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EFFECT OF SUCROSE PARTICLE SIZE, SUCROSE CONTENT, AND WATER CONTENT
ON MELT RESISTANT CHOCOLATE MADE VIA A SUGAR NETWORK

CLAIRE ROSENBERGER
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Reviewed and approved* by the following:

John N. Coupland
Professor of Food Science
Thesis Supervisor

Ramaswamy C. Anantheswaran
Professor of Food Science
Faculty Reader

Enrique Gomez
Professor of Chemical Engineering
Honors Advisor

* Signatures are on file in the Schreyer Honors College.

ABSTRACT

The creation of heat resistant chocolate would improve consumption in the summer months and in warm, tropical climates (Killian and Coupland, 2011; Dicolla, 2009). Adding water to chocolate can create a sugar network held together by capillary forces, which can increase heat resistance in chocolate products (Stortz and Marangoni, 2011). Model chocolates made with two sucrose sizes (12 μm and 60 μm), two sucrose contents (20% and 40% by mass), and three water contents (0%, 1%, 10% by mass of sucrose) underwent a melt test to determine the effects of sugar particle size on the melt resistance of chocolate. Water content was shown to have a statistically significant effect on the melt resistance of the samples, where the highest water content corresponded to the least melt resistant chocolate. This effect might have occurred because excess water may have dissolved sugar, preventing it from participating in the sugar network or because there was not enough sucrose surface area to adsorb all of the water, leading to excess water dispersed in the cocoa butter. After qualitative hexane immersion study, it does not appear that a comprehensive sugar network formed throughout the chocolate models, making the effects of sucrose particle size irrelevant; if no sugar network formed, then the size of the sugar particles could not affect the network.

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Chapter 1

Introduction

1.1 Chocolate

Chocolate is a suspension of solid particles in semi-crystalline cocoa butter, a fat. Some examples of solid particles that can be included in chocolate are cocoa powder, sucrose (sugar), and milk solids (McClements, 2007). There are three types of chocolate: dark, milk, and white chocolate. Each type has a different ingredient composition, but all types are composed of solid particles suspended in cocoa butter. Dark chocolate contains sugar and non-fat cocoa solids. Milk chocolate includes sugar, non-fat cocoa solids, milk fat, and milk solids. White chocolate includes milk solids and milk fat. Additionally, any variety of chocolate may include ingredients like emulsifiers, salt, flavoring, and spices. In the United States, the Food and Drug Administration (FDA) has a Standard of Identity for chocolate, which prohibits the use of any vegetable derived oils, fats, or stearins derived from sources other than cocoa fat in chocolate. Table 1 summarizes the requirements in the FDA's Standard of Identity (21CFR163, 2017).

Table 1.1: Standard of identity for milk, dark, and white chocolate based on FDA regulations (21CFR163, 2017)

	Chocolate Liquor	Total Milk Solids	Milk Fat	Emulsifier	Sugar	Cocoa Fat
Milk	$\geq 10\%$	$\geq 12\%$	$\geq 3.39\%$	$\leq 1\%$	-	-
Semisweet/ Bittersweet	$\geq 35\%$	$\leq 12\%$	$\leq 12\%$	$\leq 1\%$	-	-
White	0%	$\geq 14\%$	$\geq 3.5\%$	$\leq 1.5\%$	$\leq 55\%$	$\geq 20\%$

1.2 Chocolate Manufacture

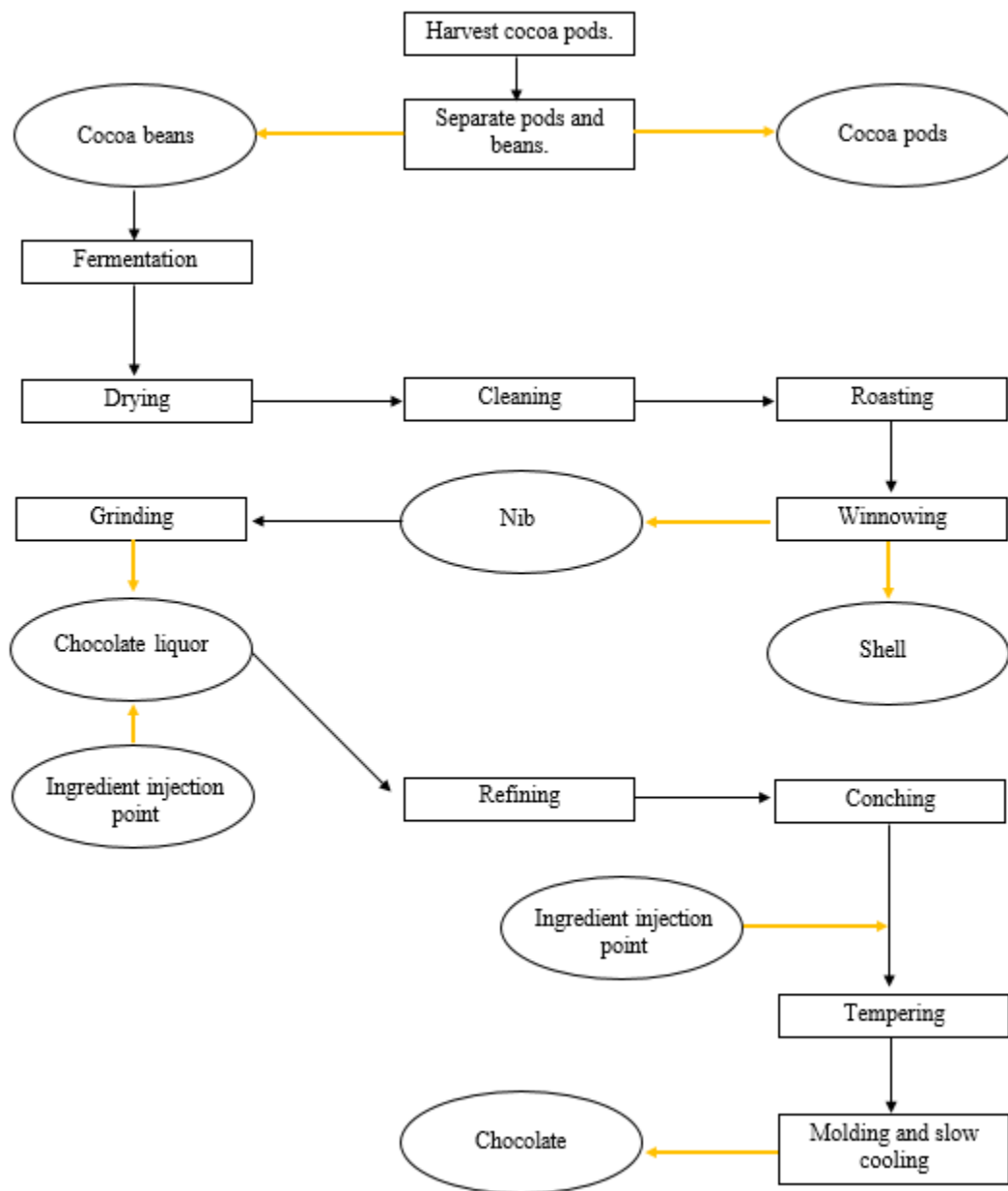


Figure 1.1 Diagram of chocolate manufacture from cocoa bean to finished product

The production of chocolate, shown in Figure 1, begins with the harvest of cocoa beans from cocoa trees (Stortz and Marangoni, 2011). Cocoa beans grow in the pods of the *Theobroma cacao* tree, which grows in warmer climates such as Central America and West Africa. Several

varieties of cocoa beans exist, and each type creates distinct flavors in finished chocolate (Adriaenssens, 2010). Cocoa beans grown in different geographic areas can produce cocoa butters with slightly different melting points (Beckett, 2000).

Cocoa beans are removed from their pods and then fermented for five to seven days. Fermentation develops the beans' colors and flavors (Fowler, 1999). After fermentation, the beans are dried, usually with sunlight (Adriaenssens, 2010).

The cocoa beans are then sent to factories where they are cleaned, metal contaminants are removed with magnets, and stones and other small particles are removed via particle density separation (Stortz and Marangoni, 2011).

After cleaning, cocoa beans are roasted at 90-170°C to generate flavor (Afoakwa, Paterson, and Fowler, 2007). Flavor is affected by the time, temperature, and water content of the roasting process (Adriaenssens, 2010). Next, beans are winnowed, which removes the nib from the shell of the cocoa bean. The beans strike plates to divide the nibs and shells, while vibrating sieves separate the nibs and shells. Cocoa nibs are then ground into chocolate liquor, a mixture that includes both cocoa solids and cocoa butter (Hancock, 1994). Cocoa butter triglycerides contains three main fatty acids; they are the palmitic, stearic, and oleic fatty acids (Schenk and Peschar, 2004).

Ingredients like sugar, extra cocoa butter, milk solids, emulsifiers, and flavors can be added to the chocolate liquor at this stage, depending on the type of chocolate being made (Stortz and Marangoni, 2011). However, emulsifiers are generally added after conching instead of prior to conching (Beckett, 1999). Liquor is then refined to reduce particle size via steel rollers. Particle size affects finished product's mouthfeel and rheological properties. Large particles

(greater than 35 micrometers) lend a gritty, sandy texture to finished chocolate (Jackson, 1994). During the refining step, some of the sugar crystals become amorphous (Beckett, 1999).

Next, chocolate is conched with shear mixers in a temperature and moisture-controlled environment (Ley, 1994). Generally, chocolate is conched above 50°C for several hours. The precise time and temperature depends on the type of chocolate being produced, with temperatures being as low as 49°C and as high as 82°C and times varying between 10 to 24 hours (Afoakwa, Paterson, and Fowler, 2007). The conching step can change the rheology of chocolate, remove volatilities, reduce moisture, and improve the mouthfeel of the final product (Ley, 1994). During conching, the chocolate mass de-agglomerates (Ley, 1994). Varying the conching time can change the viscosity and flavor of the chocolate (Beckett, 1999).

Further addition of emulsifiers, flavors, and cocoa butter can take place after conching (Beckett, 1999). Adding emulsifiers lowers the viscosity of the product, so they are sometimes used to adjust the viscosity of the product (Stortz and Marangoni, 2011). Lecithin is a popular emulsifier in chocolate manufacture (Beckett, 1999).

Next, the tempering step combines controlled heating and mixing. Tempering is performed to obtain stable crystal cocoa butter configurations. Cocoa butter can crystallize into six forms, a phenomenon known as polymorphism. The forms have varying stabilities, physical volumes, and melting points (Beckett, 1999). The melting points of various forms of cocoa butter are shown in Table 2. Since the various cocoa butter crystal forms have varying melting points, the type of cocoa butter crystals that form influence the melting point of chocolate (Beckett, 1999). The tempering step attempts to create cocoa butter than crystallizes into Form V. Form V is desirable because its melting point is at body temperature, so chocolate made with

Form V crystals will melt in consumers' mouths. Additionally, the density of Form V cocoa butter crystals is ideal for demolding chocolate (Killian and Coupland, 2010).

Table 1.2: Melting points of the polymorphic forms of cocoa butter*

Polymorphic Form	Melting Point (°C)
I	16-18
II	21-22
III	25.5
IV	27-29
V	34-35
VI	36

*Adapted from Killian and Coupland, 2010.

During tempering, chocolate is completely melted, typically at a temperature of 50°C. Then, it is cooled to at least 32°C until a few crystals have formed. It is crystallized at approximately 27°C. After crystallization, unstable crystals are melted by heating the chocolate to 29-31°C (Talbot, 1994). The amount and type of cocoa butter crystallization determines the snap, gloss, and melting point of chocolate (McClements, 2007).

Tempering also affects the viscosity of the final product (Beckett, 1999) because viscosity increases as crystals form (Afoakwa, Paterson, and Fowler, 2007). The application of the chocolate, which ranges from being molded to being used as a coating, influences the viscosity needed in the final product (Beckett, 1999). The final step in chocolate manufacturing is molding and slow cooling, during which crystals continue to form (Stortz and Marangoni, 2011).

1.4 Chocolate Microstructure

Chocolate is a suspension of solid particles, including sugar, cocoa, and milk particles, in a solid or liquid cocoa butter continuous phase. A continuous phase is the phase in which solid or fluid particles are distributed. Solid particles in chocolate are dispersed throughout cocoa butter; they are not dissolved. Particles that are dispersed are phase separated from the continuous phase, whereas dissolved particles form a solution (McClements, 2007).

Typically, solid particles are between 15 and 30 micrometers in size. The size of the particles will affect the texture, rheological properties, and mouthfeel of the final chocolate. Large particles, ones that are greater than 35 micrometers, result in gritty, sandy textures in finished chocolate (Killian and Coupland, 2010). Aggregates can also result in poor texture. Solid particles aggregate when they form large groups that are usually not evenly dispersed in the cocoa butter. Aggregates form when chocolate is not conched properly, when it is not well mixed, and when particles are too large (Glicerina et al. 2013).

White chocolate has smaller sized particles than dark and milk chocolate have; white chocolate also has less aggregate structure than either of the other two types of chocolate. Dark chocolate has the highest aggregate structure, while milk chocolate's aggregate structure is between that of white and dark chocolate (Glicerina et al., 2015).

1.5 Common Issues with Chocolate

Several common issues in chocolate manufacture include sugar bloom, fat bloom, and seizure. Sugar bloom and seizure are problems associated with the addition of water, whereas fat bloom is caused by the melting and recrystallization of chocolate (Stortz and Marangoni, 2011).

1.5.1 Issues Associated with Water Addition: Sugar Bloom and Seizure

Sugar bloom occurs when water contaminates the chocolate and dissolves the sugar in the chocolate. When the water is removed from the chocolate via evaporation, the sugar is deposited on the surface of the chocolate. Sugar bloom results in grainy mouthfeel and poor appearance because the chocolate usually turns gray (Stortz and Marangoni, 2011).

Seizure is caused when water than has been added to chocolate dissolves the sugar particles and causes them to bind to other particles, preventing the chocolate from flowing. The observed lack of flow is due an increase in viscosity (Killian and Coupland, 2010). To prevent severe increases in viscosity and seizure that can accompany water addition to chocolate, water being used to increase melt resistance is usually added in a controlled manner such as sugar, polyols, foams, or emulsions (O'Rourke, 1959; Schubiger and Rostagno, 1965; Kincs, 1992; Beckett, 1995; Mandralis and Weitzenecker, 1996; Davila and Finkel, 2005; Giddey and Dove, 1991; Giddey and Dove, 1984; Alander, Warnheim, and Luhti, 1996; Simburger, 2009).

1.5.2 Issues Associated with Fat Melting: Fat Bloom

Fat bloom occurs when cocoa butter recrystallizes into Type VI crystals (Stortz and Marangoni, 2011). Fat bloom can be caused when chocolate melts and recrystallizes into a more stable form. Type VI crystals are not as desirable as Type V crystals because they do not have the same properties, and thus, they do not produce chocolate with the same mouthfeel, gloss, and snap (Killian and Coupland, 2010).

1.6 Why does Chocolate Melt?

Chocolate that has melted before consumption is undesirable because it sticks to consumers' hands, loses its molded shape upon recrystallization, and sticks to packaging (Stortz and Marangoni, 2011). However, even at 20°C, chocolate is not completely solid; instead, it is a combination of solid and liquid cocoa butter. Generally, 70-80% of the cocoa butter is solid, while 20-30% of the cocoa butter is liquid. As the temperature increases, the amount of cocoa butter that is liquid increases until all cocoa butter in the chocolate is liquid (Dicolla, 2009). On average, conventional chocolate melts at 33.8°C, which is the melting point of Type V cocoa butter crystals (Stortz and Marangoni, 2011). Conventional chocolate melts at the melting point of cocoa butter because cocoa butter is the continuous phase. When the continuous phase melts, there is no network between the dispersed phase particles, allowing solid particles to move within the liquid (Glicerina et al. 2013). When chocolate melts, the fat crystals phase change from solid to liquid. Since human body temperature is approximately 37°C, which is greater than the melting point of chocolate, chocolate melts when placed into the mouth, creating the familiar, pleasant sensation associated with chocolate consumption (Killian and Coupland, 2010).

1.7 Heat Resistant Chocolate

1.7.1 Definition of Heat Resistant Chocolate

No formal definition of heat resistant chocolate exists but it is generally accepted that heat resistant chocolate would resist melting at temperatures above the melting point of

conventional chocolate while preserving the sensory qualities of conventional chocolate (Dicolla, 2009). Melt resistance has been defined as chocolate that does not adhere to its wrapper above 30°C (Schubiger and Rostagno, 1965), shape retention at 35°C (Alander et al., 1996), absence of stickiness to touch at 40°C (Takemori et al., 1992), and stiffness at 50°C (Giddey and Dove, 1984) while maintaining the flavor of conventional chocolate (Takemori et al. 1992). Most research on heat resistant chocolate examines shape retention at elevated temperatures (Killian and Coupland, 2010).

The creation of heat resistant chocolate would improve consumption in the summer months and in warm, tropical climates (Killian and Coupland, 2011; Dicolla, 2009). The challenge in creating heat resistant chocolate lies in creating a heat resistant chocolate that has the same flavor and texture as conventional chocolate. This challenge is exemplified by The Hershey Company's attempts to make melt resistant chocolate-like products for troops in World War II, the Korean War, the Vietnam War, and the Gulf War. These products exhibited melt resistance at elevated temperatures, but did not possess the same sensory qualities as conventional chocolate (D'Antonio, 2006).

1.7.2 Strategies for Heat Resistant Chocolate Production

Three principle techniques exist for producing heat resistant chocolate: creating a sugar network, increasing the continuous fat phase's melting point, and changing the properties of the continuous fat phase. Most research on heat resistant chocolate focuses on creating a sugar network or increasing the melting point of the continuous fat phase (Stortz and Marangoni, 2011).

1.7.3 Heat Resistant Chocolate via a Sugar Network

Creating a network between sugar molecules can be accomplished by adding water. Water adsorbs to sugar particles and links them together through the capillary force, which forms a network of sugar throughout the cocoa butter (described in detail in section 1.8). The sugar network stabilizes the chocolate at higher temperatures by providing additional structure compared to conventional chocolate; this structure can help hold the chocolate together even as the cocoa butter melts (Stortz and Marangoni, 2011). In conventional chocolate, cocoa butter gives chocolate its form, but melt resistant chocolate models attempt to change this by creating a sugar network that gives chocolate form in place of cocoa butter after cocoa butter melts (Killian and Coupland, 2010).

Addition of water to chocolate has been accomplished via direct incorporation of water, indirect incorporation of water, and addition of encapsulated water (Stortz and Marangoni, 2011). Direct incorporation of water occurs when water is directly added to the mixture (Dicolla, 2009). Indirect incorporation of water could include adding water by exposing chocolate samples to humidity. Addition of encapsulated water includes the addition of water in an emulsion, foam, or gel (Stortz and Marangoni, 2011). Most attempts at incorporating water into chocolate also resulted in increased mixture viscosity, which might make the chocolate difficult to work with commercially (Stortz and Marangoni, 2011).

Several attempts have been made to directly incorporate water into chocolate. In one study, warm water was added to warm cocoa butter, resulting in chocolate that did not melt between 37.8-48.9°C (Russell and Zenlea, 1948). Lataner proposed that heat resistant chocolate could be created by adding water directly to chocolate, heating the mixture to greater than

65.5°C to dissolve sugar into the water, and then reducing water content via evaporation (Lataner, 1949).

Encapsulated water can be added to chocolate via emulsions. Water can be added with either water-in-oil emulsions or oil-in-water emulsions. In one study, samples made with water-in-oil emulsions and oil-in-water emulsions were melt-resistant until 65.5°C (Jefferey, Glynn, and Khan 1977, 1978). Simburger patented a chocolate product that incorporates water in a water-in-oil emulsion to create products between 1.8 and 7% water (Simburger, 2009). Even smaller water droplets can be added to chocolate products via microemulsions, which should create a more uniform sugar network (Alander, Warnheim, and Luhti, 1996; Kealey and Quan, 1992). Water-in-oil emulsions produced via lab-scale cross-flow membrane emulsification were successful in increasing the melting point of chocolate models, but the degree of melt resistance, measured by hexane immersion and hot air exposure in an oven, depended on the type of emulsifier used with the emulsions (Killian and Coupland, 2011).

Emulsions that are added to chocolate do not have to contain only water and oil; some emulsions also contained gums or gelling agents, but the chocolate produced with these emulsions was chewy (Jeffery, 1979). Takemori, Tsurumi, Takagi, and Ito created chocolates that incorporated emulsions with water, fat, and emulsifiers in varying amounts. Their chocolate did not rapidly increase in viscosity and was molded easily. Melt resistance was measured by shape retention, which was maintained until 50°C (Takemori, Tsurumi, Takagi, and Ito, 1993).

Encapsulated water can be added to chocolate in a foam. Foams must evenly disperse throughout the chocolate product and withstand mixing. Water is released by the foam after the chocolate cools, causing the water to de-gas (Giddey and Dove, 1991).

Water can be indirectly incorporated into chocolate by adding ingredients that contain water instead of adding water itself. Adding corn syrup and sucrose to a chocolate mixture created a heat resistant chocolate product, but the heat resistance was attributed to a sugar skeleton formed by water from the corn syrup (Friedman, 1921). Kempf and Downey tried a shorter conching step to leave some sugar uncoated by fat. They added water when the resulting mixture had high viscosity and coated the chocolates with sugar, which gave their products heat resistance. Due to the short conching step, the chocolates probably had an unfinished, unappetizing flavor (Kempf and Downey, 1956). Water has also been indirectly added by allowing samples to absorb moisture over time, where the observed heat resistance was attributed to a sugar network (Kempf, 1958). Similarly, water can be added by exposing chocolate made with humectant and milk protein to humidity. The water added via humidity exposure allowed the formation of a sugar network that corresponded to increased heat resistance (O'Rourke, 1959). Several researchers have combined conched and non-conched chocolate with amorphous sucrose to create sugar networks in their samples (Shubiger and Rostagno, 1965, Giddey and Menzi, 1966, and Pirsch, Shubiger, and Rostagno, 1971). Amorphous sugar worked best when the particles were less than 20 micrometers, and smaller particle size was directly related to the heat resistance of the chocolate (Pirsch, Shubiger, and Rostagno, 1971).

1.7.4 Increasing the Melting Point of the Continuous Phase for Heat Resistant Chocolate

Approaches to increase the melting point of the fat phase to induce heat resistance in chocolate include addition of high melting point emulsifiers, interesterification of the fat phase, or addition of a high melting point fat. In a study that added various long chain, high melting

point emulsifiers to chocolate, the highest melting point emulsifiers corresponded to more heat resistant chocolates (Nalur and Napolitano, 2002). Some projects tried to chemically and enzymatically interesterify fats (Bruse, Wallecan, and Arruda, 2008). Incorporation of fats with higher melting points than cocoa butter, such as mahua and kokum fats, into cocoa butter can increase the melting point of the continuous fat phase. However, in the United States, the Standard of Identity for chocolate prohibits the addition of fat not derived from cocoa butter, so any heat resistant chocolates produced via the addition of non-cocoa derived fats would require a legal change to be marketed as chocolate (Jeyarani and Reddy, 1999).

1.7.5 Changing the Properties of the Continuous Phase for Heat Resistant Chocolate

Changing the properties of the continuous cocoa butter phase can also be used to increase the melting point of chocolate. The most intuitive way to increase the heat resistance of chocolate is to increase the melting point of the continuous phase, discussed in section 1.7.4. Another way to attempt to increase the heat resistance of chocolate is to increase the viscosity of the continuous phase. Liquid polyols can be added to increase the viscosity of the continuous fat phase (Finkel, 1987, 1989, 1990). However, polyols can make the chocolate product set too quickly (Davila and Finkel, 2002). Other methods to add polyols include polyol-in-fat emulsions and polyols in gels (Kincs, 1992 and Mandralis and Weitzenecker). While polyols may interact with the continuous fat phase and increase its viscosity, their ability to increase the melt resistance of chocolate may also result from sugar network formation because polyols are hygroscopic (Kincs, 1992). Orgunwolu and Jayeola incorporated gelatin and cornstarch into chocolate products and found that the chocolate products had a higher melting point than

conventional chocolate. They claimed that the chocolate product was more heat stable due to an increase in the continuous phase's viscosity, which was due to the thickening properties of cornstarch and gelatin. Cornstarch decreased chocolate sweetness, while gelatin created an unpleasant flavor (Orgunwolu and Jayeola, 2006).

Not only can the continuous phase's viscosity be manipulated, but the amount of free fat in the continuous phase can also be adjusted to influence the melting point of chocolate. Addition of an oil or fat binding polymer should decrease the amount of free fat in the sample, disrupting the cocoa butter phase and inducing heat resistance. Logan added oat powder to chocolate and concluded that it, along with milk powder, absorbed liquid fat to increase heat resistance. However, the product was too viscous and difficult to work with (Logan, 1939). Addition of liquid polyols, corn starch, oat powder, and gelatin are prohibited by the FDA's Standard of Identity for Chocolate (21CFR163, 2017).

1.8 Theory of Sugar Network Formation

Sugar network formation in chocolate occurs due to the interactions between water and sugar particles in the chocolate. Water condenses between in small spaces between the sugar particles due to the lower vapor pressure in these regions; this phenomenon is called capillary condensation. In these small spaces, liquid water adsorbs to the sugar particles and creates bridges between sugar particles (Billings, Bronlund, and Paterson, 2005). The force that holds sugar particles together is called the capillary force (F_c), summarized in EQN. 1.

$$F_c = 2\pi r \Gamma \cos \theta \quad \text{EQN 1.}$$

where r is the particle radius, Γ is the surface tension, and θ is the wetting angle (Koos and Willenbacher, 2011). Figure 2 demonstrates the expected structure of capillary bridging between two sugar particles.

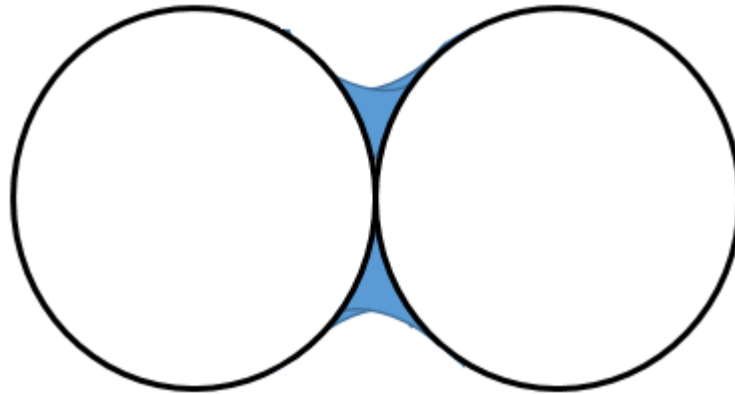


Figure 1.2: Expected structure of capillary bridge between sugar particles

To induce heat resistance in chocolate, a substantial sugar network would have to form, one that extends throughout a chocolate sample, thus bridging almost all of the sugar in the chocolate together. The larger the sugar network, the larger the sum of the capillary forces holding the sugar particles together, and thus the stronger the sugar network that holds the heat resistant chocolate together when the cocoa butter melts. If too much water is added, however, sugar can dissolve into the water, making the final product unstable (Johansson and Bergenstahl, 1992). Figure 3 demonstrates the conceptual difference between samples with and without sugar network formation.

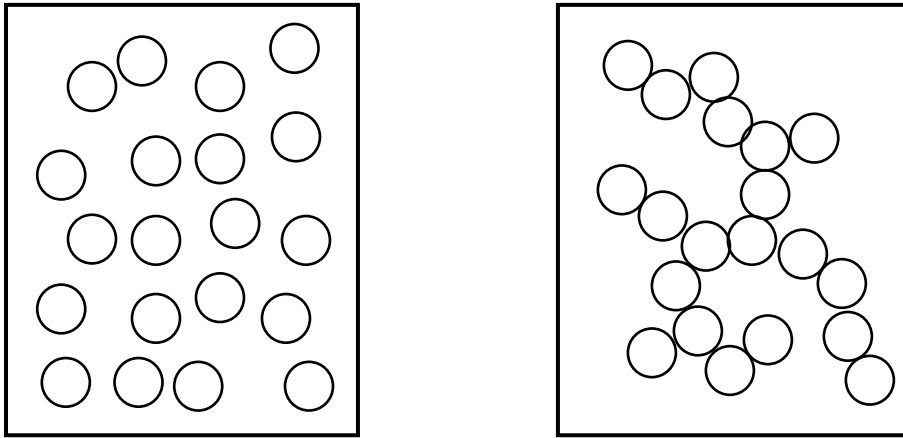


Figure 1.3: Sample with no sugar network formation (left) vs. a sample with a sugar network (right)

Chapter 2

Proposal

The overall goal of this research is to examine the effects of sugar particle size on the melt resistance and sugar network of model chocolate. Many studies have been conducted that show that melt resistance can be increased by adding water to chocolate to form a sugar skeleton (Killian and Coupland, 2010; Russell and Zenlea, 1948; Lataner, 1949; Jefferey, Glynn, and Khan 1977, 1978; Simburger, 2009; Alander, Warnheim, and Luhti, 1996; Kealey and Quan, 1992; Takemori, Tsurumi, Takagi, and Ito, 1993; Giddey and Dove, 1991). However, there is a lack of research comparing sugar particle sizes on the melt resistance of chocolates made by adding water.

2.1 Hypothesis

Adding water to chocolate increases the melt resistance of the chocolate (Killian and Coupland, 2010). Research on amorphous sugar addition to already made chocolate showed that smaller sugar particle sizes correlated to more heat resistant chocolate (Pirsch, Shubiger, and Rostagno, 1971). There is also a lack of research into the effects of changing the sugar concentration on the melt resistance of chocolate products.

1. Increasing water content will increase the heat resistance of the samples. The increased amount of water present in the samples will allow more water to be

- adsorbed onto the surface of sugar particles, increasing the total number of network connections that can form, thus increasing the strength of the sugar network.
2. Increasing sugar content will increase the melt resistance of the samples. Higher sugar concentrations will increase the amount of surface area available for water to adsorb onto, thus increasing the strength of the sugar network.
 3. Model chocolates made with smaller sugar particles will be more heat resistant than model chocolates made with large sugar particles. For the same mass of sugar, there will be a greater number, corresponding to more surface area, of small sugar particles than large sugar particles. Since there will be more surface area dispersed in the model chocolate for samples made with small sugar, more connections should be able to form in the sugar network. More connections in a sugar network should correspond to a stronger sugar network, and a stronger sugar network should create model chocolate that is more heat resistant. Consequently, model chocolate samples made with small sugar particles will be more heat resistant than samples made with large sugar particles.

Chapter 3

Methods

Cocoa butter was donated by The Hershey Company (Hershey, PA) and used without further purification. Two sizes of sucrose were donated by The Hershey Company and used without further purification. They had mean diameters of 12 μm sucrose (fine) and 60 μm sucrose (oarae). All water used was deionized water. Silicone ice cube trays (Adoric, Amazon.com) were used as molds for the chocolate models. Molds were rectangular prisms, 2.8 cm in height by 3.6 cm in length and 3.6 cm in width, and contained twenty-one individual molds. Digital calipers (General Tools & Instruments, UltraTech, No. 1433) were obtained from a local supercenter. Hexanes used were ACS grade, supplied by VWR International. Bright aluminum screening and 24 gauge beading wire were purchased from a local supercenter to use for the hexane immersion study.

Cocoa butter was weighed in a beaker and placed into an oven at 80°C. When the cocoa butter reached 70°C, sucrose was added to the cocoa butter. Samples were stirred with a metal spatula fifty times clockwise and fifty times counterclockwise, repeating the clockwise and counterclockwise pattern for a total of two hundred stirs. The mass of sucrose and cocoa butter were varied; samples were made with 20 wt. %, 40 wt. %, and 60 wt. % sucrose. Table 3 corresponds to the mass of sucrose and cocoa butter measured. The cocoa butter and sucrose mixture was measured into 40 gram samples before being returned to the oven and heated to 70°C. At this point, the samples were removed from the oven and water was added to the samples. 0 wt. % water, 1 wt. % water, and 10 wt. % water were added. See Table 4 for the actual masses of water added to each sample, where water was measured in weight percent of the total mass of sucrose in the sample. The mass of the sucrose was calculated by assuming that the

cocoa butter plus sucrose samples were well mixed, therefore, the sucrose concentration of the samples remains constant after division into 40 g samples. The samples were stirred fifty times clockwise and fifty times counterclockwise with a metal spatula before they were poured into the molds. Samples were placed into the freezer at -19.5°C for twenty-four hours, then they were taken out and given at least three hours to equilibrate to room temperature (20.4°C). The experiment was conducted in triplicate.

Table 3.1: Mass of sucrose and cocoa butter in samples

Sucrose wt. Percent	Sucrose (g)	Cocoa Butter (g)
20%	72	288
40%	144	216
60%	216	144

Table 3.2: Mass of water added to samples (grams)

	Sugar wt. Percent	
Water wt. Percent of Sugar Mass	20%	40%
0%	0	0
1%	0.08	0.15
10%	0.8	1.6

Samples were placed on petri dishes and placed in an oven maintained at 50°C . Each sample was assigned a number and a random number generator was used to determine the order in which the samples were placed into the oven. Samples remained in the oven for thirty minutes and then were removed. The height of the highest point on the sample was measured before heat

exposure and after heat exposure with digital calipers; by taking the difference between the two values, the change in height of the sample was found. EQN. 2 shows the relationship between the change in height (ΔH) of the sample, the height of the sample prior to melting (H_0), and the height of the sample after melting (H_1).

$$\Delta H = H_0 - H_1 \quad \text{EQN 2.}$$

Hexane immersion was used to qualitatively show the sucrose skeleton left behind after cocoa butter was removed by the hexanes in a manner similar to that developed by Killian and Coupland, 2010. Samples were immersed in hexane for 72 hours and objectively observed to determine if a sugar skeleton remained after immersion in hexane. Samples of only the best performing and worst performing were immersed in hexanes to show a difference between the two.

Chapter 4

Results and Discussion

4.1 Melt Resistance Test

Two sizes of sucrose particles were used, 60 μm sucrose and 12 μm sucrose. Samples were made with 20% sucrose content and 40% sucrose content by mass. Water content was based of sucrose content; samples were made with 0%, 1%, and 10% water content. The change in height, in millimeters, of the samples is shown in Table 5. A large change in height indicates that the sample melted more, and was thus less heat resistant than a sample that had a small change in height. Some of the largest changes in height were observed in samples with 10% water.

Table 4.1: Change in height (mm) of model chocolate samples

Water wt. percent of sugar mass	Sample	Sucrose wt. Percent			
		60 μm		12 μm	
		20%	40%	20%	40%
0%	1	0.86	1.29	2.07	1.15
	2	1.30	0.72	3.25	0.16
	3	1.03	0.40	0.12	1.68
1%	1	0.53	1.22	0.77	1.15
	2	0.70	0.94	1.27	0.46
	3	1.12	0.34	1.53	5.95
10%	1	0.33	4.12	1.75	4.16
	2	1.89	3.02	5.26	2.53
	3	1.42	4.00	1.76	1.69

The means and standard deviations of each group are summarized in Table 6. The standard deviations for the 12 μm sucrose sample are generally much larger than the standard deviations from the 60 μm sucrose samples. This indicates that there is more variation in the samples made with 12 μm sucrose than with the samples made with 60 μm sucrose. The largest average height changes correspond to the samples made with 10% water content regardless of sucrose size or sucrose content.

Table 4.2: Mean and standard deviation of height change (mm) for samples

	Sugar %, Water %	Mean (mm)	Standard Deviation (mm)
Sugar Size	20%, 0%	1.06	0.18
	20%, 1%	0.78	-0.25
	20%, 10%	1.21	0.65
	40%, 0%	0.80	0.37
	40%, 1%	0.83	0.37
	40%, 10%	3.71	0.49
	20%, 0%	1.81	1.29
	20%, 1%	1.19	0.32
	20%, 10%	2.92	1.65
	40%, 0%	1.00	0.63
	40%, 1%	2.52	2.44
	40%, 10%	2.79	1.03

A three-way analysis of variance (ANOVA) statistical test with significance of $\alpha = 0.05$ was performed to determine the statistical significance of sucrose particle size, sucrose content, and water content on the heat resistance of the samples. The results of the ANOVA analysis are shown in Table 7.

Table 4.3: ANOVA for height change in samples

Source of Variation	SS	degrees of freedom	MS	F	P-value
Sucrose Size (Size)	3.66	1	3.66	1.97	0.16956
Sucrose Content (SC)	1.79	1	1.79	0.96	0.33369
Water Content (WC)	16.07	2	8.04	4.33	0.02139
Size X SC	0.91	1	0.91	0.49	0.489
Size X WC	0.76	2	0.38	0.21	0.81565
SC X WC	14.10	2	7.05	3.80	0.0328
Size X SC X WC	2.12	2	1.06	0.57	0.56993
Error (within)	61.25	33	1.86	--	--
Total	100.66	44	--	--	--

With the significance at 0.05, any statistically significant values have a P-value lower than 0.05. Therefore, only the water content (P-value of 0.02139) and the sucrose and water content together (P-value of 0.0328) have a statistically significant effect on the heat resistance of the samples.

Water content was shown to have a statistically significant effect on the melt resistance of the samples. Generally, the highest water content, 10%, corresponded to the least heat resistant of samples, shown by 10% water content samples having the largest average height changes. This indicates that increasing water content might negatively impact the melt resistance of chocolate products, which is opposite of the predicted effect in Hypothesis 1 in Section 2.1. However, the means of the samples of 0% water and 1% water do not follow a trend, so it cannot be concluded that this is always the case. For example, it may be that adding water increases melt resistance initially because it allows a sugar network to form. However, adding too much water, such as 10% water, negatively impacts melt resistance. This could occur because there may not be enough surface area provided by the sugar particles to adsorb all of the water. This

would lead to excess water dispersed in the cocoa butter or phase separated from the cocoa butter but present in the chocolate. Adding too much water could also cause some sugar to dissolve in the water instead of participating in sugar network formation. Either arrangement could reduce the melt resistance of the chocolate-like samples.

Since the sugar content on its own did not have a statistically significant effect on the heat resistance of the chocolate, this may suggest that no sugar skeleton was formed. However, the water and sugar content together had a statistically significant effect on the heat resistance of the sample, so it may be that some sugar skeleton may have formed, but it was not strong enough to induce heat resistance in the chocolate. A minimal sugar skeleton could cause the sugar to form clumps throughout the samples, but it would not necessarily create a network that would bind the whole sample together and prevent melting. For the sugar network to be effective, it would need to span the whole sample. If a minimal or no sugar skeleton formed, then this would explain why the sugar size had no effect on the heat resistance of the chocolate. If no sugar skeleton formed, then there could be no way that the size of the sugar particles could affect the surface area available for the sugar network to form, and thus no way for the sugar size to affect the overall heat resistance of the samples. To examine the possibility of no sugar networks being formed, samples were immersed in hexanes to see if a sugar network remained after the samples were immersed in hexane.

4.2 Hexane Immersion Study

Selected samples were submerged in hexanes to determine if they contained a sugar skeleton. Based on the results from the melt resistance test, it was hypothesized that a sugar network had not formed in the samples, which would explain the statistical insignificance of sucrose particle size and sugar content to the melt resistance of the samples. In a procedure described by Killian and Coupland (2010), submerging the samples in hexane would allow the cocoa butter to be stripped from the samples, leaving behind a sugar skeleton, if one existed in the samples. Several samples were selected to observe the effects of the hexane immersion. These selected samples are: 60 μm , 20% sugar, 0% water, sample 3; 60 μm , 20% sugar, 1% water, sample 2; 60 μm , 40% sugar, 10% water, sample 1; 12 μm , 40% sugar, 0% water, sample 1; 12 μm , 40% sugar, 1% water, sample 2; and 12 μm , 40% sugar, 10% water, sample 1. These samples were selected based on their performance in the melt test. For example, the 12 μm , 40% sugar, 10% water, sample 1 had a large change in height (4.16 mm), indicating that it was not very melt resistant. Therefore, this sample was chosen because it was expected to have no sugar skeleton or a poor sugar skeleton. Figure 4 shows the 60 μm samples prior to hexane immersion, and Figure 5 shows the 60 μm samples after hexane immersion. Figure 6 shows the 12 μm samples prior to hexane immersion, and Figure 7 shows the 12 μm samples after hexane immersion



Figure 4.1: Model chocolate samples before hexane immersion. (60 μm sucrose, 20% sucrose, 0% water on left; 20% sucrose, 1% water middle; 40% sucrose, 10% water right)



Figure 4.2: Model chocolate samples after hexane immersion. (60 μm sucrose, 20% sucrose, 0% water on left; 20% sucrose, 1% water middle; 40% sucrose, 10% water right)



Figure 4.3: Model chocolate samples before hexane immersion. (12 μm sucrose, 40% sucrose, 0% water, left; 40% sucrose, 1% water, middle; 40% sugar, 10% water, right)



Figure 4.4: Model chocolate samples after hexane immersion. (12 μm sucrose, 40% sucrose, 0% water, left; 40% sucrose, 1% water, middle; 40% sugar, 10% water, right)

By qualitatively observing the samples, the samples show that hexane immersion did remove cocoa butter from all of the samples. In the case of the 60 μm sugar, all of the samples became much smaller after hexane immersion than they were prior to hexane immersion. Some of the mass remains, so it could be that small sugar networks formed in the models, but these networks did not extend fully throughout the sample and were therefore unable to increase the melt resistance of the sample substantially. The 12 μm samples show a pattern; the samples with water retain more mass after hexane immersion. This would indicate that adding water did form at least a partial sugar skeleton because the

samples were better able to resist hexane immersion. However, the comprehensiveness and extent of the sugar network is still undetermined.

Chapter 5

Conclusions

The objective of this work was to examine the effects of sucrose particle size on the melt resistance of chocolate and formation of a sugar network.

Increasing water content was hypothesized to increase melt resistance of samples because it would increase the amount of water available to connect the sugar particles together. Water content had a statistically significant effect on melt resistance, but since samples made with the highest water concentration appeared to be the least melt resistant, increased water content seemed to decrease the melt resistance of samples. Increasing the water content too high may decrease the melt resistance because there is not enough surface area provided by the sugar particles to adsorb all of the water, leading to an unstable water and cocoa butter mix in the samples. However, it may be true that adding small amounts of water may improve the melt resistance of chocolate.

It was hypothesized that higher sugar concentrations would increase the melt resistance of samples by providing more surface area for water to absorb to, increasing the strength of the sugar network. Sugar content and water content together had a statistically significant effect on melt resistance, but sugar content on its own did not have a statistically significant effect on the melt resistance of the samples. This was determined to be the case because only small sugar networks formed, which were not enough to significantly impact the melt resistance of the samples.

It was also hypothesized that samples made with small sugar particles would be more melt resistant than samples made with large sugar particles because the smaller sugar particles would provide more surface area for the sugar network to form. Sugar size did not have a statistically significant effect on melt resistance. Sugar content and size did not statistically affect the melt resistance of the samples because sugar networks were not formed, or only small networks were formed. Sugar networks will only induce melt resistance if the sugar networks extend throughout the whole chocolate model system, which did not occur in this case.

In the future, it is crucial to conduct this experiment with samples in which sugar networks have been formed. It would be beneficial to study more sugar sizes and higher sugar contents, such as 50-60% sugar by mass.

BIBLIOGRAPHY

Adriaenssens, M. (2010). Impact of Ingredients on Chocolate Flavor. 64th PMCA Production Conference (pp. 19-27). Bethlehem, PA: PMCA.

Afoakwa, E., Paterson, A., & Fowler, M. (2007). Factors influencing rheological and textural qualities in chocolate - a review. *Trends Food Sci. Tech.* , 18, 290-298.

Alander, J., Warnheim, T., & Luhti, E. (1996). Patent No. 5,486,376. United States of America.

Beckett, S. (1999). *Industrial Chocolate Manufacture and Use* (3rd ed.). Oxford: Blackwell Science.

Beckett, S. (2000). *The Science of Chocolate*. Cambridge: RSC Paperbacks.

Billings, S., Bronlund, J., & Paterson, A. (2006). Effects of capillary condensation on the caking of bulk sucrose. *J. Food Eng.* , 77, 887-895

Bruse, F., Wallecan, J., & Arruda, C. (2007). Patent No. 20,080,248,186 A1. United States of America.

D'Antonio, M. (2006). *Hershey: Milton S Hershey's extraordinary life and wealth, empire, and utopian dreams*. New York: Simon & Schuster.

Davila, V., & Finkel, G. (2005). Patent No. 6,841,186 B2. United States of America.

Dicolla, C. (2009). *Characterization of Heat Resistant Milk Chocolate*. Masters Thesis, The Pennsylvania State University, Food Science Department, State College, PA.

Finkel, G. (1987). U.S. Patent No. 4,664,927. Washington, DC: U.S. Patent and Trademark Office.

Finkel, G. (1989). U.S. Patent No. 4,812,318. Washington, DC: U.S. Patent and Trademark Office.

Finkel, G. (1990). U.S. Patent No. 4,980,192. Washington, DC: U.S. Patent and Trademark Office.

Fowler, M. (1999). Cocoa beans: from tree to factory. In S. Beckett (Ed.), *Industrial Chocolate Manufacture and Use* (3rd ed., pp. 8-35). Oxford: Blackwell Science.

Friedman, J. (1921). U.S. Patent No. 1,364,192. Washington, DC: U.S. Patent and Trademark Office.

Giddey, C., & Dove, G. (1984). Patent No. 4,446,166. United States of America.

Giddey, C., & Dove, G. (1991). Patent No. 5,004,623. United States of America.

Giddey, C., Menzi, R. (1966). Swiss Patent No. 409,603. Bern, Switzerland: Swiss Federal Institute of Intellectual Property.

Glicerina, V. , Balestra, F. , Rosa, M. D., Bergenstål, B. , Tornberg, E. and Romani, S. (2014), The Influence of Different Processing Stages on Particle Size, Microstructure, and Appearance of Dark Chocolate. *Journal of Food Science*, 79: E1359-E1365. doi:[10.1111/1750-3841.12508](https://doi.org/10.1111/1750-3841.12508)

Glicerina, Virginia & Balestra, Federica & Dalla Rosa, Marco & Romani, Santina. (2015). Effect of manufacturing process on the microstructural and rheological properties of milk chocolate. *Journal of Food Engineering*. 145. 45–50. [10.1016/j.jfoodeng.2014.06.039](https://doi.org/10.1016/j.jfoodeng.2014.06.039).

Hancock, B. r. (1994). Cocoa bean production and transport. In S. Beckett (Ed.), *Industrial Chocolate Manufacture and Use* (2nd ed., pp. 43-54). London: Blackie Academic & Professional.

Jackson, K. (1994). Recipes. In S. Beckett (Ed.), *Industrial Chocolate Manufacture and Use* (2nd ed., pp. 258-280). London: Blackie Academic & Professional.

Jeffery, M., Glynn, P., & Khan, M. (1977). Patent No. 4,045,583. United States of America.

Jeyarani, T., & Reddy, S. (1999). Heat-Resistant Cocoa Butter Extenders from Mahua (*Madhuca latifolia*) and Kokum (*Garcinia indica*) Fats. *J. Am. Oil Chem. Soc.* , 76, 1431-1436.

Johansson, D., & Bergenstahl, B. (1992). The Influence of Food Emulsifiers on Fat and Sugar Dispersions in Oils III. Water Content, Purity of Oils. *J. Am. Oil Chem. Soc.* , 69, 728-733.

Kealey, K., & Quan, N. (1992). Patent No. 5,149,560. United States of America.

Kempf, N. W. (1958). U.S. Patent No. 2,863,772. Washington, DC: U.S. Patent and Trademark Office.

Kempf, N., & Downey, P. (1956). Patent No. 2,760,867. United States of America

Killian, L. and Coupland, J. (2011). Development of water-in-oil emulsions for application to model chocolate products. Masters Thesis, The Pennsylvania State University, Food Science Department, State College, PA.

Kincs, F. (1992). Patent No. 5,108,769. United States of America.

Koos, E., & Willenbacher, N. (2011). Capillary Forces in Suspension Rheology. *Science* , 331, 897-900

Lataner, H. (1949). U.S. Patent No. 2,487,931. Washington, DC: U.S. Patent and Trademark Office.

Ley, D. (1994). Conching. In S. Beckett (Ed.), *Industrial Chocolate Manufacture and Use* (2nd ed., pp. 117-138). London: Blackie Academic & Professional.

Logan, P.P. (1939). U.S. Patent No. 2,176,086. Washington, DC: U.S. Patent and Trademark Office.

Mandralis, Z., & Weitzenecker, D. (1996). Patent No. 5,523,110. United States of America.

McClements, J. (2007). *Understanding and controlling the microstructure of complex foods*. Woodhead Publishing.

Nalur, S. C., Napolitano, G. E. (2002). U.S. Patent Application No. US 2002/0136818 A1. Washington, DC: U.S. Patent and Trademark Office.

Ogunwolu, S., & Jayeola, C. (2006). Development of non-conventional thermo-resistant chocolate for the tropics. *Brit. Food J.* , 108, 451-455.

O'Rourke, J. (1959). Patent No. 2,904,438. United States of America.

Pirsch, L. A., Schubiger, G. F., Rostagno, W. (1971). British Patent No. 1,219,996. New Port, South Wales, UK: Intellectual Property Office.

Russell, H.B. J.Zenlea, B. J., Zenlea, B. J. (1948). U.S. Patent No. 2,457,110. Washington, DC: U.S. Patent and Trademark Office.

Schenk, H & Peschar, R. (2004). Understanding the structure of chocolate. *Radiation Physics and Chemistry*. 71. 829-835. 10.1016/j.radphyschem.2004.04.105.

Schubiger, G.-F., & Rostagno, W. (1965). Patent No. 3,218,174. United States of America.

Simburger, S. (2009). Patent No. 7,579,031 B2. United States of America.

Terri A. Stortz, Alejandro G. Marangoni, Heat resistant chocolate, Trends in Food Science & Technology, Volume 22, Issue 5, 2011, Pages 201-214, ISSN 0924-2244,
<https://doi.org/10.1016/j.tifs.2011.02.001>.

(<http://www.sciencedirect.com/science/article/pii/S0924224411000288>)

Takemori, T., Tsurumi, T., & Takagi, M. (1992). Patent No. 5,160,760. United States of America.

Takemori, T., Tsurumi, T., Takagi, M., Ito, M. (1993). U.S. Patent No. 5,232,734. Washington, DC: U.S. Patent and Trademark Office.

Talbot, G. (1994). Chocolate temper. In S. Becket (Ed.), Industrial Chocolate Manufacture and Use (2nd ed., pp. 156-166). London: Blackie Academic & Professional.

FDA Regulations: Cocoa Products, 21 CFR 163. (2017).

ACADEMIC VITA

Academic Vita of Claire Rosenberger
Cmr5832@psu.edu

Education

Major: Chemical Engineering

Honors: Food Science

Thesis Title: Effect of Sucrose Particle Size, Sucrose Content, and Water Content on Melt Resistant Chocolate Made via a Sugar Network

Thesis Supervisor: Dr. John N. Coupland

Work Experience

Date: 05/2017-08/2017

Title: R&D Intern

Description:

Institution/Company (including location): The Promotion in Motion Company, Inc., Somerset, NJ

Supervisor's Name: Dr. Maureen Rathod

Date: 05/2016-08/2016

Title: Co-Op Engineer

Description:

Institution/Company (including location): Cypress Semiconductors, Austin, TX

Supervisor's Name: Pamela Dye

Grants Received: Schreyer Ambassador Award

Awards: McWhirter Undergraduate Chemical Engineering Scholarship , Schreyer

Academic Excellence,

Professional Memberships: SWE

Community Service Involvement: Finance Committee for THON