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Optimizing *gula apong* production with an IoT-based temperature monitoring system

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ABSTRACT

Determining the quality of *gula apong* is crucial to optimizing its production, with cooking temperature being a key factor affecting both taste and shelf life. The *gula apong* industry faced challenges due to the lack of reliable real-time temperature monitoring methods during the cooking process. Traditional approaches were inefficient and inaccurate, leading to difficulties in maintaining consistent product quality and meeting market demands. This highlights the necessity of monitoring the temperature throughout each cooking process. This research aims to develop an internet of things (IoT)-based cooking temperature monitoring system to enhance quality control measures in the production of *gula apong*. The IoT prototype collects temperature data from the thermocouple sensor, then transmits it to cloud storage through a Wi-Fi communication network, utilizing the Node-RED platform for data processing and analysis. Data obtained from the on-site measurement shows that the optimal temperature for producing standard-quality *gula apong* is approximately around 165 °C. The recommended boiling temperature for Nipah sap is 140 °C. This IoT system can reduce the cooking time of *gula apong* to 3 hours from the traditional 4 to 6 hours. Utilizing the data acquired from this study helps the producers not only maintaining the quality of *gula apong* but also reduce the cooking time and cost.

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1. INTRODUCTION

Gula apong, a signature product of Sarawak in Malaysia, is beginning to gain a place in domestic and global markets such as Saudi Arabia, Brunei, Singapore, Europe, and Japan. In 2021, Sarawak exported a total of RM1.93 million worth of *gula apong* products, producing a revenue of RM3.38 million in the domestic market [1]. Today, *gula apong* is in high demand due to its versatility in food and beverage preparations such as ice cream, milk tea, traditional desserts such as *celorot, penyaram*, and many others. The *gula apong* industry is seen as capable of supporting the local economy by providing livelihoods to rural communities and coastal areas in Sarawak and by transforming *gula apong* products into tourist attractions. In this regard, the Sarawak state government aims to boost the production of *gula apong* as an initiative to create economic activity for local makers as part of its plan to become a high-income and developed state by 2030 [2]. However, the *gula apong*-making process is both labour-intensive and time-consuming, leading to decreased interest among younger generations in continuing the production of *gula apong*.

The cooking temperature plays a crucial role in determining the overall quality of *gula apong*, directly affecting its composition and characteristics. It influences factors such as flavor, aroma, and texture, which are essential aspects of the product's quality and impact consumer perception. Additionally, variations in cooking temperature can impact the shelf life of *gula apong*. Deviations from optimal temperatures may result in premature spoilage or a decline in product quality over time. Continuous temperature monitoring during the cooking process is imperative for effective quality control. However, the *gula apong* industry faced challenges due to the lack of reliable real-time temperature monitoring methods during the cooking process. Traditional approaches were inefficient and inaccurate, leading to difficulties in maintaining consistent product quality and meeting market demands. While there is extensive research on cooking temperature in various contexts, including food processing and culinary practices, no specific research has been conducted on *gula apong*. Furthermore, optimization strategies and parameters for temperature control in *gula apong* production were insufficient, highlighting the need for advancements in this area.

Various approaches can be employed to increase production and improve the quality of *gula apong*, including the utilization of smart technology such as the internet of things (IoT). The IoT technology can analyze data and information in real-time, which allows rural and agri-food industry operators, particularly *gula apong* makers/producers, to manage their production remotely through network devices. The utilization of IoT in this industry is seen to have the potential to enhance productivity, save time and energy, and generate greater profits, making it more attractive to young people [3]–[6]. Furthermore, the IoT technology approach can also benefit various stakeholders, for example, product certification agencies such as halal, food safety is the responsible of the industry (MeSTI), good manufacturing practices (GMP), and hazard analysis and critical control points (HACCP), by obtaining complete information about products from production to marketing. This information includes raw materials and finished products, food hygiene and quality, as well as compliance with standards [7], [8].

In this paper, a practical IoT-enabled temperature monitoring system is developed and tested in real-time for continuous monitoring across different phases of the *gula apong* cooking process. This study investigated the effects of temperature variations at each phase of *gula apong* production. Data collection involved conducting on-site measurements to gather temperature data during the cooking process, while the IoT-based cloud platform was employed for efficient data processing and analysis, enabling a comprehensive examination of temperature patterns. Optimization strategies and parameters for temperature control in *gula apong* production are proposed based on the insights gained from the temperature data analysis. The findings contribute to the advancement of quality control practices in *gula apong* production, offering valuable guidance for producers to enhance product quality and meet market expectations. In addition, this research could serve as a starting point to establish an IoT-enabled framework for the *gula apong* industry to close the supply-demand gap.

The remainder of this paper is organized as follows: in section 2, an in-depth discussion of the *gula apong* industry in Sarawak is presented. It also includes the role of IoT technology within the industry as well as an overview of the various cooking phases involved in *gula apong* production. Detailed insights into the methodology used to develop the IoT-based temperature monitoring system for *gula apong* production are also discussed. Section 3 presents the empirical findings obtained from on-site measurement and analysis, focusing on temperature data collected during the cooking process of *gula apong*. Finally, section 4 offers concluding remarks based on the presented results, discussing the implications for the *gula apong* industry and highlighting opportunities for further research and development.

2. METHOD

This section outlines the methodology used to develop the IoT-based temperature monitoring system for *gula apong* production. The comprehensive discussion of the *gula apong* industry in Sarawak serves as the fundamental context for understanding the specific challenges, requirements, and opportunities associated with its production. This includes an analysis of potential IoT applications within the industry, such as real-time monitoring of production processes, quality control measures, and supply chain management. Additionally, this section encompasses the design and configuration of the overall IoT architecture required to support the real-time temperature monitoring system.

2.1. *Gula apong*

Sarawak's renowned *gula apong* is a type of sugar that comes from the Nipah palm trees. The trees grow naturally and abundantly in the mangrove forest along the coastal areas throughout Sarawak. The state has about 150,000 hectares of mangrove areas that are overgrown with Nipah trees [9]. The Nipah trees do not need replanting activities because they are able to bear fruit for more than 50 years. Figure 1 shows the Nipah palm trees in the coastal areas of Sarawak at Kampung Pinggan Jaya, Kota Samarahan. The local community in this area relies on Nipah palm for *gula apong* production. *Gula apong* is traditionally harvested by hand, and the process of making it takes a long time. It is produced from the sap of the Nipah palm tree that is extracted by making a cut on the flower bud of the tree. The collected sap will be boiled and stirred for four to six hours to allow the liquid to evaporate and become a thick caramel. The cooking time varies depending on the control of cooking gas or with firewood. Constant stirring is necessary to prevent the caramel from burning and sticking to the cooking wok or pot. The longer the sap is boiled, the darker and richer the caramel becomes. This caramel is called *gula apong*.

Approximately one kilogram of *gula apong* can be produced from 10 litres of sap. The *gula apong*'s color can range from pale brown to almost black. In terms of texture, it can be soft, crumbly, or hard. Figure 2 shows the different textures of *gula apong*. It should be noted that the texture outcome in Figure 2 does not have an exact cooking time or temperature measurement, as it is prepared manually and depends solely on the experience of the *gula apong* producers. The quality of *gula apong* depends on precise control of cooking temperature during the entire cooking process. This parameter significantly influences the composition and characteristics of *gula apong*, impacting its flavor, aroma, texture, and shelf life. Maintaining optimal cooking temperatures is essential to ensuring consistent quality and meeting consumer expectations.

Figure 1. Nipah palm trees along coastal areas of Kampung Pinggan Jaya, Kota Samarahan, Sarawak [10]

Figure 2. Textures of *gula apong*

The *gula apong* is then left to cool down and stored for packaging. The process of packaging and storage is also done manually and traditionally at home. The *gula apong* will be packed in cans, bottles, or plastic and then stored at room temperature. It will then be sold wholesale to suppliers, traders, and consumers based on demand. There are also producers using online methods to market their *gula apong* products. The traditional cooking and preparing method, with its special taste, makes the price of *gula apong* products higher than that of white or brown sugar. Since no chemicals are used and it is richer in vitamins and minerals, *gula apong* is more popular among households these days [11].

The entire process of producing *gula apong* takes a very long time, requires physical strength, and is also risky because the mangrove forest area is a swampy, muddy area [12]. The difficulty of this process is one of the reasons why the younger generation in Sarawak is less interested. Therefore, the use of smart technology needs to be utilized to develop the *gula apong* production industry on a large scale to meet the increasing demand, in addition to attracting the interest of young people to venture into this industry. The traditional approach to producing *gula apong* can be completely changed by using IoT technology. The use of this smart technology is also seen as opening up more job and business opportunities for local communities [13].

2.2. IoT opportunities for *gula apong* industry

All industries' business models are based on their interdependencies with other parties in their ecosystems. The exponential growth of digital technologies is reshaping the way various economic sectors and industries operate and perform. The agri-food sector is now moving towards modernization by using smart technologies, for instance, the IoT, to meet the growing demand. The IoT is a network of interconnected devices that collects, analyzes, and transmits data over the internet without human interaction [14], [15]. The IoT transforms everything that makes our lives easier, more distinct, and more pleasant. IoT provides innovative solutions to various business, government, and industry challenges and issues, including those in agri-food and agricultural sectors [16]. Through the utilization of IoT solutions, stakeholders in this industry can boost productivity, optimize resource allocation, minimize environmental footprints, and ultimately foster sustainable and efficient agricultural practices.

Tan *et al.* [17] states that IoT user interfaces have the potential to enable farmers to effortlessly monitor the environment, plant growth, and nutrient levels without relying on manual intervention. This IoT user interface displays pH data, total dissolved solids, oxidation reduction potential, and temperature data to control optimal nutrient solution rates. Plant growth rates are continuously monitored using cameras using a Wi-Fi-based network and message queuing telemetry transport (MQTT) protocol communication to send sensor data to cloud storage for processing. Web-based and mobile user applications are included in the user interface to allow users to monitor crops anytime and anywhere. Kamaruddin *et al.* [18] proposed technology for smart plant watering management using IoT in a wireless sensor network (WSN) environment. This system monitors and controls irrigation based on soil moisture levels and user preferences, offering both manual and automatic modes. The technology utilizes Arduino and NRF24L01 for communication. The system aims to promote smart agriculture and lifestyle, potentially saving costs and reducing water wastage.

Mathi *et al.* [19] integrated IoT with artificial intelligence algorithms to monitor and predict the appropriate amount of water for crop irrigation. Among the IoT devices used in this system is a soil moisture sensor. This IoT technology system that communicates wirelessly with nodes is proven to be able to monitor and analyze data on crop irrigation. An intelligent system for predicting soil fertility and monitoring the growth of spinach plants is also carried out by [20] which is also capable of monitoring and analyzing data on soil fertility so that spinach plants can continue to thrive. Through the integration of IoT sensors and data analysis techniques, the system offers insights into key soil properties such as moisture content, pH levels, and nutrient concentrations. It provides valuable insights into the application of IoT technology to improving soil management and agricultural practices at the backyard gardening level.

The IoT is also starting to fundamentally disrupt the agri-food sector, forcing the ecosystem to change, including the *gula apong* industry. Traditional approaches to producing *gula apong* can be completely transformed by using IoT technology [10]. With this technology, for example, it can be used to remotely monitor Nipah tree growth and take preventive measures to detect crop damage and threats. IoT can also monitor the quality of *gula apong* during preparation, processing, storage, and packaging, including sales. Utilizing IoT improves current approaches by generating new opportunities in the digital economy [21], [22].

However, the application of IoT in the *gula apong* industry is challenging because the source depends on natural conditions such as location, topography, weather, and diseases [12], [23]. Moreover, the acceptance of local *gula apong* producers toward digitalization, strategies, and policies from the Sarawak state government should be considered when IoT-based technologies are used [24]. This can be achieved through the development of practical IoT systems, which have already been used successfully in smart cities, healthcare, and smart homes [25]–[27]. The practical IoT system will facilitate *gula apong* producers to visualize the production status and improve quality management and traceability. This system will also help to identify the backlog and evaluate the prospects for the development of *gula apong* production activities.

Therefore, this paper proposes a cooking temperature monitoring system using IoT technology as part of the quality control of the *gula apong*. The use of the right temperature can ensure that each batch of production is uniform in terms of texture and taste. This process is essential to meeting customer expectations. Temperature also plays a major role in ensuring food safety [28]. Uneven and inappropriate temperature conditions might facilitate the growth of germs, particularly bacteria, posing a possible health risk to consumers.

2.3. *Gula apong* cooking phases

Cooking Nipah sap is an essential process in the *gula apong* production procedure. The *gula apong* producers do not utilize any specific method to monitor the duration and temperature during the cooking process. Optimal temperature control can expedite the cooking process and minimize dependency on cooking gas or firewood. Figure 3 shows the phases of cooking the *gula apong*. The Nipah sap will be filtered to ensure no impurities are mixed. The large pot with a hole at its bottom, which acts as a barrier Figure 4, is placed into the large wok to ensure the sap does not overflow. Then, it will be cooked until it boils, and froth is produced. The froth is then skimmed off, and the sap is once again filtered to ensure the quality of the *gula apong*. The Nipah sap is kept boiling and stirred continuously until caramelized and thickened into either a sugar syrup or solid sugar. Then, the *gula apong* will be removed from the furnace and stirred until the temperature cools down to prevent it from sticking to the wok and burning. The overall cooking process will take several hours, depending on the amount of Nipah sap, temperature, and cooking gas or firewood control.

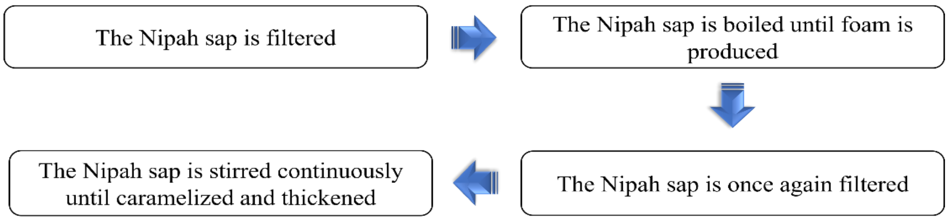


Figure 3. *Gula apong*'s cooking phases

Figure 4. The cooking pot and wok

2.4. Development of IoT-based temperature monitoring system

In this paper, an IoT-based temperature monitoring system used for monitoring the *gula apong* cooking process is developed. The overall operational methodology is shown in Figure 5. The proposed system utilizes E-type thermocouple sensor, ESP32 microcontroller with a Wi-Fi module, a MAX7655 amplifier, and the IoT development platform Node-RED. Figure 6 presents the temperature measurement unit, including the circuit connection and prototype development. The circuit connection in Figure 6(a) outlines the hardware components integrated into the proposed IoT-based temperature monitoring system. This includes the thermocouple sensor responsible for capturing temperature data during the cooking process. The thermocouple sensor has a maximum capacity to measure heat temperatures of up to 800 °C, making it suitable for application in a wide range of industries. The sensor is connected to an ESP32 microcontroller unit, which processes the temperature readings and facilitates data transmission. Figure 6(b) illustrates the physical prototype's incorporation of hardware components into a compact and practical design. The prototype incorporates necessary interfaces for connectivity, such as Wi-Fi modules, enabling seamless data transmission to the IoT-cloud platform by using the MQTT protocol.

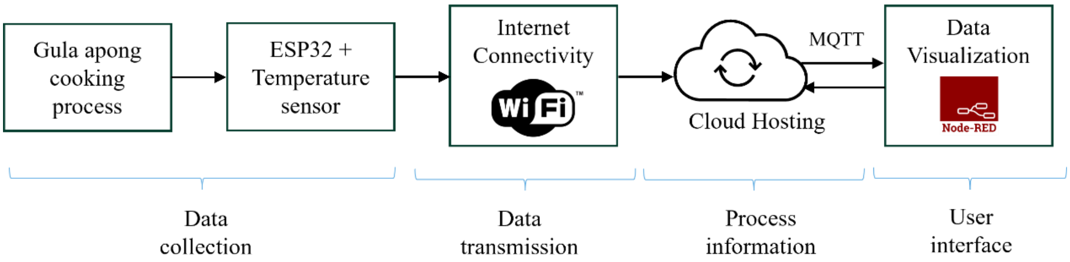
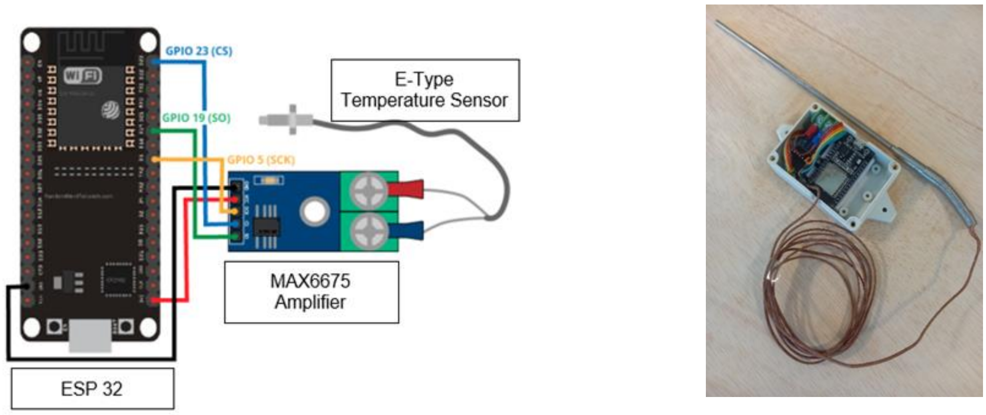


Figure 5. Operational methodology



(a) (b)

Figure 6. IoT-based temperature data measurement device (a) IoT-based temperature monitoring circuit connection and (b) IoT-based temperature monitoring prototype

In this setup, a thermocouple sensor is connected to the microcontroller ESP32, which is placed inside the cooking wok, as depicted in Figure 7. Throughout the entire cooking process of *gula apong*, this sensor continuously measures the temperature within the wok. The temperature data captured by the sensor is then transmitted via a Wi-Fi communication network to cloud storage. Utilizing the Node-RED platform, which is an open-source software designed for IoT applications and dashboards, the temperature data is processed and analyzed in real-time. This allows for comprehensive monitoring of temperature variations during the cooking process. Furthermore, users can access and monitor this temperature data conveniently from any smart device, such as a smartphone or tablet. By implementing this IoT-based system, producers can ensure effective monitoring of temperature fluctuations, enabling precise quality control and maintaining consistency in the production of *gula apong*.

Figure 7. Thermocouple sensor placement

3. RESULTS AND DISCUSSION

This study investigated the effects of temperature variations at each phase of *gula apong* production by using IoT-based temperature monitoring system in real-time. Although there is extensive research on cooking temperature in various contexts, including food processing and culinary practices, there has been no specific research conducted on *gula apong*. The proposed IoT system can benefit significantly from real-time temperature monitoring, enabling prompt identification and adjustment of any deviations from the desired temperature. This ensures that the cooking process remains on track, minimizing the risk of undercooking or overcooking the gula apong, which could result in longer cooking times.

Here, temperature measurements during the *gula apong* cooking process are taken on three separate days. The first measurement is set as a reference point for each subsequent cooking phase to control the time and temperature. Table 1 shows the temperature data readings based on the 4-point cooking conditions: i) heating up the Nipah sap after one hour; ii) Nipah sap starting to boil; iii) the froth starting to form; and iv) the Nipah sap thickening and caramelizing. The amount of Nipah sap used in this testing is approximately 10 litres (l). The duration recorded for the preparation of each *gula apong* is presented in Table 2.

Table 1. Temperature measurements during the *gula apong* cooking process

Cooking process condition	Measurement 1 Temperature reading	Measurement 2 Temperature reading	Measurement 3 Temperature reading
Heat up after 1 hour	88.75 ℃	71.75 ℃	94.25 ℃
Nipah sap started to boil	140.25 ℃	141.75 ℃	145.5 ℃
Froth is formed	150 ℃	151.25 ℃	150.5 ℃
Caramelized	166.5 ℃	164.5 ℃	167 ℃

Table 2. Time taken during the *gula apong* cooking process

Cooking process condition	Measurement 1 Time record	Measurement 2 Time record	Measurement 3 Time record
Cooking process started	8.23 am	8.15 am	8.30 am
Nipah sap started to boil	10.05 am	10.46 am	10.07 am
Froth is formed	11.06 am	11.07 am	11.00 am
Caramelized	11.13 am	11.15 am	11.12 am

It is observed that the heating temperatures vary, ranging from temperatures above 70 ℃ to 94 ℃ after one hour of cooking on a stove at medium heat. On average, it takes about 1.5 to 2 hours for the Nipah sap to come to a rolling boil and the temperature to reach above 140 ℃. The frothy substance is formed as the sap continues to boil. The temperature is observed to increase within 5 ℃ to 10 ℃. During this phase, froth is removed, and the sap is filtered to extract an impurity solid. After the sap has completely evaporated, the pot can be taken out of the wok. The temperature sensor indicates that when the temperature approaches 165 ℃, the Nipah sap will turn brown and caramelize into *gula apong*. It stays until 1-3 minutes before the *gula apong* is fully ready. The entire duration of the cooking process was approximately 3 hours.

Figure 8 presents the consistency of the *gula apong* texture during the caramelization process at varying temperatures within the range of 164.5 °C to 167 °C. Three distinct cooking outcomes, represented by Figures 8(a) to 8(c), provide visual insights into the texture variations observed at different temperature measurements. The findings indicate that an approximate average temperature of 165 °C is recommended to produce standard-quality *gula apong*. This aids in optimizing cooking parameters to achieve desired texture profiles. Figure 9 shows an example of IoT dashboard temperature monitoring when the temperature reading is 164 ℃. The proposed system offers a viable and convenient method for effective monitoring of *gula apong* cooking temperature in real-time at each phase. Through precise temperature control, *gula apong* producers can enhance consumer satisfaction, fostering increased trust and loyalty among consumers. In addition, the integration of an IoT-based temperature monitoring system also enhances production efficiency by reducing the likelihood of product defects or inconsistencies, resulting in cost savings and heightened productivity.

In summary, through the utilization of continuous and real-time temperature monitoring, our research findings demonstrate that the ideal temperature for achieving standard-quality *gula apong* is approximately 165 °C, while the recommended boiling temperature for Nipah sap is 140 °C. Our study also observed that the cooking process for *gula apong* requires 3 hours, which is shorter than the conventional duration of 4 to 6 hours. This indicates that optimizing the temperature leads to more efficient *gula apong* production compared to traditional methods. Additionally, the proposed approach could benefit from the reduced cooking duration without compromising the standard-quality outcome. For future work, this system can be improved to investigate the long-term durability and scalability of the IoT infrastructure. This includes the potential enhancements and integration of additional sensors or features in the IoT prototype, as well as practical methods for managing diverse quality control parameters.

(a) (b) (c)

Figure 8. Consistency of *gula apong* texture when it turns brown and caramelize at temperatures ranging from 164.5 ℃ to 167 ℃: *(a) Gula apong* texture for measurement 1 at 166.5 ℃, (b) *Gula apong* texture for measurement 2 at 164.5 ℃, and (c) *Gula apong* texture for measurement 3 at 167 ℃

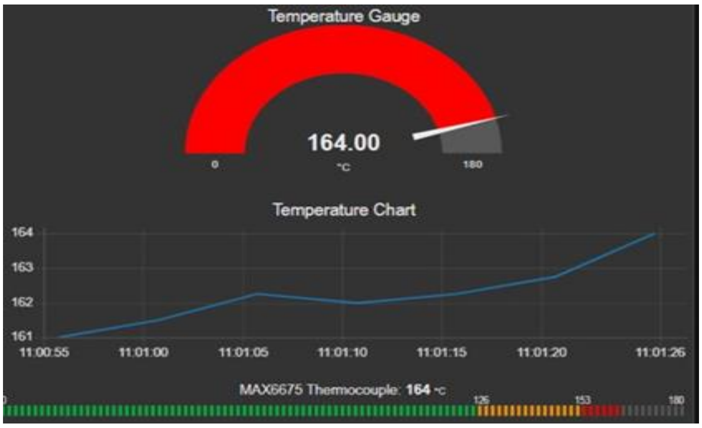


Figure 9. IoT dashboard temperature monitoring when the temperature reading is 164 ℃

4. CONCLUSION

The IoT-based temperature monitoring system was successfully developed in this paper. The findings offer valuable insights into the optimization of *gula apong* production processes through the integration of IoT technology. Gula apong's entrepreneurs can maintain consistency in the quality of *gula apong*, meeting consumer expectations and enhancing overall product satisfaction by ensuring precise control and monitoring of cooking temperature. The developed IoT prototype is designed to be easily upgraded for future enhancements, allowing for the integration of additional sensors or features to address diverse quality control parameters across various food industries. Furthermore, the implementation of IoT-based monitoring systems aids *gula apong* entrepreneurs in maintaining regulatory compliance with evolving food safety standards, facilitating streamlined documentation of temperature data for regulatory reporting purposes. The findings of this research facilitate the transfer of knowledge to other food producers facing with similar quality control challenges, thereby contributing to broader efforts within the food industry to improve product quality and safety standards. Thus, implementing IoT will also encourage more youth to continue the *gula apong* business as one of Sarawak's signature products.

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