AN ABSTRACT OF THE THESIS OF

Sebastian Ramirez for the degree of Master of Science in Food Science and Technology presented on March 20, 2020.

Title: Impact of butterfat content and composition on the quality of laminated pastries.

Abstract approved:

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Joy Waite-Cusic

Butter has long been the premium choice for producing pastries such as Danish and croissants. Its inclusion has consistently delivered characteristically light and airy crumbs with beautifully flaky crust. Once considered a delicacy, pastries have now become innocuous in our everyday lives. Once requiring a skillful hand to sculpt and bake pastries are now produced in mass to satisfy the demands of local coffee shops and grocery stores. Mass producing such fragile items comes requires precise equipment and consistent ingredients. Butter making upwards of third of the ingredients by weight has also seen technological advances in its production. The advent of the continuous churn has reduced variation in composition and quality in

butter. As control of butter quality has risen so have the expectations of bakers creating a market for specialty butter. Bakers have traditionally sought out high fat butter often referred to as European style. There are also new entries in the market with value added statements designating country of origin or type of feed. This research has been undertaken to quantify the merit of these attributes and assess their impact on both the functionality and final product.

Butter with higher fat content being the preferred ingredient amongst bakers a series of pastries were baked using butters of varying composition. Variations in butter chosen reflect parameters controlled by current industry practices and include fat content (80% and 82%) and fatty acid composition (low and high melt fractions). Butter was evaluated for its performance during the lamination process and the final product. Melting profiles of butter samples were also determined using differential scanning calorimetry. Before inclusion butter was evaluated for the ability to be manipulated without breaking under stress. Pastries, composed of the different butter samples, were tested using a texture analyzer to determine pastry strength and firmness. Final product samples were also tested for a difference in rise by measuring difference between heights of pastry after lamination and after baking. It was found that fat content influenced multiple properties of butter relevant to baking. Higher fat samples were easier to manipulate and form. Pastries produced with higher fat butter were taller and softer. Results of applying direct force to a butter sample was found to be a good indicator of performance during lamination. Physical properties associated with baking can be manipulated through fractionation. Melting point is acutely affected as well as its resistance to physical manipulation.

To investigate the difference between functional properties of commercially available butter their characteristics (butterfat, fatty acid profile, etc) were evaluated within the dough performance and finished quality of laminated pastries (height, weight). Commercial butters (n =12) were sourced from local retailers and used as the fat component in a standardized croissant dough. The dough was laminated and sheeted at approximately 12°C using the Rondo SSO615 Ecomat Floor Model Sheeter. Dough was cut and formed into croissants, proofed at 30°C for 90 min at 80% RH, and baked at 196°C for 15 min in a rotating convection oven. The butterfat content, fatty acid profiles, and melting profiles of each butter were characterized using Mojonnier method, GC-FAME, and differential scanning calorimetry, respectively. The majority of commercial butters performed acceptably (no cracks or tears) during lamination and produced finished croissants of good quality. Baking resulted in a consistent loss in moisture of four of the commercial butters produced finished pastry of low baked height. Butterfat content was not responsible for the difference in dough quality; however, increased unsaturated fat content was associated with decreased baked pastry height. When grouped as either domestic or imported there was also some differentiation. There was a significant difference in amounts of few individual fatty acids between groups. Pastries made with domestic butter were found to rise higher and have larger holes.

This research demonstrated that multiple factors impact the performance of butter in laminated products. The identification of these factors can guide current producers in how to leverage control points in butter production towards better butter for baking. Understanding how butter impacts production of pastries will also prove useful to bakers in their efforts to make the perfect pastry.

Impact of Butterfat Content and Composition on the Quality of Laminated Pastries

by

Sebastian Ramirez

A THESIS

submitted to

Oregon State University

in partial fulfillment of

the requirements for the

degree of

Master of Science

Presented March 20, 2020

Commencement June 2020

Master of Science thesis of Sebastian Ramirez presented on March 20, 2020

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ACKNOWLEDGMENTS

The author expresses sincere appreciation to Dr. Joy Waite-Cusic and Dr. Lisbeth Meunier-Goddik for the opportunity and guidance to pursue opportunities I did not know existed. Thank you Dr. Andrew Ross and Dr. Teepakorn Kongraksawech for lending me your support, advice, facilities and patience. Thank you Dr. Paul Hughes for your friendship, lessons in diplomacy, knowledge, and challenging me to be a better scientist. Thank you Dr. Frank Chaplen for all the support over the years. I am a different and hopefully better human being because of all of you and our work together. I am sincerely grateful for those whom provided funding for this study BUILD Dairy and High Desert Milk (Burley, ID). Thank you Shawn Burton and Jordan Oakes and your crew for teaching me how to make butter. I would like to thank Chefs Pascal Tisseur and Ciril Hitz for sharing their baking knowledge and expertise that guided this project and Brandon Riesgaard (OSU) for his daily support in the bakery. I would also like to thank Oregon State University's Veterinary Diagnostic Laboratory for the use of the OMAX Compound Microscope and Dr. Skip Rochefort and Merrit Barber of the Department of Biological Engineering (OSU) for training and use of the differential scanning calorimeter. Thank you to Robin Frojen (OSU) for lending expertise and facilities to this project. I would also like to thank Dr. Jadwiga Giebultowics and Eileen Chow for their advice and suggestions. Thank you to the students and staff of the Department of Food Science and Technology for their suppor. Any success I have experienced in this endeavor has been a shared and collaborative effort.

CONTRIBUTION OF AUTHORS

Dr. Joy Waite-Cusic and Dr. Lisbeth Meunier-Goddik assisted in editing and analysis of data for chapter two and three. Dr. Andrew Ross and Dr. Teepakorn Kongraksawech assisted in experiments and data collection for chapter two and three. Brandon Riesgaard assisted in data collection for chapter two and three. Quintin Ferraris assisted with analysis and data collection in chapter two and three.

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Chapter 1: Introduction

1.1 Pastry and Laminated Dough

Pastry is a category of baked products, including both sweet and savory, made from a minimum of flour, water, and fat (shortening). A sub-category of pastry is Viennoiserie ("things of Vienna") which uses yeast as the leavening agent and incorporates additional ingredients (e.g., sugar, butter, eggs) that add to the richness of the product. Viennoiserie can be further divided by dough handling or preparation methods (laminated or nonlaminated) to incorporate the fat/shortening leading to final products with characteristic textures (Suas, 2009). Laminated pastry (e.g., croissants and Danish) are prepared by folding the rich pastry dough around a large block of fat and then moving it through several labor-intensive cycles of rolling, folding, and resting. This process results in a "laminated" dough with tens to hundreds of thin alternating layers of dough and fat that have a total height of less than a centimeter (Deligny and Lucas, 2015). The final dough will typically be cut, shaped, proofed and baked. The layering of fat in this manner creates a barrier that will resist the pressure of water vaporization between dough layers during baking, resulting in a final product with a characteristic light, flaky interior crumb texture, crisp, flaky outer edge, and rich taste (Ooms et al., 2016b). Laminated pastries are defined by their characteristic light and flaky texture and a crumb with elongated alveolar structure (Deligny and Lucas, 2015).

The most well-known laminated pastry is the croissant. Although often attributed to France, croissants are actually thought to have originated from bakers in Turkey via Vienna in 1686 (N. et al., 1951). Since then, the use of laminated dough has spread across Europe and the rest of the world. Once reserved for royalty and noble classes, today these pastries are commonly found at coffee shops, restaurants, and grocery stores. Skilled home bakers, small patisseries, and large-scale baking companies are producing laminated pastry products to meet the increased consumer demand. Baker skill level, experience, and ingredient quality and will determine the finished product quality of a home-baked croissant. However, the use of automation at patisserie and industrial scales has improved production efficiency, but also requires raw ingredients, particularly the fat, to perform more consistently during dough preparation and lamination to produce final products of consistent quality (Baldwin et al., 1972).

In laminated pastries, fat is a large portion (30-35% w/w) of the composite dough and will have a significant impact on the performance of the dough during preparation and on the quality of the final product (De La Horra et al.). Butter was the traditional choice of fat used for baking laminated pastries (Suas, 2009). Alternative fats (hydrogenated fats or modified butters) have been developed to mimic butter's functional properties or provide some other advantage (e.g., cost, handling, shelflife, etc) (Baldwin et al., 1972; Lefébure et al., 2013; Mattice and Marangoni, 2017) Recently, consumers are shifting their attention to ingredient labels alternative functional ingredients have waned in popularity in search of healthier natural alternatives (Román et al., 2017; Laughman, 2018). Butter is has seen a recent resurgence in popularity due to its perception as a natural product and maintaining a “clean” label (Krause et al., 2007).

1.2 Butter

Butter is an integral part of the kitchen and although many have attempted to imitate, substitute, and replace it butter remains an integral part of the American kitchen. The unique flavor and structure of butter gives it certain advantages in the kitchen compared to other fats (Pilcher, 2017). For example, the ability to physically manipulate butter as a solid at room temperatures provides baking advantages over common vegetable oils. Culturally, butter is “vegetarian-friendly” and can be made kosher or halal; therefore, having a broader customer base as compared to lard. Butter’s mild and clean flavor profile allows for its use in a breadth of culinary applications (Clark et al., 2009).

1.2.1 Butter Production

Butter is made by a physical concentration and conversion of butterfat from liquid cream to a condensed solid fat. The butter-making process is fairly simple; however, there are multiple control points that influence the quality of the finished butter. Each step of the process from farming practices to butter storage will ultimately contribute to butter quality.

Butter begins with the cows on the farm. Most things on the farm will affect productivity but certain things like breed, feed, season, and stage in the lactation cycle can influence the fatty acid profile of the fat found in milk. Poulsen et al., (2012). O'Callaghan et al., (2016) found that differences in fatty acid composition of butter produced from cows on different feed impacted texture and flavor. Fatty acid composition also affects the amount of solid fat content (SFC) in butter(Marangoni and Rousseau, 1998). The influence of solid fat content during the shaping and laminating process can influence plasticity (Stauffer, 1996). Feed and herd management are not the only things affecting butter on the farm though. Milk quality can also be adversely affected by poor storage conditions and transportation issues (Kuhn et al., 2018).

Once received at a processing facility the milk is separated in a centrifuge and the cream standardized before pasteurization. Due to high solids content, the minimum pasteurization temperature for cream (75°C/166°F) is 5°C higher than that required for fluid milk (72°C/161°F) (Grade "A" pasteurized milk ordinance., 2001). In practice, manufacturers typically pasteurize at much higher temperatures (95°C/203°F) to extend shelf life and improve or maintain flavor (Spreer and Mixa, 2017). This higher processing temperature will further reduce the microbial load of the cream and deactivate lipase. Lipase activity leads to high levels of free fatty acids which can contribute to rancid flavors (Bylund, 1995; Spreer and Mixa, 2017). When exposed to the high heat of pasteurization, fat globules which were previously a combination of solid and liquid fat are completely melted. As fat globules cool in the heat exchanger, a thin outer layer of solid fat forms. While in this semiliquid state, the cream is pumped to a storage silo. Movement of the cooled cream needs to be gentle to minimize disruption of fat globules to optimize butter yield (Spreer and Mixa, 2017). Cream is tempered in the silo at ~10°C from anywhere between 8 to 36 hrs depending on silo size to allow the triglycerides form crystalline networks and transition the butterfat from liquid to mostly solid fat before the churn. This process is referred to as ripening or aging of the cream and will increase the latent heat of crystallization by a few degrees (Bradley, 2018).

In order to make butter, the oil-in-water emulsion (cream) must be inverted to create a water-in-oil emulsion (butter). This inversion requires mechanical action that will provide the force for two separate events to occur. First, the disruption or breaking of the phospholipid bilayer surrounding the fat globule. Second, the collision of fat particles in order to agglomerate (Spreer and Mixa, 2017). The force for butter-making is provided by a churn, either in a batch or continuous process. The continuous butter churn has become the standard method in industry due to its higher efficiency. The continuous butter churn generally consists of a churning section, a separating section, and two working sections.

Agglomeration in the churning section is influenced primarily by butterfat content and cream temperature. Butter makers have determined that using the sum of butterfat percentage and cream temperature to equal 90 provides an ideal scenario for fat agglomeration in the churning section (Bradley, 2018). For example, cream at 40% butterfat would be optimally churned at 50°F. Bradley, (2018) notes that this ratio may change with seasonal fluctuations in cream composition. In order to achieve this ratio cream is sometimes warmed in a heat exchanger prior to flowing into the churn (Bylund, 1995).

As the product leaves the churning section, butter grains have formed and are moved into the separating section to removed excess water, formally referred to as buttermilk (Spreer and Mixa, 2017). Butter will then tumble into the first of two working sections which are jacketed and chilled to facilitate agglomeration and packaging downstream. Here, two augers move the butter up a slight incline to press it through a series of plates. As the butter makes its way through the plates excess buttermilk is squeezed out determining the final moisture content (Spreer and Mixa, 2017). This section is the last opportunity to make adjustments and homogenize the product into a uniform mixture. Salt, lactic acid, and/or water may be added to the working sections depending on end product classifications.

As butter is pumped to the butter silo from the churn, product specifications (salt, moisture, density) will be measured and an operator or automated process will use these measurements to adjust to the churning process to achieve target metrics (Bylund, 1995). Adjustments to the speeds and flow rates of specific sections of the churn will not only have different effects but the magnitude of the change will also vary (Shimada et al., 2013). For example, a slight addition of salt or water will have a much more drastic effect than reducing the speed of churning section. The change will also be observed sooner by inline sensors since it is further downstream in the process.

Butter flows into a butter silo which acts as a balance tank for the packaging lines ensuring a constant flow. Common packages are 25 kg lined boxes, solid 1 lb, and 4 oz sticks. After packaging, the butter must be cooled to 7.5°C/45°F and placed in cold storage. Butter is then held in cold storage for several weeks as determined by the company's quality control program. This additional cold storage time will make the product less susceptible to deformation during transport.

1.2.2 Butter Quality

Butter quality is influenced by both the composition of the cream and processing parameters during production. Composition of the cream is determined by on-farm practices and conditions. Seasonality, either as a function of ambient temperature and/or feeding regime, will influence the fat content (percentage), milkfat globule size, and fatty acid profile of milk(J. Bent et al., 2007). This was investigated and confirmed by several studies using gas chromatography to quantify compositional differences including Fouad et al., (1990) and O'Callaghan et al., (2016). Fouad et al., (1990) confirmed a difference between summer and winter, O'Callaghan et al., (2016) between feed. Not surprisingly, feeding regimes have also been demonstrated to lead to discernable differences in butter flavor (O'Callaghan et al., (2016).

Feeding regime can influence the size of milkfat globules. Avramis et al.(2003) found that small milk fat globules obtained by adding fish meal to the cows feed made soft spreadable butter. Using differential scanning microscopy,(Truong et al., (2013) found that the crystallization temperature of emulsified fats decreased with smaller average droplet size.

Differences in cream composition can be mitigated by butter processing parameters (Bradley, 2018), but processing decisions will directly determine final quality of butter (Clark et al., 2009). Every aspect of the butter making process can have an impact on the final quality and functionality of the final product. Butter manufacturers that are aware of this and have taken strides to reduce variability and fine tune their processes. Buldo et al., (2013) found that increased ripening time led to more aggregation and larger fat globules which led to reduced churning time. Recent research by Lee and Martini, (2018) illuminated how temperature and agitation during aging cream can influence churning time and hardness of the finished butter. Homogeneity is of primary concern as insufficient working may lead to leaky butter (butter with free moisture (Clark et al., 2009). It is also possible to overwork the butter which can create a product with a gummy or sticky mouthfeel (United States standards for grades of butter, 1989). The butter will leave the churn and be pumped to a butter silo. Inappropriate storage conditions and packaging materials can lead to butter with off-flavors (Krause et al., 2008; Clark et al., 2009) .

1.2.3 Butterfat Content

Butterfat content is the primary defining characteristic for retail and wholesale butter products (Bradley, 2018). The standard of identity of butter in the United States requires a butterfat content of at least 80% w/w (CFR - Code of Federal Regulations Title 21). European Union regulations currently require >80% butterfat content in salted butter and >82% butterfat for unsalted butter. With recent changes in consumer perception of butterfat and an increase awareness of the effects of trans fats there has been a steady rise in butter consumption (Haley, 2005; Bentley, 2016). In the US, European-style butter has become synonymous with a higher fat content and is increasingly popular among consumers (Lee et al., 2018). New high end product lines are available in retail markets that bear value-added labels indicating "European-style", "grassfed", "imported" (Gale, 2018). These value-added statements have led to research necessitated an increase in precision and complexity in analysis in order to authenticate specific parameters for regulatory purposes (Gori et al., 2012).

As consumer demand for pastries made with butter continues to grow so will research into how to make butter better.

1.2.4 Butter Characteristics in Laminated Pastries

In the creation of laminated pastries, butter is subjected to significant physical pressure and stress at a variety of temperatures. The butter must be malleable, not too soft, during lamination, must also maintain enough solid fat at proofing temperatures to not "oil out" prior to baking (O'Brien, 2004).

1.2.5 Objectives

The overall objective of this research is to investigate butter characteristics that influence the qualities of laminated pastries. Our first objective was to measure the influence of butterfat and butterfat fractions on raw and baked dough characteristics. To effectively reduce confounding variables, we partnered with a regional butter manufacturer to source 80% and 82% butterfat products that were produced on the same day from the same silo. Our second objective was to characterize a diversity of domestic and imported butters available at the retail level and evaluate their relative performance in the production of croissants. Various retail butter products were purchased to cover a wide range of butterfat content and value-added statements.

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Chapter 2: Impact of Butter Fat Content and Composition Within A Pastry Matrix

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Prepared for submission to the Journal of Dairy Science

2.1 Abstract

A series of pastries were baked using butters of varying composition. The variations in butter were chosen to reflect parameters controlled by current industry practices and included fat content and fatty acid composition. Butter was evaluated for its ability to be manipulated without breaking and its ability to be included into the dough. Butter samples melting profiles were determined using differential scanning calorimetry. Pastries composed of different butter samples were tested using a texture analyzer to determine pastry strength and firmness. Final product samples were also tested for a difference in rise by measuring difference between heights of pastry after lamination and after baking. It was found that fat content influenced the properties of butter relevant to baking. Samples with higher fat were easier to manipulate and form. Pastries produced with higher fat butter were taller and softer. It

was observed that physical properties associated with baking can be manipulated through fractionation. Melting point was acutely affected as well as its resistance to physical manipulation.

2.2 Introduction

Butter serves as the premium quality fat ingredient in many foods; however, the functional properties of the butterfat are critical to a few applications. The performance and quality of baked goods is directly tied to the quality of the fat used in formulation. Bakers (professional and amateur) often choose products with higher butterfat content (>82% butterfat) and the industry is responding with a variety of options that declare certain butterfat percentages (up to 85% butterfat). Higher butterfat products are more challenging to manufacture; however, they also demand a higher price point making their production appealing to processors.

Laminated pastries, including croissants and puff pastry, are characterized by their high fat content (20-30% w/w), layering, and airy/flaky texture (Marangoni and Rousseau, 1998; Haegens, 2014; Deligny and Lucas, 2015) Laminated doughs are formed by enveloping a butter block in a dough with successive steps of folding, rolling, and retarding to create numerous repeating thin layers (tens to hundreds) of dough and butter. The dough is then shaped, proofed, and baked to create a finished pastry. The lamination process imparts the dough with the ability to rise in a characteristic manner creating an airy and flaky crumb (Bousquieres et al., 2014). Proofing supports the fermentation process as well as the softening of the butter before baking. The proofing temperature should be at least 5°C lower that the complete melting temperature of the fat to prevent oil-out which will have a negative impact on rise (Haegens, 2014). The layers of butter create a barrier impeding steam from escaping during baking. Small bubbles of air, trapped when the dough is mixed and laminated, act as nuclei for trapped steam accumulation creating lift as the dough is baked (Ooms et al., 2016).

Optimum finished pastry texture requires that the fat layer must be distributed uniformly without breaks from initial enrobing of the butter through multiple sheeting steps (O'Brien, 2004). The degree to which a baker can physically manipulate butter either by hand or machine will affect the laminating process and quality of the final product. Optimal lamination performance requires dough handling within a narrow temperature range (15-20°C) where the butter is pliable but does not become soft and begins to absorb into the dough (>20°C). Breaks in the butter layer, usually caused by a mismatch in butter-to-dough softness, will lead to production and handling challenges with the dough and the quality of the finished pastry will be reduced (Haegens, 2014). Laminated doughs rely on butter to support the layered physical structure and if the butter breaks the dough will be of uneven thickness. These breaks in the butter layer will grow wider as the dough is compressed with each subsequent sheeting step. This creates larger pockets of dough that serve as channels for steam to escape too rapidly during baking and reduce the overall height of the finished product (Renzetti et al., 2015). Alternatively, hard, brittle butter can physically rupture dough layers during sheeting (O'Brien, 2004).

While the legal definition of butter requires its major functional properties (fat, moisture, protein, ash) to fall within a narrow range, there are variations in physical and chemical properties that can influence butter performance in laminated doughs. Solid fat index (SFI), plasticity of the fat, and crystallization will influence butter performance during lamination and in finished products (Haegens 2014). These butter characteristics are influenced by numerous factors along the production chain, including farming practices, seasonality, cream ripening, churning process, and storage conditions. This complexity along with minimal testing and disclosure of the critical functional properties of butter, leave purchasers without meaningful information for logical decision-making. Therefore, bakers have inferred and likely over-simplified butter performance with the theory that butter with a higher butterfat content (82%) will outperform the standard butterfat content (80%) counterpart in laminated pastries. The plasticity of butter is influenced by the saturated fatty acid concentration and arrangement in triglycerides (Devi and Khatkar 2016). In theory, higher fat butters, especially those with elevated unsaturated fatty acid composition would have increased plasticity and therefore be easier to laminate. This difference in performance based simply on small changes in butterfat content (2-3%) has not been demonstrated and is difficult to test based on other production variables that could impact butter qualities.

Options for improving butterfat functionality include modifications in processing that could lead to the development of new products for the dairy industry. 16.7% (47/282) of the USDA-graded dairy processing facilities manufacture at least one butter product (USDA - https://apps.ams.usda.gov/dairy/ApprovedPlantList/).

There are 39 plants that manufacture bulk butter in the U.S.A. One approach to could be to fractionate butter to create products with reduced moisture content, narrower melting temperature, and modified plasticity (Yella Reddy, 2010). Fractionation of butter is rare in the U.S (Bradley, 2018); however, there are a few processing facilities that produce textured butters, anhydrous milkfat, and butteroil. Butter manufacturers have several points of control at which to modify butter composition. These include the temperature and length of time cream is crystallized, the proportion of fat, and fractionation (Yella Reddy, 2010; Buldo et al., 2013b).

The objective of this study was to characterize the performance of butters and fractionated butterfat in a model laminated pastry during shaping, lamination, proofing, and baking. Direct comparisons were made between near-identical butters differing only in fat content (80% vs. 82%). Similarly, the performance of butter fractionated into low and high melt fractions were compared in the model pastry system.

2.3 Materials and Methods

2.3.1 Butter and butter fractionation

Commercially produced butters, 80% and 82% fat, were provided by High Desert Milk (Burley, ID). All butter used in this study was produced on the same day, using cream from the same silo and churned on the same machine. Butter (25 kg) blocks were shipped from the manufacturer to Oregon State University and stored at 2°C for up to 3 months prior to use.

A stepwise temperature gradient was used to prepare fractionated butter samples. Butter (80%; 1 kg) was melted and held at 55°C for 1 hr to separate fat from protein and water. Melted butter was chilled at -10°C and the frozen protein and ice layer were separated from the solidified fat using a knife. The fat portion was transferred to a resealable plastic bag and placed into a circulating water bath (5 L) at 55°C for 1 hr until no visible solids were observed. Butter was crystallized by stepwise cooling at 40°C for 1 hr, 35°C for 1 hr, and 31°C for 2 hr. Samples were then centrifuged at 15,300 x g for 15 min at 30°C. The liquid fraction (low melt) was decanted into a resealable bag and the crystallized fraction (high melt) was remelted and decanted into a separate resealable bag. Both samples were stored at 4°C for at least 24 hr before use. A concentrated, nonfractionated control sample was prepared using the same process without separating fractions. The butter fractionation process was performed twice to create duplicate fractionated samples.

Butter blocks (25% w/w of predough) were shaped using a combination of a rolling pin, an envelope made of parchment paper (30 cm x 20 cm), and a sheeter (Rondo SSO615 Ecomat Floor Model Sheeter, RONDO, Burgdorf, Switzerland). Each butter sample was inspected for leaking: a term used by bakers and processors to describe free water expelled during the formation of a butter block (Clark et al., 2009). Visible stress fractures after initial shaping and visible gaps in butter sheet were considered breaks and documented. Butter blocks were tempered to 12°C before incorporating into laminated dough.

2.3.2 Characterization of butter and fractionated samples

Butter was tested for fat content using the Mojonnier method AOAC 922.06. Samples were analyzed in duplicate and results averaged to obtain final fat percentage.

2.3.3 Differential Scanning Calorimetry

Samples of butter weighing 10-15 mg were placed into aluminum pans and hermetically sealed. Sealed samples were analyzed using a differential scanning calorimeter (DSC, TA Instruments-Waters LLC New Castle, DE) using the following program: 2°C for 2 min then heated at 5°C/min to 70°C. DSC data were analyzed using Universal Analysis software (TA Instruments-Waters LLC New Castle, DE) to identify peak and range of melting temperature. Each sample was prepared and analyzed in triplicate.

2.3.4 Fatty Acid Composition

The fatty acid composition of each butter sample was determined by gas chromatography (GC) analysis of total fatty acid methyl esters (FAME) using a method adapted from Christie (1993). Briefly, whole butter samples were added to 1% sulfuric acid in dry methanol and incubated at 50°C for 16 hr with agitation. Samples were neutralized with 2 mL of aqueous potassium bicarbonate (2%, w/v) and FAME were extracted with 1:1 (v/v) hexane/diethylether (2 x 1 mL). FAME extracts were concentrated under nitrogen to approximately 50 μL and stored at -4°C. Samples (1 μl) were injected into a HP5890 (Hewlett-Packard, Wilmington, DE) and FAME were separated using a SLB-IL111i (60 m x 0.25 mm x 0.2 μm) column (Supelco, Bellefonte, PA) using hydrogen as the carrier gas with a 10:1 split ratio. FAME were measured using a flame ionization detector. FAME were identified by comparing retention times with an external FAME standard (Nu-Check Prep, Elysian MN) that included all fatty acids expected in butter. Fatty acid composition is reported as relative percentage of each fatty acid using data collected from four injections per sample.

2.3.5 Pastry dough preparation

Pastry dough was prepared using a method adapted from Ooms et al. (2017). Predough was prepared using the following ingredient ratios: for every 100.0 g wheat flour (protein 11.5%, Organic Artisan Bakers Craft Plus, Central Milling, UT), 10 g sugar (C&H Bakers Sugar, Domino Foods, Inc., Yonkers, NY), 6.0 g butter, 2.0 g salt (Morton table salt without iodide, Chicago, Illinois), 1.6 g yeast ((Lesaffre Gold Instant Yeast, Lesaffre Yeast Corp., Milwaukee, WI), and 50 g tap water. Predough ingredients were mixed in a Hobart A200 commercial mixer (Troy, OH) with a C-hook for 7.5 min on lowest setting at 25°C. Predoughs were proofed at 30°C for 1 hr in a standard 20 qt mixing bowl. After proofing, predoughs were chilled in a -10°C freezer to 12°C (approximately 50 min) and used immediately for lamination.

2.3.6 Lamination

Tempered butter blocks were enveloped in the chilled predough using the method described by Suas (2009). A total of 3 turns were performed with 25 min rests at -10°C; a turn consisted of sheeting, folding, and turning the dough 90°. Dough sheeting was performed by machine (Rondo SSO615 Ecomat Floor Model Sheeter, RONDO, Burgdorf, Switzerland) in eight steps to reduce dough thickness from approximately 3 cm to 1 cm. Approximately 1 to 2 cm of dough were trimmed from each end after each turn revealing the edge of the butter layer. After the third trifold, the dough was reduced by passing through the sheeter twice (once in each direction) to yield a final dough sheet of approximately 35 cm x 60 cm x 1.0 cm. Dough samples were cut from the interior of the final dough sheet using a chef's knife. Samples were evaluated for dough strength and extensibility (10 cm x 10 cm; n = 3), layer continuity (6 cm x 6 cm; n = 4), and baking qualities (6 cm x 6 cm; n = 12). Laminated dough thickness (mm) was measured using a digital height gauge (SDV-6"A Mitutoyo, Japan).

2.3.7 Dough strength and extensibility

Dough strength and extensibility were measured using a texture analyzer (TA-XTPlus) equipped with a 5 kg load cell and the TA-108 Tortilla/Film Fixture probe (Texture Technologies Corp., Hamilton, MA). The penetration speed was 2 mm/s starting plot at 5 xg of force and a total distance of 100 mm. The dough samples (10 x 10 cm) were tempered at 4°C for 10 min and placed into an acrylic cylinder (63 mm diameter) mounted on an aluminum platform. Peak force (N) was measured as the maximum force before the dough broke. Extensibility was measured as the distance (mm) that dough was extended at the point of peak force.

2.3.8 Continuity of layers

Evenness of lamination was evaluated macroscopically and microscopically. On a macroscopic level, visible stress fractures and visible gaps in the butter sheet were documented. On a microscopic level, integrity of layers were visualized by Oil Red staining of dough cross-sections using a method were adapted from Ooms et al., (2017). Dough samples (6 cm x 6 cm) were frozen using dry ice and stored at -10°C for 1-3 weeks prior to analysis. Dough subsamples (5 mm x 10 mm x 20 mm) were cut and placed in a mold with Tissue-Tek O.C.T compound (Sakura Finetek, Torrance, CA) and frozen. Casted frozen doughs were transferred to the Veterinary

Diagnostic Laboratory (Oregon State University, Corvallis OR) for slicing and mounting using a cryostat (Leica CM1850, Leica Biosystems, Buffalo Grove, Illinois). Samples were stained with Oil Red O (3 g/L) and visualized on an OMAX Compound Microscope at 2x magnification. OMAX ToupView software (OMAX microscope, China) was used to capture and optimize microscopic images. Two samples of each dough were prepared and visualized by microscopy.

2.3.9 Pastry Baking and Baked Pastry Analysis

Dough samples (6 cm x 6 cm; n = 12) from each dough sheet were evenly spaced on a full size sheet pan (46 cm x 66 cm) and proofed at 30°C at 80% relative humidity for 90 min in a proofing chamber (Doyon E 2330, Linière, Québec, Canada). Proofed dough squares were baked at 196°C for 15 min (Mini Rotating Rack Oven, Baxter, Orting,WA). The baked samples were cooled to ambient temperature (>1 hr) prior to further analysis. Pastry made with 80% and 82% butter were baked on three separate days and pastry made with fractionated samples were baked two days.

Laminated dough, proofed dough, and baked pastry heights (mm) were measured using a digital height gauge (SDV-6"A Mitutoyo, Japan). Total rise was calculated as the difference between the height of baked pastries and the height of the laminated dough.

Pastry firmness was measured using methods adapted from Mattice and Marangoni (2017) using a texture analyzer TA-XTPlus equipped with a 30 kg load cell in combination with a TA-43 bell lock holding a 1.5 mm thick blade (Double Edge Warner, Plymouth, MN). The texture analyzer was set to compression mode, lowered at a test speed of 5 mm/s with a post-test speed of 10 mm/s using target mode. Three samples of each baked pastry batch were measured for firmness.

2.3.10 Statistical analysis

Data analysis was completed using JMP 13.0 (SAS Institute Inc., Cary, NC.) T-tests were used to compare samples 80% and 82%. Fractionated samples were compared using one-way ANOVA with a post-hoc Tukey-Kramer HSD.

2.4 Results

2.4.1 Relative performance of 80% and 82% fat butter in laminated pastry dough

Performance of butter used in lamination begins with the process of shaping or extruding the butter block for inclusion. Qualitative differences were observed between the 80% and 82% fat samples during the initial shaping phase. During pounding and tempering, high quality butter should deform to the shape of the rolling pin without breaking. The 82% fat butter consistently behaved in this manner (shown in Figure 1A, upper left). In contrast, the 80% fat butter broke during shaping in 60% of the dough preparations (Figure 2.4.1A, upper right). Neither butter exhibited

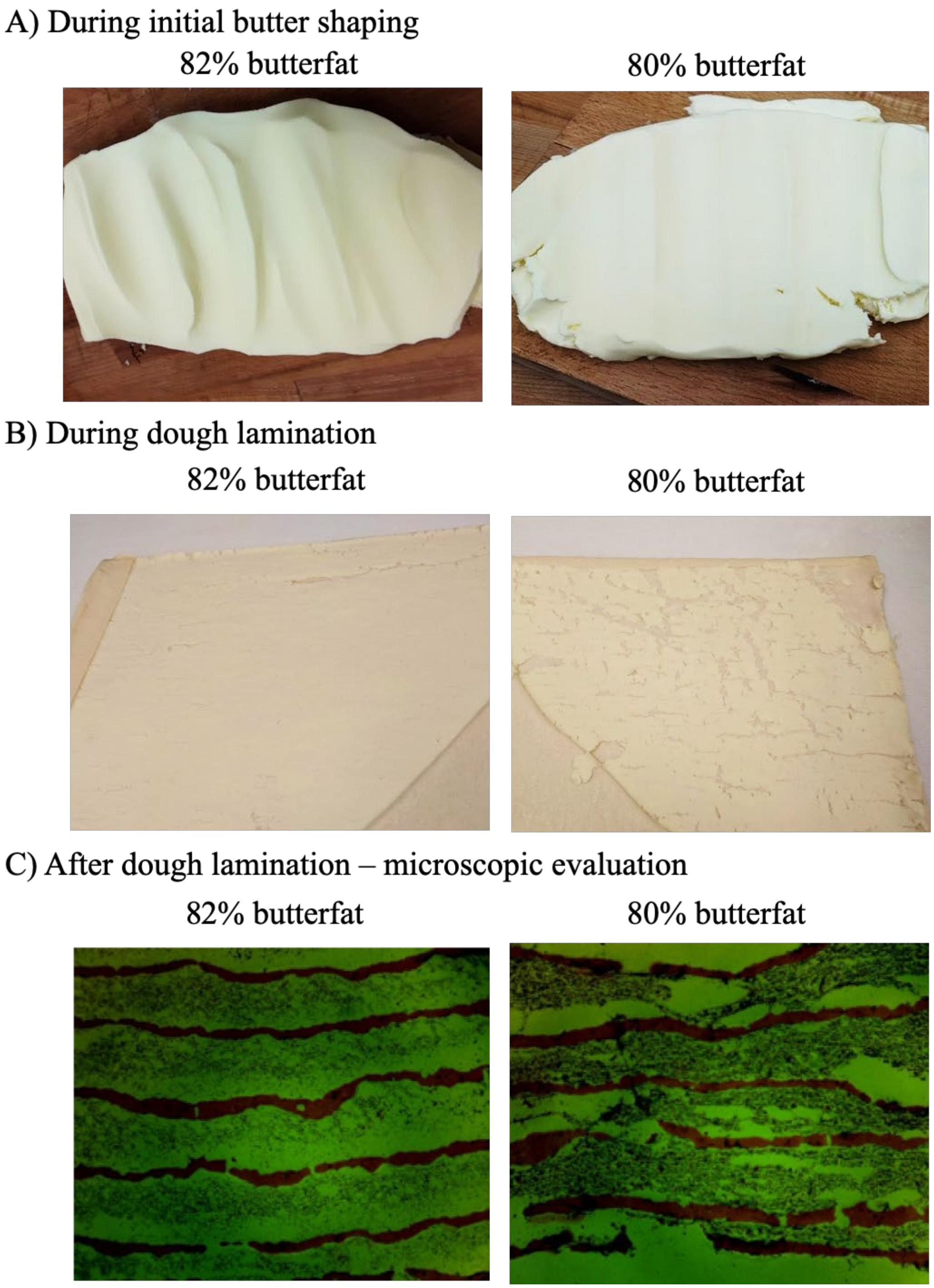

Figure 2.4.1 Representative photographs of butter performance during A) initial butter shaping (macroscopic), B) during pastry dough lamination (macroscopic), and C) after dough lamination (microscopic).

leaking or any visible accumulation of free water. The lamination process is designed to create thin continuous sheets of butter between layers of dough. To accomplish this, the butter needs to be resilient to pressure and resist cracking. As expected, the 82% fat butter performed well during lamination and did not exhibit any noticeable cracking (Figure 2.4.1B, lower left). Dough lamination using the 80% fat butter led to cracking (Figure 2.4.1B, lower right). The relative sheeting performance of pastry dough made with 80% and 82% fat butters was confirmed microscopically (Figure 2.4.1C).

Throughout the pastry production process, butter is held and manipulated at different temperatures as it goes from refrigerated storage to lamination, proofing, and finally baking. Primary working temperatures are between 10°C and 14°C for shaping or extruding into a block and between 28°C and 32°C for proofing. DSC curves of butter provide data on the status of fat crystallization and hardness of the butter at a given temperature (Figure 2). Some melting or softening should occur once butter is removed from refrigeration giving the butter more pliability. Another separate melting range spans proofing temperature so that the butter does not turn into liquid and flow out during proofing. DSC analysis of these two samples did not show a significant difference in peak melting point temperature or temperature range.

Forming croissants and Danish may take place either by hand or machine. Forming these complex shapes require laminated dough be resilient to tearing. Dough laminated with 82% butter required a peak force of 14.9 N to burst 80% butter requiring 12.6 N (Table 1). Dough samples laminated with 82% butter required a higher peak force to burst than samples made with 80% butter ($p\text{-value} < 0.05$). Dough made with 80% and 82% butter did not significantly differ in extensibility.

The amount of rise a laminated dough exhibits impacts both aesthetics and texture. Rise in part depends on the butter layer remaining continuous through

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Table 1. Dough and baked pastry characteristics of samples made with butter of 80% and 82% fat.

	Butter by fat content	
	80%	**82%**
Laminated Dough		
Dough Strength (N)	12.6 ± 1.3*[1]	14.9 ± 1.6*
Extensibility (mm)	89.7 ± 8.3	87.7 ± 6.4
Baked Pastry		
Peak Force (N)	126.7 ± 16.4*	108.2 ± 10.0*
Rise (mm)[2]	30.9 ± 2.0*	33.5 ± 1.7*

*Indicates significant difference between dough or baked pastry prepared with 80% and 82% butter (p-value < 0.05).

[1]Values presented are the mean ± standard deviation (n = 9.

[2]Rise values were calculated as the difference in baked pastry height and laminated dough height.

Pastries made with 82% fat butter rose 2.6 mm (p-value < 0.0001) more than those made with 80% fat butter, a difference in rise equal to 7.8% of the average height of samples baked. The final texture of the baked pastry will impact functional as well as sensory aspects of the product. Baked pastries made with 80% butter required a greater peak force 126.7 N to cut than those produced using 82% 108.2 N (p-value < 0.05).

2.4.2 Characteristics and performance of concentrated and fractionated butter in laminated pastry dough

It has been suggested that the high melt fraction of butter would improve baking properties (Yella Reddy, 2010). In order to better understand the impacts of each fraction within the baking process, concentrated, fractionated butter samples were produced in enough volume to bake into pastries. The fractionation process changed the fatty acid profile and removed most of the water from the samples resulting in a fat percent of 98%, 95%, and 96% for control, high, and low melt samples, respectively. This allowed the influence of fat acid composition to be made apparent. Since fatty acids are not present independently but instead distributed amongst the triglycerides that make up butter a clear separation defined by a single or even multiple fatty acids was not an ideal measure of a successful fractionation. As illustrated in Table 2, most fatty acids were found in all three samples after fractionation. Instead a clear shift in the ratio of saturated (SFA) vs unsaturated fatty acids (UFA) was noted and provided evidence of a successful fractionation. This change in the ratio of SFA vs UFA has been seen in previous studies focused on

Table 2. Fatty acid composition (g/100 g fat) of concentrated butter fractions.

	% of Total Fat		
Fatty Acid	Concentrated, Nonfractionated	Low Temperature Fraction	High Temperature Fraction
C4:0	0.29 ± 0.07[1]	0.38 ± 0.12	0.33 ± 0.06
C6:0	1.42 ± 0.35	1.80 ± 0.47	1.58 ± 0.18
C8:0	1.33 ± 0.29	1.59 ± 0.30	1.43 ± 0.08
C10:0	3.44 ± 0.60	4.15 ± 0.70	3.90 ± 0.09
C12:0	3.97 ± 0.54	3.37 ± 1.96	4.81 ± 0.23
C14:0	12.57 ± 1.20	11.41 ± 3.67	15.79 ± 0.93
C16:0	36.01 ± 4.49	28.38 ± 6.58	35.34 ± 3.97
C18:0	10.58 ± 1.90	10.68 ± 2.67	12.86 ± 0.46
C18:1	26.54 ± 3.20	33.47 ± 7.04	31.40 ± 2.53
C18:2	3.36 ± 0.37	4.16 ± 0.86	3.89 ± 0.28
C18:3	0.50 ± 0.06	0.61 ± 0.14	0.58 ± 0.05
Total SFA[2]	69.60 ± 3.62	61.76 ± 8.04	69.89 ± 2.86
Total UFA[3]	30.40 ± 3.62	38.24 ± 8.04	35.87 ± 2.86

[1]Mean ± standard deviation (n = 4)

[2]Total saturated fatty acid content

[3]Total unsaturated fatty acid content

fractionation (Fouad et al., 1990; Breeding and Marshall, 1995; Yella Reddy, 2010). The low melt fraction consistently contains less SFA and more UFA than high melt samples.

All samples of butter made through fractionation exhibited breaks in both initial shaping (Figure 2) and sheeting (Figure 2.4.2). This was unexpected as higher fat content has been considered to increase malleability. This made all three samples difficult to shape into a butter block. The control and low melt samples broke during lamination, but particles spread in a relatively homogenous manner. The high melt samples created a particularly rough surface and visibly deformed the dough. Both pitting and protrusions accompanied a generally uneven thickness both times high melt sample was laminated (Figure 2.4.2). Amongst the dough samples made with fractionated butter, the high melt sample required a significantly lower peak force (p-value < 0.05) to burst than the control (Table 3) Frozen samples of dough from fractionated butter proved too brittle to effectively slice for microtome.

During proofing, samples made with low melt "oiled out". With the melted butter acting as a lubricant, several low melt samples toppled/slid apart. The pooled butter also caused some difficulty in removing the pastries from the parchment (Figure 2.4.2). The proofed high melt sample had holes and visible pieces of butter protruding. These imperfections carried through to the final product and the baked samples were the least homogenous of all three samples in color and shape (Figure 2.4.2). DSC data confirmed that the melting profile of fractionated samples were significantly altered (Figure 5). During the initial melting phase (> 14 °C) the samples were not significantly different in peak temperature, but the low melt did display

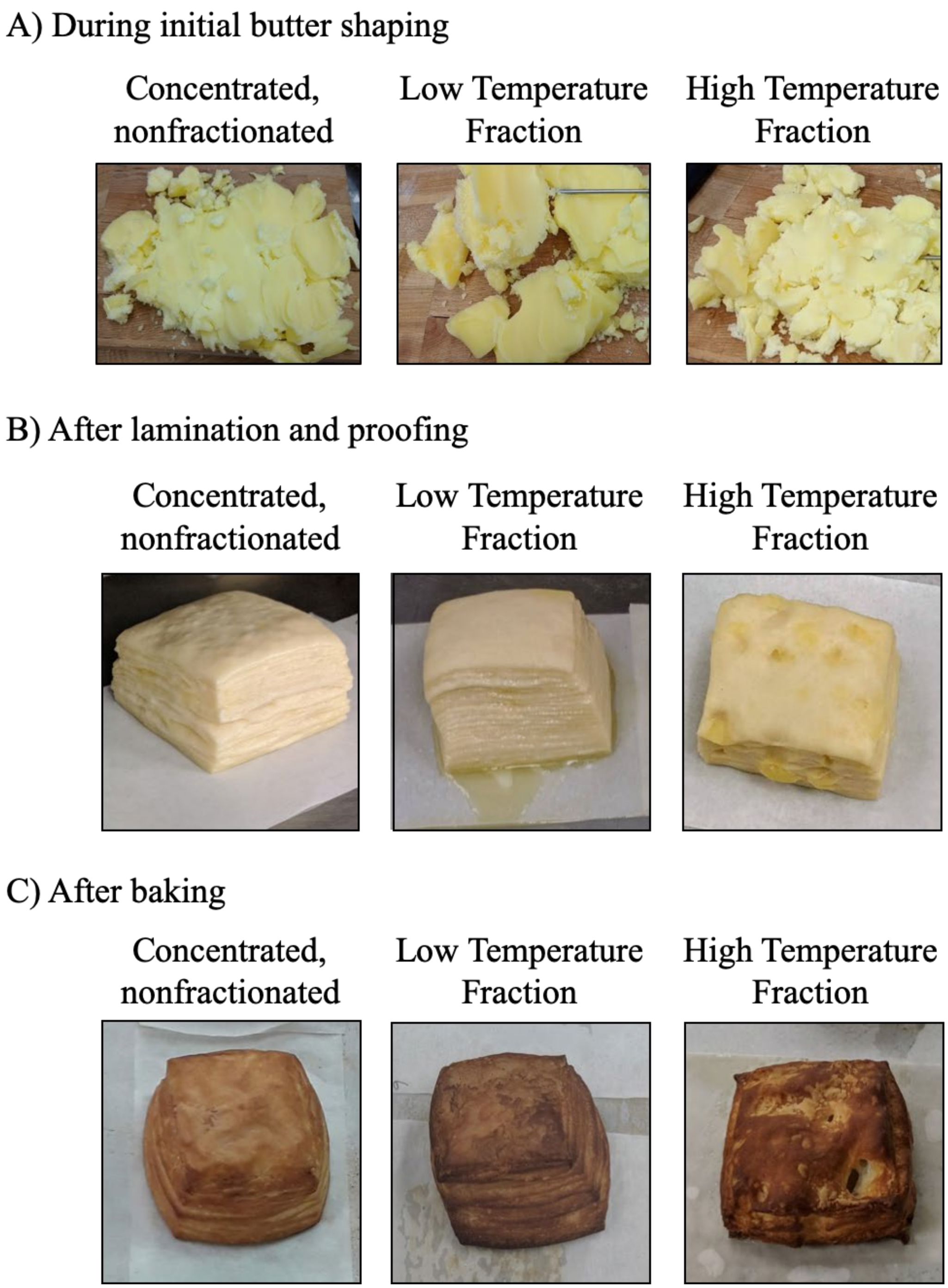

Figure 2.4.2 Representative photographs of fractionated butter sample performance in laminated dough during A) initial butter shaping, B) after lamination and proofing

Table 3. Dough and baked pastry characteristics of samples made with concentrated butter fractions.

	Concentrated, Nonfractionated	Low Melt Fraction	High Melt Fraction
Laminated Dough			
Dough Strength (N)	19.9 ± 1.7[1a]	15.4 ± 4.5[b]	18.6 ± 1.5[ab]
Extensibility (mm)	87.0 ± 5.5[a]	68.1 ± 13.2[b]	86.4 ± 4.8[a]
Baked Pastry			
Peak Force (N)	111.2 ± 6.5[a]	89.2 ± 21.4[a]	113.5 ± 30.1[a]
Rise (mm)	27.7 ± 2.7[a]	24.5 ± 3.5[b]	25.7 ± 1.2[ab]

[1]Values presented are the mean ± standard deviation (n = 6).

[a-b] Values within a row that do not share same superscript letter are significantly different (P<0.05).

[2]Rise values were calculated as the difference in baked pastry height and laminated dough height.

significantly more melting leaving less solids going into laminating and proofing. At proofing temperatures, both the high melt and low melt proved significantly different from the control (Figure 5). Low melt samples melted completely within the range of proofing temperatures, whereas high melt samples did not melt completely until >40°C. Among pastries baked with fractionated butter, those with high melt butter rose less than the control (p-value <0.05) while those made with low melt did not show a difference. There was no difference in peak force required to cut baked pastries made with the different fractions.

2.5 Discussion

2.5.1 A small increase in fat percent had a significant impact on performance of butter in laminated pastry

Butter is integral to the laminated dough process to such a degree that the physical properties of the butter will affect each part of the process. Previous studies have evaluated individual butter properties such as fat acid composition or crystallization (Yella Reddy, 2010; Buldo et al., 2013a). Evaluation of butter performance during actual production is sparse, one study evaluated butter in a pastry matrix in contrast to shortening (Mattice and Marangoni, 2017). This study directly compared the lamination and baking performance of two butters (same source milk, production day, equipment, facility, etc) differing only in fat content (80% vs. 82%) and conversely moisture content (18% vs. 16%). The 80% butter performed poorly during shaping, with frequent and expanded breaking. Visible breaks in the initial shaping were followed by additional breaks as the butter was laminated. This was confirmed by microscopic evaluation of layers. Breaks in the butter layer create a uneven and nonhomogeneous sheet of dough challenging automated equipment that rely on consistent and even shaping and cooling (O'Brien, 2004). These breaks did not manifest during shaping or lamination with 82% fat samples. Results from DSC indicate that the amount of fat itself will not have a significant effect on the melting profile. This would suggest that contributions to physical behavior from fat acid composition are not dependent on the amount.

Laminated dough made with 82% fat butter was significantly stronger than dough made with 80% fat. This may be due in part to the difference in water content of the butter, as moisture content is known to influence the viscoelastic properties of a dough (Masi et al., 1998). The difference in dough strength is of practical significance as well since laminated doughs tend to require a higher degree of physical manipulation to shape than bread (Suas, 2009).

Baked pastries made with 82% butter had significantly higher total rise and were softer than those made with 80% butter. Total product height and interior visible texture is a functional and aesthetic expectation for laminated pastries. The findings of this study confirm a previous report by Silow et al., (2017) that higher fat content produced softer puff pastry. Traditionally, laminated pastries were consumed shortly after baking; however, present market demand includes products that can withstand packaging, distribution, and extended storage. The softer crumb structure of the finished pastry made with 82% fat may extend shelf life when challenged by the staling and firming effects of starch retrogradation over time (Sternhagen and Hoseney, 1994).

2.5.2 Impact of butter fractionation on dough behavior and pastry quality

The measured differences in dough strength and rise suggest the fractionated samples were less suited for baking relative to the control (concentrated, nonfractionated). Changes made to the fatty acid composition of butter using fractionation have practical impacts when used to make pastries. The practical differences in the fractionated samples performance confirmed previous assertions that fractionation would have measurable effects (Breeding and Marshall, 1995; Yella Reddy, 2010).

The control, high, and low melt butter all broke upon initial shaping into butter blocks. The breaks were considerably more pronounced than the original butter. This change was contributed to be a result of the treatment and seemed counterintuitive to our other findings in which butter containing a higher fat percentage displayed improved malleability. It is known that crystallization and how the butter fat is churned into butter affects the malleability of the butter (Buldo et al., 2013a), here we specifically focused on the influence of the fatty acid/triglyceride composition as influenced by melting temperature. We found that there was no difference between the control and fractionated samples in frequency of breaks although there was some difference in how the breaks manifested (Figure 2).

The laminated dough samples made with the high melt fraction had significantly less dough strength and were less extensible than the control (Table 4). In addition, laminated dough made with the high melt fraction displayed visible particles of hard butter that persisted throughout the lamination process (Figure 2.4.1). The particles disrupted the surface of the dough sheet and caused snags and other imperfections, an undesirable effect in both hand shaping and automated processing (O'Brien, 2004). All samples made with low melt oiled out during proofing resulting in butter pooling around the base of the sample (Figure. 1). This created problems with samples slumping over and/or sticking to the parchment and or sheet pan. The visible loss of butter from pastries during proofing was not seen in any other laminated dough samples. This had a measurable and practical impact, low melt samples did not proof as well as the control (Table 4). DSC data confirmed that this was due to changes in the melting profile. These changes not only changed the melting points and range of temperatures but also the relative amounts of solid fat at different points in the process. Fractionation of the low melt sample caused most of the melting to occur in the temperature range before proofing. The little solid fat that did remain going into proofing melted at the low end of the proofing range allowing it to run freely and accumulate at the base of the pastry samples.

Baked pastries made with high melt fractions rose significantly less than the control (Table 4). Pastries made with the high melt fraction also had noticeable holes in the final pastry as the previously mentioned particles did not melt until in the oven (Fig. 2.4.1). DSC data confirmed that the melting profile in the high melt samples was changed and most of the solid fat was still present going into proofing (Fig.2.5.1). The melting profile and range imparted a higher peak melting point than the control and low melt samples as well as a wider range. These changes in melting profile were somewhat expected but not the practical affects. Yella Reddy, (2010) suggested

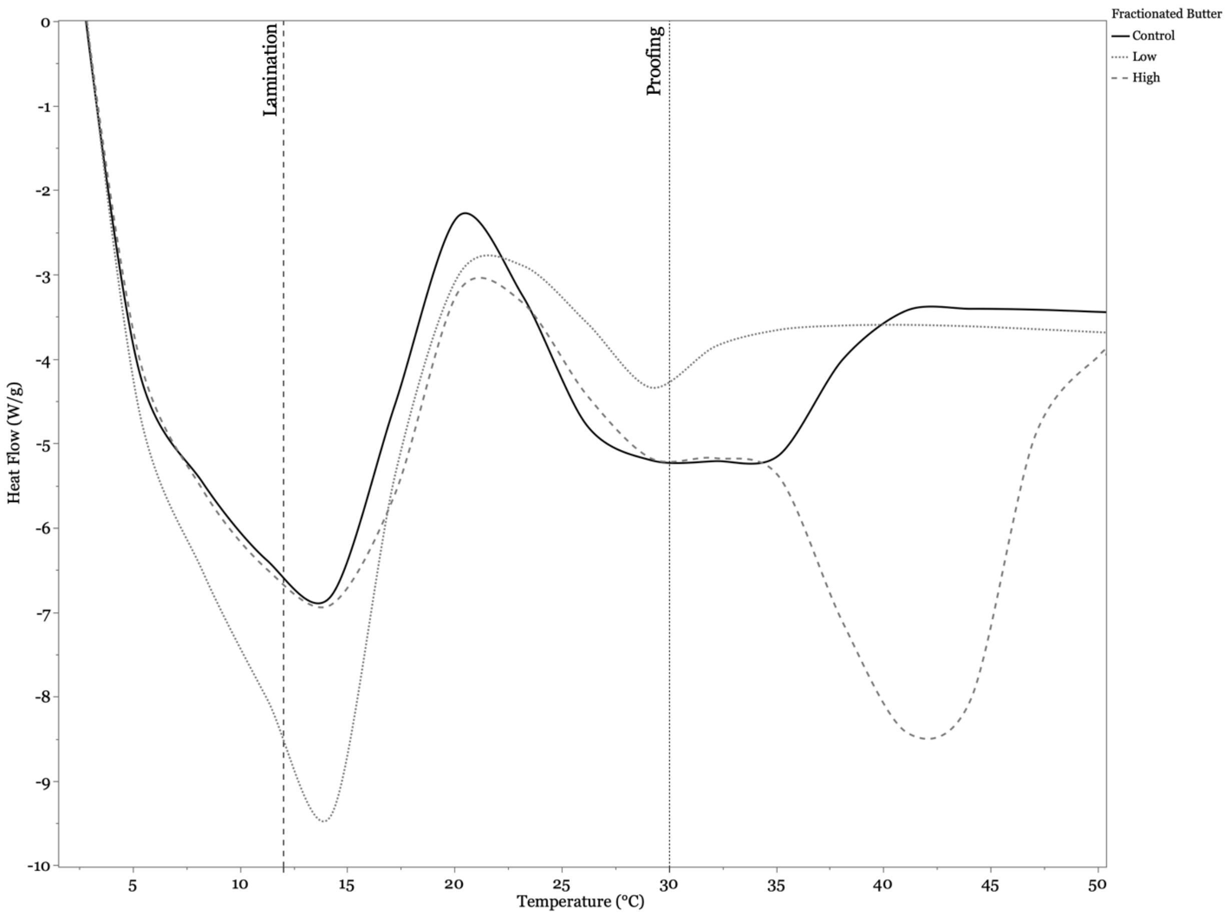

Figure 2.5.2 Average differential scanning calorimetry (DSC) scans of A) concentrated, nonfractionated butter, B) low temperature butter fraction, and C) high temperature fraction butters used to prepare laminated dough.

that the higher melt fraction would improve the baking qualities of butter. The measured differences in texture and rise between the control and high melt samples were likely due to the macroscopic imperfections described above. It is well known that minor imperfections and large holes as observed here will have a negative impact on the final product (O'Brien, 2004).

2.5.3 Fatty Acid Composition

Fatty acids do not exist independent of triglycerides in butter fat or the cream from which it is made. This is apparent in the resulting fat acid composition of samples in this study as well as those of others (Fouad et al., 1990; Breeding and Marshall, 1995; Yella Reddy, 2010). Although some methods of separation have produced more pronounced separation, the natural variation of individual triglyceride will limit any process reliant entirely on physical properties for separation. It has also been observed that variations in butter from season and feed can contribute to the physical properties relevant to baking (Bent, 2007). With the variations in fatty acid composition from season and feed it is difficult to gage the success of a fractionation solely on chromatographic analysis of individual fatty acids. Fouad et al., (1990) noted that although the difference between the compositions of fractionated samples appear minimal, fractionated butter samples would need to be evaluated in actual use to accurately assess their properties. A review of other results (Fouad et al., 1990; Breeding and Marshall, 1995; Yella Reddy, 2010) confirmed different and often small changes in the amounts of individual fatty acids. Upon further inspection they also exhibited something in common, the relative amount of total saturated fatty acids

(SFA) and unsaturated fatty acids (UFA). In each instance the “harder fraction” has more SFA and less UFA than the “softer fraction”. This change in relative amounts of SFA and UFA were also observed in the fractionated samples made during this study

2.6 Conclusions

The fat content of butter influenced its baking properties when used to produce pastries independent of the butters melting profile. Pastry dough made with 82% butterfat content were easier to manipulate and form. Breaks in butter were regularly observed in butter containing 80% butterfat content. 82% fat butter remained continuous when laminated and was more resistant to physical manipulation with direct impact on a baker’s abilities to create delicate shapes. Pastries produced with higher fat butter were taller and softer.

It was observed that specific physical properties associated with baking can be manipulated through fractionation. Melting point and range was acutely affected as well as its resistance to physical manipulation. This study did confirm that physical properties of the butter may be manipulated by fractionation. The findings suggest that further investigation into using fractionated butter to adjust a butters physical performance could be an area of butter quality and enhancement of butter for baking applications.

Acknowledgments

Funding for this study was provided by BUILD Dairy with support from High Desert Milk (Burley, ID). We would like to thank Chefs Pascal Tisseur and Ciril Hitz for sharing their baking knowledge and expertise that guided this project and Brandon Riesgaard (OSU) for his daily support in the bakery. We would also like to thank Dr. Jadwiga Giebultowics of Oregon State University's Veterinary Diagnostic Laboratory for the use of the OMAX Compound Microscope and Dr. Skip Rochefort and Merrit Barber of the Department of Biological Engineering (OSU) for training and use of the differential scanning calorimeter. The authors would also like to thank Dr. Paul Hughes and Robin Frojen (OSU) for lending their time and facilities. We would also like to thank Eileen Chow and students and staff of the Department of Food Science and Technology for their assistance and feedback throughout the course of this research.

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Chapter 3: Butter Properties Impact on Croissant Quality

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Prepared for submission to the Journal of Dairy Science

Abstract

The objective of this study was to evaluate the functional performance of commercial butters (n = 12; half domestic and half imported) and identify butter characteristics that contribute to physical quality characteristics of baked croissants. Composition, melting profile, and performance during lamination were the primary focuses of these evaluations. Twelve different butters (six domestic and six imported) were analyzed using differential scanning calorimetry to evaluate melting points. Fatty acid composition of each butter sample was determined by gas chromatography (GC) analysis of total fatty acid methyl esters (FAME). Fat content of butter samples were tested using the Mojonnier method. Butter samples were used to prepare croissants. Representative samples were cut in half and photographed. This study applies a combination of technical and practical analyses in an effort to better understand what differentiates commercially available butter.

Introduction

As consumers shift their attention to ingredient labels alternative functional ingredients have waned in popularity in search of healthier natural alternatives

(Román et al., 2017; Laughman, 2018). Butter has seen a resurgence in popularity due to various factors such as its perception as a natural product and clean label (Krause et al., 2007). This trends with increased global demand for butter seen in a increase in total global retail butter sales of 2.9% in 2018 (Gale, 2018). Driving some of this growth are recent studies highlighting the risks of trans fats, consumers are increasingly interested in natural fats, including butter. This interest has brought increasing market demand that has helped to drive butter prices up to an average retail price of $3.43/lb in 2019(Bentley, 2016). Retail butter sales in North America grew 7% since 2012 to 2017 and consumers are responding to product differentiation with packaging displaying higher fat content, European-style, cultured, grass-fed, and/or organic butters at premium prices (Gale, 2018). The U.S. standard for butter is a minimum fat content of 80% however, retail market differentiation is being created based specifically on higher fat content to market premium brand butters. For most food products, the variability of butter quality in the market would have a minimal impact on the finished product (i.e., any butter would be suitable). However, there are certain products that demand butter to perform on a functional level where the characteristics of the final product are absolutely dependent on the butter quality. Laminated pastries, specifically croissants, are an example of such a product.

Croissants are a laminated pastry composed of 18 to greater than 100 alternating layers of dough and fat. The thin layering of fat creates a barrier that traps water vapor between dough layers during baking which leads to the characteristic flaky, alveolar crumb of a croissant (Ooms et al., 2017; Lucas et al., 2018). The fat will make up 30-35% w/w of the total formulation and will have impact production processes and influence the quality of the final product (De La Horra et al.). Butter has historically been the preferred fat used for laminated pastries for its functional properties as well as its contribution to flavor (Gassenmeier and Schieberle, 1994) (Suas, 2009) (Krause et al., 2007). The amount of physical work and stress that the butter is exposed to during the lamination process requires butter to have specific qualities, such as a suitable melting profile and plasticity at working temperature (O'Brien, 2004). Practical challenges of the production process of croissants require malleability in temperature ranges between refrigerated and room temperature while maintaining enough solid fat through proofing to maintain sufficient cohesiveness to not "oil out".

Butter is typically marketed towards bakers based on fat content. Higher fat butter (>82%) is commonly labeled as European-style and commands a premium price. Recent research has demonstrated that butter with 82% butterfat was; more resistant to physical manipulation, remained continuous when laminated, and produced pastries that were taller and softer as compared to 80% fat butter made with the same cream and equipment (Ramirez et. Al 2020).

Specific properties that may have an effect on the baking properties of a butter or other fat matrix include crystallization, fat acid profile, feed, and fractionation (Breeding and Marshall, 1995; Kay et al., 2005; Yella Reddy, 2010; O'Callaghan et al., 2016a). Efforts to create lower cost alternatives that mimic butters functional properties have led to studies comparing alternatives (Lefébure et al., 2013; Ooms et al., 2016). It has been found that shortenings had an effect on hardening of croissants over time (Mattice and Marangoni, 2017). It has also been found that the amount of fat used matters (Silow et al., 2017). Although multiple studies have compared shortenings or margarines in pastry we believe this is one of a few that compares butters in the croissant matrix.

The objective of this study was to evaluate the functional performance of commercial butters (n = 12; half domestic and half imported) and identify butter characteristics that contribute to physical quality characteristics of baked croissants. Composition, melting profile, and performance during lamination were the primary focuses of these evaluations. This study applies a combination of technical and practical analyses in an effort to better understand what differentiates commercially available butter.

3.1 Materials and Methods

3.1.1 Commercial Butters.

Commercially available butters (n =12) were purchased from retail grocery stores in the Portland, Oregon area and online. Designated butter properties of commercial products are displayed in Table 1. All butters were purchased within 2 weeks of each other and stored at 2 °C for up to 4 weeks prior to use. Butter was tempered to 4°C for 12 hrs prior to shaping into butter blocks. Butter blocks (25% w/w of dough) were

Table 1. Croissant dough ingredients and formulation.

Ingredient	**Product Information**	**Ingredient ratio (baker's percent)**
Wheat flour	Organic Artisan Bakers Craft Plus (11.5% protein), Central Milling, City, UT	100 g
Sugar	C&H Bakers Sugar, Domino Foods, Inc, Yonkers, NY	10 g
Butter	Matched with butter for lamination	6.0 g
Salt	Morton Table Salt (without iodine), Company info, Chicago, IL	2.0 g
Yeast	Lasaffre Gold Instant Yeast, Lesaffre Yeast Corp, Milwaukee, WI	1.6 g
Water	Municipal tap water, Corvallis, OR	50 ml

shaped using a combination of a rolling pin, an envelope made of parchment paper (30 cm x 20 cm), and a sheeter (Rondo SSO615 Ecomat Floor Model Sheeter, RONDO, Burgdorf, Switzerland). Each butter sample was inspected for leaking, visible stress fractures after initial shaping, and visible gaps in butter sheet. Butter blocks were tempered to 12°C before incorporating into laminated dough.

3.1.2 Fat content and melting profile

Butter was tested for fat content using the Mojonnier method AOAC 922.06 at Element Materials Technology in Portland, Oregon. Samples were analyzed in duplicate and results averaged to obtain final fat percentage. A differential scanning calorimeter (DSC) was used to identify melting points or ranges of temperatures at which melting occurred in each sample (TA Instruments-Waters LLC New Castle, DE). Samples of butter weighing 10-15 mg were placed into aluminum pans and hermetically sealed. Samples were held at 2 °C for 2 min then heated at 5 °C/min to 70°C. Data were analyzed using Universal Analysis software (TA Instruments-Waters LLC New Castle, DE) to identify peak and range of melting temperature. Each sample was prepared and analyzed in triplicate. Characteristic temperatures of DSC analysis were identified following the conventions presented in ISO 11357-1:2009(en) (Figure 1)

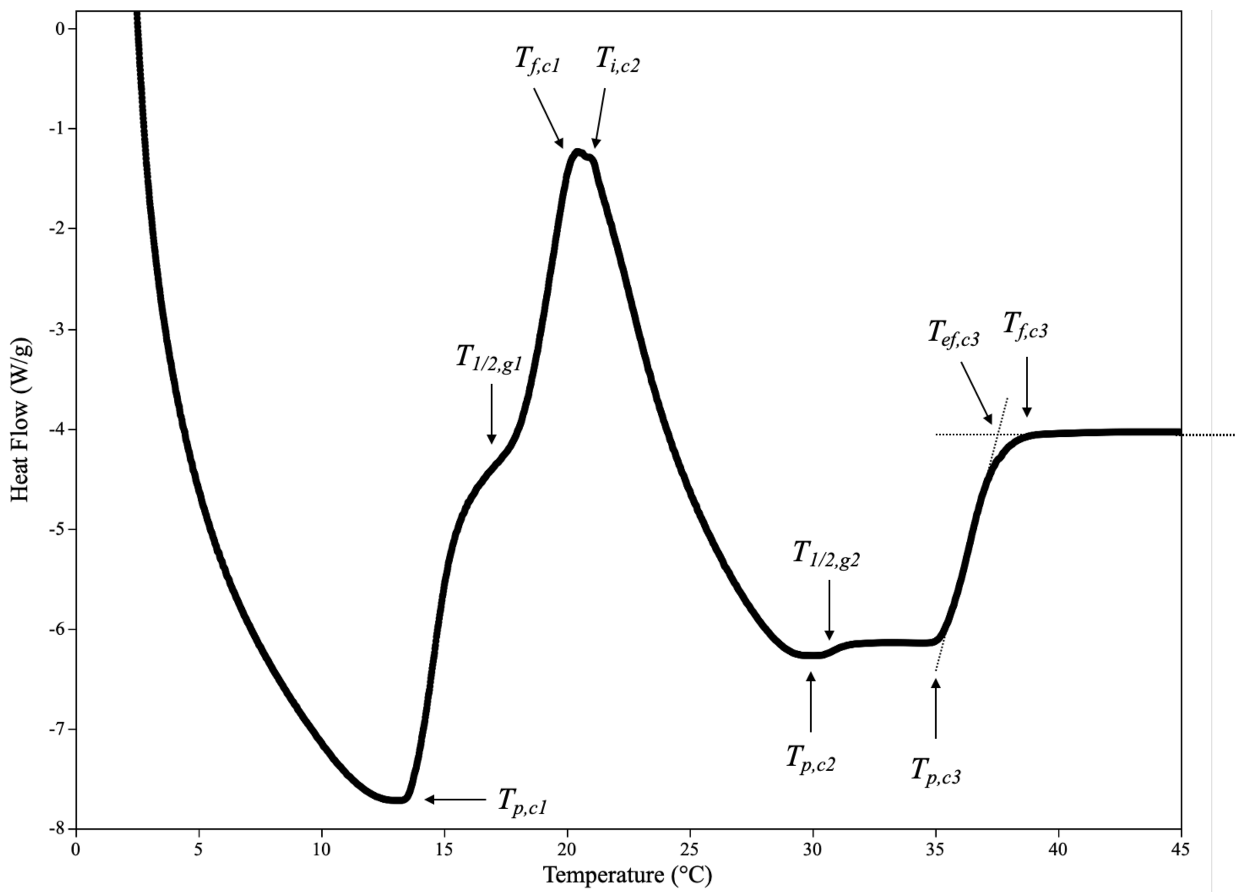

Figure 1. Representative Differential Scanning Calorimeter (DSC) profile of a single butter sample labeled with significant temperatures as described in ISO 11357-1:2009(en). T = Temperature (C), T_i = onset temperature (first detectable deviation from extrapolated baseline), $T_{1/2}$ = midpoint temperature (half-height of step), T_p = peak temperature (greatest distance between curve and virtual baseline), T_{ef} = extrapolated end temperature ((for a peak) point of intersection of interpolated virtual baseline and tangent drawn at point of inflection of far side of peak or (for a step) point of intersection of extrapolated end baseline and tangent drawn at point of inflection of step), T_f = end temperature (last detectable deviation of curve from extrapolated baseline), T_g = glass transition, and T_c = crystallization.

3.1.3 Fatty acid composition

The fatty acid composition of each butter sample was determined by gas chromatography (GC) analysis of total fatty acid methyl esters (FAME). FAME were prepared using methods adapted from Christie (1993). Briefly, FAME were synthesized from whole butter samples using 1% sulfuric acid in dry methanol up to a maximum concentration of 5mg/mL. Samples were incubated at 50°C for 16 hr with agitation. Samples were neutralized with 2 mL of aqueous potassium bicarbonate (2%, w/v) and FAME extracted with 1:1 (v/v) hexane/diethylether (2 x 1 mL). FAME extracts concentrated under nitrogen to approximately 50 μL before analysis, samples stored at -4°C until time of analysis. FAME standards (Nu-Check Prep, Elysian MN) were used to identify fatty acids reported. Samples were analyzed on a HP5890 (Hewlett-Packard, Wilmington, DE) equipped with flame ionization detection. Fatty acids were separated on a SLB-IL111i (60 m x 0.25 mm x 0.2 μm) column (Supelco, Bellefonte, PA) using hydrogen as the carrier gas, 10:1 split ratio, and 1 μL injections. Data were collected in quadruplicate (n = 4). Results are presented as percent composition of fatty acids.

3.1.4 Croissant dough preparation

Croissant dough was prepared using a method adapted from Ooms et al. (2017). Briefly, croissant dough was prepared using the formulation shown in Table 2. Dough ingredients were measured into and then mixed in a Hobart A200 commercial mixer (Troy, OH) with a C-hook for 7.5 min on lowest setting at 25°C. Dough was proofed at 30°C for 1 hr in a standard 20 qt (18.9 L) mixing bowl. After proofing, dough was punched down into a ½ sheet pan (18”x13” aluminum), and chilled in a -10°C freezer for approximately 50 min to achieve a dough temperature of 12°C. Previously formed butter blocks were tempered to 12°C and enclosed in the proofed and tempered dough using the method described by Suas (2009). The dough was sheeted (Rondo SSO615 Ecomat Floor Model Sheeter, RONDO, Burgdorf, Switzerland) in eight reducing steps using the marked intervals on the sheeter to reduce the thickness from approximately 3 cm to 1 cm and rested at -10°C for 25 min. The dough was sheeted a second time to reduce the thickness to 1 cm before folding and resting again. The dough was turned 90° between each sheeting. This sequence of folding, resting, and sheeting was performed a total of 3 times. After the final sheeting, the dough was turned and sheeted to a thickness of ~5 mm resulting in a final laminated dough of approximately 20 cm x 36 cm. A chef’s knife was used to cut the final dough sheet into 12 triangles (6 cm x 8 cm) (Figure 2). Triangles were then rolled into croissants (~32 cm in height) and evenly spaced out on a parchment paper-lined sheet pan (18”x 26” aluminum) and the height of each croissant was measured using a digital height gauge (SDV-6”A Mitutoyo, Japan). Formed croissants were proofed at 30°C for 90 min at 80% relative humidity in a proofing box (Doyon E 2330, Linière, Québec, Canada) and then baked at 196°C for 15 min in a rotating convection oven (Mini Rotating Rack Oven, Baxter, Orting,WA). Baked croissants were allowed to cool on sheet pans at ambient temperature (~22°C) for 1 hr and the baked height was measured and recorded. From each batch, one croissant was selected and cut in half with bread knife and the cross-sections were digitally photographed (Samsung Galaxy 10 Tablet, Korea).

3.1.5 ImageJ Analysis

Using the software ImageJ photos were scaled, cropped, and contrast was adjusted before a macro named CroissantHoles_rbr200.ijm. was used converted to black and white for analysis.Then a separate macro named MeasureHolesArea.ijm. was used to tabulate data.

3.1.6 Data Analysis.

Significant differences in individual variables across butters were determined using a one-way ANOVA with a Tukey's HSD ($p<0.05$). Principal Component Analysis (PCA) was used to explore correlations between variables. All measured variables were included in PCA analysis with butter brand as the supplementary variable.

Based on croissant preparation procedures, the laminated thickness and laminated weights of the croissants should have been nearly identical across all days of baking/preparation; therefore, these parameters were compared across days and by order within the day (one-way ANOVA, Tukey's HSD, $p<0.05$) to determine if day or order of preparation significantly contributed to differences in dough performance.

3.2 Results

3.2.1 Butter Composition and Melting Temperature Profiles

Butterfat content of commercial samples ranged from 80.3% to 87.2% with no significant difference between the average domestic butterfat (82.72 ± 0.88%) and average imported butterfat (84.15 ± 0.63%) (Table 2). Standard domestic retail butters were confirmed to contain 80% butterfat, whereas butters labeled to contain higher levels of butterfat contained higher than the labeled content by 0.4% to 5.2%.

Solids-nonfat ranged from 1.3 to 2.3% and salt ranged from <0.00 to 0.21% for unsalted butters, whereas the single salted butter had a salt content of 1.60%. The

Table 2. Commercial butter composition. Table 2. Commercial butter composition.

Source	**Butter Sample**	**Butterfat (%)**	**Solids-Nonfat (SNF; %)**	**Salt (%)**	**Moisture (%)**
Domestic	12; 80%	80.3 ± 0.2^{C}	1.3	1.60	18.5
	3; 80%	80.3 ± 0.2^{C}	1.6	<0.00	18.1
	7; 82%	82.4 ± 0.6^{C}	2.3	0.07	15.8
	11; 82%	83.5 ± 0.6^{C}	2.1	0.02	16.0
	1; 73%	84.1 ± 0.3^{BC}	2.2	0.04	14.8
	10; 85%	85.7 ± 0.2^{AB}	2.1	0.02	13.9
	Average Domestic	**82.72 ± 0.88**	**1.94 ± 0.16**	**0.29 ± 0.26**	**16.22 ± 0.74**
Imported	5; 82%	83.0 ± 0.2^{C}	1.9	0.21	15.7
	6; 82.4%	83.2 ± 0.1^{C}	2.2	0.10	15.7
	8; 80%	83.5 ± 0.2^{C}	2.2	0.07	15.4
	4; 82.9%	83.8 ± 0.4^{BC}	1.7	0.02	15.4
	2; 82%	84.2 ± 0.6^{BC}	1.8	<0.00	15.3
	9; 82%	87.2 ± 0.1^{A}	1.9	<0.00	12.5
	Average Imported	**84.15 ± 0.63**	**1.94 ± 0.09**	**0.06 ± 0.03**	**15.00 ± 0.50**

Table 3. Fatty acid composition (g fatty acid/100 g total fat) of commercial butters

Source	Butter Sample	C4:0	C6:0	C8:0	C10:0	C12:0	C14:0	C16:0	C18:0	C18:1	C18:2	C18:3	SFA	UFA
Domestic	12	0.53 ± 0.01^{AB}	1.33 ± 0.00	1.03 ± 0.06^{AB}	2.71 ± 0.04^{AB}	3.35 ± 0.04^{CD}	10.85 ± 0.07^{FG}	35.31 ± 0.06	14.28 ± 0.02^{AB}	26.78 ± 0.13	3.39 ± 0.01^{A}	$0.47 \pm 0.01B^{C}$	69.37 ± 0.11^{AB}	30.63 ± 0.11^{AB}
	3	0.29 ± 0.04^{CDE}	1.42 ± 0.17	1.33 ± 0.15^{A}	3.44 ± 0.30^{A}	3.97 ± 0.27^{BC}	12.57 ± 0.60^{BCD}	36.01 ± 2.24	10.58 ± 0.95^{D}	26.54 ± 1.60	3.36 ± 0.18^{A}	0.50 ± 0.03^{BC}	69.60 ± 1.81^{AB}	31.80 ± 1.81^{AB}
	7	0.40 ± 0.01^{ABCD}	1.17 ± 0.01	1.03 ± 0.02^{AB}	2.58 ± 0.07^{B}	3.63 ± 0.13^{BCD}	11.22 ± 0.09^{DEFG}	32.70 ± 0.01	15.12 ± 0.17^{A}	28.34 ± 0.18	3.33 ± 0.01^{A}	0.50 ± 0.01^{BC}	67.83 ± 0.17^{B}	30.43 ± 0.17^{B}
	11	0.44 ± 0.02^{AB}	1.13 ± 0.02	0.91 ± 0.02^{B}	2.57 ± 0.06^{B}	3.24 ± 0.03^{D}	10.33 ± 0.08^{G}	36.45 ± 0.16	14.50 ± 0.07^{A}	26.79 ± 0.31	3.21 ± 0.01^{A}	0.43 ± 0.01^{C}	69.57 ± 0.31^{AB}	30.43 ± 0.31^{AB}
	1	0.39 ± 0.01^{BC}	1.06 ± 0.06	0.88 ± 0.02^{B}	2.54 ± 0.03^{B}	3.42 ± 0.00^{CD}	11.18 ± 0.03^{EFG}	35.74 ± 0.09	13.37 ± 0.03^{ABC}	27.81 ± 0.10	3.09 ± 0.04^{AB}	0.52 ± 0.01^{BC}	68.58 ± 0.05^{AB}	31.42 ± 0.05^{AB}
	10	0.56 ± 0.03^{A}	1.20 ± 0.08	0.98 ± 0.05^{B}	2.74 ± 0.14^{AB}	3.74 ± 0.05^{BCD}	12.11 ± 0.22^{CDEF}	38.01 ± 0.44	11.78 ± 0.16^{CD}	25.67 ± 1.04	2.66 ± 0.04^{B}	0.55 ± 0.01^{B}	71.12 ± 1.00^{AB}	28.88 ± 1.00^{AB}
	Average Domestic	**0.43 ± 0.04**	**1.22 ± 0.05**	**1.03 ± 0.07**	**2.76 ± 0.14**	**3.56 ± 0.11***	**11.38 ± 0.34***	**37.70 ± 0.71**	**13.27 ± 0.72***	**26.98 ± 0.39**	**3.17 ± 0.11***	**0.49 ± 0.02***	**69.34 ± 0.45**	**30.65 ± 0.45**
Imported	5	0.30 ± 0.01^{DE}	1.34 ± 0.02	1.09 ± 0.00^{AB}	3.00 ± 0.02^{AB}	4.07 ± 0.10^{B}	13.55 ± 0.02^{AB}	36.29 ± 0.35	11.70 ± 0.15^{CD}	26.38 ± 0.29	1.59 ± 0.05^{CDE}	0.75 ± 0.01^{A}	71.09 ± 0.28^{AB}	28.91 ± 0.28^{AB}
	6	0.48 ± 0.02^{AB}	1.04 ± 0.02	1.02 ± 0.00^{AB}	2.96 ± 0.04^{AB}	3.97 ± 0.13^{BCD}	12.63 ± 0.14^{ABCDE}	35.83 ± 0.02	11.41 ± 0.03^{CD}	28.08 ± 0.18	2.06 ± 0.03^{C}	0.55 ± 0.01^{B}	69.32 ± 0.22^{AB}	30.68 ± 0.22^{AB}
	8	0.52 ± 0.01^{AB}	1.32 ± 0.03	1.12 ± 0.01^{AB}	2.99 ± 0.01^{AB}	4.25 ± 0.02^{B}	13.41 ± 0.02^{ABC}	33.57 ± 0.01	11.67 ± 0.04^{CD}	28.89 ± 0.03	1.42 ± 0.01^{DE}	0.84 ± 0.04^{A}	68.85 ± 0.02^{AB}	31.15 ± 0.02^{AB}
	4	0.40 ± 0.03^{BC}	1.21 ± 0.07	0.95 ± 0.05^{B}	2.78 ± 0.09^{AB}	5.88 ± 0.11^{A}	13.99 ± 0.06^{A}	36.02 ± 0.12	10.85 ± 0.07^{D}	25.91 ± 0.17	1.21 ± 0.02^{E}	0.81 ± 0.01^{A}	64.88 ± 0.18^{AB}	35.12 ± 0.18^{AB}
	2	0.40 ± 0.02^{ABC}	1.14 ± 0.03	1.00 ± 0.02^{AB}	2.76 ± 0.07^{AB}	3.75 ± 0.10^{BCD}	12.86 ± 0.22^{ABCDE}	34.83 ± 0.51	12.03 ± 0.14^{BCD}	27.76 ± 1.07	2.65 ± 0.04^{B}	0.80 ± 0.01^{A}	67.76 ± 0.03^{B}	32.25 ± 0.03^{B}
	9	0.18 ± 0.00^{E}	1.30 ± 0.14	1.06 ± 0.01^{AB}	3.15 ± 0.01^{AB}	4.30 ± 0.04^{B}	13.61 ± 0.08^{AB}	37.73 ± 0.32	11.59 ± 0.05^{CD}	24.78 ± 0.52	1.81 ± 0.04^{CD}	0.49 ± 0.01^{BC}	72.92 ± 0.56^{A}	27.08 ± 0.56^{A}
	Average Imported	**0.37 ± 0.05**	**1.23 ± 0.13**	**1.04 ± 0.03**	**2.95 ± 0.16**	**4.39 ± 0.76***	**13.37 ± 0.21***	**35.61 ± 0.56**	**11.54 ± 0.39***	**27.00 ± 0.62**	**1.79 ± 0.21***	**0.71 ± 0.06***	**70.50 ± 0.72**	**29.49 ± 0.72**

Values presented are the mean ± standard error (n = 3).
Samples within the same column that do not share the same superscript letter are significantly different (p-value <0.05).
*Indicates significant differences between domestic and imported butters (p-value <0.05; n = 6 butters per source).

moisture content of butters ranged from 12.5% to 18.5%, with no significant difference between domestic and imported butters.

The fatty acid content profile varied across commercial butter samples (Table 3). Commercial butters contained the highest levels of palmitic acid (C16:0) and oleic acid (C18:1) averaging from 35.7 g/100 g and 26.9 g/100 g, respectively. There were no significant differences in the content of these fatty acids between commercial butters or between domestic and imported butters. Oleic acid (C18:1) and myristic acid (C14:0) content differed

When grouped into domestic and import butters only differences in C 12:0, C 14:0, C 18:0, C 18:2, and C 18:3 were significant ($p<.05$) (Table 3). Sample 9 had the highest saturated fatty acid levels (72.92% saturated fat), whereas sample 2 and 7 had significantly lower saturated fatty acid levels (67.76% and 67.83%, respectively). C14:0 (12.3%) and C18:0 (12.5%) accounted for a large percentage of the remaining fatty acids in the butters. Remaining fatty acids (C4:0, C6:0, etc) each accounted for less than 4% of the fat weight of the butter (Table 3).

3.2.2 Differential scanning calorimetry

Analysis revealed a significant difference between melting points of domestic and imported butter (Table 4). On average domestic butters melting points were 2.1°C higher than the same imported. The difference was greatest between the two groups at $T_{p,c1}$ 2.71°C and $T_{1/2g1}$ 2.4°C(Table 4). This is particularly interesting since these temperatures are in the working temperature range at which we shaped and laminated the butter. This slight shift towards higher temperatures across melting profiles would

Table 4. Differential scanning calorimetry (DSC) transitions for commercial butters.

Source	Butter Sample	T_{pc1}	$T_{1/2g1}$	T_{fc1}	T_{ic2}	T_{pc2}	$T_{1/2g2}$	T_{pc3}	T_{efc3}	T_{fc3}
Domestic	12	14.12 ± 0.04^{B}	17.88 ± 0.12^{A}	21.35 ± 0.11^{B}	21.96 ± 0.12^{A}	31.14 ± 0.33^{A}	31.66 ± 0.25^{AB}	35.55 ± 0.06^{AB}	37.86 ± 0.11^{AB}	39.28 ± 0.03^{AB}
	3	13.61 ± 0.026^{C}	17.23 ± 0.18^{ABC}	20.42 ± 0.06^{CD}	21.03 ± 0.01^{B}	30.23 ± 0.01^{BC}	31.09 ± 0.04^{B}	34.71 ± 0.02^{CD}	37.24 ± 0.02^{ABC}	38.60 ± 0.04^{BC}
	7	13.44 ± 0.09^{C}	17.34 ± 0.15^{AB}	20.76 ± 0.10^{C}	21.35 ± 0.14^{B}	30.32 ± 0.24^{B}	30.96 ± 0.21^{BC}	35.14 ± 0.26^{BC}	37.64 ± 0.16^{AB}	39.66 ± 0.18^{A}
	11	14.60 ± 0.03^{A}	18.32 ± 0.02^{A}	21.91 ± 0.03^{A}	22.44 ± 0.03^{A}	31.33 ± 0.17^{A}	32.12 ± 0.13^{A}	36.08 ± 0.08^{A}	38.33 ± 0.20^{A}	39.79 ± 0.13^{A}
	1	13.40 ± 0.10^{CD}	17.14 ± 0.07^{ABC}	20.57 ± 0.11^{C}	21.25 ± 0.11^{B}	30.22 ± 0.10^{B}	31.03 ± 0.16^{B}	35.33 ± 0.07^{BC}	37.59 ± 0.06^{AB}	38.69 ± 0.19^{BC}
	10	13.09 ± 0.05^{DE}	17.65 ± 0.60^{A}	19.96 ± 0.05^{D}	20.51 ± 0.02^{C}	29.60 ± 0.13^{C}	30.29 ± 0.19^{CD}	34.48 ± 0.16^{D}	36.99 ± 0.08^{BCD}	38.49 ± 0.11^{C}
	Average Domestic	**13.71 ± 0.22***	**17.59 ± 0.18***	**20.86 ± 0.28***	**21.42 ± 0.28***	**30.47 ± 0.26***	**31.19 ± 0.26***	**35.20 ± 0.25***	**37.61 ± 0.19***	**39.18 ± 0.26***
Imported	5	12.62 ± 0.04^{FG}	15.94 ± 0.13^{DE}	17.89 ± 0.05^{F}	19.39 ± 0.04^{D}	28.55 ± 0.07^{D}	29.26 ± 0.05^{E}	33.10 ± 0.01^{EF}	35.00 ± 0.03^{EF}	36.65 ± 0.04^{EF}
	6	12.34 ± 0.12^{GH}	15.98 ± 0.01^{CDE}	18.86 ± 0.14^{E}	19.40 ± 0.15^{D}	28.77 ± 0.14^{D}	29.53 ± 0.24^{E}	33.61 ± 0.10^{E}	35.80 ± 0.05^{DE}	37.30 ± 0.04^{DE}
	8	11.26 ± 0.06^{I}	15.18 ± 0.07^{EF}	17.88 ± 0.05^{F}	18.33 ± 0.04^{E}	27.55 ± 0.03^{E}	28.32 ± 0.05^{F}	32.26 ± 0.01^{G}	34.04 ± 0.56^{F}	36.38 ± 0.06^{F}
	4	10.52 ± 0.10^{J}	14.09 ± 0.04^{F}	15.83 ± 0.02^{G}	17.58 ± 0.04^{F}	26.95 ± 0.04^{E}	27.76 ± 0.07^{F}	32.86 ± 0.12^{FG}	35.19 ± 0.05^{EF}	36.15 ± 0.06^{F}
	2	12.18 ± 0.09^{H}	15.28 ± 0.11^{DEF}	19.02 ± 0.19^{E}	19.72 ± 0.18^{D}	28.72 ± 0.07^{D}	29.42 ± 0.02^{E}	33.23 ± 0.04^{EF}	35.38 ± 0.19^{E}	36.48 ± 0.06^{EF}
	9	12.79 ± 0.03^{EF}	16.45 ± 0.04^{BCD}	19.24 ± 0.08^{E}	19.70 ± 0.07^{D}	28.94 ± 0.06^{D}	29.71 ± 0.06^{DE}	33.68 ± 0.04^{E}	36.08 ± 0.14^{CDE}	37.47 ± 0.25^{D}
	Average Domestic	**11.95 ± 0.36***	**15.49 ± 0.34***	**18.12 ± 0.51***	**19.02 ± 0.35***	**28.25 ± 0.33***	**29.00 ± 0.32***	**33.12 ± 0.21***	**35.25 ± 0.29***	**36.74 ± 0.22***

Values presented are the mean ± standard error (n = 3).
Samples within the same column that do not share the same superscript letter are significantly different (p-value <0.05).
*Indicates significant differences between domestic and imported butters (p-value <0.05; n = 6 butters per source).

suggest a slightly higher proportion of solid fat content in domestic butters in working temperatures.

3.2.3 Baked Croissant Quality – Baked height, moisture loss, and crumb analysis

Final baked height of croissants ranged from 38 mm to 54 mm. Two samples (9.45 mm and 7.21 mm, respectively) rose significantly less than the rest ($p<.05$). An increase of >50% rise in the height of the croissant from laminated, shaped dough to final baked height is considered to be of high quality. Sample 14 had the highest level of rise at 22 mm. Samples 1, 4, 10, and 12 all exhibited rise >17.5 mm. Moisture loss from baking was nearly identical (8.5%) for croissants (by dough and by individual croissant), indicating that moisture loss is driven by water content of the dough and not by the moisture content of the butter. Interestingly, one butter (sample 8) had significantly higher variability in moisture loss across the 12 croissants in the batch (Figure 4). We did not find there to be any significant difference between the average rise between domestic and imported butter (Table 5). The rate of moisture lost across the different samples is very consistent except in sample 8. This suggests that rise and internal structure is independent of the amount of moisture present (Figure x).

The average eye size of croissants was 12.75 mm^2 with sample 12 having the largest average eye size 17.85 mm^2 and sample 6 the smallest eyes 8.35 mm^2 (Table x). The average eye size measured in the croissants made with domestic butter was 2.54 mm^2 ($p<.05$) larger than those made with imported butter. There was also a difference in the distribution of eye size with domestic samples producing croissants

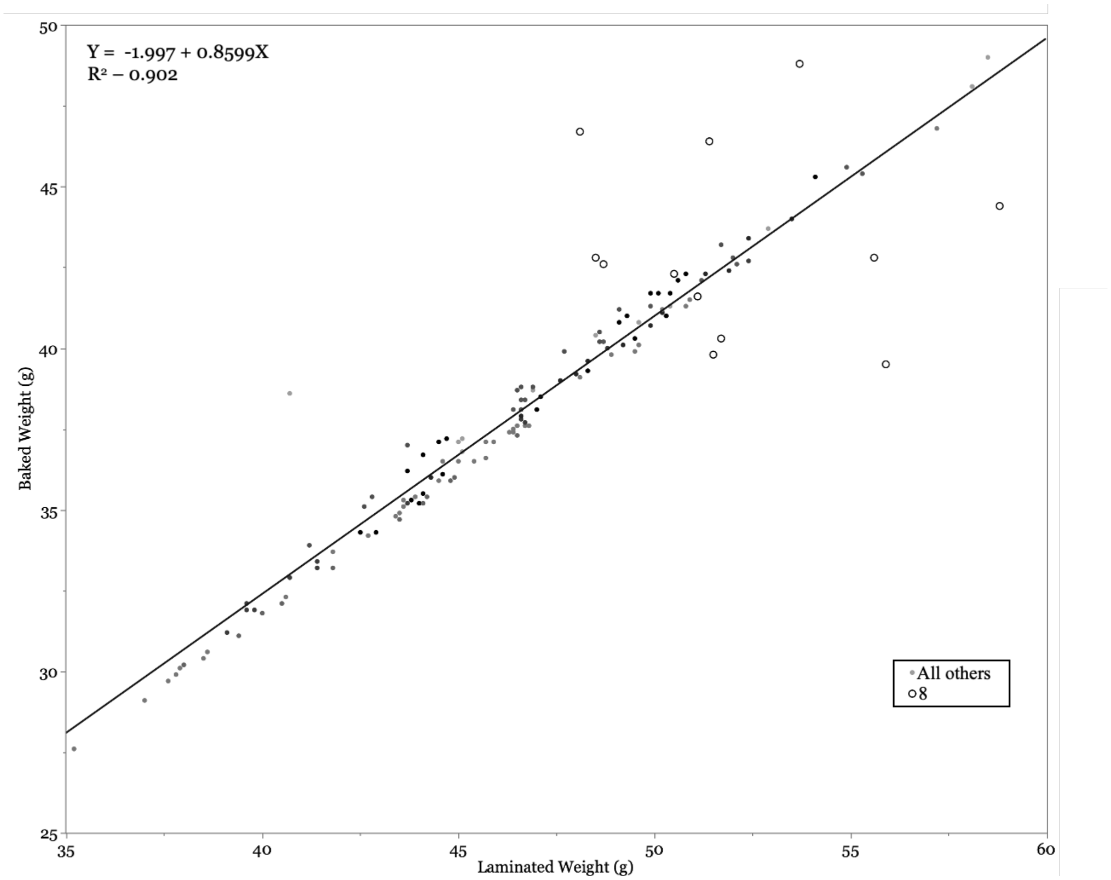

Figure 4. Final weight (g) of baked croissants correlated with weight (g) of laminated dough using commercial butters. Dots represent individual croissants (n = 12) for each commercial butter (n = 12).

2.2.3 Principal component analysis

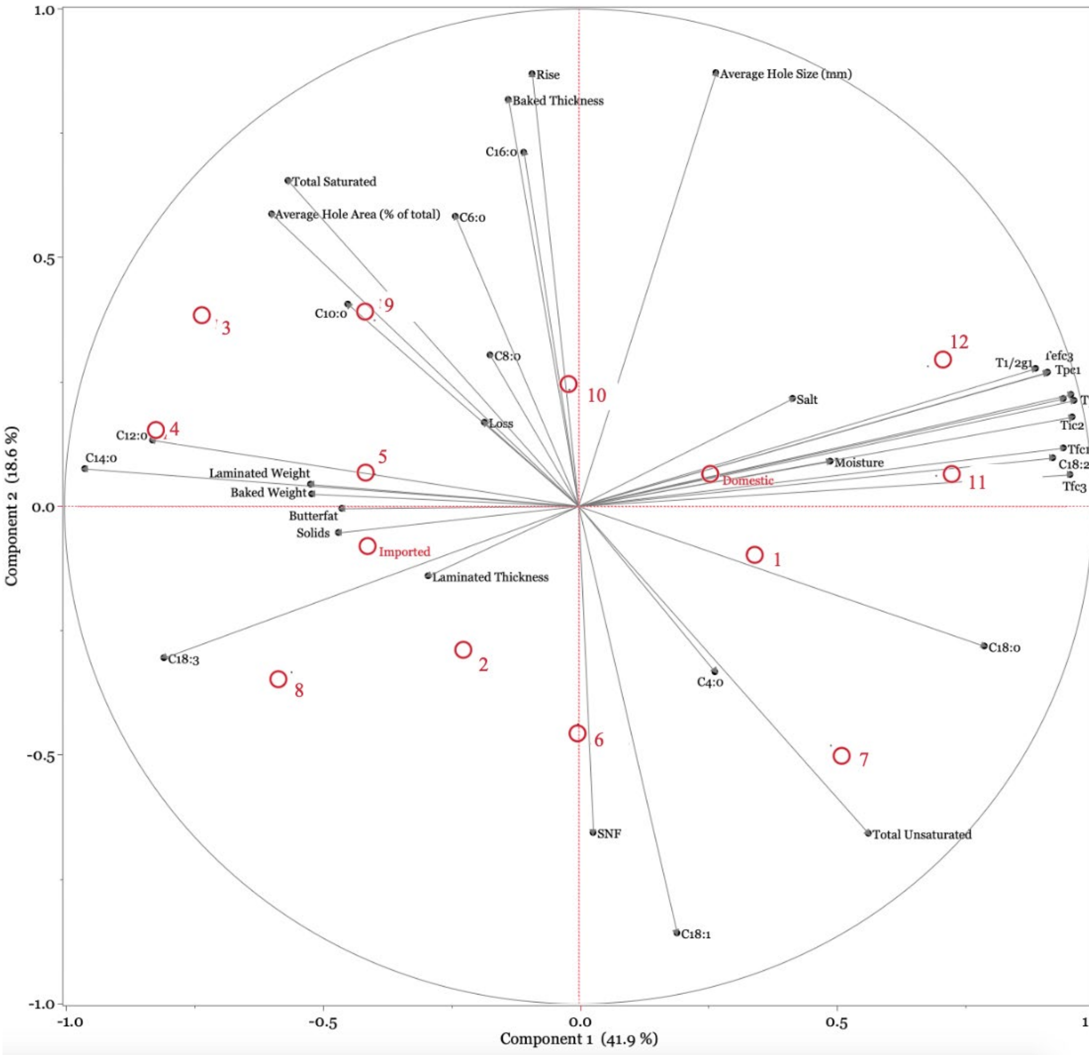

Figure 5. Principal component analysis of butter, dough, and croissant variables using butter brand and source (domestic or imported) as the supplementary variable.

Table 5. Laminated and shaped dough characteristics of individual croissants made with different commercial butters.

Source	Butter Sample	Laminated and Shaped Height (mm)	Laminated Weight (g)
Domestic	12	31.71 ± 0.27^{BCD}	43.32 ± 1.25^{CDE}
	3	31.81 ± 0.13^{BCD}	46.11 ± 0.63^{BCD}
	7	32.85 ± 0.26^{AB}	46.33 ± 0.91^{BCD}
	11	30.76 ± 0.25^{D}	42.80 ± 0.80^{DE}
	1	32.76 ± 0.19^{AB}	47.92 ± 1.15^{ABC}
	10	32.47 ± 0.25^{AB}	49.43 ± 0.76^{AB}
	Average Domestic	**32.06 ± 0.32**	**45.99 ± 1.05**
Imported	5	31.91 ± 0.18^{BCD}	48.44 ± 0.96^{AB}
	6	31.03 ± 0.34^{CD}	39.88 ± 0.93^{E}
	8	33.23 ± 0.27^{A}	52.12 ± 0.95^{A}
	4	31.75 ± 0.12^{BCD}	45.88 ± 0.75^{BCD}
	2	32.00 ± 0.21^{BC}	49.75 ± 0.96^{AB}
	9	32.73 ± 0.35^{AB}	49.28 ± 1.54^{AB}
	Average Imported	**32.11 ± 0.31**	**47.56 ± 1.74**

Values presented are the mean ± standard error (n = 12).
Samples within the same column that do not share the same superscript letter are significantly different (p-value <0.05).

Table 6. Characteristics of baked croissants.

Source	Butter Sample	Baked Height (mm)	Rise (mm)	Baked Weight (g)	Moisture Loss (g)	Average Eye Size (mm^2)	% of Eyes >25 mm^2	Total Eye Area (%)
Domestic	12	49.57 ± 0.46^{CD}	17.87 ± 0.43^{BCD}	35.00 ± 1.07^{DEF}	8.32 ± 0.19	17.85 ± 0.30^{A}	12.05	47.50 ± 2.72^{AB}
	3	53.80 ± 0.34^{A}	21.99 ± 0.30^{A}	37.32 ± 0.53^{BCDE}	8.78 ± 0.11	16.87 ± 0.28^{AB}	11.70	46.52 ± 0.75^{AB}
	7	42.30 ± 0.37^{G}	9.45 ± 0.22^{G}	38.56 ± 0.79^{BCD}	7.77 ± 0.14	8.35 ± 1.02^{C}	7.62	41.18 ± 2.39^{B}
	11	46.36 ± 0.77^{EF}	15.60 ± 0.66^{DEF}	34.17 ± 0.69^{EF}	8.63 ± 0.11	14.23 ± 2.48^{ABC}	9.29	47.04 ± 1.13^{AB}
	1	51.00 ± 0.59^{BC}	18.24 ± 0.62^{BC}	38.83 ± 0.98^{BCD}	9.08 ± 0.17	13.44 ± 0.06^{ABC}	11.06	45.11 ± 1.00^{AB}
	10	52.63 ± 0.63^{AB}	20.16 ± 0.63^{AB}	40.47 ± 0.67^{ABC}	8.96 ± 0.10	13.16 ± 1.07^{ABC}	14.35	49.00 ± 1.98^{AB}
	Average Domestic	**49.28 ± 1.75**	**17.22 ± 1.79**	**37.39 ± 0.98**	**8.59 ± 0.20**	**13.98 ± 1.36**	**11.01 ± 0.95***	**46.06 ± 1.10**
Imported	5	47.59 ± 0.36^{DEF}	15.69 ± 0.35^{DE}	40.32 ± 0.82^{ABC}	8.12 ± 0.15	10.50 ± 1.61^{ABC}	9.91	48.25 ± 2.57^{AB}
	6	38.24 ± 0.38^{H}	7.21 ± 0.43^{G}	31.68 ± 0.81^{F}	8.19 ± 0.12	8.75 ± 0.50^{C}	5.82	42.69 ± 0.63^{AB}
	8	47.75 ± 0.32^{DE}	14.52 ± 0.45^{EF}	43.17 ± 0.84^{A}	8.95 ± 1.30	11.11 ± 1.52^{ABC}	6.87	48.26 ± 2.03^{AB}
	4	51.00 ± 0.31^{BC}	19.26 ± 0.34^{BC}	37.10 ± 0.67^{CDE}	8.78 ± 0.10	13.50 ± 1.59^{ABC}	9.15	54.75 ± 0.15^{A}
	2	45.36 ± 0.37^{F}	13.36 ± 0.45^{F}	40.90 ± 0.82^{ABC}	8.85 ± 0.16	13.27 ± 1.76^{BC}	7.39	45.75 ± 1.19^{AB}
	9	50.11 ± 0.36^{C}	17.38 ± 0.57^{CD}	41.45 ± 1.17^{AB}	8.13 ± 0.58	14.68 ± 0.28^{ABC}	11.76	48.79 ± 3.38^{AB}
	Average Imported	**46.68 ± 1.87**	**14.57 ± 1.70**	**39.05 ± 1.68**	**8.51 ± 0.16**	**11.44 ± 0.97**	**8.48 ± 0.89***	**48.08 ± 1.63**

Values presented are the mean ± standard error (n = 12).
Samples within the same column that do not share the same superscript letter are significantly different (p-value <0.05).
*indicates significant difference between domestic and imported butters (p-value < 0.05; n = 6 per category).

with 2.0% more eyes greater than 51 mm^2 ($p<.05$). This difference is observable with the naked eye as the larger eyes take up a disproportional amount of space. Croissant with higher amounts of 18:2 also had a higher Tfc1 while T1/2g1, Tefc3, and Tpc3 had an inverse correlation to 18:3. Total saturated fatty acid content correlated strongly with average eye size. This appeared to be driven primarily by the presence of C16:0 and a lack of C18:1, which correlated with the total rise in baked croissants.

3.3 Discussion

In this study we evaluated the functional performance of commercial butters (n = 12; half domestic and half imported) by composition, melting profile, and performance during lamination. Of the 11 fatty acids quantified 5 (C12:0, C14:0, C18:0, C18:2, and C18:3) were significantly different ($p<.05$) composition between domestic and imported samples. Previous research has linked variation in the amounts of specific fatty acids due to feed regimes and genetics of herds (Kay et al., 2005; Poulsen et al., 2012; O'Callaghan et al., 2016). O'Callaghan et al., (2016) found significant differences in the amount of individual fatty acids based on diet such as higher amounts of C15:0 in cows fed total mixed ration and C18:2 cis- 9,trans-11 in grass fed. Poulsen et al., (2012) found that the variation in amount of C6:0 to C14:0 was limited but that distribution of individual fatty acids to be important. This suggests that different farming practices including feed and herd types may have been a contributing factor as three samples of the imported group were labeled as grass or hay fed suggesting a specific diet while only one of domestic samples, only had language that would suggest a large portion of their diet to be grass.

The results from DSC indicate the different temperatures at which melting occurred were found to span different aspects of production. The influence of solid fat content during the shaping and laminating process can influence plasticity (Stauffer, 1996). The first melting point Tpc1 (average 12.83°C) was below room temperature (20°C-25°C) for all samples. Which would be temperature at which the dough undergoes lamination and physical manipulation. While the second melting point Tpc2 (average 29.36°C) falls into the high proofing range (25°C-30°C) and third final Tpc3 (average 34.16°C) above and melt during baking. These temperature ranges are similar to those measured by Mattice and Marangoni, (2017) when comparing melting profiles of butter to shortenings. DSC indicated that melting points of the butter at different working temperatures ranges were different among domestic and foreign producers. O'Callaghan et al., (2016) found there to be a similar difference between butter derived from pasture and total mixed ration fed cows, with pasture fed having lower first and second peaks of crystallization. This supports our findings as the large portion of imported butter samples were marked as grass fed and that group had lower melting points.

All croissants made exhibited the ideal characteristics of a croissant, airy, flaky, and elongated eyes to various degrees. As a group domestic butter had significantly more rise, larger average eye size, and larger distribution of eye size. Previous research into croissants has been conducted using small pastries Previous research has shown that rise can be affected by number of layers (Deligny and Lucas, 2015) or fragmentation of the fat (Lucas et al., 2018). Research on Though there has been research to Composition of fat is known to affect plasticity and crumb structure, which ultimately determines the characteristic light airy quality of a croissant (Stauffer, 1996).

3.4 Conclusions

The rise and crumb structure of the croissants made were all of an acceptable quality and varied only in degree. Our results suggest that melting point of the butter used affects crumb structure, which ultimately determines the characteristic light airy quality of a croissant. As a group domestic butter performed better when rise and eye size and distribution were the applied criteria. Rise seemed to be a reasonably good indicator of the quality of the crumb and it may prove useful to use it as metric for quality assurance once a particular process has been standardized.

Acknowledgments

Funding for this study was provided by BUILD Dairy with support from High Desert Milk (Burley, ID). We would like to thank Chefs Pascal Tisseur and Ciril Hitz for sharing their baking knowledge and expertise that guided this project and Brandon Riesgaard (OSU) for his daily support in the bakery. We would also like to thank Dr. Skip Rochefort and Merrit Barber of the Department of Biological Engineering (OSU) for training and use of the differential scanning calorimeter. The authors would also like to thank Dr. Paul Hughes and Robin Frojen (OSU) for sharing their time and facilities. We would also like to thank Eileen Chow and students and staff of the Department of Food Science and Technology for their assistance and feedback throughout the course of this research.

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Conclusion

Butter impacts the quality of pastries made with laminated dough such as croissants throughout the production process. If all other parameters are the same, a butter with higher (82%) fat outperforms a butter made with the standard amount (80%) of fat. The butter quality will have a direct impact on the ability to manipulate the butter into the desired form. Butter with more fat proved more resistant to the multiple physical stresses applied as part of the laminating process. The impact on malleability is of particular interest to large manufacturers whose automated processes demand a product that will not break. The impact on the quality of the final product were measurable but all pastries produced were of good quality.

Commercial butters performed acceptably (no cracks or tears) during lamination and produced finished croissants of good quality. Butterfat content was not found to be responsible for the difference in quality of the final product. Increased saturated fatty acid content and C16:0 correlated with an increase in eye size and rise (i.e., better quality croissants). On average, domestic butters produced croissants with a larger number of large eyes – one characteristic of high quality croissants. None of the other measured characteristics were associated with finished product quality.

It is worth noting that all croissants produced were of good quality. Assesments were made based on what the literature and experts describe as ideal characteristics. In practice, it may be useful to know that a pastry made with higher fat butter will bake up softer or that using a domestic butter will produce an airy crumb, but a baker will make the judgement as to whether or not this is a benefit.

Since pastries are no longer a specialty product, judgement of quality may be subjective to their utility. For example, a patisserie and a sandwich shop will have a different assessment of the quality of a croissant. The patisserie will most likely have a display case and the croissants will be sold individually to a customer. This requires that the croissant have as close to ideal characteristics as possible since it may be under the scrutiny of a customer sans any accoutrements. A sandwich shop, on the other hand, may require a denser crumb in order to be able to use a vehicle for sliced meats and dressings. This requires that a baker have the information to use ingredients that will produce the specific characteristics they desire. This is not different when the process is scaled up to industrial scale. When choosing the butter for their product, a producer must balance functionality with final product quality.

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Appendix I

Croissant hole-measuring directions

- A picture with a ruler in front of Croissants was used to scale
- Heights of Croissants measured can be compared to measured distance

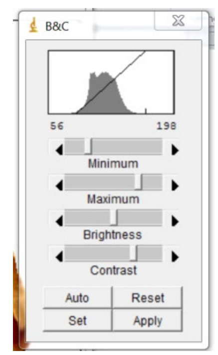
1. Open the image in ImageJ.
   Set scale: draw a line on ruler.
   Use Analyze > Set Scale based on known measurements.
   Use the same pixel/mm ratio for the left and right sides of the same croissant.

2. **Crop image** to show only the left or right side of croissant. Save a copy of this image.

3. **Exclude the outside areas and crust**: With the freehand selection tool, select the area of the croissant without the crust. Go to Edit > Clear Outside. Use the paintbrush tool (white) to exclude any remaining crust. Save a copy of this image.

4. **Measure area of interest**. At this point you will have your area of interest showing. Use the wand tool to select it (may have to adjust threshold). Measure the area with Analyze > Measure to get the **total section area**. Record this area in Excel.

5. **Adjust contrast**: Before measuring the holes, the contrast may have to be adjusted. Go to Image > Adjust > Brightness/Contrast. It's usually at a pretty good level if the contrast line is diagonal to the little histogram looking thing, kind of like this (see right):



6. **Convert image to binary**: Run the macro CroissantHoles_rbr200.ijm. to convert holes into black areas, and non-holes into white areas.

   Compare the converted image with the original image to make sure it got most of the holes (especially the smaller ones near the center of the cross section). If not, then you'll have to start over from Step 1 and adjust the contrast a little more.
   If it looks good, save a copy of this image.

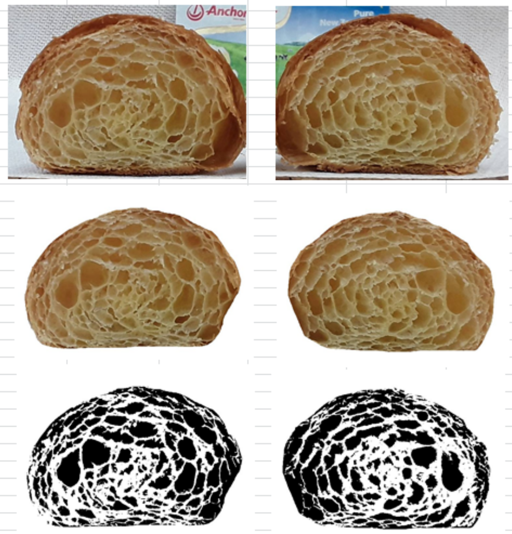
7. **Measure area of holes**: Run the macro MeasureHolesArea.ijm. Paste this data into Excel. Exclude any holes less than 1 mm^2 (these are too tiny & are probably shadows anyway). Calculate average hole size. Also calculate the sum of the areas to get the **total hole area**. Divide the Total Hole Area by the Total Section Area from Step 4, to get the percentage of hole/non-hole area.

8. **Get size distribution**: With the hole measurements still open in ImageJ, under the Results menu, select Size distribution. Uncheck Automatic binning. Specify 100 bins, with a range of 1-101. This will give you a size distribution of holes from $1mm^2$ to $100mm^2$.

   Example:

	A	B
1	285.55	381.92
2	97.76	58.76
3	54.51	56.96
4	53.46	50.89
5	37.77	41.78
6	33.75	37.3
7	32.8	36.31
8	27.32	29.32
9	22.62	28.89
10	20.57	23.25
11	20.55	22.56
12	16.76	21.71
13	15.61	19.22
14	14.17	18.15
15	13.87	16.79
16	13.71	16.78
17	12.28	16.18
18	11.54	14.43
19	11.4	13.68
20	11.28	11.63
21	10.49	11.01
22	10.26	9.15
23	9.87	8.66
24	9.68	8.54
25	9.31	8.33
26	9.09	7.61
27	8.2	7.44
28	7.97	7.12
29	7.82	6.5
30	7.71	6.42
31	7.44	5.57
32	7.41	5.08
33	7.16	4.93
34	7.06	4.92
35	6.99	4.77
36	6.69	4.17
37	6.34	3.9
38	6.08	3.83
39	5.98	3.35
40	5.98	3.32
41	5.94	3.27

ANCHOR	**Scale:**	10.3011	pixels / mm		
Excluding holes < 1 mm2:	**Total # of holes:**	**Avg hole area (mm2)**	**Sum of all holes area (mm2)**	**Total section area (mm2):**	**% Hole area / Total area:**
Left side (A)	92	11.91	1095.69	2071.46	52.89%
Right side (B)	73	15.09	1101.51	2057.00	53.55%



Size distribution

Hole Area (mm2)	Left Count	Right Count	Avg Count	S.D.
1	25	22	23.5	2.12
2	7	10	8.5	2.12
3	11	5	8	4.24
4	7	4	5.5	2.12
5	4	2	3	1.41
6	4	2	3	1.41
7	7	3	5	2.83
8	1	3	2	1.41
9	4	1	2.5	2.12
10	2	0	1	1.41
11	3	2	2.5	0.71
12	1	0	0.5	0.71
13	2	1	1.5	0.71
14	1	1	1	0.00
15	1	0	0.5	0.71
16	2	3	2.5	0.71
17	0	0	0	0.00
18	0	1	0.5	0.71
19	0	1	0.5	0.71
20	2	0	1	1.41
21	0	1	0.5	0.71
22	1	1	1	0.00
23	0	1	0.5	0.71
24	0	0	0	0.00
25	0	0	0	0.00
26	0	0	0	0.00
27	1	0	0.5	0.71
28	0	1	0.5	0.71
29	0	1	0.5	0.71
30	0	0	0	0.00
31	0	0	0	0.00
32	1	0	0.5	0.71
33	1	0	0.5	0.71
34	0	0	0	0.00
35	0	0	0	0.00
36	0	1	0.5	0.71
37	1	1	1	0.00
38	0	0	0	0.00