Effect of Moisture Content on The Melting Points of Different Sugar Types

Emma Coupal, Roya Farkhani, Alana Kerr, Hanaa Punja

emma.h.coupal@gmail.com, farkhaniroya@gmail.com, alanavkerr@gmail.com, hanaap28@gmail.com

Abstract

The objective of this study is to determine if the moisture content of various sugar types— white, brown, icing, and coconut sugar, affects their respective melting points. Research methods for this study consisted of acquiring mean moisture contents of the four sugar types from literature, followed by using a kitchen oven to test at what temperature the various sugar types melt at. Icing sugar was found to have the highest mean moisture content, followed by brown sugar, coconut sugar and lastly, white sugar. We proposed that sugar with higher moisture content will have a lower melting point. With that said, icing sugar will have the lowest melting point, followed by brown, coconut, and then white sugar. From this study, the melting points of each type of sugar were found to be 368.7°F (white sugar), 340.0°F (brown sugar), 350.0°F (icing sugar), and 306.7°F (coconut sugar). Using linear regression analysis to identify a relationship between moisture content and the melting points of the sugar types, a p-value of 0.53 was obtained, which was greater than the significance value of 0.05. This indicated that there was no statistically significant correlation between moisture content and the melting point of the sugar types. Thus, it cannot be concluded that moisture content is correlated to the melting point of the different sugar types. Potential reasons for this may be due to both the moisture content of each sugar type being very low and not different enough from each other.

Introduction

Sugar is an essential source of energy and a major source of carbohydrate (“The Basics”). It is found in the majority of plants; however, sugar is mostly harvested from sugarcane and sugar beets because they contain higher sugar concentrations (Singh and Clarke). Sugar, chemically known as sucrose ($C_{12}H_{22}O_{11}$), is a disaccharide made up of one molecule of glucose linked to one molecule of fructose (Singh and Clarke). The formation of sugar is a result of a dehydration reaction that combines glucose and fructose by releasing one water molecule (H_2O) (Singh and Clarke). Too much moisture, in terms of hydration with H_2O, can disrupt the bond between glucose and fructose and thus its crystal structure (“6.1C: Melting Point Theory.”). To determine the extent to which moisture can disrupt a sugars’ crystal structure, sugar types with various moisture contents and their respective melting points were compared. The results from this comparison can be beneficial in choosing which type of sugar would provide advantages in cooking or baking. This study tested the effect, or lack thereof, of moisture content on the melting point of four different sugar types— white, brown, icing, and coconut sugar.

Moisture content is the measurement of how much water a substance retains (“Measuring Moisture Content & Water Activity”). This is often measured by subtracting a substance's weight, after drying, from its initial weight, and then dividing that number by the dry or total weight (“Measuring Moisture Content & Water Activity”). This yields units of grams of water per grams of solid substance (“Measuring Moisture Content & Water Activity”). The mean moisture content of the sugars that were tested are as follows: white sugar at 0.035%, icing sugar at 3.5%, brown sugar at 3%, and coconut sugar at 2.39% (“Moisture Monitoring”; “Powdered Sugar”; “Brown Sugar”; Nurhadi et al.). The null hypothesis of this study is that the moisture content does not have an effect on the melting points of each sugar type. The alternative hypothesis is that moisture content does have an effect on the melting points of each sugar type, specifically, sugar types with a higher moisture content will have a lower melting point. This would be due to the presence of impurities, in this case being molecules of H_2O, which will disrupt the crystal structure and decrease the energy required to break the linkage between glucose and fructose (“6.1C: Melting Point Theory.”). The disruption of the crystal structure significantly lowers the substance's stability, which will lower its melting point threshold (“6.1C: Melting Point Theory.”). That being said, it was predicted that icing sugar would have the lowest melting point amongst the sugar types as it has the highest moisture content.

Materials and Methods

This experiment was conducted using a kitchen oven, aluminum foil, white, brown, icing, and coconut sugar. The oven used in this study had previously been calibrated using white sugar and it was found that the actual oven temperature runs 12°F higher than the dial temperature. Aluminum foil trays (2x2 inches) were made to hold each sugar sample. For white, icing, and brown sugar, melting points were researched to be 367°F (Leander), 320°F (Schmidt), and 320°F (Schmidt), respectively. The oven was set to 355°F as the initial dial temperature for white sugar and 308°F for the remaining sugar types. There were no sources found on the approximate melting point of coconut sugar, so the same initial dial temperature for brown and icing sugar (308°F) was used, as it was lower than that of white sugar. For each round of heating, one teaspoon of the sugar of interest was added to a tray and carefully placed into the center of the preheated oven for 15 minutes. Once removed from the oven, the sugar was observed as either melted or not melted. If any region of the sugar had liquified, it was considered as melted and was then thrown out and a new tray of that type was added into the oven at a dial temperature 5°F below the prior temperature. This process was repeated, decreasing by 5°F increments each time until the lowest temperature was found at which the sugar began to melt. If the sugar sample did not melt initially, the dial temperature was increased by 5°F increments using the same tray, until the lowest temperature was found at which the sugar began to melt. This process was repeated until three melting points were collected from all four types of sugar, yielding 12 melting point temperatures, which were considered to be our sample size ($n = 12$). Once all the dial temperature melting points were obtained, they were averaged for each sugar type and then converted to actual melting points using the following formula: *dial temperature* + 12°F = *actual* *temperature*. For statistical analysis, linear regression was performed using the converted melting points in Excel to identify if a correlation between moisture content and mean melting points of the four sugars existed.

Results

In Figure 1, moisture content was compared to the mean melting points of the four different sugar types tested in this study. Moisture content being the independent variable and melting point being the dependent variable.

White sugar was found to have the highest melting point, followed by icing, brown, and coconut sugar. However, the icing sugar had the highest moisture content, followed by brown, coconut, and white sugar. This allowed us to reject our hypothesis as icing sugar, the sugar with the highest moisture content, did not have the lowest melting point.

The mean melting points for each of the sugar types are shown in Figure 1: 368.7°F for white sugar, 340.0°F for brown sugar, 350.0°F for icing sugar, and 306.7°F for coconut sugar. No trends were identified in Figure 1 as the R^2 value (0.2168) obtained was quite low, indicating that the data does not measure closely to the linear regression line. Further, a linear regression analysis with a significance level of $\alpha = 0.05$ was performed on this data using Microsoft Excel. This significance level was chosen as it is the standard in biology. This analysis tested if there was a correlation between the moisture content and melting points of the four sugar types. A p-value of 0.53 was obtained, which is larger than the significance level ($0.53 >> 0.05$), indicating that there was no statistically significant correlation between moisture content and the melting points of the four sugars ($df = 3$, $F = 0.55$, $p = 0.53$).

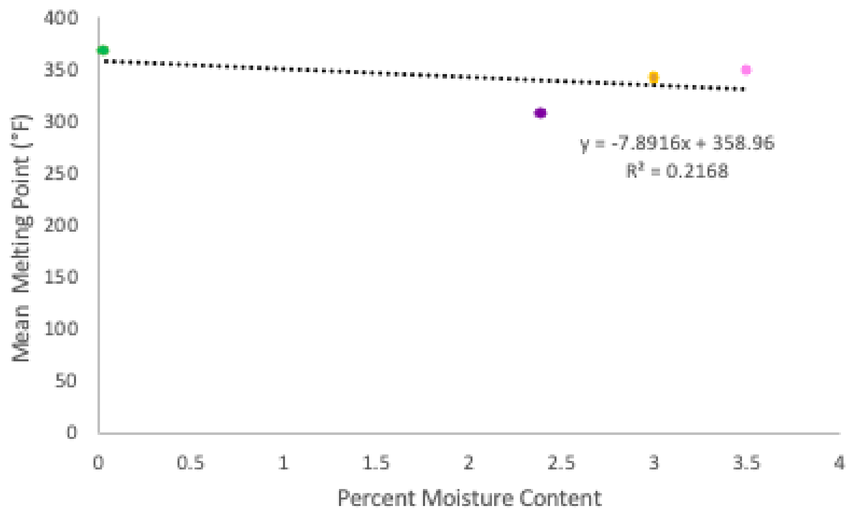

Figure 1. The percent moisture content from left to right, white sugar, coconut sugar, brown sugar and icing sugar (n = 4) were compared to their respective melting points. Linear regression was performed which yielded a p-value of $p = 0.53$. $R^2 = 0.2168$, indicating that the moisture content explains 21% of the melting point data, and therefore the data does not measure closely to the linear regression line.

Discussion

The p-value ($p = 0.53$) obtained from the linear regression analysis is much larger than 0.05, therefore we fail to reject the null hypothesis, that there is no statistically significant effect of moisture content against melting points. Thus, we must reject the alternative hypothesis that moisture content would indeed have an effect on the sugar's melting point. The results from this experiment did not align with the knowledge presented in previous literature, which suggests that the presence of impurities in a substance will result in a lower melting point due to the disruption of the crystal structure ("6.1C: Melting Point Theory."). The moisture content for each of the sugar types were relatively low, possibly explaining why the presence of these water impurities did not have a significant effect on the sugar samples. This was evident in a study that tested the effect of moisture content on the melting and physical ageing of cornstarch (Shogren, 83-90). In this study, the cornstarch with a lower level of moisture did not have as significant of an impact on the melting and degradation of itself as did the cornstarch with a higher level of moisture (Shogren, 83-90). This demonstrated that cornstarch with less moisture has greater melting and degradation capacities (Shogren, 83-90). Another study tested the effect of moisture content on the melting of wheat starch (Jang and Pyun). The wheat starch moisture levels were 40% and 50%, which is significantly greater (around 10 fold) than the moisture content of the sugar samples tested in this experiment (Jang and Pyun). Therefore, the low moisture content of the sugars used in this study may be a contributing reason explaining why a correlation was not seen between moisture content and melting points. Also, there may not have been a big enough difference between moisture contents of sugars in this experiment— they were all relatively similar, which could have contributed to producing the statistically insignificant results.

Humidity changes and moisture fluctuations that occur in the oven as trials progress can create a bias, as the moisture content in the sugar may be affected and alter expected results. This is because sugar is hygroscopic, meaning it can absorb moisture from the air ("Cucumber Chemistry: Moisture Capture with Desiccants"). Without humidity being controlled for, the sugars' moisture contents may have been altered due to the environment created by the oven. As a result, the melting points obtained may be skewed. Additionally, the sugar trays were placed on the top rack of the oven, which could have affected the melting points of the sugar samples. Ovens use air to transfer heat, and since the source of heat is located at the bottom, hot air rises— this makes the top part of the oven significantly hotter than the bottom (Baguley). To prevent this in the future, multiple replicates can be done on various racks in the oven to ensure no variability exists between different rack levels. One possible way to increase the accuracy of the experiment would be to purchase sugar types at the same time, ensuring production dates are within a similar range to avoid stale or expired sugar. Another solution would be to add the sugar into the tray right before placing it in the oven to avoid them from oxidizing and hardening, as the brown sugar did during this experiment. Finally, it would have been beneficial to shake the trays before placing them into the oven to ensure a more even spread of sugar and therefore a more consistent melting process.

Conclusion

In conclusion, there was no statistically significant correlation between the melting points of the four different sugar types and their respective moisture contents. Therefore, we cannot conclude that moisture content has an effect on the melting points of sugar. The insignificant results could have been due to the low moisture contents of the sugars and the lack of diversity between them. In the future, sugar types with higher moisture content should be tested to see if a relationship between moisture content and melting points exists.

Acknowledgments

We would like to begin by acknowledging that the land which we gathered to conduct this experiment is on the unceded territory of the Coast Salish Peoples, including the territories of the xwməθkwəy̓əm (Musqueam), Skwxwú7mesh (Squamish), Stó:lō and Səl̓ílwətaʔ/Selilwitulh (Tsleil- Waututh) Nations. We would also like to recognize the contributions of our professor Celeste Leander and the University of British Columbia for providing us with the opportunity to take this course. Lastly, we would like to recognize the contributions of our teaching assistants: Tessa Blanchard, Sofya Langman, and Jordan Hamden, for providing us with invaluable feedback throughout this term.

Works Cited

Baguley, Richard. “Appliance Science: The Circulating Physics of Convection Ovens.” *CNET*, CNET, 18 Mar. 2015, www.cnet.com/home/kitchen-and-household/appliance-science-the-circulating-physics-of-the-convection-oven/#:~:text=Convection ovens add a fan,top of the cooking space.

Britannica, The Editors of Encyclopaedia. "Melting point". *Encyclopedia Britannica*, 29 Jan. 2020, https://www.britannica.com/science/melting-point. Accessed 7 April 2021.

Campos, Adriane Mulinari. “A Complete Guide to Brown Sugars-from Unrefined to Raw and Refined.” *WhatSugar Blog*, WhatSugar Blog, 1 Jan. 2021, www.whatsugar.com/post/complete-guide-to-brown-sugars.

“Cucumber Chemistry: Moisture Capture with Desiccants.” Scientific American, Scientific American, 15 Oct. 2015, www.scientificamerican.com/article/cucumber-chemistry-moisture-capture-with-desiccants/#:~:text=Salt has a strong ability, water molecules in its surroundings.

Jang, J. K. and Y. Pyun. “Effect of Moisture Content on the Melting of Wheat Starch.” *Starch-starke* 48 (1996): 48-51.

Leander, C. (2020, November 30). Biology 342 UBC laboratory manual. Retrieved February 6, 2021, from https://canvas.ubc.ca/courses/63230/pages

Mermelstein, Neil H. “Measuring Moisture Content & Water Activity.” *IFT.org*, 1 Nov. 2009, www.ift.org/news-and-publications/food-technology-magazine/issues/2009/november/columns/laboratory.

"Moisture Monitoring During Sugar Production." *Moist Tech*, 25 Oct. 2018, www.moisttech.com/moisture-monitoring-sugar-production/.

Nurhadi, Bambang, et al. "Comparison of Crystallized Coconut Sugar Produced by Traditional Method and Amorphous Coconut Sugar Formed by Two Drying Methods: Vacuum Drying and Spray Drying." *International Journal of Food Properties*, vol. 21, no. 1, 2018, pp. 2339–2354., doi:10.1080/10942912.2018.1517781.

"Powdered Sugar." *Wikipedia*, Wikimedia Foundation, 4 Feb. 2021, en.wikipedia.org/wiki/Powdered_sugar.

Schmidt, S.J. Exploring the sucrose-water state diagram. *Manufacturing Confectioner,* January 2012, 79-89.

Shogren, R.l. "Effect of Moisture Content on the Melting and Subsequent Physical Aging of Cornstarch." *Carbohydrate Polymers*, vol. 19, no. 2, 1992, pp. 83–90., doi:10.1016/0144-8617(92)90117-9.

Singh, R. Paul and Clarke, Margaret A.. "Sugar". *Encyclopedia Britannica*, 12 Dec. 2019, https://www.britannica.com/science/sugar-chemical-compound. Accessed 7 April 2021.

“Sucrose.” *Wikipedia*, Wikimedia Foundation, 1 Feb. 2021, en.wikipedia.org/wiki/Sucrose.

“The Basics.” *The Sugar Association*, 28 May 2019, www.sugar.org/health/the-basics/.

“6.1C: Melting Point Theory.” *Chemistry LibreTexts*, Libretexts, 5 Mar. 2021, chem.libretexts.org/Bookshelves/Organic_Chemistry/Book:_Organic_Chemistry_Lab_Techniques_(Nichols)/06:_Miscellaneous_Techniques/6.01:_Melting_Point/6.1C:__Melting_Point_Theory.

Appendix

Table 1. Dial melting point temperatures of different sugar types

Trial #	White Sugar	Brown Sugar	Icing Sugar	Coconut Sugar
1	360°F	323°F	338°F	308°F
2	355°F	328°F	338°F	288°F
3	355°F	333°F	338°F	288°F

Example calculation (converting white sugar dial temperature to the actual temperature):

$$Actual\ temperature\ =\ 12°F\ +\ Dial\ temperature$$

360°F + 12°F = 372°F

Table 2. Actual melting point temperatures of different sugar types after calibration

Trial #3	White Sugar	Brown Sugar	Icing Sugar	Coconut Sugar
1	382°F	335°F	350°F	320°F
2	367°F	340°F	350°F	300°F
3	367°F	345°F	350°F	300°F