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Innovative Semi-Automated Kuih Kapit Production: Leveraging Infrared Heating for Consistent Quality and Sustainability

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ABSTRACT

Traditional Southeast Asian snacks like *kuih kapit* are prized for their crunchy texture and intricate patterns, but making them by hand takes a lot of time and effort. High labor expenses, uneven product quality, and the cost of purchasing large-scale equipment make it difficult for small businesses to scale up production. By utilizing infrared (IR) heating technology, this study suggests a semi-automated production technique that tackles these problems. With an emphasis on energy economy and heat dispersion, the study optimizes the design of an infrared heater appropriate for *kuih kapit* molds using the Stefan-Boltzmann law. The process entails choosing materials with high emissivity and creating a small-scale, compact system. The proposed machine could perform at an optimal temperature of 160°C, or 3.6 microns, the peak infrared wavelength, by employing infrared (IR) heating. This preserves the snack's traditional quality, ensures consistent cooking, and lessens reliance on manpower. When compared to the conduction processes, IR technology shows that it offers constant heating, improving product consistency and consuming less energy. This creative method offers small businesses a sustainable and affordable alternative by fusing traditional craftsmanship with contemporary efficiency. In order to maximize manufacturing at different scales, future studies should concentrate on improving the design for affordability and investigating new IR wavelength configurations.

1. Introduction

The traditional Southeast Asian cookie known as *kuih kapit*, or "love letters," is prized for its delicate, crispy texture and elaborates designs. *Kuih kapit*, which has roots in Peranakan, Chinese, and Malay traditions, is an inherent part of joyous occasions like Chinese New Year and Hari Raya. The cookie is made using a traditional technique that includes rapidly folding the batter while it is still warm after it has been cooked over charcoal in intricate brass molds. Although this meticulous approach ensures authenticity and quality, it is time-consuming and labor-intensive, which poses difficulties for small-scale retailers trying to satisfy the growing demand during the busiest holiday seasons.

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The traditional approach has disadvantages in terms of consistency and scalability, especially for small enterprises, despite its cultural relevance. The dependency on manual labor, along with the difficulty of establishing uniform heat control and consistent product quality, generates a substantial gap in production efficiency. It is getting harder for small-scale vendors to compete with larger producers who use more advanced methods as the demand for *kuih kapit* rises, particularly during holiday times. It is critical to investigate cutting-edge, reasonably priced technologies that can preserve the distinctive qualities and authenticity of kuih kapit while improving production efficiency and scalability.

Modern food processing technology must be energy efficient, especially as manufacturers aim to reduce operating costs and minimize their adverse impacts on the environment. Due to energy losses in intermediary media, conventional heating techniques like convection and conduction show notable inefficiency. Convection heating, which has an efficiency of only 50% to 65%, loses energy by warming the surrounding air. Conduction heating, which has an efficiency range of 60% to 70%, also depends on direct contact with cookware, which results in losses through surface imperfections and intermediate layers. On the other hand, infrared (IR) heating immediately transforms radiant energy into heat at the food surface, providing energy transfer rates of 80% to 90%. In addition to reducing heat loss, this direct engagement speeds up heating times and provides even energy distribution.

These benefits make infrared heating a preferable option, lessening the drawbacks of conventional methods while providing a more cost-effective and ecologically friendly solution for grilling, drying, and baking. This study intends to address those concerns by investigating the feasibility of creating *kuih kapit* using infrared technology to its full potential. The key goal is to use infrared's energy efficiency while preserving traditional snacks' great taste, texture, and aesthetic appeal.

2. Literature Review

Producing *kuih kapit*, a classic egg-based wafer snack, by hand is a time-consuming procedure requiring much experience and dedication. Usually, the batter is poured into iron molds, which are then pressed together and cooked over a charcoal flame. Charcoal adds a delicate smokiness and crispness that is hard to achieve with contemporary techniques, making this traditional process prized for the unique flavor and texture it provides. Furthermore, making *kuih kapit* by hand is a cultural custom that is frequently carried out during the holiday seasons and is appreciated for its handmade nature.

Despite these gastronomic and cultural benefits, manual production has several limitations that prevent it from being scaled up. To prevent overcooking, workers must carefully flip the iron molds and keep an eye on the heat, which is both physically demanding and time-consuming. Charcoal heat can vary, causing variations in thickness, size, and browning, making uniformity difficult to achieve. This may result in inconsistent and ineffective products, particularly in high-demand settings. Another disadvantage is labor intensity since manual production depends on knowledgeable workers who can precisely control the conventional process.

According to evaluations by Hasanain [1], several machines are assessed, focusing on production capacity, ergonomic challenges, and space requirements. Conventional methods to produce *kuih kapit* such as using coconut coir or charcoal, for instance, yield 70 to 90 pieces, but they take a lot of time and effort due to inconsistent heating. AEC Machinery's large, semi-automatic machines produce 400–600 pieces per mold with temperature control, although they are more costly and take up many workspaces. Small businesses often struggle to expand their output without significantly increasing their workforce or working hours, which is impractical during periods of peak demand like Chinese New Year or Hari Raya. Infrared semi-automated technology offers a solution by enabling higher production volumes with fewer resources. By automating critical steps in the process, small-scale producers can efficiently scale up their operations to meet surging demand while maintaining product quality and reducing operational strain.

Kamboj *et al.,* [2] also looks at various fuel sources for both conventional and contemporary machines which emphasize the need to balance traditional and modern food production methods with sustainable fuel sources. Conventional techniques, which frequently use charcoal or coconut husks as fuel have drawbacks such as inconsistent heating and contribute to environmental emissions and waste [3]. Modern techniques, on the other hand, use gas or electricity, which greatly boosts production rates and keeps the temperature constant [4]. The evaluation also emphasizes design advancements that make modern machines more appropriate for higher-output requirements, such as the inclusion of infrared heating elements [5]. Infrared semi-automated technology provides a cleaner, more energy-efficient alternative, reducing environmental impact while improving operational sustainability. Although the upfront costs for purchasing equipment are higher, the long-term savings in labor and increased efficiency make it a more cost-effective option for small businesses, allowing them to remain competitive in the evolving market.

Numerous engineering disciplines employ infrared technology for various objectives. It assists in examining materials for flaws without causing harm, such as identifying walls or enhancing building maintenance [6]. It aids in identifying locations with moisture issues or heat loss during building construction. Additionally, infrared is also used in medicine to detect bodily problems like inflammation, in agriculture [7] to evaluate the quality of products, and of course in food technology [8].

The traditional method of *kuih kapit* production is labor-intensive and time-consuming, relying heavily on manual processes such as pouring the batter, cooking on charcoal-heated molds, and folding the cookies while warm. Each cookie requires individual attention, significantly limiting the production speed. This inefficiency becomes problematic during festive seasons when demand surges, especially for traditional foods [9]. Semi-automatic *kuih kapit* machines are essential for companies looking to boost output in light of these constraints. In contrast, infrared semi-automated technology streamlines the process, allowing multiple cookies to be cooked simultaneously with minimal manual intervention. Automation in batter pouring, heating, and folding not only reduces dependency on skilled labor but also accelerates production, enabling small businesses to meet higher demand efficiently.

Maintaining consistency in *kuih kapit* production is challenging due to the reliance on manual techniques and conventional heating. Open flame or charcoal-based methods and conduction methods often result in uneven heat distribution, leading to variations in the texture, thickness, and crispness of the cookies. The skill of the operator also plays a significant role, further contributing to variability. Infrared semi-automated technology addresses these issues by providing precise and more reliable heat distribution by sending heat directly to the batter through infrared radiation [10, 11]. This results in consistently thin and crispy wafers with intricate patterns and flavors intact, meeting consumer expectations more reliably.

Additionally, infrared baking uses less energy because it precisely targets the batter's surface without losing too much heat, which makes it a sustainable choice for manufacturing big batches of *kuih kapit* [12,13]. In contrast to the conventional methods, this type of heat transfer involves heating the surrounding air by conduction or convection, which indirectly warms the batter. With infrared baking, the batter's surface absorbs heat nearly quickly, allowing for quicker cooking with less energy loss.

Infrared heat has many benefits for *kuih kapit*, which requires a delicate, even crispness. The temperature is raised uniformly as IR energy permeates the batter's surface, allowing for steady moisture evaporation throughout the thin batter layer. Instead of requiring the continuous flipping required in conventional procedures, this process produces a consistent, crisp texture. Additionally, *kuih kapit's* thin, wafer-like texture is achieved by precisely adjusting the heat to match the necessary baking intensity thanks to the control provided by infrared wavelengths. The baking process is made faster and more flexible by the easy modulation of IR technology, which lowers the possibility of burnt edges or undercooked areas [14].

In terms of sustainability, infrared heating uses less energy than conventional baking techniques. Less energy is needed to reach ideal cooking temperatures because infrared radiation heats the target directly without dispersing too much heat into the surrounding environment [15]. Because of this, infrared baking is an economical and sustainable option, particularly useful for commercial-scale *kuih kapit* manufacturing, where accurate heat control is essential to preserving excellent quality.

3. Methodology

The parameters of the infrared heating material must be established before the design work is completed. Thus, the Stefan-Boltzmann law is used to predict the temperature distribution of heating work for *kuih kapit*. We could examine the heating process when baking kuih kapit utilizing infrared (IR) technology by looking at the fundamental radiant heat transfer equation and applying it to the particulars of this technique. The Stefan-Boltzmann law can be used to describe infrared heat transport [16], Q_{rad}, as mentioned in equation (1).

$$Q_{rad} = \in \sigma A(T_s^4 - T_{env}^4) \tag{1}$$

where:

Q_{rad}: Radiant heat transferred per unit time (W).
∈: Emissivity of the material (dimensionless, ranges between 0 and 1).
σ: Stefan-Boltzmann constant, 5.67×10−8 W/m^2·K^4
A: Surface area of the *kuih kapit* batter exposed to infrared (m²).
T_s: Surface temperature of the batter (K).
T_{env}: Temperature of the surrounding environment or background (K).

An important factor is the batter's surface emissivity. Usually, batter's materials have a high emissivity, effectively absorbing infrared light. Effective heat absorption from high emissivity enables the batter to reach the target temperature more quickly [17]. The temperature differential between the batter surface and the surrounding air determines the heat transmission rate. The batter's surface temperature T_s rises quickly when IR heating is used because IR radiation immediately transfers energy to the batter, raising its temperature above the surrounding air.

We consider that the emissivity, ϵ, is 0.9 in the current matter. Materials with high thermal emissivity, or those that radiate heat efficiently, typically have an emissivity value. This emissivity value typically correlates to non-metallic surfaces for batter materials, such as on-reflective surfaces, flour-based batters, and water-based batters. Pancakes, crepes, and *kuih kapit* are examples of thin baked goods that are frequently made with water-based batters. The batter's high emissivity is a result of its water content. In contrast, batters made with flour and additional components (such as sugar, eggs, and milk) frequently have emissivity values near 0.9. This is due to the efficient absorption and emission of heat by the water-rich and organic components. Ibarra *et al.,* [18] has mentioned that the emissivity of raw, uncured chicken breast was consistently measured at 0.91 in the mid-infrared spectral range (3.4 to 5.0 µm). The batter may inherit the surface's emissivity along with its intrinsic qualities if it is cooked on a non-reflective metal or ceramic surface.

The effectiveness of infrared heating at high temperatures is demonstrated by the fourth power reliance on temperature difference, which makes it ideal for baking thin goods like *kuih kapit* that need rapid, intense heating without heat loss [15]. The batter's exposed surface area greatly impacts how much heat is conveyed. The thin, crisp quality of *kuih kapit* depends on an even bake, which can be achieved using IR heating since more consistent heat can be distributed over the batter's broad surface.

Returning to *kuih kapit* baking, we examine the batter's surface being heated directly. This is because the batter's surface temperature is directly raised by IR heating, which also maximizes the rate of energy absorption. This facilitates quick moisture evaporation from the surface, which is essential for producing *kuih kapit's* wafer-thin crispness. We used 0.01 m^2 as a value of surface area because is suitable for a *kuih kapit* mold, as traditional molds are generally small and designed to make thin, crispy wafers. Kuih kapit molds typically produce individual pieces with dimensions ranging from approximately 10–15 cm in diameter or square, aligning well with the given area of 0.01 m^2. This size ensures even cooking and proper handling during the baking process. Practically, a mold of this area is convenient to handle over an open flame or electric griddle. Larger molds may become unwieldy or may not distribute heat evenly, leading to inconsistent cooking.

Controlling the baking intensity and temperature is another aspect. To achieve consistent baking throughout the batter, the surface temperature T_s can be precisely adjusted by varying the wavelength and intensity of the infrared source. The baking intensity and temperature can be precisely controlled using infrared (IR) radiation, particularly with wavelengths between 2 and 3 microns, which are effective for removing moisture and promoting surface browning in food [19,20]. The infrared technique reduces energy waste because it directly targets the batter's surface without greatly heating the surrounding air, making it more energy-efficient for baking [21]. Because less total power is required to maintain the optimal baking temperature, this energy efficiency makes it a viable choice for increasing the production of *kuih kapit*.

The approach used in this study focuses on contrasting the infrared and conduction heating methods for making *kuih kapit*. The fuel source for both techniques is liquefied petroleum gas (LPG), which is delivered directly from a burner. In order to determine heat efficiency and consistency, the burning process is closely observed, with special emphasis paid to flame production. While proper flame control is essential for reaching the necessary temperatures, large flames are recognized as a sign of heat waste. Each heating method's effectiveness in reaching and sustaining two specific temperatures; 160°C, which was chosen for its capacity to avoid overcooking, and 208°C, which serves as a higher threshold for comparison—is evaluated by recording time data. The study sheds light on the energy efficiency and applicability of each technique for controlled cooking applications by examining flame generating and operating time.

3. Results and Discussion

3.1 Modelling Batter's Surface of Kuih Kapit based on Stefan-Boltzmann Equation

In the outcome, the Stefan-Boltzmann equation measures radiant heat transmission, demonstrating how well-infrared technology works to provide reliable, superior heat for baking *kuih kapit* while using the least amount of energy possible. This process offers a uniform, regulated heat distribution that is essential for creating the fine texture of these conventional wafers. The surface temperature of the batter as it absorbs infrared radiation over time can be used to visualize the heat distribution when baking *kuih kapit* using infrared (IR).

The heat transfer across the batter's thin layer will be modeled to demonstrate how infrared radiation produces an equal temperature distribution on the batter's surface. When subjected to infrared radiation, a 2D heat map shows the anticipated temperature profile on the *kuih kapit* batter's surface. This heat distribution plot can be seen in Figure 1. This heat distribution map displays the surface temperature profile of *kuih kapit* after baking with infrared (IR) heating.

The direct absorption of infrared radiation is reflected in the surface's comparatively uniform temperature. Because of the IR energy focusing, the center could be a little warmer, but the edges still get enough heat to guarantee equal baking. Without flipping or continual supervision, as would be necessary with conventional heat sources, this even heat distribution helps produce the consistently crisp texture that is typical of *kuih kapit*. The heat distribution plot demonstrates how infrared (IR) heating provides a concentrated, even application of heat to the *kuih kapit* batter's surface.

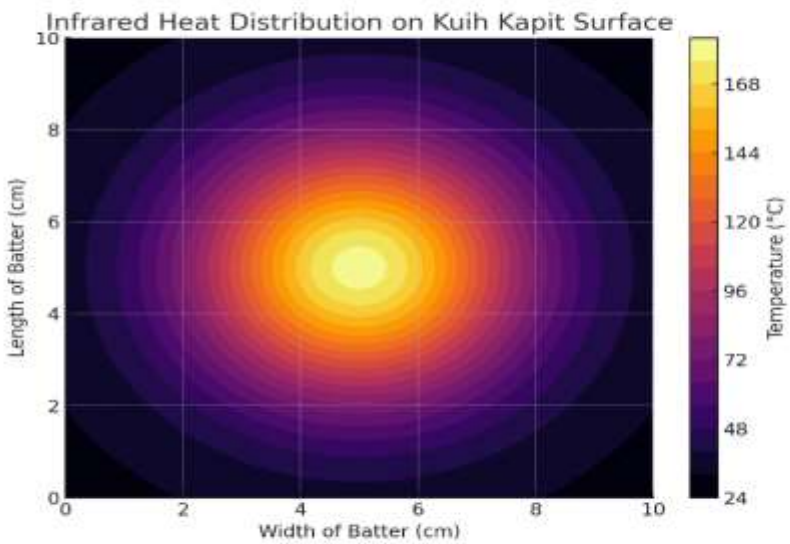

Fig. 1. 2D heat map anticipation temperature profile on the kuih kapit batter's surface

The plot's center displays the highest temperature, suggesting that the batter's core absorbs a little more infrared radiation. Because infrared sources are frequently strongest right beneath them, this effect happens. The heat progressively tapers down toward the margins, indicating a regulated heating environment, and this concentrated focus is negligible.

The perimeter must not be undercooked for a consistently crisp texture across the wafer, which is avoided by slow cooling toward the edges. The majority of the figure stays within a narrow temperature range of 168°C, demonstrating that the IR technique consistently heats the batter's surface. This homogeneity is crucial for *kuih kapit* baking to prevent hotspots or cold spots that could result in an inconsistent texture or flavor.

Without preheating or circulating hot air, the batter's surface can reach high temperatures because infrared radiation distributes heat directly to it, minimizing heat loss to the surrounding environment. The batter is heated directly and rapidly, which is ideal for evenly eliminating moisture from the wafer. This concentrated heat distribution is also energy-efficient and efficient for baking thin, delicate wafers like *kuih kapit* fast and consistently.

This plot's uniform heat distribution suits *kuih kapit's* structural needs. To get the right level of crispiness without burning or leaving undercooked areas, each thin layer needs to be baked quickly but evenly. Infrared baking offers the precision control required for thin-layer baking by effectively focusing heat over the surface. The pattern of heat distribution highlights how infrared technology, with its consistent and concentrated heating, may improve the consistency and quality of *kuih kapit*, giving it the ideal texture while maximizing energy efficiency and minimizing the need for manual changes.

3.2 Infrared Energy Efficiency in Kuih Kapit Production

The material selection analysis for the infrared heat source requires being determined using the recommended operating temperature of 160^{o}C based on Figure 1. The peak energy wavelength can be determined using Wien's Displacement Law. Wien's Law, sometimes called Wien's Displacement Law, is a law that determines at what wavelength the intensity of radiation emitted from a blackbody reaches its maximum point as shown in Equation (2).

$$\text{Peak Wavelenght } (\mu) = \frac{5269\ \mu/\text{R}}{\text{Source Temperature (F)}+460} \tag{2}$$

$$\text{Peak Wavelenght } (\mu) = \frac{5269\ \mu/\text{R}}{1000+460}$$

$$= \frac{5269\ \mu}{1460}$$

$$= 3.6\mu$$

Core temperature, 160^{o}C = 780^{o}F, then radiation at this temperature (about 1000°F), as seen in Figure 2, is in the infrared spectrum, making it appropriate for effectively heating the *kuih kapit* batter. This suggests that, for that temperature, the radiant energy is best emitted at this wavelength. At this temperature, the mold's mid-IR radiation aids in uniformly cooking the batter and producing the crispy texture that characterizes *kuih kapit*. For fragile wafers, this temperature and wavelength work well with standard baking and cooking procedures, ensuring rapid and effective heat transfer without overheating or burning the batter then the recommended source temperature that needs to be used is 1000^{o}F based on Figure 2.

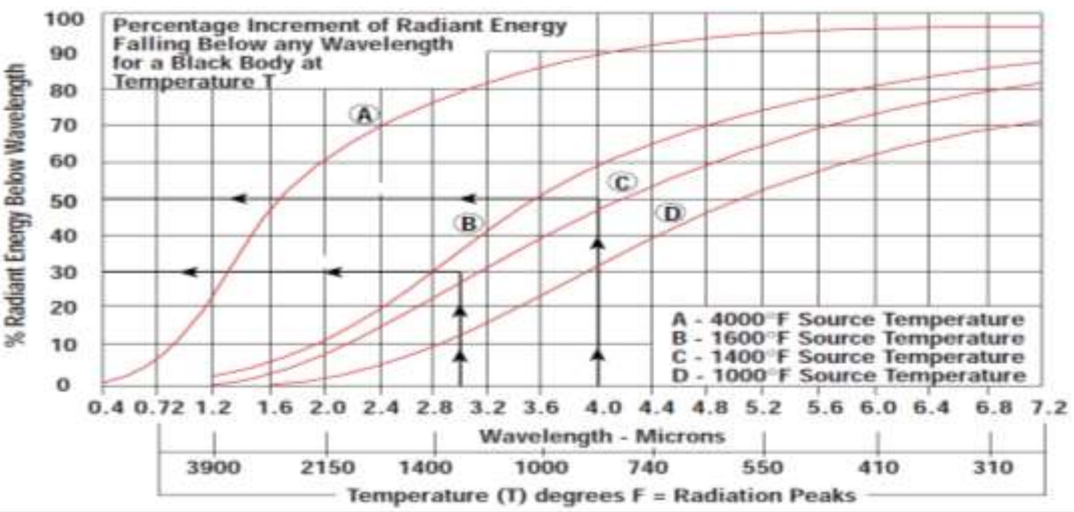

Fig. 2. Percentage increment of radiant energy based on wavelength (microns) [21]

According to the peak wavelength result, 3.6µ we mapped to Table 1 to determine the best Infrared Heat Source that needs to apply to the *kuih kapit* heater. The infrared heating elements made of ceramic display particular traits. Their operating wavelengths span from 3 to 4 microns, resulting in brightness that ranges from dark to dull red. Compared to other sources, the heating and cooling response times are slower, ranging from 5 to 7 minutes. Because of its high mechanical toughness and resistance to thermal shock, ceramic is dependable under pressure and temperature changes. These characteristics make ceramic appropriate for steady, longer-duration heating applications by striking a balance between durability and efficiency.

Table 1
Characteristics of commercially used infrared heat source [21]

Infrared Source	Tungsten Filament		Nickel Chrome Resistance Wire			Wide Area Panels	
	Glass Bulb	T3 Quartz Lamp	Quartz Tube	Metal Sheath	Ceramic	Ceramic Coated	Quartz Face
Source Temperature (°F)	3000-4000 °F	3000-4000 °F	Up to 1600 °F	Up to 1500 °F	Up to 1600 °F	Up to 1600 °F	Up to 1700 °F
Brightness	Intense white	Intense white	Bright Red to Dull Orange	Dull to Bright Red	Dark to Dull Red	Dark to Cherry Red	Dark to Cherry Red
Typical Configuration	G-30 Lamp	3/8 Dia. Tube	3/8 or ½" Tube	3/8 or ½" Tube	Various Shapes	Flat Panels	Flat Panels
Type of Source	Point	Line	Line	Line	Small Area	Wide Area	Wide Area
Peak Wavelength (microns)	1.16	1.16	2.55	2.68	3-4	2.25-7.9	2.5-6
Maximum Power Density	1 kW/ft^2	3.9 kW/ft^2	1.3-1.75 kW/ft^2	3.66 kW/ft^2	Up to 3.6 kW/ft^2	3.6 kW/ft^2	5.76 kW/ft^2
Watts per Linear Inch	N/A	100	34-45	45-55	N/A	N/A	N/A
Conversion Efficiency Infrared Energy	86%	86%	40-62%	40-56%	40-50%	40-55%	40-55%
Response Time Heat/Cold	Seconds	Seconds	1-2 Minutes	2-4 Minutes	5-7 Minutes	5-8 Minutes	6-10 Minutes
Color Sensitivity	High	High	Medium	Medium	Medium	Low to Medium	Low to Medium
Thermal Shock Resistance	Poor	Excellent	Excellent	Excellent	Good	Good	Good
Mechanical Ruggedness	Poor	Fair	Good	Excellent	Good	Good	Fair
Chromalox Model	-	QR	QRT	RAD,URAD	RCH	CPL, CPLI, CPH	CPHI

Table 2 shows the operating times for six molds using two temperatures (160°C and 208°C) and two heating techniques (infrared and conduction). Infrared heating takes 4.5 to 4.9 seconds to operate at 160°C, but conduction heating takes 6.4 to 7 seconds. On the other hand, at 208°C, conduction heating takes 4.1 to 4.5 seconds, whereas infrared heating takes 2.4 to 2.8 seconds. When producing *kuih kapit*, a temperature of 160°C is used to avoid overcooking because higher temperatures, such as 208°C, result in faster cooking periods, which can easily lead to overcooking.

Table 2
Comparison of infrared and conduction methods in two temperature differences

Temperature (°C)	Heated Operation	Mold					
		1	2	3	4	5	6
		Time Operation					
160	Infrared	4.7	4.5	4.9	4.8	4.6	4.7
	Conduction	6.5	6.7	6.9	6.4	6.8	7.0
208	Infrared	2.6	2.8	2.5.	2.6	2.4	2.7
	Conduction	4.2	4.3	4.1	4.5	4.2	4.4

Based on Table 3, since overcooking of *kuih kapit* can happen at higher temperatures due to excessive heat, a temperature of 160°C was selected. Flame generation frequently causes overheating, as big flames not only raise the possibility of burning the product but also result in heat waste. This regulated temperature ensures effective heat transfer without sacrificing the *kuih kapit's* quality.

Table 3
Comparison of two distinct methods for flame formation at two distinct temperatures

Temperature (^{o}C)	Heated Operation	
	Conduction	Infrared
160		
208		

4. Conclusions

The issues that small enterprises encounter in creating this traditional treat in large quantities are addressed by leveraging infrared energy efficiency in *kuih kapit* production, as investigated in this study. Despite being valued for their taste and sincerity traditional *kuih kapit* production techniques are time-consuming and difficult to scale. The production process can achieve uniformity, boost output, and preserve the unique quality of the product by implementing semi-automated technologies, especially infrared (IR) heating. By applying heat directly to the batter's surface, infrared heating provides accurate, energy-efficient baking that eliminates the need for frequent flipping and speeds up moisture evaporation. This technique is a sustainable alternative for large-scale manufacturing since it guarantees consistent baking while using less energy.

It is recommended that semi-automated machinery designed for small enterprises be further improved for upcoming projects. The focus should be on creating small, affordable devices that replicate the classic tastes and feel. Furthermore, experimenting with various infrared wavelength configurations and machine designs may enhance the control over baking intensity, ensuring the best quality at various production sizes. Small firms can extend the usage of infrared burning to other traditional cakes that require direct burning, like pancakes, crepes, and so forth.

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