A Choco-Lot About Chocolate

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02.20.21

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Acknowledgments

I would like to give a huge shoutout to my parents for (A)—being supportive enough to dish out $60 on good quality chocolate and (B)—for being willing to hide in their rooms so that I could record the sound of chocolate snapping. Also, this project would not have been possible without good ‘ole Bulk Barn, who so graciously supplied such delicious chocolate at a (somewhat) reasonable price.

Timeline

Monday, February 1 - Have collected all materials

Wednesday, February 3 - Finish all research and procedure, start experimentation and take pictures,

Wednesday, February 10 - Finish experimentation and start conclusion, graphs, and report

Monday, February 15 - Complete sources list - APA format and report

Tuesday, February 16 - Start virtual presentation (Google Slides) and video?

Monday, February 22 - School Science Fair Day and Virtual Presentations * Need recording of presentation.

Wednesday, February 24 - Students chosen for the Calgary Youth Science Fair will be notified

Scientific Question

What is the effect of temperature on the tempering of chocolate under controlled conditions?

Why This Project?

As an avid chocolate connoisseur, I've always been interested in the process of making my favorite treat. One day, while I was watching a baking show, one of the contestants was having difficulty achieving a shiny and snappy chocolate through a process called tempering. The judges had mentioned how tempering chocolate was one of the most technically challenging skills in dessert-making, so naturally, I wanted to test it out. When I found out about this science fair, I knew immediately that this was my opportunity to fulfill my Food Network fantasies. Moreover, I conducted this experiment in particular to find the results of temperature changes on the tempering or setting of chocolate. I wanted to learn why a chocolate easter bunny from last year's easter no longer resembled the shiny and smooth state that it had originally been in, and why my homemade chocolate-covered strawberries looked nothing like the ones at the supermarket. Thus, I decided to try and recreate the conditions that may have caused these changes. Besides, this project is an excellent excuse to buy a whole lot of chocolate!

Variables

Manipulated Variable: Temperature of chocolate

Responding Variable: The qualities of the set chocolate (cloudy, glossy, snappy, soft, crumbly, etc.)

Controlled Variables: Brand of chocolate, starting stage of chocolate (pre-tempered wafers), chocolate molds, sizes of bowls and mixing utensils, temperature of room, brand of thermometer, amount of chocolate used.

Background Research Notes

Information About Manipulated Variable: Why does temperature affect the chocolate crystal structures?

- Chocolate gets its structure from cocoa butter (theobroma oil) which is comes from the nibs of cocoa beans
- Cocoa butter is a six-phase polymorphic crystal, which means it can recrystalize in 6 different ways
- The 6 different crystal structures (I, II, III, IV, V, VI) melt at different temperatures
- From I melts at
- The lower the roman numeral, that lower the temperature needed to melt that specific crystal structure
- The higher the roman numeral, the more stable and dense the chocolate is so form VI is the most stable crystal structure and melts at the highest temperature
- Form VI crystals can only be found in chocolate that has been allowed to sit for several months (remaining energy in form V crystals eventually cause change) and can't be formed using melting chocolate as the cooling temperature is too low
- The crystal structure that creates tempered chocolate is form V which melts at 33.8°C or 93°F; about body temperature
- Melting chocolate destroys all pre-existing crystal formations
- To temper, you need to bring temperature up to destroy all crystal formations, then cool it to just below where form V crystals and some other structures are formed. Then heat the chocolate a little to get rid of all but V form crystal structures
- At home, tempering chocolate using "seeding" method is best
- To seed, heat ¾ of chocolate and cool down using remaining ¼ of pre-tempered chocolate, and then bring temperature back up to keep only form V crystals
- Seed chocolate (the remaining ¼) introduces form V crystals into the melted chocolate to encourage melted crystals to also get into form V formation

Information About Responding Variable: What qualities can the cooled/set chocolate have?

- Each crystal structure produces chocolate with different qualities
- Forms I and II are both soft and crumbly when cooled with fat bloom
- Fat bloom is when the fats in the cocoa butter melt and separate from the cocoa solids and resolidify as white streaks
- Forms III and IV have a higher melting point than forms I and II so they are firmer and more stable. They produce chocolate that is not quite snappy and still has some fat bloom
- Cooled chocolate with crystal structure forms I, II, III, and IV will melt in your hands
- The most desired crystal structure form V is quite stable, shiny, snappy, smooth, and won't melt in your hands but will melt easily in the mouth

- Form VI crystals are the most stable, but produce hard and waxy chocolate with fat bloom that won't easily melt in the mouth

Other Interesting Information: How is this used in the real world?

- Tempering or heating and cooling glass or metal improves durability and hardness. The same goes for chocolate
- Adding any water to melted chocolate will destroy the texture entirely as the water doesn't react well with the melted cocoa fats
- Different types of chocolate (white, milk, dark) require different temperatures for each of the 3 stages of tempering
- Big companies will often use chocolate tempering machines to create a consistent result and to aid with mass production
- The best environment for tempering chocolate is a cool, dry room that's around 21°C or cooler
- Heating chocolate using indirect heat such as steam (double boiler) prevents chocolate from burning
- Tempered chocolate is not only more visually appealing, but it's also easier to ship out because of its low melting point
- Professional and experienced chocolatiers will spread the melted chocolate on a large marble/granite surface to cool it (sometimes called "table tempering", a traditional method)
- If you've left chocolate in your pantry throughout the summer and it turned cloudy, that because some of the chocolate melted and cooled in other crystal structures
- Milk chocolate is less likely to transform in form VI crystals because milk solids and fats slow the transition

Research Paper

Angela Qin
A Choco-Lot About Chocolate

Chocolate plays an enormous role in most peoples' lives— from the hollow milk-chocolate bunnies at Easter to Forrest Gump's famous analogy about life. The point is, everybody loves chocolate. But it doesn't make sense that we know so little about our favorite sweet treat— like why it can't survive a few months in the back corner of a pantry, or why the chocolate that you tried to drizzle over baked goods always melted so fast. These are the type of questions that I sought to answer when it came time to choose a science fair project. Originally, I had only wanted to know why store-bought chocolate never looked the same after it had gone through a microwave, but instead, I stumbled across the incredibly complex nature of chocolate, with all of its various properties and specific crystalline structures. I learned about the relationship between chocolate and its crystal formations, and how the variable of temperature factored into this sweet equation. It turns out that there is a (choco) lot more to chocolate than meets the eye, and I was going to have to get my hands dirty.

Temperature plays a key role in the chocolate-making process. Chocolate is incredibly sensitive to changes in temperature, so a few degrees too hot could make it dry and crumbly, while a couple of degrees too cold might leave you with soft and splotchy chocolate. So why is this? Chocolate gets its structure from cocoa butter, or otherwise known as theobroma oil. Cocoa butter is a fat that is extracted from cocoa nibs— which are basically dried and fermented cocoa beans. This fat is actually a six-phase polymorphic crystal, which essentially means that it can crystalize in 6 different formations— I, II, III, IV, V, and VI. Each of these crystal formations or crystal structures melts at different temperatures, with the lower roman numerals — I, II, and III — melting at lower temperatures and the greater roman numerals melting at higher temperatures. This means that form VI crystals require the most amount of heat to melt, while form I crystals melt with the least amount of heat. Unsurprisingly, form VI crystals are also the most stable cocoa butter crystals. Crystal formations with higher melting points— like forms V and VI— are more dense and stable than those with lower melting points. If you tried to eat a piece of chocolate that predominantly contained form VI crystals, you'd probably be chewing for a long time before it melted. Contrarily, a piece of chocolate with mostly form I, II, and III crystals would probably disappear the second it hit your tongue.

In order to achieve a chocolate with a smooth, sheeny finish that melts easily, but not too quickly in the mouth, the chocolate has to undergo a process called tempering. The reason that tempered chocolate is so desirable is solely because of the form V crystals that it contains. The crystalline structures within form V crystals result in a more durable and smooth chocolate. Form V crystals also just happen to melt at 33.8°C or 93°F, which is around body temperature and makes them perfect for consumption. Tempering chocolate requires the chocolate to be heated, cooled, and then heated again to very specific temperatures. The initial heating is just hot enough to completely melt the chocolate and destroy all pre-existing crystal formations, leaving a "blank canvas" of sorts. The melted chocolate then needs to be cooled to a temperature just below where form V crystals start to appear. The final heating then brings the melted chocolate to a temperature where all other crystal formations— I, II, III, or IV — are destroyed, leaving only the desirable form V crystals. For smaller-scale batches of chocolate—like this project—the "seeding" method of tempering chocolate is best. The seeding method basically entails the introduction of pre-tempered chocolate into the already-melted chocolate during the cooling stage of tempering. These pre-tempered pieces of chocolate, otherwise known as "seed chocolate", incorporate form V crystals into the melted chocolate, which encourages the melted, scattered crystals to also get into the same formation. I like to think of this process as "follow the leader".

After melted chocolate cools and solidifies, it can often look very different from your typical grocery store chocolate. This is caused by the different cocoa butter crystal structures, which each produces chocolate with different qualities. Form V crystals— the finest of the fine, the greatest of them all, the crème de la crème of the crystalline structures— creates the perfect tempered chocolate. It's smooth, shiny, snappy, and won't melt easily and dirty your hands like crystal structure forms I, II, III, and IV will. In other words, form V crystals are like the flashy lamborghinis while the other crystal formations are more like honda civics. Because of their unstable and easily-meltable nature, chocolate with crystal forms I and II will usually be soft and crumbly, with obvious fat bloom. Fat bloom is the result of the pale-yellow cocoa fat melting and separating from the brown cocoa solids, and appears as white-ish streaks or dots. Crystal forms III and IV have a slightly higher melting point, so the chocolate that they produce tends to be firmer and more stable with less fat bloom, though not quite snappy like tempered chocolate. Finally, the less-commonly seen form VI crystals will result in the most stable chocolates, but sacrifice texture and appearance in the process. Chocolate with form VI crystals are quite difficult to eat, as they're incredibly hard and waxy, with significant fat bloom. You've probably eaten chocolate with this type of crystal structure, as it's usually found in the chocolates that are forgotten in the back of a pantry or the bottom of a purse.

Tempering chocolate is arguably the most important step in the chocolate making process. Just as tempered glass phone-protectors are more durable than their non-tempered counterparts, tempered chocolate is much more structurally stable than non-tempered chocolate. This, along with its low melting point and aesthetic appeal, helps in distribution and marketing, which makes tempered chocolate the go-to option for big-name companies like Cadbury and Lindt— so much so that it has become the industry standard. However, tempering chocolate is an incredibly complex and involved process. This is why big chocolate manufacturers will typically use specialized chocolate-tempering machines to do their dirty work for them. While these machines are helpful in mass-production and for ensuring product consistency, the chocolates that they produce will never quite measure up to the handmade works of professional chocolatiers. Experienced chocolate makers will spend years perfecting the precise art of tempering. While amateur "do-it-yourselfers" like myself need to rely heavily on a thermometer, these experts can assess the temperature of the chocolate simply by looking at and feeling it. Expert chocolatiers will typically use a traditional process known as "table-tempering", which starts by melting the chocolate through indirect heat using a double boiler. This ensures that the chocolate won't burn. Then, to cool it down, they'll spread the melted chocolate over the large marble or granite surface of a table— hence the name "table-tempering".

No matter how experienced the chocolatier, home cook, or even machine, there are always basic ground rules that need to be followed in order to produce a well-tempered chocolate. Number one: the melted chocolate must *never* come into contact with water of any kind. Water molecules don't react well with melted cocoa fats, which causes the chocolate to seize up. In an article, master chocolatier and business owner Richard Tango-Lowy once said, "We joke that we don't even think about water while we're working with chocolate." (Smithsonian Magazine, What Physics Tells Us About Making the Perfect Chocolate) Rule number two: chocolate should always be tempered in a cool and dry environment— around 21°C — to optimize crystal formation. If the room is too cold, the chocolate will cool too fast, and the wrong crystals may start to form. If the room temperature is too warm, the beautiful form V crystals might start to disappear, again leaving you with the wrong crystal formations. It's also good to remember that different types of chocolate require different temperatures for each of the three stages of tempering. This makes sense as chocolate variations are just a result of the different ingredients being added or removed from a basic cocoa and cocoa butter mixture. For instance, white chocolate is just chocolate with more added sugar and without the cocoa solids. Milk chocolate is just dark chocolate that contains added milk solids and fats. Another important rule that doesn't apply so much to the tempering process is that chocolate needs to be stored in a cool and dry place. If you've ever left chocolate in the backseat of your car in the summer just to later find that it had turned cloudy, that means that some of the form V crystals had melted in the heat and then cooled into other crystal structures.

Overall, I think I've gained a considerable amount of respect for chocolate. Like a small child, it can be very particular, and will fuss and become upset if it's in unhappy conditions. However, despite the exhausting mood swings, you can't help but love it. Through my research, I've learned that temperature makes all the difference when it comes to tempering chocolate and it can affect anything from the texture to the physical appearance of the chocolate. Slight tweaks in the temperature can turn a firm chocolate soft, or even a shiny chocolate dull and streaky. This research will have enormous effects on the results of my experiments, seeing as I now understand exactly *why* my tests may be going astray. Armed with all of this newfound knowledge, I can't wait to get my hands dirty and see what the big deal is about tempering chocolate (and hopefully taste-test a few samples along the way!)

Hypothesis: Dark chocolate will only temper when heated to the right temperatures, and if the temperatures are too low or too high, the chocolate will be too soft and unstable when held.

Materials

- 2304g of Belcolade Extra Dark Chocolate 72% Wafers (768g per trial)
- Food scale
- Knife
- Cutting board
- Medium-sized metal bowl
- Instant read thermometer (measured in degrees Celsius)
- Stove
- Rubber spatula
- Small saucepan
- Water
- Refrigerator
- Silicon molds

Optional but recommended:
- Paper towels for cleaning
- Plates for setting down chocolate-covered utensils

Procedure

Important Notes:

- Remember to clean **all** utensils in between experiments including bowls, mixing utensils, thermometer, and molds.
- **DO NOT** let any water get into the chocolate.
- Instructions below are for **one trial only.** Repeat three times for dependable results.
- If temperature has accidentally gone too high or too low, move on to the next step anyways

For Properly Tempered Chocolate:

1. Check the thermostat to make sure room is 21°C or colder.
2. Measure out and roughly chop 256g of Belcolade Extra Dark Chocolate 72% Wafers.
3. Remove 25% or 64g of the chopped chocolate and set aside.
4. In a small saucepan, bring about an inch of water to a gentle simmer and turn the heat down to the lowest setting.
5. Place the remaining 75% of the chopped chocolate in a medium-sized metal bowl and set it over the saucepan, making sure the bottom of the bowl never touches the water underneath.
6. Stirring and scraping down the sides with a rubber spatula, heat until the thermometer reads 45°C and remove from the saucepan.
7. Continuously stir in reserved 25% of the chopped chocolate in small increments until all chocolate has melted and the mixture has reached 27°C.
8. As soon as the chocolate has reached the correct temperature, return it to the heat and stir gently until it just reaches 32°C.
9. Remove from heat and pour into molds, remembering to level off the tops.
10. Depending on the size of molds used, wait until chocolate has completely hardened at room temperature to remove from the molds.
11. Record findings in log book.

For Incorrectly Tempered Chocolate at Lower Temperatures:

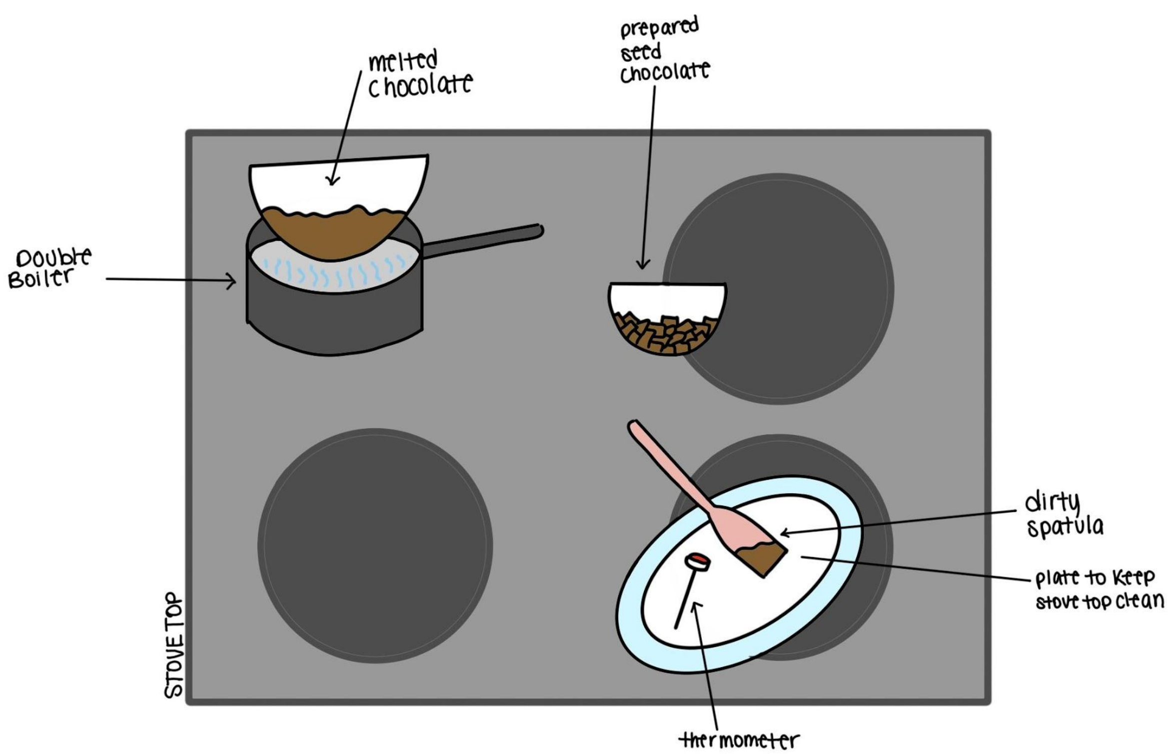
1. Check the thermostat to make sure room is 21°C or colder.
2. Measure out and roughly chop 256g of Belcolade Extra Dark Chocolate 72% Wafers.
3. Remove 25% or 64g of the chopped chocolate and set aside.
4. In a small saucepan, bring about an inch of water to a gentle simmer and turn the heat down to the lowest setting.
5. Place the remaining 75% of the chopped chocolate in a medium-sized metal bowl and set it over the saucepan, making sure the bottom of the bowl never touches the water underneath.
6. Stirring and scraping down the sides with a rubber spatula, heat until the thermometer reads 45°C and remove from the saucepan.
7. Continuously stir in reserved 25% of the chopped chocolate in small increments until all chocolate has melted and the mixture has reached **25°C**.
8. As soon as the chocolate has reached the correct temperature, return it to the heat and stir gently until it reaches **30°C**.
9. Remove from heat and pour into molds, remembering to level off the tops.
10. Depending on the size of molds used, wait until chocolate has completely hardened at

room temperature to remove from the molds.
11. Record findings in logbook

For Incorrectly Tempered Chocolate at Higher Temperatures:

1. Check the thermostat to make sure room is 21°C or colder.
2. Measure out and roughly chop 256g of Belcolade Extra Dark Chocolate 72% Wafers.
3. Remove 25% or 64g of the chopped chocolate and set aside.
4. In a small saucepan, bring about an inch of water to a gentle simmer and turn the heat down to the lowest setting.
5. Place the remaining 75% of the chopped chocolate in a medium-sized metal bowl and set it over the saucepan, making sure the bottom of the bowl never touches the water underneath.
6. Stirring and scraping down the sides with a rubber spatula, heat until the thermometer reads 45°C and remove from the saucepan.
7. Continuously stir in reserved 25% of the chopped chocolate in small increments until all chocolate has melted and the mixture has reached **30°C**.
8. As soon as the chocolate has reached the correct temperature, return it to the heat and stir gently until it reaches **36°C**.
9. Remove from heat and pour into molds, remembering to level off the tops.
10. Depending on the size of molds used, wait until chocolate has completely hardened at room temperature to remove from the molds.
11. Record findings in logbook.

Experimental Diagram:



Control: Store-bought, pre-tempered chocolate

	Physical Appearance	Texture/ Snapiness	Taste	Mouthfeel/ Does it melt when held?
Belcolade Extra Dark Chocolate 72% Wafers	Some pieces had white spots (could be chocolate dust), others were clear and had slight sheen	Very hard and has a loud snap when broken. Texture is very smooth and uniform	Very strong dark chocolate flavor	Melts slowly on the tongue, requires some chewing to get it to melt quicker. Will not melt in hands.

Observations and Data

Test #1, 02/08/21 - 02/09/21:

	Temperatures Reached (°C)	**Physical Appearance**	**Texture/ Snapiness**	**Taste**	**Mouthfeel/ Does it melt when held?**
Properly Tempered Chocolate	**Goal:** 45°C, 27°C, 32°C **Actual:** 47°C, 26°C, 33°C	Very shiny exterior, uniform coloring (no white spots/fat bloom)	Made some noise when broken, interior is uniform and smooth	Very strong dark chocolate flavor	Very smooth and melts relatively quickly on tongue, little chewing required. Leaves some residue in hands.
Incorrectly Tempered Chocolate at Lower Temperatures	**Goal:** 45°C, 25°C, 30°C **Actual:** 50°C, 25°C, 35°C	Developed some small air bubbles and grey fat bloom on exterior. Has a slight sheen.	Makes very little noise when broken. Chocolate is a little crumbly, and fat bloom is slightly gritty.	Very strong dark chocolate flavor	Slightly soft and yields easily when chewed on. Leaves residue when held in hands
Incorrectly Tempered Chocolate at Higher Temperatures	**Goal:** 45°C, 30°C, 36°C **Actual:** 53°C, 35°C, 37°C	Very shiny exterior, uniform coloring (no white spots/fat bloom)	Made a subtle snapping noise when broken, and interior (broken face) is sharp and jagged	Very strong dark chocolate flavor	Somewhat soft but slightly firmer than previous trial (too-low temperatures). Leaves some residue when held.

Test #2, 02/10/21 - 02/11/21:

	Temperatures Reached (°C)	**Physical Appearance**	**Texture/ Snapiness**	**Taste**	**Mouthfeel/ Does it melt when held?**
Properly Tempered	**Goal:** 45°C, 27°C, 32°C	Very shiny exterior,	Very snappy, almost bubbly	Very strong dark	Firm and melts relatively quickly

Chocolate	**Actual:** 55°C, 27°C, 33°C	uniform coloring (no white spots/fat bloom)	interior	chocolate flavor	on tongue, some chewing required. Leaves very little residue in hands.
Incorrectly Tempered Chocolate at Lower Temperatures	**Goal:** 45°C, 25°C, 30°C **Actual:** 46°C, 26°C, 30°C	Very shiny exterior, uniform coloring (no white spots/fat bloom). Chunky and has air bubbles in some places.	Loud snap when broken, has jagged texture on broken face.	Very strong dark chocolate flavor	Very firm and takes some time to melt on tongue. Chewing first breaks up chocolate then melts it (doesn't immediately melt). Leaves little to no residue on hands.
Incorrectly Tempered Chocolate at Higher Temperatures	**Goal:** 45°C, 30°C, 36°C **Actual:** 45°C, 30°C, 37°C	Dull exterior with evident fat bloom and air bubbles.	Had a snap when broken, but sound was dull. Many small air bubbles inside, texture not uniform.	Very strong dark chocolate flavor	Slightly soft and yields easily when chewed on. Has somewhat crumbly and gritty texture. Leaves residue when held in hands.

Test #3, 02/11/21:

	Temperatures Reached (°C)	Physical Appearance	Texture/ Snapiness	Taste	Mouthfeel/ Does it melt when held?
Properly Tempered Chocolate	**Goal:** 45°C, 27°C, 32°C **Actual:** 45°C, 27°C, 32°C	Shiny exterior, some air bubbles and uniform coloring	Very loud snap when broken, inside is very smooth and uniform.	Very strong dark chocolate flavor	Very firm and smooth. Doesn't melt immediately when chewed, and leaves little to no residue on hands.

Incorrectly Tempered Chocolate at Lower Temperatures	**Goal:** 45°C, 25°C, 30°C **Actual:** 47°C, 25°C, 31°C	Shiny exterior, air bubbles present, and some streakiness from fat bloom.	Very loud snap when broken, inside is textured and jagged.	Very strong dark chocolate flavor	Very firm and smooth. Doesn't melt immediately when chewed, and leaves little to no residue on hands.
Incorrectly Tempered Chocolate at Higher Temperatures	**Goal:** 45°C, 30°C, 36°C **Actual:** 45°C, 30°C, 38°C	Shiny exterior, some air bubbles, and some pieces had evident fat bloom.	Snaps when broken but not very loudly, many small air bubbles on the inside—not uniform at all.	Very strong dark chocolate flavor	Somewhat firm and has crumbly/gritty texture. Melts very quickly when chewed, and leaves some residue when held in hands.

Overall Summary

After completing the experiments, I've realized that chocolate is very sensitive to and will show significant physical changes when exposed to different temperatures. If the chocolate isn't heated and cooled to specific temperatures that are best suited for tempering chocolate, it won't be able to achieve the glossy, firm, and smooth texture we're used to. Based on the test results, it seems that if the temperatures that the chocolate is heated and cooled to are significantly higher or lower than the preferred tempering temperatures, the chocolate will end up being dull, soft, and crumbly. However, in all of my experiments, the taste of the resulting chocolate was never affected despite the temperature changes.

Project Journal

02/04/21- While writing the procedure, I decided to choose the "too low" and "too high" temperatures that I did so that there would be a big enough difference to be noticeable. I made sure to keep the "too low" temperatures high enough so that the chocolate wouldn't set in the bowl. I also made a point to bold the modified temperatures in the instructions to make them more noticeable as well. I'm running a little bit behind schedule, but hopefully it will all work out!

02/08/21- During the properly tempered chocolate part of Test #1, I realized that the temperatures of the chocolate change very quickly, and on multiple occasions accidentally allowed the chocolate to become too cool or too hot, which may have skewed the results of this test. I also realized that chopping solid chocolate is incredibly tedious.

02/09/21- With more experience, I found that the process for tempering at both too-low and too-high temperatures went a lot more smoothly. I was more efficient in cleaning up, wasted less chocolate, and even chopping the chocolate seemed easier. However, I still need to keep a better eye on the thermometer to prevent the chocolate from getting too cool or too hot. I think for Tests #2 & #3 I will keep the thermometer inside the bowl at all times instead of removing and re-inserting it. Overall, I'm very happy with the way the Test #1 turned out and had a lot of fun.

02/10/21- Today I did the **Properly Tempered Chocolate** and **Incorrectly Tempered Chocolate at Lower Temperatures** portions of Test #2. I feel quite confident in the properly tempered chocolate, but for some reason the chocolate tempered at lower temperatures wouldn't go down to 25°C. The mixture kept getting more and more viscous, but the temperature would stay the same. This resulted in lots of small lumps of unmelted chocolate in the molds, so it will be interesting to see how that turns out. I also quickly realised that keeping the thermometer inside the bowl at all times was simply not possible, as it kept falling over into the chocolate and made stirring the chocolate incredibly difficult.

Since starting the actual experimentation portion of this project, I've realized just how time consuming this project is. Not only is the clean up a chore, I have to wait at least 90 minutes for the chocolate in the molds to set. However, now that I've had more experience with the melted chocolate, I find that stirring the beautiful concoction can be quite mesmerizing and calming.

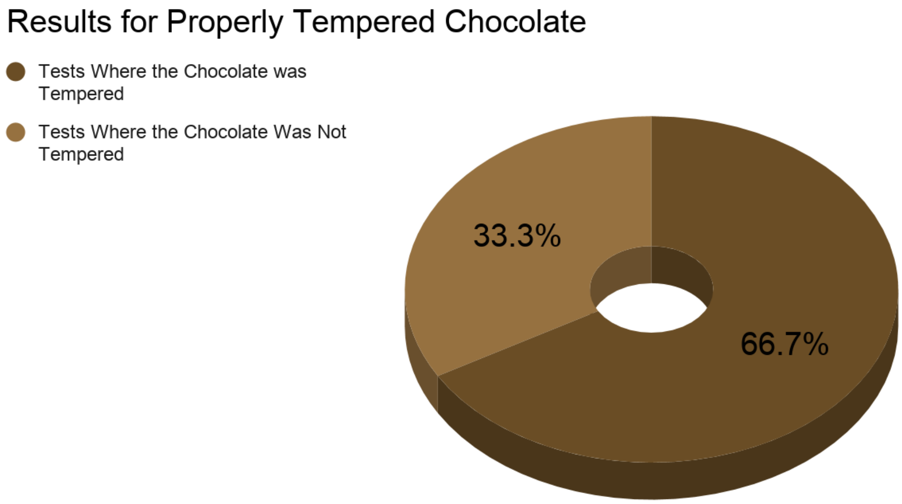
02/11/21- Today I did the **Incorrectly Tempered Chocolate at Higher Temperatures** portion of Test #2 and all of Test #3.

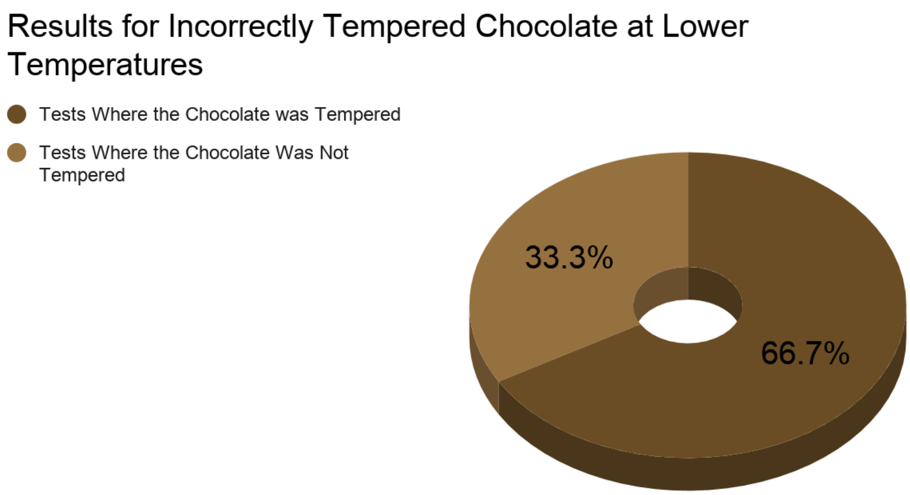
I checked on the Test #2 chocolate made with lower temperatures from the previous day, and somehow it seemed perfectly tempered and was the snappiest out of all the previous Tests. I hypothesize that this is because the "lower" temperatures ended up being quite close to the proper temperature for tempering chocolate. As I said in the last journal entry, I had had difficulty bringing the "too low" temperature down to 25°C, and only managed to get it to 26°C before it started getting too viscous. 27°C is the temperature that creates properly tempered chocolate, so it makes sense that chocolate that was brought down to 26°C would be pretty close to tempered as well. However, though this experiment created the most tempered chocolate, it's worth noting that the chocolate has chunks of chocolate that had not yet fully melted when it was poured in the molds. The chocolate also had the most air bubbles out of all the test, as it was stirred the longest in an effort to bring the temperature down.

I also noticed that in all of the tests, the batches of chocolate that were melted at the right temperatures and the batches that were melted at lower temperatures all hardened quicker than the batches of chocolate that were melted at higher temperatures. When I would go to clean up the chocolate that had accidentally dripped onto the counter, the chocolate that was melted at higher temperatures had always remained liquid while the drippings from the other batches would already be solidified into little droplets.

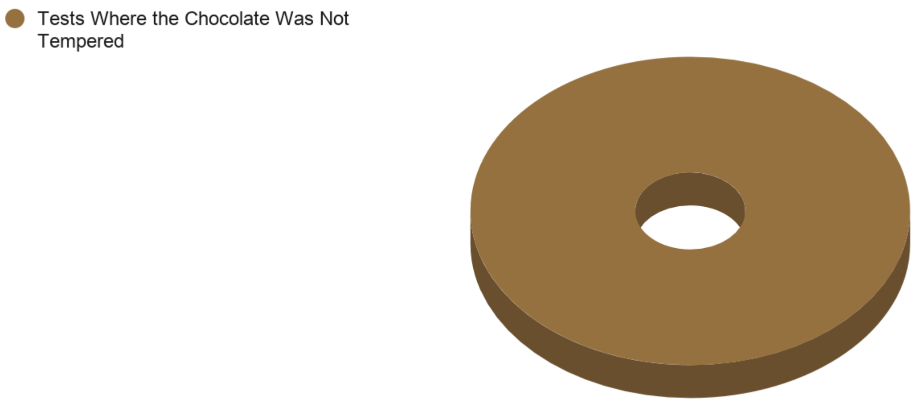
Sometimes there are still unmelted chunks of seed chocolate in the final mixture when it's poured into molds, but I've decided to just let them be. Normally, if you were to temper chocolate to make decorations, you would make the seed chocolate larger so the unmelted bits would be easier to fish out. However, we aren't going for aesthetics in this experiment and the chunks don't really affect the final result so I just left them in.

Managed Data





Results for Incorrectly Tempered Chocolate at Higher Temperatures



Conclusion

Based on some previous background research, I hypothesized that chocolate would only temper when heated to specific temperatures, and if these temperatures were too low or too high, the resulting chocolate would be too soft and unstable when held. My research showed that different cocoa butter crystals will form at different temperatures, so changes in temperature would create new crystalline structures. Since there is only one crystal formation that produces shiny and firm chocolate, the presence of any other crystalline structures would result in negative alterations to the texture and physical properties of the chocolate. After completing the chocolate-focused experiment, it’s evident that temperature plays an immense role in the state of cooled and set chocolate.

Throughout the experiment, I made several mistakes regarding the temperature of the chocolate— sometimes allowing it to get too hot, other times not hot enough. As shown in the data tables, each time I’d allowed the chocolate to reach the wrong temperature, the results would be different from the other tests. For instance, in the three “Properly Tempered Chocolate” tests, the only test that resulted in un-tempered chocolate was the first— in which I had drastically botched the temperatures. In the tests that I had used the correct temperatures, I found that there was a more drastic difference between the “just-right” and the “too-high or too-low” tempering temperatures, the farther the properties of the resulting chocolate were from tempered chocolate. In other words, since the temperatures used in the tests of “Incorrectly Tempered Chocolate at Lower Temperatures” had only a small difference—only about 2°C— from temperatures used in “Properly Tempered Chocolate” tests, more of the resulting chocolates from the “Incorrectly Tempered Chocolate at Lower Temperatures” tests had properties of tempered chocolate. On the other hand, the temperatures used in the tests of “Incorrectly Tempered Chocolate at Higher Temperatures” had a much larger difference—about 3°C to 6°C— from temperatures used in “Properly Tempered Chocolate” tests and less of the resulting chocolates from the “Incorrectly Tempered Chocolate at Higher Temperatures” tests had properties of tempered chocolate. The properties of these incorrectly-tempered chocolates ranged from evident fat bloom or white streaks, a dull and matte exterior, soft or crumbly texture, inconsistent and bubbly interior, and being melting too quickly when held in the hands or on the tongue. However, despite these differences, I found that there was always one property that stayed constant no matter what temperatures the chocolate was brought to— the dark-chocolaty taste. Based on these observations, I can confidently say that my hypothesis was correct, though it left out a few points (such as the taste and physical appearance of the chocolate).

Applications

Tempering chocolate is a universal and essential component of the chocolate and dessert industry, and is practiced by all big-name chocolate companies, including Lindt, Ferrero, Cadbury, Hershey, and Nestle. With its glossy complexion and smooth texture, tempered chocolate made with form V cocoa butter crystals produces the most aesthetically pleasing chocolates out of all the different crystalline structures. Not only does the appearance of tempered chocolate help with marketing, but it also offers the most satisfying eating experience for consumers. Tempered chocolate melts perfectly and smoothly in the mouth— not too fast and not too slow. The V form crystals found in tempered chocolate also produce a more stable and firm chocolate, which makes it perfect for transportation. Aside from a manufacturing standpoint, learning about tempering chocolate can also benefit regular people in their day-to-day lives. Having knowledge of chocolate and its complex crystalline structures could possibly prevent you from finding grey, crumbly, and streaky chocolate bars in the bottom of your purse.

Questions

- What is the amount of the different crystal structures in the chocolate?
- Was the experiment inaccurate because the thermometer was faulty?
- What happens to the cocoa butter crystals when chocolate burns?
- Why can't form VI crystals be formed by melting?
- How do master chocolatiers know exactly when to stop heating and cooling the chocolate using the "table tempering" method?

Improvements

Experimental Errors

Despite my best efforts, there were several errors that could have occurred and skewed the results of the experiment. Often times the chocolate would heat or cool much faster than I had anticipated—sometimes a whole 10°C hotter— and I should have been more diligent and kept a better eye on the chocolate. These errors in temperature could have easily affected the results for some of the tests. Another possible mistake on my part was buying a cheap grocery store thermometer. Though affordable, the cheaper options are often less precise than their more expensive counterparts, which could have resulted in some inaccuracies regarding the temperature of the chocolates. Furthermore, if there had been any cocoa butter residue that hadn't been fully washed off of the molds, it would have resulted in the cooled chocolates appearing like they had fat bloom. I had done my best to thoroughly clean all of the equipment after each test, but there is still a possibility that some of the stubborn, oily substance was left on the molds. Perhaps the point that I could have improved the most upon would have been the amount of time that the chocolate cooled for. For some tests, I had waited only about two hours before recording results, while other tests spent a whole night in the molds. Keeping the cooling time as a controlled variable would have made the experiment much more accurate as a whole, though nobody can say for sure how big of a difference doing so would have made. It's obvious that there are many aspects of this experiment that could have been improved, and many more things that could have been done differently, but I'm still proud of the work that I did with the resources that I had.

How Could the Project be Done Differently?

Looking back at the planning and procedure of this project, it's now evident that there are several swaps that could have been made. For starters, the entire experiment could have been conducted using degrees fahrenheit instead of celsius. I had initially chosen the latter option as Canada uses the metric system of measurement, but both units of temperature would have worked equally well. I also had the option of doing the experiment with other types of chocolate— like white or milk chocolate. However, dark chocolate with a high percentage of cocoa content tends to have fewer additives than milk or white chocolate. These additives can include sugar, milk ingredients, and even flavorings— all of which could impact the final results of the experiment. Besides the “seeding” method of tempering used in this project, there are also other methods that don’t require quite as much hands-on work. One of these methods involves pre-tempered cocoa butter, which is exactly what it sounds like— cocoa butter that already contains form V crystals. The purpose of adding these pre-tempered cocoa butter bits to the melted chocolate is essentially the same as using seed chocolate— to encourage the rest of the crystals to take the same form as the incorporated form V crystals. However, this method of tempering almost always results in perfectly tempered chocolate, which was not the goal of this experiment.

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