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Investigating the rate of heat transfer through chocolate varieties

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Abstract

This study investigates the effect of different chocolate fillings on the rate of conductive heat transfer through various chocolate bars. Using four varieties from Cadbury's 'Favourites'; Dairy Milk, Caramilk, Cherry Ripe, and Crunchie, the experiment used hotplates set to 70 °C to heat the chocolates, and IR cameras to measure both inner and surface temperatures as the chocolates were heated. The setup was designed to mimic a squat rectangular fin in order to allow for analysis based on Fourier's law in order to estimate the heat flux through the chocolates. Data was collected through manual repositioning of the IR camera, however technical limitations in the IR camera software necessitated the use of linear interpolation to recover data. This encompassed both the Dairy Milk and Crunchie datasets, but only Dairy Milk could be successfully recovered. While limited, the results indicate that Cherry Ripe exhibits delayed heat conduction compared to chocolates with no filling such as Dairy Milk and Caramilk. Despite the uncertainties introduced by measurement variability, convective heat losses that were not accounted for, and the destruction of the Crunchie thermal data, the findings indicate that further research should be done into the thermal performance of filled versus non-filled chocolates in order to optimise manufacturing processes and improve the thermal resistance of chocolate products in warm environments.

1. Introduction

While the mechanics and rate of heat transfer through chocolate may seem an irrelevant field of study, it is highly relevant to globalised chocolate manufacturers such as Cadbury and Hershey, where any melting or softening of their products can cost millions of dollars. This is especially relevant in warm climates such as Australia, where summer temperatures can regularly exceed 33.8 °C, the temperature at which chocolate generally melts as the solid cocoa butter transitions to liquid [1]. It is therefore critical in these environments to consider the thermal properties of chocolate in order to provide guidelines on refrigeration, maximum environmental exposure times and, if these guidelines prove to be too restrictive or inefficient, potential additives to increase the melting point of the chocolate.

1.1 Literature review

Due to the industrial relevance of the subject matter, this field has been researched extensively, with particular focus on various techniques for adjusting thermal properties, as well as how they affect manufacturing viability and consumer sentiment. D. Bikos et al. [2] highlights how micro-aeration can be used to increase specific heat capacity by 10%, as well as decrease thermal conductivity by 20%, however, this technique can affect both the flavour profile and the texture of the chocolate. H. Tewkesbury et al. [3] demonstrates how different polymorphic forms of chocolate have different properties, with Form V possessing the most desirable confectionery. Unfortunately, Form V is difficult to achieve through simple cooling, and specialised 'cooling tunnels' must be used in order to achieve specific temperature control [3]. While temperature is highly controlled during manufacturing, it is almost impossible to maintain a similar level of control during shipping and sale, and as such, many heat-related issues can present. These are investigated by both R.E. Timms [4] and P. Figoni [5], and include seizing [5] as well as sugar and fat bloom [4]. They elucidate how heat can contribute to seizure of chocolate, where molten chocolate is vulnerable to small amounts of water or polyols incorporating into it and causing it to become an unusable solid-like chocolate mass [5]. They also discuss the blooming of sugar and fat, where sugar is recrystallised on the surface of the chocolate and the solid fat phase grows [4]. These defects create highly undesirable properties in the chocolate, and as such, attempts are made to avoid them, mostly through storage at 18-20 °C and less than 50% humidity [1]. Attempts are also made through manipulation of chocolate's thermal properties, via the micro-aeration mentioned earlier in [2], or through Ethylcellulose, Interesterification of Cocoa Butter and Water-in-Oil Emulsion-Based Chocolate techniques evaluated in [1]. Unfortunately, none of these techniques achieve simple, cost-effective and highly heat-resistant results while maintaining the taste profile and mouthfeel of the chocolate. While further research should be done on the manufacture of heat-resistant chocolates, it is also industrially relevant to consider the effects on heat transfer that common chocolate fillings have. This is in order to determine whether certain varieties of chocolate should use current techniques for manufacturing of heat-resistant chocolate that have greater costs and produce a less desirable product for consumers. This is the area which this paper seeks to investigate, as despite the breadth of research on the thermal properties of chocolate in general, there is a large focus on the performance of pure milk chocolate, with little to no consideration of how fillings affect these properties.

1.2 Objectives

As indicated briefly in the literature review, this article will investigate the effects of chocolate fillings on heat transfer, specifically conduction, as due to the position of the filling inside the chocolate, it is the only method of heat transfer that is directly relevant to the thermal effects of the filling. While it is not directly related, convection will also be addressed briefly in relation to the experimental conditions and limitations. This research is relevant due to the current lack of fully effective heat resistant chocolate manufacturing techniques [1]. It is therefore desirable to evaluate how fillings affect the heat resistance of chocolate, in order to determine if specific confections can avoid utilising production methods that increase cost or reduce the consumer appeal of the product.

2. Methods

2.1 Experimental setup

In order to examine how chocolate fillings affect heat transfer through conduction, hotplates set to 70 °C were used to provide heat to the chocolates, while InfiRay Pro 2 IR cameras were used to measure the temperatures of the chocolates. Hotplates were set up with a small water-filled beaker for calibration and a thin piece of wax paper on which three identical chocolates were placed. This experimental setup can be found in Figure 1. The chocolates were placed on wax paper on top of the hotplate in order to protect the hotplates from melting chocolate while having minimal impact on heat transfer due to the thinness of the paper sheets (<1mm). As the precise melting point of the chocolates was unknown, and the aim of the experiment was focussed on the rate of heat transfer rather than any specific changes in the material properties of the chocolate as it heated, the chocolates were heated to 55 °C surface temperature rather than the melting point.

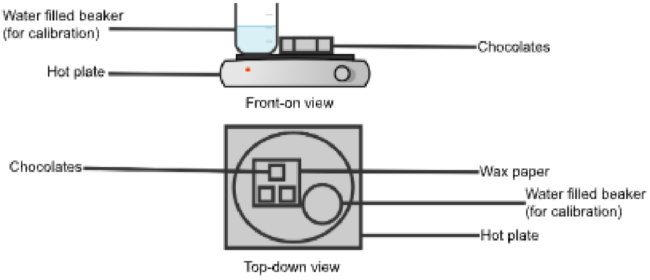


Figure 1: Experimental Setup

2.2 Chocolate selection and preparation

In selection for the chocolate varieties we would test, we chose four types of Cadbury chocolates that are all found in 'Favourites', and all chocolates were sourced from the same box for standardisation of age. The chocolates chosen were: Dairy Milk, as a control with no filling; Caramilk, to determine how a different variety of chocolate affects heat transfer (although this choice may have been a mistake, as it would be more beneficial to specialize the experiment for chocolate filling only); Cherry Ripe, to test how the viscous liquid cherry filling affects heat transfer; and Crunchie, to determine how solid honeycomb affects heat transfer. Before the chocolates were heated, they were bisected, measured for the cross sectional area of the bottom, and weighed. This was done in order to allow for standardisation in the data.

2.3 Data collection and analysis

Due to limitations in the IR camera software, only three points could be used to measure temperature. In order to circumvent this limitation, the cameras were handheld and the points were periodically moved from the center of the chocolates to the top surface in order to obtain measurements for both inner and surface temperature. Unfortunately, this movement introduced a large amount of variability in the data as the points were not taken in the exact same location each time.

2.4 Converting RGB values to temperature

Data from some of the videos was unfortunately obscured due to technical errors. However, the first half of the videos was able to collect data, which enabled the use of linear interpolation to predict the temperatures, given the RGB values of the video. This technique was effective in capturing the data for the Dairy Milk temperatures, however it failed on the Crunchie, as there was not enough data to form an accurate linear interpolation. The RGB values matched the predicted structure following the color spectrum, where the blue values were highest at the lowest temperature, green values were highest at the median temperature, and red values were highest at the highest temperature. This can be seen in Figure 2 below, where as the temperature increases, the RGB units of blue decrease, units for green reach its peak at the middle, and the units for red increase.

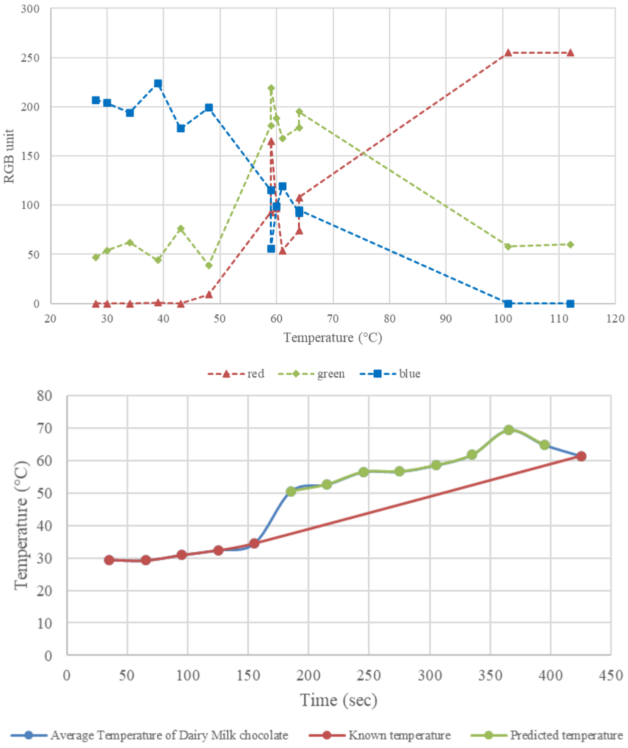


Figure 2: (top) Relationship between RGB values and temperature. (bottom) Relationship of the known temperature and the predicted temperature of the Dairy Milk chocolate

Although the scale differs, the correlation between RGB values and temperature aligns with the color space. This alignment supports the validity of employing linear interpolation to estimate temperature based on RGB values. However, due to the missing data for the range of 30 °C to 60 °C, the linear interpolation was not as accurate. As shown in the bottom graph of Figure 2, the predicted temperatures exhibit noticeable deviations from the known temperatures. The nature of linear interpolation requires the linear prediction of the two nearest data points. Thus, as seen in the bottom graph of Figure 2, the predicted temperatures at the ranges 30 °C to 60 °C were not as accurate.

3. Results and Discussion

In order to conduct analysis on the effect of various chocolate fillings on the melting characteristics and thermal conductivity, thermal camera data was collected to measure the internal and surface temperatures of the chocolates over time. Thermal shots of the sides of the chocolates were also taken to observe how the heat transferred through the chocolate from the bottom in contact with the hotplate, through the centre where the side shots measured the temperatures, to the surface where the temperature was also monitored. This data collection was completed for the Cherry Ripe, Caramilk, and Dairy Milk varieties from Cadbury's favorites range. The full tabulated data can be found in the supplementary and is also shown in Figures 3, 4 and 5 below, error bars were also added and calibrated to the standard deviations of the gathered data.

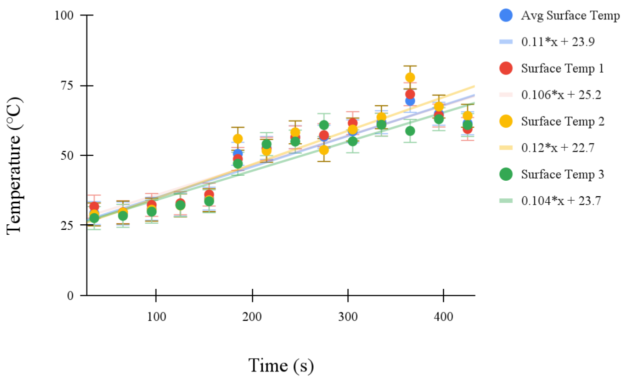


Figure 3: Temperature versus time for Dairy Milk

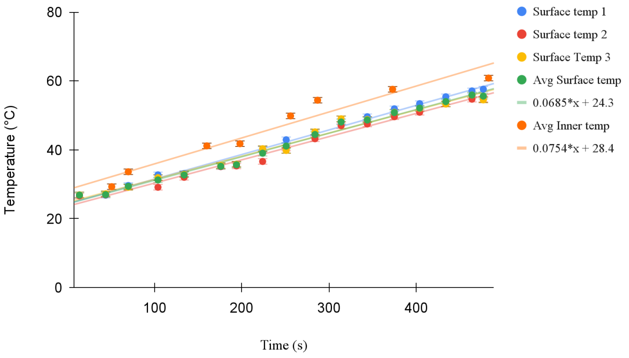


Figure 4: Temperature versus time for Cherry Ripe

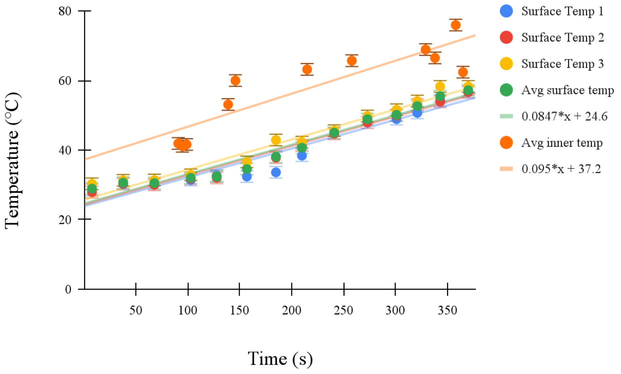


Figure 5: Temperature versus time for Caramilk

3.1 Appropriate modelling of heat transfers occurring

In order to analyse these results correctly, we must first consider the types of heat transfer acting within the melting chocolate model system, as well as the points at which these occur and how changing the type of chocolate could potentially affect the heat transfer throughout the system. When considering the physical situation of the chocolate sitting on top of the hotplate, it can be considered analogous to a rectangular fin, except where fins are typically long and thin in order to maximise surface area for heat dissipation, the chocolate is wide and short. Nevertheless, the heat transfer principles can be applied in the same way. This means that there is conductive heat transfer moving from the hot plate through the chocolate, where it eventually reaches the surface of the chocolate and then convective heat transfer occurs from the surface of the chocolate. It is important to note that all convection within the experimental design was natural convection rather than forced convection. See Figure 6 for a visual representation of the model.

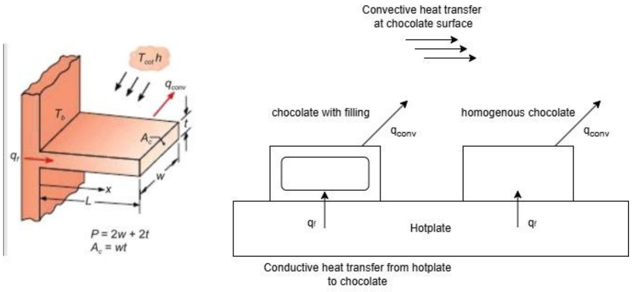


Figure 6: Rectangular fin heat transfer diagram to model heat transfer components present within our experimental design [6]

Once these concepts are established, it is clear that our data is investigating the differences in the heat distribution as well as the rate of heat distribution caused by differences in composition between chocolates. The utilisation of this fin model to analogise chocolate melting on a hotplate was inspired by M. M. Dreger et al's work in [7]. While the fin model is accurate to model our experiment, as mentioned earlier in the objectives of the experimental design, the primary focus of the experiment was on the inner thermal conductivities of the chocolate rather than the convective heat transfer. Therefore, the convection heat transfer element was left out completely in order to focus more fully on the conductive properties of chocolate. While applying Newton's law of cooling in order to account for convective heat transfer as well as taking into account the transient conditions of the temperature distribution within the chocolate would allow for a more accurate analysis, it is simply not feasible for the scope of this experiment. This is a considerable limitation within the experimental design, however potential error margins due to omitting this are discussed and quantified in 3.4.

3.2 Qualitative analysis of data

Figures 4 and 5 show that, using the Caramilk data as a baseline for homogenous chocolates, the coconut centre filling within the Cherry Ripe has caused it to conduct heat through it much slower. This is indicated by the 370 second experiment runtime for the Caramilk to reach a surface temperature of 57°C, whereas the Cherry Ripe took 477 seconds to reach a similar surface temperature of 55°C. This means the Cherry Ripe took approximately 29% longer to reach the same surface temperature as the Caramilk despite the relatively smaller distance the heat had to travel through the Cherry Ripe. The Cherry Ripe's 1.2cm height being characteristically shorter than the standard height of the Cadbury Dairy Milk or Caramilk share size bars [8] (This height was obtained by assuming that the width of a standard size Cherry Ripe and the share size Cherry Ripe are the same, which is reasonable as they appear to differ in only length, not width or height). Further, Dairy Milk was the fastest to reach the same temperature at 245 seconds, indicating that the homogenous Dairy Milk chocolate composition has the highest thermal conductivity. This is not certain however, as the Dairy Milk data is far less reliable due to the method of obtaining data values via linear interpolation of RGB values rather than direct temperature measurements. This difference in time to reach the same temperature indicates that the Cherry Ripe has a lower thermal conductivity, likely due to the different composition of the dark chocolate layers and/or from the coconut cherry filling. These layers also likely hold different thermal resistivities due to their different composition compared to the Dairy Milk and Caramilk which also impede its ability to conduct heat. The faster heating rate of the Dairy Milk comparatively to the Caramilk indicates that its composition must lend itself to conduct heat better as they both have the exact same dimensions. Furthermore, the difference between the inner and outer temperature measurements on the Cherry Ripe data is much less than that of the Caramilk as observed in Figure 4 by the difference in the trendline intercept point differences. Where the Cherry Ripe inner to surface temperature difference was 28.4-24.3 = 4.1 °C, the Caramilk had a difference of 37.2-24.6 = 12.6 °C (roughly a 3x difference). This may seem to indicate a higher thermal conductivity for the Cherry Ripe, but it is quite possible that this large difference is simply due to the thickness difference between the chocolates.

3.3 Compositions of chocolate

According to [9], the main differences in composition between dark, milk and white chocolate are the ratios between sugar, cocoa liquor, cocoa butter and full cream milk powder used when creating the product. This is in agreement with the ingredient information on the official Cadbury websites for product information for the Cherry Ripe and Caramilk [10],[11]. The Cherry Ripe is advertised as composed of a dark chocolate outer coating with a centre filling, a mix of coconut and glace cherries (cherries mixed with wheat glucose syrup) as the main components. The Caramilk is advertised as a 'Caramelised White Chocolate' [11] and so is presumably of a similar composition to white chocolate. This means that the Caramilk is composed of around 47% sugar, 31% cocoa butter and 21.5% full cream milk powder and the Cherry Ripe dark chocolate component is 39.52% sugar, 53% cocoa liquor and 7% cocoa butter[9]. These differences in compositions affect the physical properties of each chocolate and so it is important to be aware of them.

3.4 Calculating experimental thermal conductivity

While the effect of convection will be disregarded in calculations of thermal resistance for simplicity, the effect that the convective heat transfer has on the results can be estimated by observing the differences in the gradient of the inner vs outer temperature trendlines. This is because in a system where there is no convective heat transfer present, they would have the same gradient as the two points should theoretically heat at the same rate. The only difference being one lagging behind the other due to distance from the source of heat. However, since there was convective heat transfer present within the obtained experimental data, we can attribute the differences in gradient to this and use the difference to estimate the relative error throughout our results for thermal conductivity data via purely conductive calculations. By taking a percentage difference between the trendline gradients, we get a relative error of 1 - 0.0847/0.095 = 10.8% for the Caramilk values and a relative error of 1 - 0.0685/0.0754 = 9.2% for the Cherry Ripe values. The inability to account for the convective heat transfer within our experimental design is a considerable limitation, however, since the focus of the experiment is to investigate the effect of fillings within the chocolates on the conductive heat transfer, it is acceptable.

To calculate the heat flux through the chocolates, we can use Fourier's Law (1).

$$q = k\frac{dT}{dx} = k\frac{T_{Inner} - T_s}{L} \quad (1)$$

Where k = 0.26W/K.m is the thermal conductivity of the chocolate[12],$T_s$isthesurfacetemperatureofthechocolate,T_{inner} is the inner temperature of the chocolate and for Cherry Ripe L = 0.012/2 = 0.006m, and for Caramilk L = 0.015/2 = 0.0075m [13] (closest available measurements) (halved since measurements were taken roughly halfway through the chocolate). We will use documented values from literature to find k [7] and then calculate the heat flux. Using the heat flux the total thermal resistivity can be determined (2) and then the thermal resistivity split into its component parts (3). [14]

$$q = \frac{T_H - T_s}{R_T} \quad (2)$$

Where T_H = 90 C° and is the temperature of the hotplate

It is important to note that since the experimental heat flux value was not measured it is not possible to calculate the experimental thermal conductivity of any of the chocolates or component fillings. To get around this, a standard thermal conductivity value of chocolate was taken from available literature [12] which falls within the expected range among other sources available. However the calculations conducted are not of an extremely high accuracy due to this fact as some data had to be supplemented from outside sources. As a result, the values obtained may not be accurate but they are still comparatively useful as any error is systematic, so the chocolates can still all be compared to each other effectively.

$$R_T = R_1 + R_2 + R_3 = \frac{L_1}{k_1} + \frac{L_2}{k_2} + \frac{L_3}{k_3} \quad (3)$$

Since a single unit area is used, the A term is omitted. Using literature values for k value of the cherry filling we can find their specific thermal resistivity. Knowing that the cherry filling is a mix of cherries, coconut and sugar it is expected that its thermal conductivity is somewhere from 0.3-0.49 as it would fall between a sugar heavy composition and water heavy composition [15]. However, after isolating the cherry filling thermal conductivity value, it was back calculated as k=0.0676W/K.m which aligns with the experimental results as it took much longer for the Cherry Ripe to reach its final temperature. The length of dark chocolate coating was estimated at 1mmx2 for each side.

Table 1: Calculated thermal resistivity for different chocolate layers via approximated thermal conductivity using (3) and total thermal resistivity

Layer	Dairy Milk	Caramilk	Cherry Ripe
	K.m/W	K.m/W	K.m/W
R_T	0.0769	0.120	0.156
Dark Choc	N/A	N/A	0.00769
Cherry Filling	N/A	N/A	0.148

These thermal resistivity values are valuable as they are inversely proportional to the thermal conductivity of their components. Figure 7 shows a diagram for how the thermal resistivity circuit would appear within the Cherry Ripe. The Dairy Milk and Caramilk diagrams would be the same except only one layer as they are homogenous, hence why they only have one resistivity value in Table 1.

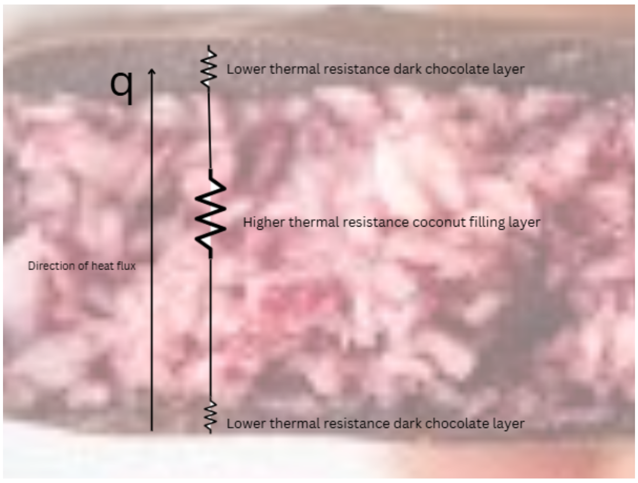
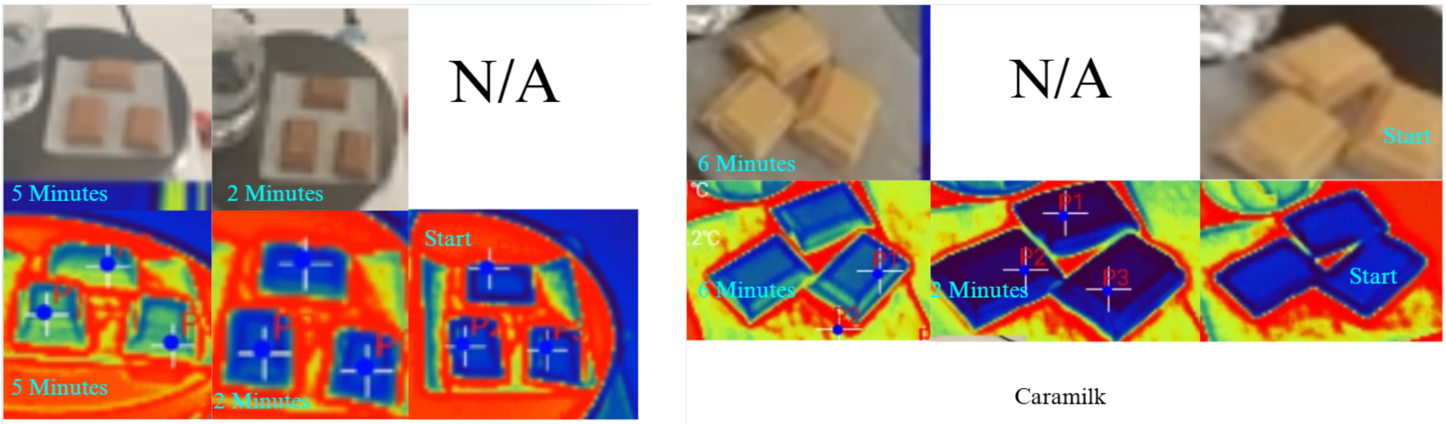


Figure 7: Thermal resistivity diagram for Cherry Ripe layers

The results in Table 1 make sense within the context of this investigation as the calculated values, while not very accurate, are of enough quality to compare to other values within this experiment. The thermal resistivity of the Cherry Ripe filling being higher than that of either Caramilk or Dairy Milk corresponds with the long time for the Cherry Ripe chocolate to transfer heat to the surface. The total calculated resistivity values explain why the Dairy Milk was the fastest to heat up and why the Cherry Ripe took so long since its internal layers are more resistive than that of standard chocolate. This can even explain why, despite the runtime taking so long, there was such a little instantaneous difference between the inner and outer surface temperatures of the Cherry Ripe. It was due to all the heat accruing in the centre with the higher resistance filling and as it slowly heats up as expected the lower resistance thin dark chocolate layer was able to heat quickly by comparison. This is in contrast to the data of the Dairy Milk and Caramilk data which had higher instantaneous temperature differences between the inside and surface despite heating up faster overall.

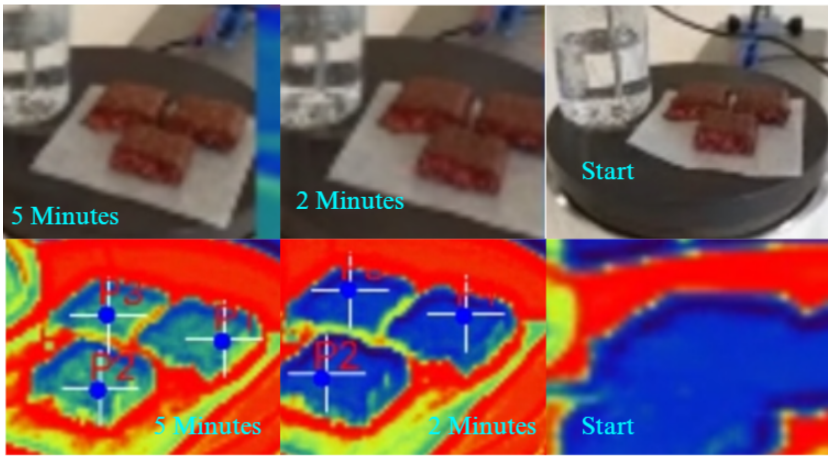
3.5 Thermal gradients of chocolates over time

Figures 8a, 8b and 8c below contain both regular and thermal images of the chocolates on the hotplates at time intervals of 0 seconds, 2 minutes and 5 minutes (the empty slots did not have an available image).



Dairy Milk

Caramilk



Cherry Ripe

Figure 8 a) Dairy Milk thermal images, b) Caramilk thermal images, c) Cherry Ripe thermal image

3.6 Applications to industrial uses

While it is clear that the thermal properties of chocolate are essential to industrial manufacture, transport, and storage of confectionery in order to ensure that it retains desirable qualities for consumers and avoids potentially damaging effects such as melting or fat and sugar bloom, there are also less obvious benefits to this research from the perspective of the consumer. If the thermal effects of chocolate fillings are made more clear, it may inform how purchased chocolates are treated, such as allowing more thermally resistive chocolates to remain in hot environments for longer without melting, or the opposite, reducing heat exposure time of chocolates that are more likely to melt.

In another vein, global chocolate consumption is consistently trending upward. In particular, the consumption of chocolate and cacao products in Asia is increasing at a very high rate compared to the rest of the world [16] [17]. Traditionally, Europe and North America represent the overwhelming majority of this consumption [18], but as demand in Asia increases, companies may seek to gain footholds in what could be a lucrative market due to the large population. As discussed in the literature review section, temperature throughout the distribution from manufacture to the point of sale is an important consideration in maintaining product quality. The average temperature of many countries in Asia is quite high [19], and so research into the rate of heat transfer through different chocolate varieties would be significant in the production of chocolate products for sale. As seen in the data, chocolates with fillings/different compositions tended to conduct heat much slower, and so such products may be prioritised in asian marketplaces.

While not directly connected to this research, further consideration is that of the supply of cocoa. Both constraints such as climate change, disease and falling nutrient quality in cocoa production, along with global demand constantly increasing [17] creates a situation where chocolate suppliers may need to increase the production of other products instead. As chocolate bars with fillings can take the space of a chocolate product while using significantly less cocoa, producers may look to the thermal data of such fillings as one consideration of manufacturing selection.

3.7 Error analysis

Errors in collecting data proved to be a serious limiting factor for the investigation, as errors were both significant and numerous throughout this phase. The existence of such errors greatly reduced the quality and quantity of data available, and perhaps presents the need for further trials. Of most importance was the utilisation of a thermal (IR) camera connected to a mobile device for temperature readings. Inexperience in utilising this equipment led to the recordings of data for the Crunchie being rendered unusable, representing approximately one quarter of the total data. Furthermore, the use of an IR camera means that our measurements for the ‘inside’ temperature are not truly inside the solid; rather, they are measurements of the exposed filling on the side of the chocolate. In terms of the recording of data, random errors existed from numerous sources. As discussed briefly, software limitations allowed only for three points of data to be collected, requiring the cameras to be handheld. The imprecision of human measurement leads to inconsistencies in the data points recorded. The positioning of each chocolate on the hotplates was different by some unmeasured amount, which may vary the heat flow supplied for each. Furthermore, the proximity of the chocolates on the hotplate would impact the air flow around each other. We know that the convection coefficient between a solid and fluid is affected by air flows, and as such, each chocolate would have different, unquantifiable heat loss rates at the surface due to convection.

3.8 Quantitative errors/uncertainty

The loss of data from the use of the IR camera necessitated the use of a linear interpolation model in order to complete and compare datasets. The effect of errors on data would be significant due to both the lack of repetitions and the quality of such repetitions. With such a small number of repetitions, the effect of errors is much more difficult to observe. In terms of quality, as the repetitions were carried out simultaneously within the same system, any such errors in the system would apply to each repetition, allowing them to carry into the final data. Thus, the value is significantly diminished. For further study into this area, the quality of data can be improved quite readily. Increasing the allotted time to the testing phase is key. By allowing more time to take an increased number of repetitions of higher quality, the amount and effect of errors on data would be greatly reduced. Furthermore, improving the method of temperature measurement, be it by changing the device used or improving the current thermal camera use. Combining this with an increased variety in samples would allow a much more detailed analysis of the rate of heat transfer through chocolate varieties.

4. Conclusion

Unfortunately, this experiment did not achieve its aim of accurately quantifying the thermal effects of fillings in chocolate, this was due to several limitations in the experimental method, including the lack of proper mounts for the thermal cameras, the inability to properly insulate the chocolate from heat loss through convection and radiation in order to increase the accuracy of the calculations. The most impactful error was the loss of the data for Crunchie, which limited the scope of the experiment to Dairy Milk, Caramilk, and Cherry Ripe. These flaws could be remedied by further pre-planning before the experiment, potentially including custom-made insulation rigs and mounts, as well as improved software for the thermal cameras that allow for a wider selection of test points and more accurate point-setting methods. As stated in the discussion, increasing both the repetition of tests as well as the variability of the chocolates tested would also improve the reliability and validity of this study. It may also be beneficial to vary heating sources in order to more accurately model the thermal conditions in the real world. Despite the lack of complete success in this case, there is still some value in the data produced as it was able to be internally compared to determine the thermal properties of the Cherry Ripe filling. This field of study remains relevant to the industry and should be more properly explored in future due to its applications and impact on the storage and transport of chocolate confectionery.

5. Acknowledgements

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Toby Downes, Douglas Cameron, Braden Raffo and Hamyung Jang designed the experiment and recorded and collected data; Toby Downes gathered and prepared data for the Caramilk and Cherry Ripe chocolates as well as conducting analysis and calculations of all sets of data, as well as writing the article from point 3 to point 3.5 inclusive and all associated figures and diagrams; Douglas Cameron completed the abstract, introduction, materials and methods,

and conclusion, as well as assisting with section 3.6 and finalising the formatting and editing the article; Braden Raffo wrote section 3.6 with assistance, along with sections 3.7-3.8 and further formatting and editing; Hamyung Jang gathered and performed the preparation of data for the Dairy Milk chocolate and the linear interpolation analysis, as well as contributing in the writing, formatting, and editing of the article; Minghao Zhang, Sebastian Dominguez and Juanita Suarez provided task direction and project assistance, and Dr. Gobinath Rajarathnam provided conceptual direction, research and writing guiding frameworks, facilitated project resources, and directed project supervision.

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7. Supplementary:

Table 2: Cherry Ripe surface temperature values

Time(s)	Surface temp 1	Surface temp 2	Surface Temp 3	Avg Surface temp
14	26.9	26.6	26.9	26.8
44	26.8	26.9	27.2	26.96666667
70	29.6	N/A	29.1	29.35
104	32.7	29.1	31.9	31.23333333
134	33.1	32	32.9	32.66666667
176	35.1	35.1	35.4	35.2
194	35.8	35.3	35.8	35.63333333
224	40.1	36.6	40.3	39
251	42.9	40.5	39.8	41.06666667
284	44.9	43.2	45.2	44.43333333
314	48.2	47	49	48.06666667
344	49.6	47.5	48.8	48.63333333
375	51.9	49.6	50.9	50.8
404	53.4	50.9	52	52.1
434	55.4	53.3	53.3	54
464	57.1	54.7	55.9	55.9
477	57.6	54.7	54.5	55.6

Table 3: Cherry Ripe inner temperatures values

Time (s)	Inner temp 1	Inner temp 2	Inner temp 3	Avg Inner temp
51	28.7	31.5	27.6	29.26666667
70	N/A	33.6	N/A	33.6
160	41.7	41.2	40.5	41.13333333
198	41.4	41.3	42.6	41.76666667
256	47.4	55.3	46.8	49.83333333
287	53.9	58.8	50.5	54.4
373	58.6	57.1	57	57.56666667
483	61.8	60.1	60.6	60.83333333

Table 4: Caramilk surface temperature values

Time (s)	Surface Temp 1	Surface Temp 2	Surface Temp 3	Avg surface temp
8	28.5	27.9	30.3	28.9
38	30.2	30.4	31.3	30.63333333
68	30.1	30	31.4	30.5
103	31.4	31.8	32.9	32.03333333
128	32.7	32	32.4	32.36666667
157	32.4	34.6	36.6	34.53333333
185	33.6	37.8	42.9	38.1
210	38.4	41.3	42.3	40.66666667
241	44.7	44.7	45.6	45
273	48.9	47.9	49.8	48.86666667
301	48.9	49.9	51.6	50.13333333
321	50.7	53.1	54.1	52.63333333
343	54.3	53.9	58.3	55.5
370	56.6	56.7	58.3	57.2

Table 5: *Caramilk inner temperature values*

Time (s)	Inner temp 1	Inner temp 2	Inner temp 3	Avg inner temp
91	N/A	N/A	41.9	41.9
95	N/A	41.1	N/A	41.1
99	41.6	N/A	N/A	41.6
139	N/A	N/A	53.1	53.1
146	N/A	61.6	58.4	60
215	N/A	63.3	63.1	63.2
258	N/A	66.1	65.3	65.7
329	N/A	66.7	71.1	68.9
338	66.5	N/A	N/A	66.5
358	N/A	79.7	72.2	75.95
365	62.4	N/A	N/A	62.4