	200 100%
Dry whole eggs (Judee's, Plain City, OH)	50 25%	50 25%	50 25%	50 25%
1 st Stage Water (Municipal Water, Manhattan, KS)	88.21 44%	88.21 44%	88.21 44%	88.21 44%
White Pearled Grain Sorghum Flour (NuLife, Scott City, KS)	160 80%	0 0%	160 80%	0 0%
Pastry Flour (Miller Milling, Eden Prairie, MN)	0 0%	160 80%	0 0%	160 80%
Potato Starch (Anthony's, Vista, CA)	40 20%	40 20%	40 20%	40 20%
Grindsted Xanthan Gum 200 (Danisco, New Century, KS)	2 1%	2 1%	2 1%	2 1%
Iodized Salt (Sysco, Houston, TX)	9 5%	9 5%	9 5%	9 5%
Baking Soda (AB Mauri, St. Louis, MO)	2.28 1%	2.28 1%	2.28 1%	2.28 1%
Baking Powder (SAPP) (Corbion Ingredients, Lenexa, KS)	1.72 1%	1.72 1%	1.72 1%	1.72 1%
Rum (Genuine Bacardi Spiced Rum 35% alc/vol, Cataño, Puerto Rico)	61.79 31%	61.79 31%	0 0%	0 0%
2 nd Stage Water (Municipal Water, Manhattan, KS)	0 0%	0 0%	61.79 31%	61.79 31%
Total	815	815	815	815

Baking Procedures

Ingredients were measured beforehand. All ingredients were stored at room temperature except for butter and dry whole eggs which were stored in a walk-in refrigerator (4±1°C). Using

a KitchenAid Commercial 8 qt. mixer (KitchenAid, Benton Harbor, MI), butter and sugar were creamed together for one minute at speed two. The bowl was scraped, then mixing resumed at speed six for two minutes, scraping the sides of the bowl after one minute and after two minutes. In a separate container, the dry whole eggs were rehydrated with the first water. The egg mixture was added to the butter and sugar and mixed at speed two for thirty seconds, scraped, and then mixed at speed four for two minutes. In a separate container, dry ingredients (flour, potato starch, baking powder, baking soda, xanthan gum, and salt) were combined. One third of the dry mixture (71 g) was then added to the mixer and mixed for thirty seconds at speed two. The bowl was scraped. Depending on formulation, the second water or rum was added and mixed for 30 seconds at speed 2 then scraped. The remaining dry ingredient mixture was added and mixed for two minutes at speed four.

The specific gravity and temperature of the batter were measured before weighing the batter into pans. Batter was then weighed (220g/cake) into greased (Crisco All-Vegetable Shortening (Parsippany, NJ)) and floured (sorghum or wheat) pup loaf pans (top pan dimensions (140mm (length) x 76mm (width) x 55mm (height) and bottom pan dimensions (130 mm (length) x 64 mm (width) x 55 mm (height)). Pans were labeled then placed on a baking sheet together and put in the oven (4-shelf retailer oven 4-26 x 56, Reed Oven Co., Kansas City, MO) at 177°C for 32 minutes. When the cakes were removed from the oven, the internal temperature was measured. Cakes were then set on a rack to cool. Approximately ten minutes after being removed from the oven, the pans were inverted to remove the cakes and place on a cooling rack. Cakes were cooled for an hour before testing.

Batter Properties

After mixing, the batter temperature was measured using a thermometer (Taylor Model 9842, Oakbrook, IL). The thermometer was placed approximately 5 cm into the batter in the middle of the bowl.

An empty ½ cup measuring cup was weighed. The measuring cup was then filled with water and weighed. The cup weight was subtracted to obtain the water weight. Then for each batch, a spoon was used to scoop batter into the measuring cup, leveled with a flat metal spatula, and then weighed. The cup weight was subtracted to obtain the batter weight.

$$\text{Specific Gravity} = \frac{\text{batter weight}}{\text{water weight}}$$

Weight and Volume

For each batch, two loaves were weighed after cooling. From each batch, two loaves were analyzed for volume, surface area, and the middle slice height. These parameters were measured by laser topography (Volscan 600, Stable Micro Systems, Surrey, United Kingdom) with cake parameters and a 2 mm step size.

Color

A colorimeter (MiniScan EZ 4500L, HunterLab, Reston, VA) was used to evaluate the color of one loaf from each batch. The L*, a*, and b* values were recorded for external (crust) and internal (crumb) scans of the cakes. Three measurements of each (external and internal) were collected from each loaf. The placement of the probe was randomized for each measurement.

Internal Structure

C-Cell analysis (CC.300.05 Calibre, Warrington, United Kingdom) determined slice area, top concavity, bottom concavity, number of cells, area of cells, and wall thickness according to

manufacturer's instructions. Two middle slices from each batch were scanned using C-Cell analysis.

Texture Analysis

One loaf per batch was used for a double-compression test (Texture Analyzer TA-XT plus, Stable Micro Systems, Surrey, United Kingdom) to measure hardness, adhesiveness, springiness, cohesiveness, and chewiness. The end “crusts” were removed using a serrated knife. A ruler and marker were used to mark 25mm (1”) thick slices. Slices were cut using a serrated knife and a wooden bread slicing guide. Four slices of cake per loaf were tested. Slices were tested in order from end-to-end of the cake. A 25 mm (1”) diameter acrylic cylinder probe was used. Samples were centered underneath the probe to avoid the edges. The pretest speed was 2 mm/s, the test speed was 1 mm/s, and the post-test speed was 10 mm/s. The target strain was 50%. The hold time was 5 s, and the trigger weight was 5 g. The probe and plate testing surface were cleaned between each test.

Alcohol Testing

Three cakes per group were weighed individually, then combined with 1 L of deionized (DI) water in a large vessel. The mixture was manually homogenized using a stir rod until no large pieces remained, and a uniform slurry was achieved. From this slurry, three 454 g aliquots were taken and transferred into 500 mL Kjeldahl flasks, each fitted with a 3 cm magnetic stir bar and a Kjeldahl distillation apparatus. Each distillation outlet was directed into a 50 mL centrifuge tube held in an ice bath. The samples were distilled at (about) 80°C with continuous high-speed stirring for 4 h. After distillation, each collection tube was brought to a final volume of 50 mL using DI water and homogenized. Two subsamples from each replicate were syringe-filtered through 20 µm filters into high-performance liquid chromatography (HPLC) sample vials.

Ethanol concentration was measured using an Agilent 1260 HPLC system equipped with an HPX-87H organic acid column (7.8×300 mm) maintained at 60°C . Concentration data from each replicate were used to calculate the average ethanol content per cake.

Statistical Analysis

Eight structural measurements of C-cells were analyzed to evaluate the effects of treatment (Trt) and replication (Rep). The variables examined were Slice Area, Top Concavity, Bottom Concavity, Number of Cells, Area of Cells, Wall Thickness, Cell Diameter, and Average Cell Elongation. For each response variable, a linear mixed-effects model was fit using the PROC MIXED procedure in SAS. The fixed effects included treatment (Trt) and replicate (Rep), while a random intercept for slice nested within treatment accounted for potential correlation due to hierarchical structure.

The model for each response variable Y_{ijk} can be expressed in general form as:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + u_{k(ij)} + \varepsilon_{ijk}$$

where:

- μ is the overall mean,
- α_i is the fixed effect of the i th treatment (Trt),
- β_j is the fixed effect of the j th replicate (Rep),
- $u_{k(ij)}$ is the random effect of the k th slice nested within treatment and rep, assumed to follow a normal distribution with mean 0 and variance σ_u^2 ,
- ε_{ijk} is the residual error, assumed to follow a normal distribution with mean 0 and variance σ^2 .

Least-squares means (LS-means) were estimated for both treatment and replicate effects. Pairwise comparisons were conducted using Tukey's adjustment to control the familywise error rate. Confidence intervals for LS-mean differences were also reported.

The same statistical analysis was conducted for the following variables: Specific Gravity, Batter Temperature, Bake Loss, Volume, Surface Area, Middle Slice Height, External Color, Internal Color, Hardness, Adhesiveness, Springiness, Cohesiveness, And Chewiness.

Results and Discussion

Batter Characteristics

The specific gravity for batter varied significantly between all formulations (Table 5-2). Sorghum formulations had significantly lower specific gravity than their corresponding wheat formulations (SN<WN, SR<WR). For both flours, adding rum significantly decreased specific gravity. A decreased specific gravity indicates more air entrapment. Higher air entrapment can lead to increased volume.

The batter temperature was significantly decreased by the addition of rum. Sorghum formulations had significantly higher batter temperatures than their corresponding wheat formulations (SN>WN, SR>WR). This could indicate that rum has a higher friction factor than water and/or that sorghum flour has a higher friction factor than wheat flour. Lower specific gravity can also be associated with higher batter temperature. Rum decreased SG and increased batter temperature. Sorghum also decreased SG and increased batter temperature.

Table 5-2. Batter characteristics

Treatment	Specific Gravity		Batter Temperature (°C)	
	Least Squares Means	Standard Error	Least Squares Means	Standard Error
Sorghum Without Rum	0.902 ^b	±0.0068	21.24 ^a	±0.06
Sorghum With Rum	0.831 ^d	±0.0068	20.57 ^b	±0.06
Wheat Without Rum	0.950 ^a	±0.0068	20.44 ^b	±0.06
Wheat With Rum	0.869 ^c	±0.0068	19.37 ^c	±0.06

^{abcd}Superscripts with different letters in a column are different ($p < 0.05$).

Cake Dimensions

Volume and surface area of the cakes both varied significantly in the same way between all formulations (WN>WR>SN>SR) (Table 5-3). Both sorghum formulations had significantly lower final volumes and surface areas than both wheat formulations despite the use of xanthan gum and potato starch to assist with structure formation. This indicates wheat-based cakes have better air retention, despite sorghum batters having higher specific gravities. This is likely due to sorghum products having decreased starch gelatinization which leads to the system not being able to support its own weight and collapsing (Curti et al., 2022; Derby et al., 1975; Glover et al., 1986). Pound cakes were traditionally made without chemical leaveners and instead relied on the separation and beating of egg whites to create a structure (Patent, 2009). Adding egg whites that have been separately beaten has been shown to improve the volume of sorghum baked goods by creating structure (Cairns et al., 2023). It is possible that using chemical leaveners and unbeaten egg whites did not provide sufficient structure to the sorghum cakes.

Adding rum significantly decreased ($p < 0.05$) the volume and surface area for both flour types. This is also in contrast to rum lowering the SG of batter. Protein stability and solubility are

decreased when in an ethanol solution (Nick Pace et al., 2004). Decreased stability might contribute to collapse. Collapse can also originate from delayed gelatinization (Curti et al., 2022). Sugar has been shown to increase the gelatinization temperature (delay gelatinization) in batter by “limiting the water availability to starch molecules and lowering water activity (Wilderjans et al., 2013). The sugar content in rum can vary, but Bacardi spiced rum has only 1 gram of sugar per 1.5 oz serving (Bacardi Limited, n.d.). Any sugar present in the finished product was added post fermentation for flavor. The conversion factor for pure alcohol is 0.6 fl. oz/14 g (NIH/NIAAA, 2024). A formulation containing 61.79 g of rum would be around 2.65 oz of liquid, which would mean only 1.77 g of added sugar from rum. This would be unlikely to affect a formulation that also contains 200 g of pure sugar.

The laser topography results for the middle slice height were inconclusive. The data showed no significant differences between the formulations, despite the volumes and surface areas varying significantly for all formulations. The same pan size and type was used for all formulations. Height differences between formulations can be visibly observed in cakes (Figure 5-1). The middle slice heights ranged from 64-76mm and the standard error was ± 4.69 mm. The cakes had a crack in the middle (Figure 5-2). Because of this high degree of error, the demonstrated significant difference in volume and surface area, and the visibly observable height difference, it is likely that in some cases the machine recorded the height at the point of the crack instead of at the highest part of the middle slice. This would explain the variability.

Table 5-3. Volume and surface area of cakes

Treatment	Volume (mL)		Surface Area (mm ²)	
	Least Squares Means	Standard Error	Least Squares Means	Standard Error
Sorghum Without Rum	396.33 ^c	±2.81	37,947 ^c	±306.57
Sorghum With Rum	368.50 ^d	±2.81	36,326 ^d	±306.57
Wheat Without Rum	437.00 ^a	±2.81	43,208 ^a	±306.57
Wheat With Rum	416.67 ^b	±2.81	40,626 ^b	±306.57

^{abcd}Superscripts with different letters in a column are different ($p < 0.05$).

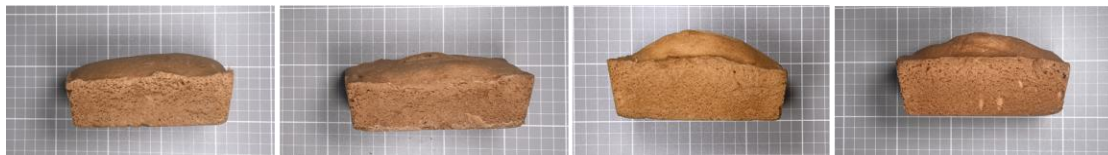


Figure 5-1. Sideview of cakes, from left to right: Sorghum without rum, sorghum with rum, wheat without rum, wheat with rum



Figure 5-2. Top view of cakes, from left to right: Sorghum without rum, sorghum with rum, wheat without rum, wheat with rum

Bake Loss

Average bake loss ranged from 5.92-6.55% with a standard error of ± 0.26 . There were no significant differences in bake loss between formulations, suggesting that the inclusion of a liquid with a lower evaporation point than water did not significantly increase bake loss.

Color

Externally, wheat with no rum was the only treatment that varied significantly from the other treatments in terms of lightness. This can be explained by sorghum products being generally darker than wheat products (Badi & Hosene, 1976; Gigliotti et al., 2025). Adding spiced rum to a wheat cake will make it darker. For both grains, adding rum significantly increased the redness of the outside of the cake. The outside of the sorghum cakes (SN and SR) was less red than the corresponding wheat cakes (WN and WR). Both sorghum cakes had a less yellow exterior than both wheat cakes. Adding rum to the sorghum cakes had no impact on the b^* value. Adding rum to the wheat cakes resulted in a less yellow exterior. Because there was no significant difference in moisture loss between formulations, external color differences cannot be attributed to evaporative cooling and dehydration.

Table 5-4. External (crust) color of cake

Treatment	External L*		External a*		External b*	
	Least Squares Means	Standard Error	Least Squares Means	Standard Error	Least Squares Means	Standard Error
Sorghum Without Rum	55.85 ^b	±0.69	12.85 ^c	±0.47	32.80 ^c	±0.33
Sorghum With Rum	53.78 ^b	±0.69	15.02 ^b	±0.47	32.93 ^c	±0.33
Wheat Without Rum	61.02 ^a	±0.69	15.43 ^b	±0.47	40.43 ^a	±0.33
Wheat With Rum	53.56 ^b	±0.69	18.30 ^a	±0.47	36.38 ^b	±0.33

^{abcd}Superscripts with different letters in a column are different ($p < 0.05$).

Internally, both sorghum treatments were darker (had lower L^* values) than the wheat treatments. The addition of rum to wheat created a darker product. This is likely because the rum used was spiced rum (which has a dark caramel color). Alternatively, rum significantly increased

the lightness in sorghum cakes. This might be due to the significantly increased number of cells (Table 5-6) observed in SR. There was no significant difference in internal a* values between SN and SR. Both wheat treatments had lower a* values than the sorghum treatments. This suggests that sorghum creates a redder product internally. The addition of rum to the wheat cake resulted in a redder cake as well. This could also be explained by the original color of the rum used. Both sorghum cakes were less yellow than the wheat cakes. Adding rum to the wheat cake made the cake more yellow. This could have been due to the color of the rum used.

Table 5-5. Internal (crumb) color of cake

Treatment	Internal L*		Internal a*		Internal b*	
	Least Squares Means	Standard Error	Least Squares Means	Standard Error	Least Squares Means	Standard Error
Sorghum Without Rum	61.61 ^d	±0.27	5.29 ^a	±0.09	29.08 ^c	±0.11
Sorghum With Rum	62.87 ^c	±0.27	5.53 ^a	±0.09	29.32 ^c	±0.11
Wheat Without Rum	77.06 ^a	±0.27	1.98 ^c	±0.09	34.44 ^b	±0.11
Wheat With Rum	75.16 ^b	±0.27	3.25 ^b	±0.09	35.22 ^a	±0.11

^{abcd}Superscripts with different letters in a column are different (p<0.05).

Internal Structure

Adding rum significantly decreased the slice area for both flour types. Both sorghum formulations had lower surface areas than both wheat formulations. These results are consistent with the volume data collected. Adding rum significantly increased the top concavity for both flours. This suggests that rum causes increased collapse (possibly due to delayed or inadequate structure setting). Changing the flour type did not significantly impact top concavity. Bottom concavity did not significantly vary for any of the treatments and ranged from 0.59-0.98%. This low value indicates that there was no lift from the bottom of the pan. Both sorghum treatments

had lower numbers of cells than both wheat treatments. This indicates that wheat cakes have a finer cell structure. Adding rum significantly decreased the number of cells in wheat cake but significantly increased the number of cells in sorghum cake. Sorghum with rum was the only treatment that had a significantly different (lower) area of cells. Sorghum with no rum had thicker cell walls than wheat with no rum, but adding rum significantly decreased the wall thickness for both flour types.

Table 5-6. Internal structure of cakes

Treatment	Slice Area mm ²		Top Concavity %		Number of Cells		Area of Cells %		Wall Thickness (mm)	
	LSM ¹	SE ²	LSM ¹	SE ²	LSM ¹	SE ²	LSM ¹	SE ²	LSM ¹	SE ²
Sorghum Without Rum	3165.33 ^c	±31.68	0.38 ^b	±0.13	2774.67 ^d	±39.25	49.83 ^a	±0.26	0.402 ^a	±0.002
Sorghum With Rum	2903.00 ^d	±31.68	1.30 ^a	±0.13	2990.50 ^c	±39.25	48.55 ^b	±0.26	0.372 ^c	±0.002
Wheat Without Rum	3863.67 ^a	±31.68	0.52 ^b	±0.13	3555.17 ^a	±39.25	50.65 ^a	±0.26	0.385 ^b	±0.002
Wheat With Rum	3363.50 ^b	±31.68	1.13 ^a	±0.13	3243.33 ^b	±39.25	50.63 ^a	±0.26	0.375 ^c	±0.002

^{a,b,c,d}Superscripts with different letters in a column are different (p<0.05).

¹Least square means

²Standard error

Texture Analysis

Sorghum and wheat cakes without rum had statistically similar hardness values (Table 5-7). The addition of rum significantly increased cake hardness for both flour types but significantly increased it more in wheat cakes. Rum may have significantly increased hardness because it significantly decreased volume, which would lead to a more compact and dense cake. Despite not being significantly different, there was a trend of rum increasing adhesiveness for both flours. Depending on the surface effects the rum had on the starch, it could have impacted the starch's swelling abilities (Zhang et al., 2012). If the starch's swelling abilities were decreased or if shrinkage occurred, this would have left more water unbound. This could be the cause of the increased adhesiveness. Sorghum with rum was the only treatment that had a significantly different result for springiness, and it had a lower springiness. Adding rum did not significantly impact the cohesiveness of either flour. Both sorghum treatments were less cohesive than both wheat treatments. Decreased cohesiveness may indicate a more fragile

product. This is likely related to sorghum not forming an adequate starch structure (Glover et al., 1986). This is consistent with previous research that found sorghum crumb to be fragile, inflexible, and less cohesive (Chiremba et al., 2009; Gigliotti et al., 2025; Glover et al., 1986). Both sorghum treatments were less chewy than both wheat treatments. This is likely also related to sorghum's lack of structure in baked goods. Adding rum to the sorghum cake did not impact chewiness ($p>0.05$). Adding rum to the wheat cake significantly increased chewiness. Rum might have not had an effect on the sorghum cake because the sorghum cake already did not have enough structure to be chewy.

Table 5-7. Texture analysis of cakes

Treatment	Hardness (g)		Adhesiveness (g/sec)		Springiness		Cohesiveness		Chewiness (g)	
	LSM ¹	SE ²	LSM ¹	SE ²	LSM ¹	SE ²	LSM ¹	SE ²	LSM ¹	SE ²
Sorghum Without Rum	734.28 ^c	±25.07	-16.023 ^{ab}	±1.70	0.896 ^a	±0.006	0.338 ^b	±0.005	222.74 ^c	±10.20
Sorghum With Rum	892.61 ^b	±25.07	-19.944 ^b	±1.70	0.870 ^b	±0.006	0.322 ^b	±0.005	250.58 ^c	±10.20
Wheat Without Rum	781.56 ^c	±25.07	-11.744 ^a	±1.70	0.916 ^a	±0.006	0.451 ^a	±0.005	321.59 ^b	±10.20
Wheat With Rum	990.31 ^a	±25.07	-17.32 ^{ab}	±1.70	0.914 ^a	±0.006	0.447 ^a	±0.005	405.32 ^a	±10.20

^{abcd}Superscripts with different letters in a column are different ($p<0.05$).

¹Least square means

²Standard error

Alcohol Testing

Analysis showed that sorghum rum cakes had 0.1588% g/g ethanol remaining after baking, and wheat rum cakes had 0.214% g/g ethanol remaining after baking. Sorghum's protein kafirin is a prolamin but is more hydrophobic than wheat prolamins (Belton et al., 2006). This higher hydrophobicity increases the difficulty of extracting kafirins with ethanol (Belton et al.,

2006). This could explain why the wheat rum cakes retained more ethanol than the sorghum rum cakes.

A previous study found that 0.12% g/g ethanol remained in pancakes which had been formulated with 7.04% pilsner (4.6% v/v alcohol) (Ryapushkina et al., 2016). The spiced rum used in our study was 35% v/v alcohol and was included at a rate of 7.6% of the batter. This was a higher inclusion rate of a stronger alcohol than was used in the pancakes. However, the rum cakes were baked for longer than the pancakes. This could explain why the rum cakes had a higher percentage of alcohol remaining than the pancakes.

Conclusion

Aeration, collapse, and gluten structures play important roles in cake quality. Sorghum and rum contributed to increased batter aeration, however cakes containing sorghum and/or rum had lower volumes. The increased top concavity in formulations containing rum suggests collapse caused by delayed or inadequate structure setting. Rum increased the hardness of cakes, which could have been related to the decreased volume and therefore increased density of the cakes. Sorghum cakes were less cohesive and less chewy than wheat cakes, which may have been caused by inadequate structure formation. With the current trend for alcohol-flavored baked goods, understanding the ingredient functionality of alcohol in baked goods can improve future products. This work indicates product structure is of primary concern in both wheat and gluten-free flours.

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Appendix A - Interdisciplinary Framework Supplemental Material

A1 -IRB Exempt: 12516



Office of Research Integrity,
Compliance and Security

TO: Kelly Getty
Food Science Institute
Manhattan, KS 66506

Proposal Number: IRB-12516

FROM: Lisa Rubin, Chair
Committee on Research Involving Human Subjects

DATE: 12/10/2024

RE: Proposal Entitled, "Framework for Interdisciplinary Food Science Capstone Class and Undergraduate Research Experience."

The Committee on Research Involving Human Subjects / Institutional Review Board (IRB) for Kansas State University has reviewed the proposal identified above and has determined that it is EXEMPT from further IRB review. This exemption applies only to the proposal - as written - and currently on file with the IRB. Any change potentially affecting human subjects must be approved by the IRB prior to implementation and may disqualify the proposal from exemption.

Based upon information provided to the IRB, this activity is exempt under the criteria set forth in the Federal Policy for the Protection of Human Subjects, **45 CFR §104(d), category:Exempt Category 2 Subsection ii.**

Certain research is exempt from the requirements of HHS/OHRP regulations. A determination that research is exempt does not imply that investigators have no ethical responsibilities to subjects in such research; it means only that the regulatory requirements related to IRB review, informed consent, and assurance of compliance do not apply to the research.

Any unanticipated problems involving risk to subjects or to others must be reported immediately to the Chair of the Committee on Research Involving Human Subjects, the University Research Compliance Office, and if the subjects are KSU students, to the Director of the Student Health Center.

Electronically signed by Lisa Rubin on 12/10/2024 3:20 PM ET

A2 -Past Years Survey Informed Consent Form

3/27/25, 1:02 PM

Qualtrics Survey Software



Introduction

As a student in FDSCI 740 you were part of a group of students that were encouraged to develop food products for the K-State Dining Center. During this time, your group developed a product and presented your prototypes to dining center staff, grain science faculty, and an advisory board. They provided feedback on your products. As a student involved in this project, we are asking for you to reflect on how the skills and knowledge you learned have impacted your career in Food Science or other areas. This survey should take around 10-15 minutes to complete. The next page includes the informed consent information.

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1/27

3/27/25, 1:02 PM

Qualtrics Survey Software

IRB

Informed Consent:

Project Title: Framework for Interdisciplinary Food Science
Capstone Class and Undergraduate Research Experience

Project Approval Date: September 1, 2024
Project Expiration Date: December 31, 2025
Length of Study: 16 Months

Principal Investigator: Kelly J.K Getty, Department of Animal
Sciences & Industry, Food Science Institute
Co-investigator: Kelly Whitehair Department of Food, Nutrition,
Dietetics and Health

Contact details for problems/questions: Kelly J.K Getty, (785)
532-2203, email address: kgetty@ksu.edu.
IRB Chair Contact Information: Lisa Rubin, Chair, Committee on
Research Involving Human Subjects, 203 Fairchild Hall, Kansas

https://ksstate.yu1.qualtrics.com/Q/EditSection/Blocks/Jsx/GetSurveyPrintPreview?ContextSurveyID=SV_0cyN4vdOerSW1g&ContextLibraryID=UR_1QZcFZ1D4aN665T

2/27

State University, Manhattan, KS 66506, (785) 532-3224; Brad Woods, Associate Vice President for Research Compliance, 203 Fairchild Hall, Kansas State University, Manhattan, KS 66506, (785) 532-3224.

Project Sponsor: United States Department of Agriculture's Agricultural Marketing Service, Federal State Marketing Improvement Program

Purpose of the research: The purpose of this research is to evaluate the effectiveness of a course framework for teaching product development of food products to food science students. We hope this framework provides valuable experience (in product development, interdisciplinary work, teamwork, writing, presenting, and research) for students as well as providing new formulations for university dining centers.

Procedures to be used: If you choose to participate in this research, you will be asked to complete an online survey about your experience taking the Kansas State University Course "FDSCI

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3/27

740 – Research and Development of Food Products".

Risks or discomforts anticipated: There are no known risks associated with participation in this study.

Benefits anticipated: By participating in this research, you will contribute to the development of a better course framework for food science undergraduate students.

Extent of Confidentiality: All data collected will be kept confidential. Your responses to the survey will be aggregated and anonymized. Only aggregated and anonymized information from this research could be used for future research studies without additional informed consent. If your comments or direct quotes are included in the final research findings, this will only happen if you provide explicit written consent.

Terms of participation: I understand this project is research, and that my participation is voluntary. I also understand that if I decide to participate in this study, I may withdraw my consent at

https://ksstate.yul1.qualtrics.com/Q/EditSection/Blocks/Ajax/GetSurveyPrintPreview?ContextSurveyID=SV_0cyN4vdOerSW1g&ContextLibraryID=UR_1QZcFZ1D4aN665T

4/27

any time, and stop participating at any time without explanation, penalty, or loss of benefits, or academic standing to which I may otherwise be entitled. I verify that my signature below indicates that I have read and understand this consent form, and willingly agree to participate in this study under the terms described, and that my signature acknowledges that I have received a signed and dated copy of this consent form.

Informed Consent Survey Participation

- ☐ I have read and understand the information that is outlined to me above and I consent to participating in the study.
- ☐ I do not consent to participating in the study.

I consent to allowing direct quotes of my responses to be used in this research. These quotes will be anonymous.

- ☐ Yes
- ☐ No

A3 -2024 Survey Informed Consent Form

7/21/25, 12:48 AM

Qualtrics Survey Software



Introduction

As a student in FDSCI 740 you were part of a group of students that were encouraged to develop food products for the K-State Dining Center. During this time, your group developed a product and presented your prototypes to dining center staff, grain science faculty, and an advisory board. They provided feedback on your products. As a student involved in this project, we are asking for you to reflect on how the skills and knowledge you learned have impacted your career in Food Science or other areas. This survey should take around 10-15 minutes to complete. The next page includes the informed consent information.

https://kstate.yul1.qualtrics.com/Q/EditSection/Blocks/Ajax/GetSurveyPrintPreview?ContextSurveyID=SV_0cyNj4vdOerSW1g&ContextLibraryID=UR_1QZcFZ1D4aN665T

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7/21/25, 12:48 AM

Qualtrics Survey Software

IRB

Informed Consent:

Project Title: Framework for Interdisciplinary Food Science Capstone Class and Undergraduate Research Experience

Project Approval Date: September 1, 2024

Project Expiration Date: December 31, 2025

Length of Study: 16 Months

Principal Investigator: Kelly J.K Getty, Department of Animal Sciences & Industry, Food Science Institute

Co-investigator: Kelly Whitehair Department of Food, Nutrition, Dietetics and Health

Contact details for problems/questions: Kelly J.K Getty, (785) 532-2203, email address: kgetty@ksu.edu.

IRB Chair Contact Information: Lisa Rubin, Chair, Committee on Research Involving Human Subjects, 203 Fairchild Hall, Kansas

https://kstate.yul1.qualtrics.com/Q/EditSection/Blocks/Ajax/GetSurveyPrintPreview?ContextSurveyID=SV_0cyNj4vdOerSW1g&ContextLibraryID=UR_1QZcFZ1D4aN665T

2/27

740 – Research and Development of Food Products”.

Risks or discomforts anticipated: There are no known risks associated with participation in this study.

Benefits anticipated: By participating in this research, you will contribute to the development of a better course framework for food science undergraduate students.

Extent of Confidentiality: All data collected will be kept confidential. Your responses to the survey will be aggregated and anonymized. Only aggregated and anonymized information from this research could be used for future research studies without additional informed consent. If your comments or direct quotes are included in the final research findings, this will only happen if you provide explicit written consent.

Terms of participation: I understand this project is research, and that my participation is voluntary. I also understand that if I decide to participate in this study, I may withdraw my consent at

https://kstate.yul1.qualtrics.com/Q/EditSection/Blocks/Ajax/GetSurveyPrintPreview?ContextSurveyID=SV_0cyNj4vdOerSW1g&ContextLibraryID=UR_1QZcFZ1D4aN665T

4/27

State University, Manhattan, KS 66506, (785) 532-3224; Brad Woods, Associate Vice President for Research Compliance, 203 Fairchild Hall, Kansas State University, Manhattan, KS 66506, (785) 532-3224.

Project Sponsor: United States Department of Agriculture's Agricultural Marketing Service, Federal State Marketing Improvement Program

Purpose of the research: The purpose of this research is to evaluate the effectiveness of a course framework for teaching product development of food products to food science students. We hope this framework provides valuable experience (in product development, interdisciplinary work, teamwork, writing, presenting, and research) for students as well as providing new formulations for university dining centers.

Procedures to be used: If you choose to participate in this research, you will be asked to complete an online survey about your experience taking the Kansas State University Course “FDSCI

https://kstate.yul1.qualtrics.com/Q/EditSection/Blocks/Ajax/GetSurveyPrintPreview?ContextSurveyID=SV_0cyNj4vdOerSW1g&ContextLibraryID=UR_1QZcFZ1D4aN665T

3/27

any time, and stop participating at any time without explanation, penalty, or loss of benefits, or academic standing to which I may otherwise be entitled. I verify that my signature below indicates that I have read and understand this consent form, and willingly agree to participate in this study under the terms described, and that my signature acknowledges that I have received a signed and dated copy of this consent form.

Informed Consent Survey Participation

- ☐ I have read and understand the information that is outlined to me above and I consent to participating in the study.
- ☐ I do not consent to participating in the study.

I consent to allowing direct quotes of my responses to be used in this research. These quotes will be anonymous.

- ☐ Yes
- ☐ No

A4 -Interview Informed Consent



Institutional Review Board (IRB) Informed Consent Template Form

comply@k-state.edu | 785-532-3224

PROJECT TITLE:

Framework for Interdisciplinary Food Science Capstone Class and Undergraduate Research Experience

**PROJECT APPROVAL
DATE:**

September
1, 2024

**PROJECT EXPIRATION
DATE:**

December
31, 2025

**LENGTH OF
STUDY:**

16
months

PRINCIPAL INVESTIGATOR:

Kelly J.K Getty, Department of Animal Sciences & Industry,
Food Science Institute

CO-INVESTIGATOR(S):

Kelly Whitehair
Department of Food, Nutrition, Dietetics and Health

CONTACT DETAILS FOR PROBLEMS/QUESTIONS:

Kelly J.K Getty, (785) 532-2203, email address:
kgetty@ksu.edu.

IRB CHAIR CONTACT INFORMATION:

Lisa Rubin, Chair, Committee on Research Involving Human
Subjects, 203 Fairchild Hall, Kansas State University,
Manhattan, KS 66506, (785) 532-3224; Brad Woods,
Associate Vice President for Research Compliance, 203
Fairchild Hall, Kansas State University, Manhattan, KS
66506, (785) 532-3224.

PROJECT SPONSOR:

United States Department of Agriculture's Agricultural Marketing Service,
Federal State Marketing Improvement Program

PURPOSE OF THE RESEARCH:

The purpose of this research is to evaluate the effectiveness of a course framework for teaching product development and scale-up of food products to food science students. We hope this framework will provide valuable experience (in product development, interdisciplinary work, teamwork, writing, presenting, and research) for students as well as providing new formulations for university dining centers.

PROCEDURES OR METHODS TO BE USED:

If you choose to participate in this research, you will be asked to complete an online survey about your experience taking the Kansas State University Course "FDSCI 740 - Research and Development of Food Products".

RISKS OR DISCOMFORTS ANTICIPATED:

There are no known risks associated with participation in this study.

BENEFITS ANTICIPATED:

By participating in this research, you will contribute to the development of a better course framework for food science undergraduate students.

EXTENT OF CONFIDENTIALITY:

All data collected will be kept confidential. Your responses to the survey will be aggregated and anonymized. Only aggregated and anonymized information from this research could be used for future research studies without additional informed consent. If your comments or direct quotes are included in the final research findings, this will only happen if you provide explicit written consent.

Terms of participation: I understand this project is research, and that my participation is voluntary. I also understand that if I decide to participate in this study, I may withdraw my consent at any time, and stop participating at any time without explanation, penalty, or loss of benefits, or academic standing to which I may otherwise be entitled.

I verify that my signature below indicates that I have read and understand this consent form, and willingly agree to participate in this study under the terms described, and that my signature acknowledges that I have received a signed and dated copy of this consent form.

PARTICIPANT NAME:

PARTICIPANT SIGNATURE:

DATE:

WITNESS TO SIGNATURE:
(PROJECT STAFF)

DATE:

I consent to allowing direct quotes of my responses to be used in this research. These quotes will be anonymous.

PARTICIPANT NAME:

PARTICIPANT SIGNATURE:

DATE:

WITNESS TO SIGNATURE:
(PROJECT STAFF)

DATE:

A5 -Survey Debriefing Statement

12/18/24, 4:32 PM

Qualtrics Survey Software

Survey Debriefing Statement

Survey Debriefing Statement

We would like to thank you for participating in the course framework survey. We appreciate your completion of the survey as it will help us to develop and deliver more effective course work for food science students. If you have any questions or concerns regarding this research, please feel free to contact:

Kelly J.K. Getty, Principal Investigator Phone: 785-532-2203

Email: kgetty@ksu.edu OR

Lisa Rubin, Chair, Committee on Research Involving Human Subjects, 203 Fairchild Hall, Kansas State University, Manhattan, KS 66506, (785) 532-3224

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https://kstate.yul1.qualtrics.com/Q/EditSection/Blocks/Ajax/GetSurveyPrintPreview?ContextSurveyID=SV_6rmngvQOmaAGMiG&ContextLibraryID=... 24/24

A6 -Interview Debriefing Statement

We would like to thank you for participating in this course framework interview. We appreciate your completion of the interview as it will help us to develop and distribute more effective course work for food science students.

If you have any questions or concerns regarding this research, please feel free to contact:

Kelly J.K. Getty, Principal Investigator

Phone: 785-532-2203 Email: kgetty@ksu.edu

OR

Lisa Rubin, Chair, Committee on Research Involving Human Subjects, 203 Fairchild Hall,
Kansas State University, Manhattan, KS 66506, (785) 532-3224

-sent to participants by email immediately following the interview

A7 -Past Years Survey Statements and Abbreviations

Previous Years (PY) Survey Statements and Abbreviations		
Label	Abbreviation	Full Question
<i>Research and Laboratory Skills (RL)</i>		
PY RL Q1	Scientific Method	This product development course/project improved my understanding of the scientific method.
PY RL Q2	Scientific/Technical Writing	This product development course/project improved my scientific/technical writing skills.
PY RL Q3	Collecting Data	Collecting data helped me to better understand product development research.
PY RL Q4	Data Interpretation	This product development course/project improved my data interpretation skills.
PY RL Q5	Analytical Equipment	This product development project gave me experience using analytical equipment.
PY RL Q6	Focus Group	This product development course/project taught me how to organize and run a focus group.
PY RL Q7	Evaluate Consumer Needs/Wants	Organizing and running a focus group helped me to understand how to evaluate consumer needs and wants.
PY RL Q8	Improve Product's Sensory Attributes	Organizing and running a focus group helped me to improve my product's sensory attributes (flavor, texture, color, etc.).
PY RL Q9	Informed Consent Practices	This product development course/project taught me about common informed consent practices.

PY RL Q10	Allergy Statements	This product development course/project taught me about the importance of including allergy statements when conducting consumer testing.
<i>Food Production Knowledge (FP)</i>		
PY FP Q1	Dining Center Categories/Guidelines	The categories/guidelines provided by the dining center helped me to develop an initial product concept.
PY FP Q2	Concept Pitch	Putting together a food product concept pitch after doing market screening developed my understanding of market desires and trends.
PY FP Q3	Novel Ingredients	This product development project gave me the opportunity to work with ingredients I had not previously used.
PY FP Q4	Ingredient Functionality	Developing a product increased my understanding of ingredient functionality.
PY FP Q5	Food Safety and Regulatory Controls	This course/project put my knowledge of food safety and regulatory controls into practice.
PY FP Q6	Quality Control Parameters	This course/project taught me about quality control parameters (such as color and size of product, specifications, grade standards, etc.) for food products.
PY FP Q7	Labeling Requirements	This course/project increased my understanding of nutritional and ingredient labeling requirements.
PY FP Q8	Economic Feasibility	This course/project helped me to understand economic feasibility and cost analysis when developing products.
<i>Interdisciplinary Aspects (IA)</i>		

PY IA Q1	Packaging Design Perspectives	Collaborating with the packaging design class gave me different perspectives on packaging design and layout.
PY IA Q2	Different Major's Skill Set	Collaborating with the packaging design class taught me about the skill set of a different major.
PY IA Q3	Collaboration Elevated Experience	Collaborating with the packaging design class elevated my experience in this class.
PY IA Q4	Dining Center Perspectives	Interacting with the dining center staff and advisory board gave me a different perspective on how to improve my product.
<i>Soft Skills (S)</i>		
PY S Q1	Communication	Presenting to and interacting with the dining center staff/advisory board provided experience that enhanced my communication skills.
PY S Q2	Teamwork	Working in a group enhanced my teamwork skills.
PY S Q3	Public Speaking	Giving a presentation enhanced my public speaking skills.
PY S Q4	Problem Solving	Facing difficulties while developing my product enhanced my problem-solving skills.
PY S Q5	Adaptability	Facing difficulties while developing my product enhanced my adaptability skills.
PY S Q6	Organization	Being responsible for managing, labeling, storing, and requesting more ingredients enhanced my organizational skills.
<i>Career Preparedness and Course Experience (CP)</i>		

PY CP Q1	Capstone Course	FDSCI 740 connected material I learned throughout my degree program.
PY CP Q2	Enjoyed Course	I enjoyed this product development course/project.
PY CP Q3	Influenced Career Path/Goals	My experiences with this course/project influenced my career goals/path.
PY CP Q4	Relevant Skills and Knowledge	I use/will use the skills and knowledge I learned in this product development course/project in my career.
PY CP Q5	Insight into Industrial Product Development	This course/project provided me with insight into industrial food product development practices.
PY CP Q6	Professional Presentation	Preparing and giving a presentation in this product development project was a similar experience to presentations I have given/would give in a professional setting.
PY CP Q7	Prepared for Career/Grad School	My experiences with this product development project prepared me for a career in food science and/or graduate school.
PY CP Q8	Similar Experience to Industry	The benchtop food product development project in FDSCI 740 is similar to product development in industry.

A8 -Undergraduate Research Interview Statements and Abbreviations

Undergraduate Research (UR) Interview Statements and Abbreviations		
Label	Abbreviation	Full Question
<i>Research and Laboratory Skills (RL)</i>		
UR RL Q1	Collecting Data	Collecting data helped me to better understand product development research.
UR RL Q2	Scientific Method	This product development project improved my understanding of the scientific method.
UR RL Q3	Scientific/Technical Writing	This product development project improved my scientific/technical writing skills.
UR RL Q4	Analytical Equipment	This product development project gave me experience using analytical equipment.
UR RL Q5	Consumer Acceptability Test	This product development project taught me how to organize and run a consumer acceptability test.
UR RL Q6	Evaluate Consumer Needs/Wants	Organizing and running consumer acceptability test(s) helped me to understand how to evaluate consumer needs and wants.
UR RL Q7	Improve Product's Sensory Attributes	Organizing and running consumer acceptability test(s) helped me to improve my product's sensory attributes.
UR RL Q8	Data Interpretation	This product development project improved my data interpretation skills.
UR RL Q9	Scientific Abstract	This product development project enhanced my ability to write a scientific abstract.
UR RL Q10	Research Poster	This product development project enhanced my ability to put together and present a research poster.
<i>Food Production Knowledge (FP)</i>		
UR FP Q1	Larger Scale Food Production	Scaling up a product in the dining center increased my understanding of larger scale food production.
UR FP Q2	Dining Center Operations	This product development project increased my understanding of how dining centers operate.
UR FP Q3	Larger Food Production Equipment	This product development project gave me the opportunity to experiment with larger food production equipment I had not previously used.
UR FP Q4	Writing Processing Methods	Using Computrition, gave me experience with writing detailed methods that can be understood by dining center staff.
UR FP Q5	Dining Center Goals	This product development project increased my understanding of dining center menu

		goals related to wheat, sorghum, and/or soy products.
UR FP Q6	Technical Feasibility	This product development project increased my understanding of technical feasibility requirements in food service
UR FP Q7	Dining Center Perspectives	Working with the dining center staff gave me different perspectives on product development and scale up.
UR FP Q8	Impact of Scale on Formulation	Scaling up a product gave me insight into how scale-up can affect formulations/recipes.
UR FP Q9	Novel Ingredients	This product development project gave me the opportunity to work with ingredients I had not previously used.
UR FP Q10	Ingredient Functionality	Developing a product increased my understanding of ingredient functionality.
<i>Soft Skills (S)</i>		
UR S Q1	Public Speaking	Giving a presentation improved my public speaking skills.
UR S Q2	Communication	Working with the dining center staff improved my communication skills.
UR S Q3	Problem Solving	Facing difficulties, such as unacceptable flavor profile or texture, while developing my product(s) improved my problem-solving skills.
UR S Q4	Adaptability	Facing difficulties, such as unacceptable flavor profile or texture, while developing my product(s) improved my adaptability skills.
UR S Q5	Time management	Borrowing kitchen space and equipment from the dining center improved my time management and coordination skills.
UR S Q6	Organization	Being responsible for managing, labeling, storing, and requesting more ingredients improved my organizational skills.
<i>Personal Impact (CP)</i>		
UR CP Q1	Enjoyed Course	I enjoyed this product development project.
UR CP Q2	Influenced Career Path/Goals	My experiences with this product development project influenced my career goals/path.
UR CP Q3	Prepared for Career/Grad School	My experiences with this product development project better prepared me for a career in food science and/or graduate school.

UR CP Q4	Relevant Skills and Knowledge	I use/will use the skills and knowledge I learned in this product development project in my career.
UR CP Q5	Networking Connections	This product development project gave me networking connections
UR CP Q6	Work was Published	Participating in this product development project led to my work being published.
UR CP Q7	Presented Work at Conference	Participating in this product development project led to me presenting my work at a conference.

A9 -2024 Survey Statements and Abbreviations

2024 (TF) Survey Statements and Abbreviations		
Label	Abbreviation	Full Question
<i>Research and Laboratory Skills (RL)</i>		
TF RL Q1	Scientific Method	This product development project improved my understanding of the scientific method.
TF RL Q2	Scientific/Technical Writing	This product development project improved my scientific/technical writing skills.
TF RL Q3	Collecting Data	Collecting data helped me to better understand product development research.
TF RL Q4	Data Interpretation	This product development project improved my data interpretation skills.
TF RL Q5	Analytical Equipment	This product development project gave me experience using analytical equipment.
TF RL Q6	Consumer Acceptability Test	This product development project taught me how to organize and run a consumer acceptability test. (This is referencing the consumer acceptability test you conducted in the dining center.)
TF RL Q7	Evaluate Consumer Needs/Wants	Organizing and running a consumer acceptability test helped me to understand how to evaluate consumer needs and wants.
TF RL Q8	Improve Product's Sensory Attributes	Organizing and running consumer acceptability test(s) helped me to improve my product's sensory attributes (flavor, texture, color, etc.).
TF RL Q9	Informed Consent Practices	This product development project taught me about common informed consent practices.
TF RL Q10	Allergy Statements	This product development project taught me about the importance of including allergy statements when conducting consumer testing.
<i>Food Production Knowledge (FP)</i>		

TF FP Q1	Dining Center Categories/Guidelines	The categories/guidelines provided by the dining center helped me to develop an initial product concept.
TF FP Q2	Concept Pitch	Putting together a food product concept pitch after doing market research developed my understanding of market desires and trends.
TF FP Q3	Novel Ingredients	This product development project gave me the opportunity to work with ingredients I had not previously used.
TF FP Q4	Ingredient Functionality	Developing a product increased my understanding of ingredient functionality.
TF FP Q5	Technical Feasibility	This course increased my understanding of technical feasibility requirements in food service.
TF FP Q6	Food Safety and Regulatory Controls	This course put my knowledge of food safety and regulatory controls into practice.
TF FP Q7	Quality Control Parameters	This course taught me about quality control parameters (such as color and size of product, specifications, grade standards, etc.) for food products.
TF FP Q8	Labeling Requirements	This course increased my understanding of nutritional and ingredient labeling requirements.
TF FP Q9	Economic Feasibility	This course helped me to understand economic feasibility and cost analysis when developing products.
TF FP Q10	Larger Scale Food Production	Scaling up a product in the dining center taught me about larger scale food production.
TF FP Q11	Impact of Scale on Formulation	Scaling up a product gave me insight into how scale-up can affect recipes.
TF FP Q12	Benchtop Development to Full Scale	Taking my product from an initial concept to a scaled up and ready-to-produce formulation gave

		me insight into the product development process and how all the steps fit together.
<i>Interdisciplinary Aspects (IA)</i>		
TF IA Q1	Packaging Design Perspectives	Collaborating with the packaging design class gave me different perspectives on packaging design and layout.
TF IA Q2	Dining Center Goals	Interacting with the dining center staff helped me to better understand their needs and goals.
TF IA Q3	Dining Center Perspectives	Working with the dining center staff gave me different perspectives on product development and scale up for food service.
TF IA Q4	Dining Center Operations	This product development project increased my understanding of how dining centers operate.
TF IA Q5	Larger Food Production Equipment	Working with the dining center gave me the opportunity to experiment with larger food production equipment I had not previously used.
<i>Soft Skills (S)</i>		
TF S Q1	Communication	Interacting with the dining center staff provided experience that developed my communication skills.
TF S Q2	Teamwork	Working in a group improved my teamwork skills.
TF S Q3	Public Speaking	Giving a presentation improved my public speaking skills.
TF S Q4	Problem Solving	Facing difficulties while developing my product improved my problem solving skills.
TF S Q5	Adaptability	Facing difficulties while developing my product improved my adaptability skills.
TF S Q6	Organization	Being responsible for managing, labeling, storing, and requesting more ingredients improved my organizational skills.

TF S Q7	Time management	Collaborating with dining center staff to borrow kitchen space and equipment improved my time management skills.
<i>Career Preparedness and Course Experience (CP)</i>		
TF CP Q1	Capstone Course	FDSCI 740 connected material I learned throughout my degree program.
TF CP Q2	Enjoyed Course	I enjoyed this product development project.
TF CP Q3	Influenced Career Path/Goals	My experiences with this course influenced my career goals/path.
TF CP Q4	Relevant Skills and Knowledge	I will use the skills and knowledge I learned in this product development project in my career.
TF CP Q5	Insight into Industrial Product Development	This course provided me with insight into industrial food product development practices.
TF CP Q6	Professional Presentation	Preparing and giving a presentation in this product development project was a similar experience to presentations I would give in a professional setting.
TF CP Q7	Dining Center Equipment Improved Experience	Using the dining center equipment improved my experience in learning product development.

Appendix B - Impact of Rum on Pound Cakes Supplemental

Material

B1 -SAS Code C-Cell

```
%web_drop_table(WORK.IMPORT);
```

```
FILENAME REFFILE '/home/u63451450/C-Cell.csv';
```

```
PROC IMPORT DATAFILE=REFFILE
```

```
    DBMS=CSV
```

```
    OUT=WORK.IMPORT;
```

```
    GETNAMES=YES;
```

```
RUN;
```

```
DATA WORK.CCELL;
```

```
    SET WORK.IMPORT(KEEP=Rep Trt Slice SliceArea TopConcavity BottomConcavity  
NumberCells AreaCells WallThickness CellDiameter AverageCellElongation);
```

```
RUN;
```

```
PROC CONTENTS DATA=WORK.CCELL; RUN;
```

```
%web_open_table(WORK.CCELL);
```

```
/* Analysis for each measurement variable using PROC MIXED */
```

```
%let measvars = SliceArea TopConcavity BottomConcavity NumberCells AreaCells  
    WallThickness CellDiameter AverageCellElongation;
```

```

%macro run_mixed;
  %do i=1 %to %sysfunc(countw(&measvars));
    %let var = %scan(&measvars, &i);

    proc mixed data=WORK.CCELL;
      class Rep Trt Slice;
      model &var = Rep Trt;
      random Slice(Rep Trt);
      lsmeans Rep Trt / diff adjust=tukey cl; /* <-- Pairwise comparisons */
      ods output LSMeans=LSMeans_&var
        Diff=Diffs_&var; /* <-- Save outputs to datasets */
      title "MIXED model with pairwise comparisons for &var";
    run;
    quit;

  %end;
%mend;

%run_mixed;

```

B2 -SAS Code Dimensions

```
%web_drop_table(WORK.IMPORT);

FILENAME REFFILE '/home/u63451450/Volume, dimensions, batter SG, batter temp
2.csv';

PROC IMPORT DATAFILE=REFFILE
    DBMS=CSV
    OUT=WORK.IMPORT;
    GETNAMES=YES;
RUN;

DATA WORK.DIMENSIONS;

    SET WORK.IMPORT(KEEP=rep trt loaf batterSG BatterTemp TempPostBake
BakeLoss Volume SurfaceArea HeightMiddleSlice);
RUN;

PROC CONTENTS DATA=WORK.DIMENSIONS; RUN;

%web_open_table(WORK.DIMENSIONS);
```

```

/* Analysis for each measurement variable using PROC MIXED */

%let measvars = batterSG BatterTemp TempPostBake BakeLoss Volume SurfaceArea
HeightMiddleSlice;

%macro run_mixed;

%do i=1 %to %sysfunc(countw(&measvars));

%let var = %scan(&measvars, &i);

proc mixed data=WORK.DIMENSIONS;

class rep trt loaf;

model &var = rep trt;

random loaf(rep trt);

lsmeans rep trt / diff adjust=tukey cl; /* <-- Pairwise comparisons */

ods output LSMeans=LSMeans_&var

Diff=Diffs_&var; /* <-- Save outputs to datasets */

title "MIXED model with pairwise comparisons for &var";

run;

quit;

%end;

%mend;

```

```
%run_mixed;
```

B3 -SAS Code External Color

```
%web_drop_table(WORK.IMPORT);
```

```
FILENAME REFFILE '/home/u63451450/Colorimeter Outside.csv';
```

```
PROC IMPORT DATAFILE=REFFILE
```

```
    DBMS=CSV
```

```
    OUT=WORK.IMPORT;
```

```
    GETNAMES=YES;
```

```
RUN;
```

```
DATA WORK.OUTSIDECOLOR;
```

```
    SET WORK.IMPORT(KEEP=rep trt scan L a b);
```

```
RUN;
```

```
PROC CONTENTS DATA=WORK.OUTSIDECOLOR; RUN;
```

```
%web_open_table(WORK.OUTSIDECOLOR);
```

```
/* Analysis for each measurement variable using PROC MIXED */
```

```

%let measvars = L a b;

%macro run_mixed;

%do i=1 %to %sysfunc(countw(&measvars));

%let var = %scan(&measvars, &i);

proc mixed data=WORK.OUTSIDECOLOR;

class rep trt scan;

model &var = rep trt;

random scan(rep trt);

lsmeans rep trt / diff adjust=tukey cl; /* <-- Pairwise comparisons */

ods output LSMeans=LSMeans_&var

Diff=Diffs_&var; /* <-- Save outputs to datasets */

title "MIXED model with pairwise comparisons for &var";

run;

quit;

%end;

%mend;

%run_mixed;

```

B4 -SAS Code Internal Color

```
%web_drop_table(WORK.IMPORT);
```

```
FILENAME REFFILE '/home/u63451450/Colorimeter Inside.csv';
```

```
PROC IMPORT DATAFILE=REFFILE
```

```
    DBMS=CSV
```

```
    OUT=WORK.IMPORT;
```

```
    GETNAMES=YES;
```

```
RUN;
```

```
DATA WORK.INSIDECOLOR;
```

```
    SET WORK.IMPORT(KEEP=rep trt scan L a b);
```

```
RUN;
```

```
PROC CONTENTS DATA=WORK.INSIDECOLOR; RUN;
```

```
%web_open_table(WORK.INSIDECOLOR);
```

```
/* Analysis for each measurement variable using PROC MIXED */
```

```

%let measvars = L a b;

%macro run_mixed;

%do i=1 %to %sysfunc(countw(&measvars));

%let var = %scan(&measvars, &i);

proc mixed data=WORK.INSIDECOLOR;

class rep trt scan;

model &var = rep trt;

random scan(rep trt);

lsmeans trt / diff adjust=tukey cl; /* <-- Pairwise comparisons */

ods output LSMeans=LSMeans_&var

Diff=Diffs_&var; /* <-- Save outputs to datasets */

title "MIXED model with pairwise comparisons for &var";

run;

quit;

%end;

%mend;

%run_mixed;

```

B5 -SAS Code Texture

```
%web_drop_table(WORK.IMPORT);

FILENAME REFFILE '/home/u63451450/Texture.csv';

PROC IMPORT DATAFILE=REFFILE

    DBMS=CSV

    OUT=WORK.IMPORT;

    GETNAMES=YES;

RUN;

DATA WORK.TEXTURE;

    SET WORK.IMPORT(KEEP=rep trt slice Hardness Adhesiveness Springiness
Cohesiveness Chewiness);

RUN;

PROC CONTENTS DATA=WORK.TEXTURE; RUN;

%web_open_table(WORK.TEXTURE);

/* Analysis for each measurement variable using PROC MIXED */
```

```

%let measvars = Hardness Adhesiveness Springiness Cohesiveness Chewiness;

%macro run_mixed;

%do i=1 %to %sysfunc(countw(&measvars));

%let var = %scan(&measvars, &i);

proc mixed data=WORK.TEXTURE;

class rep trt slice;

model &var = rep trt;

random slice(rep trt);

lsmeans rep trt / diff adjust=tukey cl; /* <-- Pairwise comparisons */

ods output LSMeans=LSMeans_&var

Diff=Diffs_&var; /* <-- Save outputs to datasets */

title "MIXED model with pairwise comparisons for &var";

run;

quit;

%end;

%mend;

%run_mixed;

```