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Development and Performance Evaluation of a Low-Cost, Energy-Efficient Air Fryer Prototype Using Incandescent Bulb Heating for Oil-Free Food Processing.

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Abstract. Oil-free cooking technologies are increasingly important for promoting healthier diets, reducing dependency on volatile oil markets, and enabling sustainable food processing—particularly in rural and resource-constrained environments. This study presents the design and evaluation of a low-cost air fryer prototype powered by incandescent bulbs (60–150 W), constructed using locally available materials. Thermal performance testing showed that the prototype achieved stable chamber temperatures up to 115 °C, enabling effective oil-free frying of potato slices, banana slices, and chicken nuggets. Frying performance, measured through cooking time, moisture reduction, and sensory evaluation, demonstrated acceptable product quality with significant energy savings: only 25–75 Wh per cycle, roughly one-tenth the energy use of conventional commercial air fryers. The prototype also offers potential as a multifunctional device for dehydration and defrosting, supporting broader postharvest applications in smallholder agritech. These results highlight a promising pathway for low-power, low-cost, and sustainable food processing technologies suitable for deployment in rural communities. Future work will focus on optimizing performance, expanding product capabilities, and validating user acceptance in real-world agritech settings.

Keywords: Low-power Air fryer, incandescent bulb heating, oil-free cooking, energy-efficient food processing, sustainable technology.

INTRODUCTION

Postharvest processing plays a critical role in maintaining the quality, safety, and shelf life of agricultural products (Kumar, 2025). Among various processing techniques, deep frying remains one of the most common methods used at both household and small and medium enterprise levels in Indonesia. This method enhances the sensory attributes of food, making products more appealing to consumers. However, it is highly dependent on the availability of cooking oil as the primary frying medium. In recent years, Indonesia has experienced significant fluctuations in cooking oil prices, driven by global market dynamics and domestic supply and demand challenges. According to data from the National Food Agency in April 2025, the average retail price of bulk cooking oil ranged from IDR 17,000 to IDR 19,000 per liter. Beyond economic concerns, shortages of cooking oil in several regions have led to negative social impacts (Reuters, 2025). One widely reported incident in Gorontalo involved the tragic death of a woman who collapsed while waiting in line to purchase scarce cooking oil (Liangga, 2022).

This situation highlights the broader socioeconomic vulnerabilities caused by excessive reliance on cooking oil for food preparation (Pipil, 2025). Government interventions such as market stabilization programs and subsidies have provided temporary relief but have not addressed the underlying structural dependence on this commodity. There is a clear need to develop alternative food processing technologies that can reduce oil dependence while offering sustainable and practical solutions for both households and small businesses. One method for cooking without oil is using an air fryer (Téllez-Morales, 2023).

Air frying has emerged as an attractive alternative, leveraging circulating hot air to achieve crispy textures with little to no oil use. A 2025 study on Brassica vegetables demonstrated that air frying at 160 °C for 10 minutes significantly increased total phenolic and flavonoid contents—indicators of antioxidant activity—compared to other conventional thermal methods (Nandasiri et al., 2025). Moreover, a broader review in 2024 highlighted air frying's ability to maintain food quality and reduce acrylamide formation, although it—like traditional deep frying—may induce lipid oxidation under certain conditions (Téllez-Morales et al., 2024). Despite these health and nutritional advantages, most commercial air fryers require more than 1,000 W and cost several hundred rupiahs, rendering them unsuitable for many households in rural agrarian regions.

To address energy efficiency, researchers have investigated infrared (IR) heating technologies for food processing. IR methods offer rapid, uniform heating with high energy efficiency and improved preservation of color, texture, and nutrients (Anumudu et al., 2024). IR heating has been applied successfully in applications such as fruit and vegetable drying, microbial inactivation, and peeling (Manyatsi et al., 2023). Additionally, hybrid solar-powered cooking devices—such as solar-assisted air fryers—have been prototyped (e.g., a solar-air fryer built in 2024 that integrated thermal efficiency analyses and environmental assessments) (Hayelom et al., 2024). Yet technologies reliant on solar insolation still face challenges of intermittency, bulkiness, and user complexity, limiting their deployment in off-grid or small-scale agritech environments.

Given these limitations, there remains a clear gap: the need for an affordable, low-power air-frying solution that is portable and deployable in rural agritech settings. One promising direction involves leveraging simple, locally available heating sources—such as incandescent bulbs—to replicate IR principles at low wattage, enabling effective cooking without heavy power infrastructure.

This research aims to design and develop a low-cost air fryer prototype using incandescent bulbs (60–150 W total) as the heat source. The study tests the device's thermal performance, energy consumption, and cooking quality, using potato, banana, and chicken nugget samples as typical agrifood products. Sensory evaluation and antioxidant analysis will be conducted, comparing results against conventional deep frying and commercial air-fryer benchmarks. Ultimately, this prototype is positioned as a practical agritech innovation—energy-efficient, cost-effective, and suitable for rural smallholders and community kitchens.

By merging insights from air frying research, heating efficiency, and agritech design, this study addresses a critical need in sustainable food processing. It aspires to provide an accessible, healthy, and resilient cooking technology for low-resource settings, aligning with goals of rural development and food value-chain innovation.

RESEARCH METHOD

This research involved the design, assembly, and performance evaluation of a low-power air fryer prototype utilizing incandescent light bulbs as the primary heat source. The study aimed to investigate the prototype's ability to process common agricultural products through oil-free frying, while minimizing energy consumption.

Prototype Design and Components

The air fryer prototype was designed to achieve oil-free frying of food products using a low-power heating system based on incandescent light bulbs. The main objective was to create an energy-efficient and affordable device using easily accessible components, suitable for rural or low-resource settings.

The design consisted of three main functional components:

1. A heating chamber constructed from insulated steel and heat-resistant plastic, providing thermal containment and food safety.
2. A forced air circulation system, using a 12V DC axial fan to promote uniform heat distribution within the chamber.
3. A replaceable heating element, utilizing commercially available incandescent bulbs (40 W, 60 W, 100 W, and 150 W ratings), chosen for their ability to emit both infrared and visible radiation, contributing to surface heating and cooking efficiency.

A modular frame design was used to facilitate easy assembly and future scalability. The fan was powered by an external AC/DC adapter (220 V AC input to 12 V DC output), connected through a step-down converter. A stainless-steel mesh tray served as the food placement platform, ensuring unobstructed airflow around the food items.

Thermal insulation was incorporated around the heating chamber walls using high-density fiberglass insulation, aimed at minimizing heat loss and improving energy efficiency. Real-time temperature monitoring was achieved using a digital thermometer (±1 °C accuracy), with a sensor probe positioned at the center of the food tray.

The overall schematic of the prototype is shown in Figure 1, illustrating the arrangement of heating elements, air flow path, and chamber construction

Table 1. summarizes the key components and their specifications

Component	Specification
Heat source	Incandescent bulbs (40 W–150 W)
Air circulation fan	12V DC axial fan, 0.18 A
Cooking chamber	Insulated steel with heat-resistant plastic
Food tray	Stainless steel mesh
Temperature monitoring	Digital thermometer, ±1 °C accuracy
Power supply	AC 220 V with step-down converter (fan)

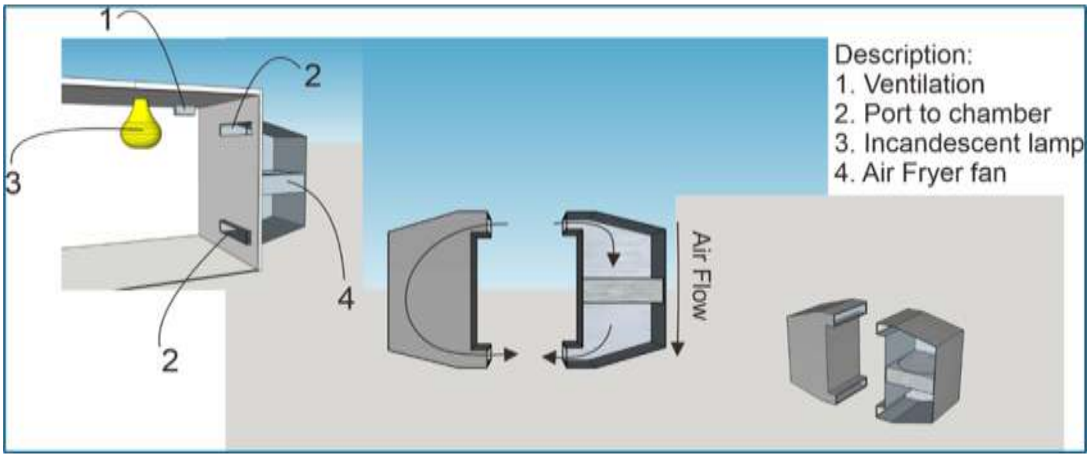

Figure 1. Prototype Design and Schematic Layout

The schematic layout of the air fryer prototype is illustrated in Figure 1. The heating chamber is centrally located and is designed to promote even distribution of heated air. The primary heating source consists of incandescent bulbs (component 3), selected for their ability to emit both infrared and visible radiation, providing sufficient thermal energy for the cooking process. Forced air circulation is achieved by a 12V DC axial fan (component 4), which is mounted externally and connected to the chamber through a dedicated port (component 2). This port serves as a controlled entry point for the airflow, ensuring directed movement of heated air around the food tray. To prevent excessive heat buildup and allow for controlled heat dissipation, ventilation ports (component 1) are incorporated at the upper section of the chamber, maintaining internal air pressure balance. The combination of these design features ensures uniform temperature distribution, minimizes localized overheating, and promotes consistent cooking performance across the food samples.

Food Materials

Three commonly consumed food products were selected as representative agricultural materials for performance testing of the prototype: potato slices (Solanum tuberosum), banana slices (Musa spp.), and commercial chicken nuggets. These items were chosen to provide a range of textures, moisture contents, and surface properties, enabling evaluation of the prototype's versatility across different food types.

Fresh potatoes of the Granola variety were sourced from a local agricultural market in Manado, Indonesia. Potatoes were washed, peeled, and sliced to a uniform thickness of 4 mm using a calibrated mandoline slicer. Bananas (Cavendish variety) at the ripe stage (yellow peel with slight brown spotting) were similarly sliced to 4 mm thickness. Commercial frozen chicken nuggets were purchased from a local supermarket, stored at −18 °C, and thawed to 4 °C in a refrigerator for 6 hours prior to testing.

All food samples were prepared in batches of 10 slices or nuggets per test cycle, with initial weights recorded using a precision electronic balance (±0.01 g accuracy). The sample preparation protocol aimed to ensure uniformity in size, shape, and moisture content, thereby enabling consistent heating profiles and reliable evaluation of the prototype's performance.

No pre-treatment (such as soaking, blanching, or pre-seasoning) was applied to the food materials in order to isolate the effects of the air fryer prototype itself on texture, moisture loss, and sensory attributes.

Experimental Procedure

All experiments were conducted in a controlled indoor laboratory environment at an ambient temperature of 27 ± 1 °C. Prior to each test cycle, the air fryer prototype was positioned on a heat-resistant surface, and the selected incandescent bulb was installed in the heating chamber. Three different power levels were evaluated: 60 W, 100 W, and 150 W, in order to assess their influence on heating performance and cooking outcomes. Before loading samples, the chamber was preheated for 5 minutes with the fan operating at full speed. Chamber temperature was continuously monitored using a digital thermometer, with the sensor probe positioned at the center of the food tray, to record air temperature in the vicinity of the samples.

After preheating, prepared food samples were loaded onto the stainless-steel mesh tray in a single layer to allow unrestricted airflow. Each frying cycle followed the same standardized procedure:

1. Preheating: 5 minutes with selected bulb and active air circulation

2. Sample loading: 10 slices of potato or banana, or 10 nuggets per batch
3. Continuous frying: samples cooked until target texture and color were achieved
4. Temperature recording: chamber temperature logged at 1-minute intervals throughout each cycle
5. Time recording: total cooking time per batch recorded (in minutes)
6. Moisture loss measurement: post-cooking sample weight measured to calculate % moisture reduction
7. Energy consumption recording: total electrical consumption per cycle measured using an inline power meter (accuracy ±1 Wh)

Each food type was tested in triplicate at each power level to ensure statistical reproducibility (n = 3 per condition). A fresh batch of samples was used for each test replicate. Between cycles, the chamber was allowed to cool for 10 minutes before initiating the next preheating phase. Testing matrix is summarized in Table 2.

Table 2. Testing matrix for evaluating the performance of the air fryer prototype under varying heating power conditions.

Product Type	Sample Size per Batch	No. of Batches	Power Levels Tested (W)	No. of Replicates
Potato slices	10 slices	3 batches	60, 100, 150	3
Banana slices	10 slices	3 batches	60, 100, 150	3
Chicken nuggets	10 nuggets	3 batches	60, 100, 150	3

The testing matrix summarized in Table 2 outlines the structure of the performance evaluation for the air fryer prototype. For each food type (potato slices, banana slices, and chicken nuggets), three independent batches were prepared, with each batch consisting of 10 standardized samples. Each batch was tested under three different heating power conditions (60 W, 100 W, and 150 W incandescent bulbs), with three replicates performed at each power level to ensure data reliability and statistical validity. This design resulted in a total of 9 cooking trials per food type (3 power levels × 3 replicates), yielding a comprehensive dataset for comparing the effects of heating power on cooking performance, energy consumption, moisture reduction, and sensory quality.

The criteria for cooking endpoint were based on achieving acceptable visual appearance (surface browning or caramelization), target texture (crispness or softness as appropriate), and internal doneness, as verified by a trained sensory panel (see Sensory Evaluation Section)

Measurement Parameters

The performance of the air fryer prototype was evaluated through a set of quantitative and qualitative parameters designed to assess thermal behavior, energy efficiency, and cooking quality.

The following parameters were measured and analyzed:

1. Maximum chamber temperature (°C)

The peak internal temperature reached during each frying cycle was recorded using a calibrated digital thermometer. The sensor probe was positioned at the center of the food tray to capture the air temperature directly surrounding the food samples.

2. Time to reach steady-state temperature (minutes)

The duration required for the internal chamber to reach a stable temperature plateau after preheating and sample loading was measured. This parameter reflects the prototype's heating responsiveness and thermal stability.

3. Total frying time (minutes)

For each batch, the time required to achieve target cooking endpoints (visual browning, textural crispness, internal doneness) was recorded, providing insight into cooking efficiency at different power levels.

4. Moisture content reduction (% weight loss)

Sample weight was recorded before and after frying using a precision balance (±0.01 g). The percentage of moisture loss was calculated as:

Moisture Reduction (%) = [(Initial Weight − Final Weight) / Initial Weight] × 100%

This value indicates dehydration efficiency and texture development.

5. Energy consumption (Wh per cooking cycle)

Total electrical energy used during each frying cycle was measured using an inline digital power meter (±1 Wh accuracy). This metric reflects the overall energy efficiency of the prototype under different power settings.

6. Sensory evaluation (texture, color, and overall acceptability).

A trained sensory panel evaluated the final products using a structured 5-point hedonic scale (1 = poor; 5 = excellent) for three attributes: surface texture (crispness), visual color, and overall acceptability. The panel scoring procedure is further detailed in Sensory Evaluation Section.

Sensory Evaluation

Sensory quality of the fried products was assessed by a trained panel of five adult evaluators (3 males and 2 females, aged 25–40 years). Testing sessions were performed in the late morning, with panelists instructed to refrain from eating or drinking strong flavors (e.g., coffee, spicy foods) at least 1 hour before testing.

Each food product (potato slices, banana slices, chicken nuggets) was coded with random three-digit numbers and presented to panelists in randomized order to prevent bias. All products were served within 5 minutes after cooking to ensure consistency in temperature and texture during evaluation. Panelists rated three attributes for each product using a structured 5-point hedonic scale, Sensory attributes were evaluated according to the structured scale shown in **Table 3**.

Table 3. Sensory evaluation scoring scale for product quality attributes.

Attribute	1 (Poor)	2	3 (Moderate)	4	5 (Excellent)
Texture (crispness)	Not crisp	Slightly soft	Moderately crisp	Crisp	Very crisp
Color (appearance)	Undesirable color	Slightly pale	Acceptable color	Desirable color	Golden/caramelized color
Overall acceptability	Unacceptable	Slightly acceptable	Moderate acceptance	Acceptable	Highly acceptable for consumption

Table 3 presents the structured 5-point hedonic scale used by the sensory panel to evaluate product quality attributes. The three evaluated attributes were: texture (crispness), color (visual appearance), and overall acceptability. For each attribute, panelists assigned a score from 1 to 5, with 1 indicating poor performance and 5 indicating excellent quality. The scale descriptors were carefully defined to ensure consistency among panelists and improve the reliability of sensory data. Panelists were trained to calibrate their ratings based on reference samples before formal testing began. The structured scoring system allowed quantitative comparison of sensory outcomes across different heating power levels and food types.

Each panelist evaluated all samples from each power level in triplicate sessions. Mean scores and standard deviations were calculated for each attribute across all panelists.

Data Analysis

Experimental data from all trials were recorded and analyzed using Microsoft Excel 2021 and IBM SPSS Statistics version 27 (Nalendra et al., 2021; Nunes et al., 2015). Descriptive statistics (mean ± standard deviation) were calculated for each measurement parameter, including maximum chamber temperature, time to steady-state temperature, total frying time, moisture content reduction, energy consumption, and sensory evaluation scores.

To assess the effects of heating power level (60 W, 100 W, 150 W) on cooking performance and product quality, a one-way analysis of variance (ANOVA) was performed for each food type. Where significant differences were detected ($p < 0.05$), Tukey's Honest Significant Difference (HSD) post-hoc tests were conducted to identify pairwise differences between power levels (Alqahtani et al., 2025).

Prior to performing ANOVA, data normality was assessed using the Shapiro–Wilk test(Gasperoni et al., 2025; Souza et al., 2023), and homogeneity of variance was evaluated with Levene's test. All statistical analyses used a significance level of $\alpha = 0.05$. The results were interpreted to determine optimal heating conditions for oil-free frying performance of the prototype.

RESULTS AND DISCUSSION

Final Prototype

Within Figure 2a. The chamber contain lamp that will become heat source and we can also look at top left there is a hole where air flow can go inside the chamber. Within figure 2b. The fan module can be plug out for easy maintenance and future development.

Thermal Performance

The thermal behavior of the air fryer prototype was evaluated at three different heating power levels: 60 W, 100 W, and 150 W. The time required to reach a stable internal temperature and the maximum steady-state temperature achieved under each condition are summarized in Table 4.

From Table 4. At 150 W, the prototype achieved a stable chamber temperature of 115 °C within approximately 5 minutes, while at 100 W, the chamber stabilized at 87 °C after approximately 6 minutes. The lowest heating power (60 W) resulted in a slower heating rate, with a stabilization temperature of 54 °C after approximately 10 minutes.

(a) (b)

Figure 2. 100W lamp inside chamber (a), and airfryer from prespective view (b).

Table 4. Thermal performance of the air fryer prototype at different heating power levels.

Heating Power (W)	Time to Stable Temperature (min:sec)	Maximum Chamber Temperature (°C)
60	10 min 5 sec	54
100	6 min 15 sec	87
150	4 min 54 sec	115

These results reflect the expected behavior of the incandescent bulb heating system, where thermal output increases nonlinearly with input power. The lower maximum temperatures compared to commercial air fryers (typically 150–200 °C) are consistent with the lower overall power input of this prototype. However, the system demonstrated good thermal stability, maintaining constant chamber temperatures once equilibrium was reached at each power level. We can look at Figure 3 to look at chamber temperature profile.

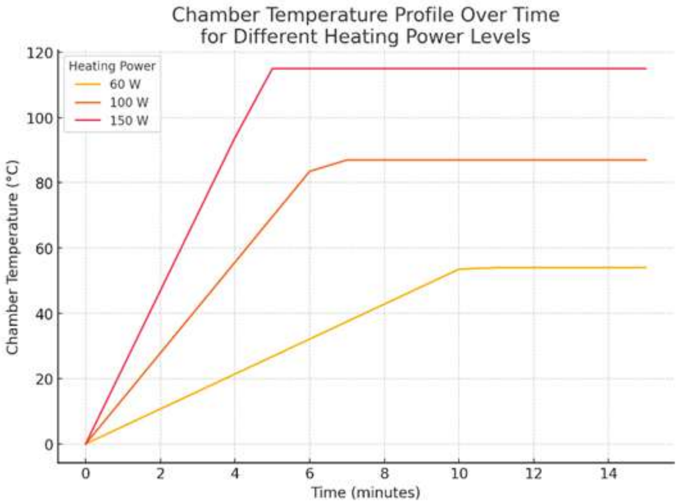

Figure 3. Chamber temperature profile over time for different heating power levels (60 W, 100 W, 150 W).

Figure 3 illustrates the chamber temperature profiles of the air fryer prototype over time for each heating power level tested (60 W, 100 W, 150 W). The heating dynamics show that at higher power levels, the prototype achieved faster temperature increases and higher maximum temperatures. At 150 W, the chamber reached approximately 115 °C in under 5 minutes, followed by stabilization. At 100 W, the temperature rose to 87 °C in about 6 minutes, while the lowest power setting (60 W) reached a steady 54 °C after approximately 10 minutes.

These results confirm that the heating performance of the prototype is strongly influenced by input power, as expected. While maximum temperatures were lower than those typically reported for commercial air fryers (150–200 °C), the prototype demonstrated adequate thermal stability and energy efficiency. The gradual and consistent heating profile achieved by the incandescent bulbs supports their suitability for low-power cooking applications in resource-constrained environments.

Figure 4 provides photographic confirmation of the chamber temperature exceeding 100 °C during operation at 150 W, supporting the recorded thermal performance results.

Frying Time and Energy Consumption

The frying time required to achieve target product quality (based on texture, color, and internal doneness) varied with heating power level and food type. Similarly, total energy consumption per cooking cycle reflected the different power inputs and cycle durations. Table 5 summarizes the average frying time and total energy consumption for each combination of food type and heating power level.

Figure 4. Photo of analog thermometer indicating chamber temperature above 100 °C during operation at 150 W.

Table 4. Insect Evenness Index Analysis

Food Type	Heating Power (W)	Frying Time (min)	Energy Consumption (Wh per cycle)
Potato slices	60	40	40
	100	30	50
	150	25	65
Banana slices	60	25	25
	100	18	30
	150	15	38
Chicken nuggets	60	45	45
	100	35	55
	150	30	75

From Table 5. At the highest power level (150 W), potato slices required approximately 25 minutes to reach optimal crispness and color, while banana slices required only 15 minutes and chicken nuggets about 30 minutes. Lower power levels (60 W and 100 W) resulted in significantly longer frying times, especially for the more moisture-rich samples (potatoes and chicken nuggets).

Energy consumption per cycle ranged from 25 Wh (for banana slices at 60 W) to a maximum of 75 Wh (for chicken nuggets at 150 W). Compared to typical commercial air fryers operating at 1,200–1,500 W, which consume approximately 1.5 kWh per hour (or ~375–500 Wh per 20-minute cycle) , the prototype demonstrated substantially lower energy requirements—approximately 5 to 10 times less energy per cycle.

These findings highlight the suitability of the prototype for energy-constrained environments such as rural households or off-grid agricultural processing operations. Although frying times were longer than those of commercial systems, the significant reduction in energy demand offers practical benefits where power availability is limited or expensive.

Moisture Content Reduction

Moisture loss is a key factor influencing texture, crispness, and overall product quality in air frying. The percentage of moisture reduction for each product type under different heating power levels is summarized in Table 6.

Table 6. Percentage of moisture reduction after frying at different heating power levels

Food Type	Heating Power (W)	Moisture Reduction (%) ± SD
Potato slices	60	35.2 ± 2.1
	100	47.8 ± 1.8
	150	54.6 ± 2.0
Banana slices	60	28.5 ± 1.5
	100	40.7 ± 2.2
	150	46.9 ± 1.7
Chicken nuggets	60	32.1 ± 2.3
	100	43.5 ± 1.9
	150	51.2 ± 2.4

From Table 6. For all product types, moisture reduction increased with heating power level. At 150 W, potato slices exhibited an average moisture reduction of approximately 54.6%, producing a desirable crisp texture. Chicken nuggets and banana slices also showed significant moisture loss at higher power settings (51.2% and 46.9%, respectively).

Statistical analysis (ANOVA, $p < 0.05$) confirmed that heating power level had a significant effect on moisture reduction for all products tested. Post-hoc comparisons (Tukey HSD) indicated that moisture loss at 150 W was significantly greater than at 60 W ($p < 0.01$), consistent with the observed improvements in crispness and drying efficiency.

These results demonstrate that although the prototype operates at lower temperatures than commercial air fryers, it is capable of achieving effective moisture reduction, supporting development of texture and shelf-life in oil-free fried products.

Sensory Evaluation

The sensory quality of the fried products was evaluated by a trained panel based on texture (crispness), color (visual appeal), and overall acceptability (see Table 3 for scoring scale). The mean panel scores for each attribute and heating power level are summarized in Table 7.

Table 7. Mean sensory scores (± SD) for texture, color, and overall acceptability at different heating power levels.

Food Type	Heating Power (W)	Texture (crispness)	Color (appearance)	Overall Acceptability
Potato slices	60	2.8 ± 0.4	3.0 ± 0.5	3.0 ± 0.5
	100	3.6 ± 0.5	4.0 ± 0.6	4.0 ± 0.4
	150	4.5 ± 0.3	4.8 ± 0.2	4.6 ± 0.3
Banana slices	60	3.0 ± 0.5	3.2 ± 0.4	3.4 ± 0.4
	100	3.9 ± 0.4	4.1 ± 0.5	4.0 ± 0.3
	150	4.4 ± 0.3	4.7 ± 0.2	4.5 ± 0.2
Chicken nuggets	60	2.9 ± 0.4	3.1 ± 0.4	3.2 ± 0.5
	100	3.8 ± 0.5	4.0 ± 0.4	4.0 ± 0.4
	150	4.6 ± 0.3	4.9 ± 0.1	4.7 ± 0.3

From Table 7. Across all product types, sensory scores improved significantly with increasing heating power (ANOVA, $p < 0.05$). At 150 W, potato slices achieved the highest ratings for crispness (4.5 ± 0.3) and color (4.8 ± 0.2), resulting in an overall acceptability score of 4.6 ± 0.3. Similar trends were observed for banana slices and chicken nuggets, where higher power levels produced better surface color development and desirable crisp textures.

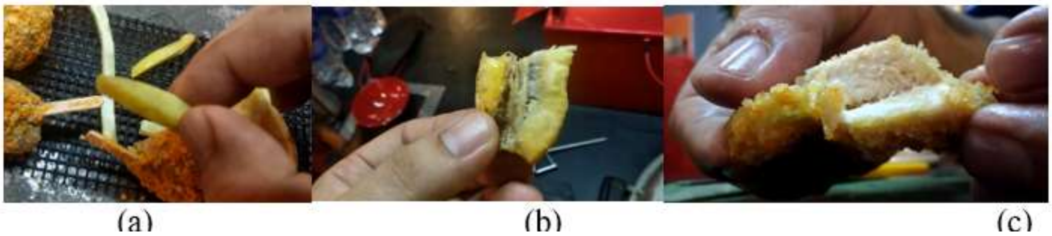

Figure 5. (a) Potato, (b) Banana, (c) Chicken Nugget. All cooked with 100W

At lower power settings (60 W), panelists consistently rated texture and color as less acceptable, reflecting the slower heating and reduced moisture loss at these settings. The 100 W setting provided moderate sensory quality, with acceptable scores for typical household use.

These findings indicate that even with lower maximum chamber temperatures than commercial air fryers, the prototype is capable of producing air-fried products with good sensory quality when operated at higher power settings (≥100 W). This performance suggests practical utility for oil-free cooking in rural or low-energy environments.

Comparison to Commercial Systems

Compared with standard commercial air fryers—typically operating between 800 W and 2,000 W (most often 1,200–1,500 W)—which reach internal temperatures of around 150–200 °C within 5–10 minutes, our incandescent-bulb prototype operates at a far lower power level (≤150 W) and achieves a maximum temperature of only 115 °C in approximately 5 minutes . While commercial systems deliver rapid, high-temperature cooking, they incur substantial energy costs—drawing around 0.9–1.5 kWh per hour (~450–750 Wh per 30-minute cycle) .

In contrast, our prototype consumes only 25–75 Wh per cooking cycle—about one-tenth the energy of conventional units—making it far more efficient in power-limited contexts. Although the prototype's lower maximum temperatures result in slower browning, it achieves adequate crispness and color, while operating below the threshold (~120 °C) at which acrylamide formation becomes significant (Téllez-Morales et al., 2024).

Practical Implications and Future Work

The prototype's low-power design (≤150 W) is ideally suited for rural households and small-scale agricultural settings that often rely on solar-powered systems or limited-capacity inverters—areas where high-power appliances are impractical or prone to causing power outages. Built using locally available materials and basic components, the device promotes sustainable, DIY agritech innovation while reducing reliance on volatile cooking oil markets.

For future development, several enhancements are recommended. First, improving chamber insulation, optimizing bulb-to-tray distance, and refining airflow with variable-speed fans could boost heating efficiency and shorten cooking times. Second, there is strong potential to adapt the prototype into a multi-functional device by adding modes for dehydration (fruit and vegetable drying) and defrosting (safe, gentle thawing of frozen products). Both applications can be supported using the same low-power lamp-based heating and airflow system, with minor design adjustments (e.g., adjustable temperature control, humidity vents). Such multi-use capability would significantly increase the value and practicality of the device for smallholder farmers and rural processors.

In addition, comparative studies with other sustainable cooking technologies—such as solar-air fryers and hybrid solar-electric systems—could further establish the optimal role of this design in low-energy agritech. Finally, scaling up for community kitchen use, conducting extended sensory and durability trials, and incorporating consumer feedback from rural communities will be essential to validate broader adoption.

Overall, this prototype demonstrates a promising path toward affordable, energy-efficient, and versatile food processing tools that support healthier and more sustainable diets in underserved agritech environments.

Limitations of the Prototype

While the prototype demonstrated promising performance in energy efficiency and oil-free cooking, several limitations should be acknowledged. First, the maximum chamber temperature (115 °C) is lower than that of typical commercial air fryers (150–200 °C), resulting in longer cooking times, particularly for products with higher moisture content. Second, the relatively simple control system lacks precise temperature regulation or programmable settings, which may affect cooking consistency across different food types or batch sizes. Additionally, the use of incandescent bulbs as heating elements—though effective and locally available—raises questions about long-term durability and replacement availability. Finally, the sensory evaluation was conducted in a controlled laboratory environment with a small, trained panel; broader consumer acceptance and performance in real-world rural settings remain to be validated through extended field trials. Addressing these limitations will be an important focus of future development work.

CONCLUSION

This study successfully demonstrated the design, development, and performance evaluation of a low-cost air fryer prototype powered by incandescent bulbs. Operating at heating power levels between 60 W and 150 W, the prototype achieved stable chamber temperatures up to 115 °C, enabling oil-free frying of common agricultural products such as potato slices, banana slices, and chicken nuggets.

Despite operating at lower temperatures than commercial air fryers, the prototype delivered acceptable sensory quality, effective moisture reduction, and substantial energy savings—consuming only 25–75 Wh per cycle, approximately one-tenth the energy use of standard systems. These results highlight the prototype's suitability for use in rural households and small agribusinesses with limited access to electrical infrastructure.

In addition to reducing cooking oil dependency, the prototype offers a potential platform for future multi-functionality, including dehydration and defrosting applications. Its construction from low-cost, locally available materials enhances its accessibility and replicability, supporting self-reliance in agritech innovation.

Future work will focus on optimizing the prototype's thermal and airflow performance, expanding its capabilities for multi-purpose food processing, and conducting larger-scale trials with broader product categories and consumer evaluations. Overall, this technology offers a promising contribution to sustainable, low-energy food processing in underserved agricultural contexts.

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