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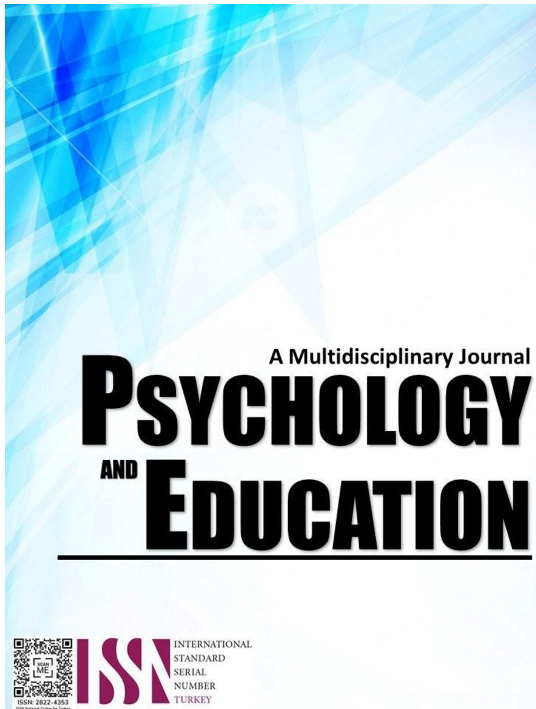

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Research Article

CrispCassa (Creating Reliable Innovations in Sustainable Processing of Cassava): An Automated Solution for Efficient Drying

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Abstract

This study investigates the development and testing of CrispCassa, an automated cassava dryer aimed at supporting farmers in Manolo Fortich, Bukidnon, in Northern Mindanao, where cassava is extensively cultivated. Traditional drying methods which are labor-intensive, inefficient, and struggle to meet increasing cassava demand due to outdated practices and climate vulnerabilities. An automated dryer was designed to improve heat transfer and moisture removal in response to these challenges. A quasi-experimental design was employed, with multiple trials conducted to compare pre-test and post-test results, assessing the impact of the dryer on drying efficiency. Statistical analysis, including t-tests and ANOVA, revealed significant differences in final weight, moisture removal, and cassava moisture content between pre-test and post-test measurements. The t-test produced a p-value of 0.000, leading to the rejection of the null hypothesis. ANOVA results from four trials also rejected the null hypothesis, with p-values of 0.000 and 0.001, confirming the automated dryer's superior performance. The findings demonstrate that the automated cassava dryer is a promising alternative to conventional methods, increasing productivity and reducing labor demands. The study highlights the potential of the dryer to bridge technological gaps in post-harvest processing, helping local farmers adapt to rising cassava demand despite climate-related challenges. Ultimately, this research provides valuable insights into the development of affordable and efficient drying technologies, fostering agricultural resilience and economic growth in the region.

Keywords: *Cassava dryer, automated drying, post-harvest processing, moisture removal, smallholder farmers*

Introduction

In today's rapidly advancing world, the agricultural sector urgently needs technological advancements, as many farmers rely on conventional methods. While innovations in automation, artificial intelligence, and data-driven systems transform industries like manufacturing and healthcare, agriculture often lags. In Manolo Fortich, Bukidnon, one of the most crucial problems is the lack of access to contemporary technologies that enhance productivity, agricultural production, and sustainability. This situation leaves farmers behind, particularly in rural and developing areas. Despite having a solid cultural foundation, conventional farming practices are often ineffective and labor-intensive, making them unable to meet the rising global demands for food and address environmental issues.

Over the last 50 years, the agricultural industry has undergone tremendous transformations. Machines have increased farm equipment's scale, speed, and productivity, resulting in more efficient land cultivation (Lutz Goedde et al., 2020). The province of Bukidnon is not exempt from the growing divide between innovation and agriculture, exacerbated by a lack of accessible technology, poor training, and insufficient digital infrastructure.

Manihot esculenta (Cassava) is a valuable root crop that provides human food, animal feed, and raw materials for ethanol production in the Philippines and other countries worldwide. It is the sixth most significant food crop, consumed by 800 million people globally (Amelework & Bairu, 2022). It is mainly grown on small-holder farms, where its resilience to adverse weather conditions attracts low-income and resource-constrained farmers who depend on the crop for both food and a living. Food security and poverty reduction are thus impacted by the growth of the cassava sector (Landicho et al., 2024). It is highly abundant in the area situated in Mindanao's northern corridor. This covers the provinces of Misamis Occidental, Zamboanga del Norte, Misamis Oriental, and Bukidnon. Even though the Philippines' cassava chip business is still in its early stages, Filipinos rely on this crop as a staple. Every year, roughly 120,000 hectares of agricultural land in the Philippines are planted with cassava, yielding approximately 1.8 million tons of cassava roots (Bacusmo, n.d.).

However, agriculture in the Philippines, specifically in Manolo Fortich in Bukidnon, faces significant challenges, including declining productivity, outdated farming methods, and vulnerability to climate change. Over the years, the sector has struggled with reduced output as farmers, many of whom are aging, continue to use conventional practices with limited access to modern agricultural technologies. Small-scale farmers, who comprise a significant portion of the farm workforce, often need help to afford expensive inputs like fertilizers, high-quality seeds, or machinery, which are essential for improving yields. Outdated farming methods also remain a vital issue. Many Filipino farmers still rely heavily on manual labor and need access to scientific approaches like soil testing, crop rotation, or precision farming, which are critical for enhancing productivity. Moreover, inadequate post-harvest facilities and poor storage systems lead to significant crop losses, especially in perishable produce like fruits and vegetables, reducing profitability and food security. The lack of efficient mechanical dryers is the most significant constraint in improving the quality and expanding the production of dried cassava chips (Bacusmo, n.d.). Access to these technologies remains limited due to high costs and lack of technical infrastructure, thus stunting the growth of the cassava chip industry in the country. Manual processing is labor-intensive and time-consuming, but most smallholder processors need access to mechanized or other improved processing methods. This is because the enhanced methods involving the use of motorized equipment are expensive and unaffordable to individual smallholders (Abass et al., 2018). Currently, many cassava farmers rely on conventional sun-drying methods, which are highly weather-dependent and can lead to inconsistent drying. This affects not only the quality of the chips but also the speed and scale of production. Inconsistent drying results in uneven moisture content, which makes the chips susceptible to spoilage, fungal contamination, and quality degradation (Adnouni et al., 2023).

As stated by Precoppe et al. (2020), product quality has a direct impact on costs. However, the type of dryer and its operating circumstances are equally significant because they directly impact product quality, which affects consumer acceptance or rejection. Consumers primarily appraise the quality of food based on its appearance, and color is the most influential factor in their selection. This is especially true for dried products, with whiteness being the most essential color criterion for dried cassava.

Moreover, Cassava is a perishable, dense vegetable (Okonkwo et al., 2019). According to Atlaw (2018), cassava roots have a shelf life of only 48 hours after harvest. According to Pechaporn Pornpraipech et al. (2017), dry cassava chips must meet a moisture content of 14–17% as a requirement in order to be marketed. In the food industry, drying is a conventional and unmatched physical food preservation method used for direct product preparation and subsequent processing. It has long been a valuable and widespread conservation technique, guaranteeing the year-round availability of food and pharmaceuticals (Calín-Sánchez et al., 2020).

However, drying relies heavily on the weather (Joardder et al., 2021). It is less effective during the wet season since the drying time increases (Heri et al., 2023). During rainy seasons, when sun-drying is impractical, production often halts, leading to supply shortages and lost income for farmers. Efficient mechanical dryers would allow processors to maintain consistent quality, ensure faster production cycles, and extend the shelf life of cassava chips, making them more competitive in local and international markets.

A study by A.K. Babu et al. (2018) entitled “Review of leaf drying: Mechanism and influencing parameters, drying methods, nutrient preservation, and mathematical models” stated that the oldest technique for keeping leaves is drying. Food germs proliferate when there is moisture present during storage. In addition to the active components, a significant portion of bound and unbound water is present in all fresh agricultural products, including fruits, vegetables, and leaves. The agricultural product can be securely preserved for several days if dried without negatively affecting the active nutrients and with as much moisture removed as feasible. Unwanted biochemical reactions should be prevented by removing liquid water during the dehydration process. Through carefully regulated drying, dried leaves can preserve their nutrients, color, and aroma. This is supported by Ogawa & Adachi (2014), who stated that high outside temperatures and frequently insufficient refrigeration and storage facilities make it more difficult to safely store food with a high moisture content in developing nations. As a result, drying food items is a widespread practice to prevent food spoiling. Food drying extends its shelf life when proper storage is unavailable by lowering the moisture available to enable microbial growth.

Moisture content is an essential indicator in drying experiments because the purpose of drying is to remove moisture contained in the material (Chen et al., 2023). Microbial growth brought on by moisture is the leading cause of these post-harvest losses, which can render food unfit for human consumption and cause disease or even death. Temperature, pH, and water activity (aw) are some variables that affect the pace of microbial development. In mathematics, water activity is the ratio of water vapor pressure in food to pure water's vapor pressure. It measures the amount of water available for biological reactions (“Water Content and Water Activity: Two Factors That Affect Food Safety,” 2018).

Research supports the importance of achieving optimal moisture content, typically around 30%, for ensuring cassava is suitable for further processing into high-quality starch or flour (Adejumo et al., 2014). Moreover, automated systems, like pneumatic and flash dryers, have been shown to outperform conventional methods in terms of speed and product consistency, reducing drying times while ensuring better preservation of cassava's nutritional and commercial value. Despite being a staple in Filipino households, the lack of efficient mechanical dryers remains a significant constraint in improving the quality and production of dried cassava chips (Bacusmo, n.d.). Manual processing is labor-intensive and time-consuming, but most smallholder processors cannot access mechanized or improved methods. Currently, many cassava farmers rely on conventional sun-drying methods, which are highly weather-dependent and can lead to inconsistent drying, impacting both quality and profitability.

The foundation of this study on automated cassava drying is built on several key concepts in agricultural technology and moisture extraction efficiency. Conventional methods like open-air sun drying are widely recognized for their inefficiency, often resulting in uneven moisture removal that affects the overall quality of cassava, particularly its starch content and shelf life (Chapuis & Müller, 2020).

In response to the challenges cassava farmers face in the Philippines, particularly in Manolo Fortich, Bukidnon, this research project focuses on developing and innovating an automated Arduino-based cassava dryer. This innovation aims to provide a cost-effective, sustainable, and efficient solution to improve the drying process, critical for ensuring high-quality cassava chip production. By incorporating advanced heat transfer and moisture removal technologies, the dryer is designed to optimize the cassava drying process, ensuring consistency, speed, and quality even during unfavorable weather conditions such as the rainy season. This addresses the most significant challenge local farmers face—dependence on conventional sun-drying methods.

Nowadays, microcontroller-based systems are standard. They vary from fans, T.V. remote controllers, and incubators to airconditioning systems. According to Akinwole OO and Oladimeji TT (2018), A microcontroller is a tiny computer on a chip that, in contrast to a microprocessor, consists of a processor, memory locations for storing and executing programs, and input and output ports for receiving instructions and communicating with the outside world, respectively. The core of this dryer is the Arduino Uno microcontroller, which serves as the central control unit for the entire drying system. The Arduino platform is a highly customizable and programmable device that allows precise control over the dryer’s functions, including temperature regulation, air circulation, moisture removal, and the automatic home itself. The microcontroller interfaces with various components, such as the D.H.T. (Digital Humidity and Temperature) -11 Sensor and LCD I2C (Liquid et al. with Inter-Intergrated Circuit Interface), to automate and monitor the drying process.

The automated cassava dryer offers several significant benefits that address critical challenges cassava farmers face, particularly in rural areas. By integrating microcontroller technology, temperature and humidity sensors, active buzzers, and push buttons, this dryer provides a more consistent and scalable solution for the drying process. It improves efficiency by significantly reducing drying time while maintaining optimal conditions, leading to higher-quality cassava chips. This consistency not only enhances the market value of the final product but also reduces post-harvest losses, which are familiar with conventional sun-drying methods that are highly weather-dependent. As a result, farmers can maintain production even during adverse weather, increasing their output and income while minimizing spoilage. Additionally, the automated system reduces the labor intensity involved in the drying process, freeing up time for farmers to focus on other aspects of their work. By ensuring a more reliable and faster production cycle, this technology contributes to greater food security by enabling a steady supply of cassava, which is essential for both local consumption and commercial use. The dryer also promotes economic growth in rural areas, enabling smallholder farmers to improve their productivity and competitiveness, supporting livelihoods, and fostering sustainable development in cassava-dependent communities

The automated cassava dryer benefits various sectors by improving agricultural productivity, reducing post-harvest losses, and enhancing food security. It supports the Department of Agriculture’s modernization goals, providing a model for sustainable farming technologies. Government bodies, N.G.O.s and L.G.U.s, can leverage this dryer to promote rural development, reduce poverty, and create job opportunities in cassava-producing regions. Agribusinesses benefit from consistent, high-quality production, boosting competitiveness and profitability. For farmers, mainly smallholders, the dryer increases efficiency, minimizes labor, and ensures produce quality, even during the rainy season, leading to higher incomes and economic resilience. It fosters community self-sufficiency and food sovereignty by extending cassava’s shelf life and reducing waste.

This research focuses on developing the CrispCassa prototype, an automated cassava dryer designed to improve the efficiency, speed, and consistency of drying Manihot esculenta (Cassava). It uses temperature and humidity sensors controlled by a microcontroller to optimize the drying process and produce high-quality cassava chips. The study is limited to cassava drying, as the dryer is designed explicitly for its moisture and heat requirements. Several constraints, such as financial limitations, unpredictable weather, power disruptions, limited access to advanced materials, and the rural setting, impact the prototype's scale, testing, and precision.

This study aims to develop and evaluate an automated cassava dryer that integrates advanced heat transfer and moisture removal technologies to improve drying efficiency, enhance cassava quality, and support local farmers with a reliable, cost-effective solution. The study will focus on designing the dryer with critical considerations such as mass, temperature capacity, cost, structure, and power source. It will test the dryer’s efficiency across durations (1 to 4 hours) and assess moisture content and temperature. Additionally, the study will compare the pre-and post-test results, evaluate the impact of drying duration, and analyze the advantages of the automated dryer over traditional methods.

Methodology

Research Design

This study utilized a quasi-experimental research design to evaluate and compare the efficiency and effectiveness of an automated cassava dryer, termed "CrispCassa," with a commercialized cassava dryer and conventional sun-drying methods. The independent variable was the type of cassava drying method, while the dependent variables included efficiency parameters such as drying speed, energy consumption, output quality (measured in terms of moisture content, color, and texture), and task success rate. To ensure consistency, controlled variables such as environmental conditions, cassava batch size, and drying duration were standardized. Identical cassava roots were harvested, peeled, and sliced uniformly before being subjected to drying. The automated and commercialized dryers operated under controlled conditions for durations of 1, 2, 3, and 4 hours, with pre-test temperatures ranging from 53°C to 59°C and post-test temperatures between 97°C and 107°C.

A control group using conventional sun-drying methods was also included for comparison. Each drying duration was replicated four times to ensure reliability, and quantitative assessments were performed using moisture analyzers, colorimeters, and texture analyzers to evaluate drying time, moisture content, color, and texture. Statistical analyses, including t-tests, were applied to determine significant differences between the drying methods, and a cost analysis compared labor expenses for the conventional and automated systems. The findings provided robust evidence supporting the potential of the "CrispCassa" to enhance productivity, improve cassava chip quality, and offer a cost-effective drying solution for local farmers, contributing to regional food security and economic viability.

Instrument

The following materials stated below are used in order to construct the model:

Table 1. *Materials and Processes involved*

Input	*Process*	*Output*
1 Arduino Uno R3 1 Breadboard 1 DHT 11 1 LCD I2C 1 Active Buzzer 1 Arduino Push Button 13 Dupont Wires 1 Electrical Switch 2m Electrical Wire 0.5m Cable Wire 1 AC Motor 1 Steel Plate (1ft. by 2 ft.) 1 Steel Rod (8mm) 1 Charging Brick 1 Temperature Controller (XH-W3002)	Creating a design for the model of the Cassava dryer Checking and finalization of the design with experts and teachers Gathering of materials Building the frame for the model Attaching the AC Motor Constructing the automated hoe Integration of coding and programming Finalization of the constructed model	Automated Cassava Dryer

Arduino Uno R3

A microcontroller board that controls the robotic system of the dryer by processing sensor data and managing operations.

Breadboard

A prototyping tool for easily connecting components without soldering, allowing flexible circuit arrangements.

DHT11 Sensor (Digital Humidity and Temperature Sensor)

Measures temperature and humidity, providing data to the Arduino for regulating the drying process.

LCD I2C (Liquid Crystal Display with Inter-Integrated Circuit Interface)

A display module with an I2C interface presents real-time temperature and humidity data, enabling easy monitoring of the drying process.

Active Buzzer

Provides audible alerts for temperature thresholds, ensuring user awareness of critical conditions during the drying process.

Push Button

A programmed setup used to stop the buzzer once the system reaches the maximum temperature, ensuring the alarm is deactivated promptly.

Dupont Wire

Jumper wires for connecting various components, ensuring proper electrical connections in the dryer.

Electrical Switch

Controls the dryer's power supply, allowing manual operation.

Electrical Wires

Conduct electricity between components, facilitating communication and power distribution.

Cable Wire

The cable wire in the dryer setup connects the various electrical components, allowing for the smooth transmission of power and signals between the Arduino, sensors, buzzer, and motor.

AC Motor

An electric motor that operates on alternating current (AC). It drives rives the rotation of the drying chamber, ensuring uniform exposure of cassava to heat.

Steel Plate

Forms the durable outer structure of the dryer, ensuring stability.

Steel Rod

Used in the internal mechanism to support the rotating drying chamber for even heat distribution.

Charging Brick

Supplies low-voltage power to the dryer's overall robotic components.

Digital Temperature Controller (XH-W3002)

Regulates the heating element by receiving sensor signals, and controls heaters, maintaining optimal drying conditions.

Power Supply Unit (PSU)

Converts AC mains voltage to DC (direct current), providing the necessary power for the dryer's components.

Hinges

The mechanical bearings that is connected to the dryer door, allowing easy access for loading and unloading cassava.

Heating Element

The component that converts electrical energy into heat through resistive heating, which is essential for the drying process.

Procedure

In this study, the researchers employed a combination of experiments, observation, document analysis, and focus group discussions to assess the cassava dryer's performance. Four identical cassava samples each weighing 250 grams with temperatures of 53°C-59°C during pre-testing and 97°C-107°C in post-testing, with drying durations of 1, 2, 3, and 4 hours. According to Pechaporn Pornpraipech et al. (2017), dry cassava chips must meet a moisture content of 14–17% to be marketable. The primary focus was to measure the moisture content of each sample post-drying to determine the optimal drying time for maximum moisture removal while maintaining cassava quality. This quantitative data provided insights into the effectiveness of the dryer.

Table 2. *Composition of Trials (Pre-test)*

No. of Trials	*Mass of Cassava*	*Temperature*	*Duration*
Trial 1	250 g	53°C-59°C	1 hour
Trial 2	250 g	53°C-59°C	2 hours
Trial 3	250 g	53°C-59°C	3 hours
Trial 4	250 g	53°C-59°C	4 hours

Table 3. *Composition of Trials (Post-test)*

No. of Trials	*Mass of Cassava*	*Temperature*	*Duration*
Trial 1	250 g	97°C-107°C	1 hour
Trial 2	250 g	97°C-107°C	2 hours
Trial 3	250 g	97°C-107°C	3 hours
Trial 4	250 g	97°C-107°C	4 hours

Observation was conducted throughout the experiment, noting changes in cassava texture, color, and appearance and evaluating the functionality of the Arduino-based system. These qualitative observations identified potential operational issues and areas for improvement. Document analysis involved reviewing existing studies on cassava drying methods, technical specifications of the dryer's components, and local climate data. This secondary data guided the refinement of the dryer design and ensured that chosen temperature and moisture settings aligned with industry standards and environmental conditions, particularly for solar-powered applications. Focus group discussions with local cassava farmers gathered feedback on the dryer's practicality and usability. Farmers shared experiences with conventional drying methods and offered suggestions for improving the design to meet their needs better. This combined approach ensured a holistic evaluation of the dryer's efficiency, user-friendliness, and potential for adoption by local farmers.

The data-gathering procedure began with the selection and acquisition of essential materials. The Arduino R3 Starter Kit was the control hub, while a digital temperature sensor monitored the drying chamber's internal conditions. Electrical switches allowed manual control of features, and electrical wires connected various components. An A.C. motor was selected to rotate the drying chamber, ensuring cassava was exposed to heat. An outlet and power supply adapter were also chosen for reliability.

In line with the project's sustainability goal, recycled materials were incorporated. A recycled steel plate formed the outer structure, and a recycled steel rod constituted the core of the internal rotating mechanism. Cutting disks shaped these components, while a recycled heatsink from an old Central Processing Unit (CPU) was used to prevent overheating. Hinges were installed on the external door for easy loading and unloading, ensuring operational efficiency.

On the other hand, the dryer's physical structure was constructed using a large recyclable metal can designed to resemble a traditional clothes dryer. This can act as the central drying chamber, rotating via an AC motor and rod to promote even heat distribution. To effectively control the drying process, a DHT11 sensor was connected to the Arduino Uno R3 to measure temperature and humidity levels, enabling real-time data monitoring. An active buzzer was also integrated as a safety feature to alert users when the temperature exceeded critical thresholds.

Before final design implementation, pre-tests were conducted using a hair dryer heating element to assess performance in creating a warm environment. Preliminary trials provided valuable data on the drying process, allowing adjustments to be made before finalization. After assembling all components, post-tests were conducted to evaluate the final design's effectiveness, including a recycled heating coil as the primary heat source. This testing confirmed the dryer's efficiency in drying cassava while maintaining optimal temperature and humidity levels.

After the pre-tests and post-tests, comprehensive evaluations were carried out under controlled and natural conditions. These tests ensured the proper functioning of the sensors, buzzer, and display and confirmed that the drying system operated efficiently across various scenarios.

Ethical Considerations

The study's researchers confirmed that no deliberate tampering with the tests or data occurred to produce desired outcomes. Facts were stated based on the findings of the study. Supporting statements were provided, giving appropriate credit via full citation to the authors. Responsibility was taken for any misconceptions and harm the product might cause to human, animal, and environmental health. The study's references were legally published within a ten-year period, cited by readers and other researchers, and were reputable, trustworthy, and reliable sources of knowledge from top scholars used as a basis for research. The study took care to avoid any manipulation or bias in the outcomes. Instead, diligent and honest efforts were made to achieve accurate and relevant results.

Results and Discussion

Problem 1. How will the design and innovation of an automated Manihot esculenta (Cassava) dryer incorporate efficient heat transfer and moisture removal technologies in terms of its:

Automated Manihot Esculenta (Cassava) Dryer

Mass and Measurement

Table 4. *Body Composition of the automated dryer during Pre-test*

Manihot esculenta (Cassava) Dryer Body Composition during Pre-test		
Material	*Mass*	*Measurement*
Galvanized Steel Plate (Body)	5.25 kg	10 inches (diameter) x 11 inches
Marine Board Plywood (Control Circuit)	2.75 kg	9 inches x 10.7 inches x 4 inches
Hair Dryer Heating Element	0.06 kg	4 inches x 2 inches
Heatsink as Fan	0.248 kg	3 inches x 3 inches

Table 5. *Body Composition of the automated dryer during Post-test*

Manihot Esculenta (Cassava) Dryer Body Composition during Post-test		
Material	*Mass*	*Measurement*
Galvanized Steel Plate (Body)	5.25 kg	10 inches (diameter) x 11 inches
Marine Board Plywood (Control Circuit)	2.75 kg	9 inches x 10.7 inches x 4 inches
Heating Coil from Junk Oven	0.5 kg	13.5 inches x 4 inches
Heatsink as Fan	0.248 kg	3 inches x 3 inches

The size of a dryer affects the drying process and the quality of the products inside in various ways. Larger dryers allow for better air circulation and heat distribution, which leads to more even drying and faster moisture removal. This is particularly beneficial when drying bulky items like cassava, as it ensures consistent drying across all pieces. A giant dryer also helps reduce the risk of over-drying or burning, as the products have more space to spread out, preventing hot spots from forming. However, larger dryers can consume more energy, especially when not fully loaded, which may reduce their efficiency for smaller batches. On the other hand, smaller dryers, while more energy-efficient for small loads, may result in uneven drying if the products are too densely packed, increasing the risk of incomplete moisture removal or case hardening (Archer, 2024). The table illustrates that the CrispCassa, or the automated cassava dryer, is primarily constructed using two essential materials: a galvanized steel plate for the main body and marine board plywood for the control circuit. These materials have been carefully selected for their strength, durability, and suitability for the operating conditions of the dryer. The galvanized steel plate is the main structural component of the dryer’s body, weighing 5.25 kg. The steel plate has a cylindrical shape with a diameter of 10 inches and a height of 11 inches, offering stability and protection for the internal mechanisms during the drying process.

Meanwhile, the marine board plywood control circuit weighs around 2.75 kg and measures 9 inches x 10.7 inches x 4 inches. Instead of bringing the air out, the heatsink is used as a fan to generate air inside the dryer to circulate, allowing for more efficient drying. During the pre-test, the researchers found that the hair dryer heating element, weighing 0.06 kg with dimensions of 4 inches by 2 inches, could not withstand prolonged use and frequently tripped off. To address this issue, the researchers replaced it with a more robust heating coil weighing 0.5 kg and measuring 13.5 inches by 4 inches, recycled from a junk oven for enhanced durability and performance.

Temperature Capacity

Table 6. *Temperature Capacity of Each Trial (Pre-test)*

Temperature Capacity of Each Trial during Pre-test	
No. of Trials	*Temperature Capacity*
Trial 1	53°C-59°C
Trial 2	53°C-59°C
Trial 3	53°C-59°C
Trial 4	53°C-59°C

Table 7. *Temperature Capacity of Each Trial (Post-test)*

Temperature Capacity of Each Trial during Post-test	
No. of Trials	*Temperature Capacity*
Trial 1	97°C-107°C
Trial 2	97°C-107°C
Trial 3	97°C-107°C
Trial 4	97°C-107°C

Based on Deymi-Dashtebayaz et al. (2024), higher temperatures generally lead to faster drying rates by enhancing moisture evaporation. The table indicates that, for each trial, the temperature capacity of the Automated Manihot esculenta (Cassava) Dryer during the pre-test ranges from 53°C to 59°C and 97°C-107°C during the post-test. While higher drying temperatures can accelerate the drying process, they may also lead to increased energy consumption. It is essential to find a balance between effective drying and energy efficiency (A'yuni, D.Q. et al., 2024). The dryer was pre-heated to 53°C during the pre-test due to the smaller coil. Once this temperature was reached, the system automatically activated the heating element, gradually increasing the temperature until it hit the programmed maximum of 59°C. In the post-test, after replacing the heating element with a more durable coil from a junk oven, the researchers expanded the temperature range, allowing the system to heat from 97°C to 107°C, as the new coil could withstand higher temperatures.

Cost

Materials Used

Table 8. *Total Cost of Materials Used*

Method	*Specifications*	*Quantity*	*Unit Price*	*Estimated Cost*
Automated Manihot Esculenta (Cassava) Dryer				
	Arduino R3 Starter Kit	1	P1,234.00	P1,234.00
	Digital Temperature Sensor	1	P86.00	P86.00
	Electrical Switch	2	P30.00	P60.00
	2m Electrical Wire	1	P0.00	P0.00
	AC Motor	1	P174.00	P174.00
	Outlet	1	P200.00	P200.00
	Female Socket	1	P25.00	P25.00
	AC Power Supply Adaptor	1	P200.00	P200.00
	Recycled Steel Plate	1	P0.00	P0.00
	Recycled Steel Rod	1	P0.00	P0.00
	Cutting Disk	3	P100.00	P300.00
	Charging Brick	1	P0.00	P0.00
	Recycled Heatsink from old CPU	1	P0.00	P0.00
	Hinge for External Door	1	P50.00	P50.00
	Hair Dryer Heating Element	1	P255.00	P255.00
	Recycled Heating Coil	1	P0.00	P0.00
Onsite Installation and Efficacy Testing Location: PCH-2, San Miguel, Manolo Fortich, Bukidnon	Transportation Fee	6 (Back and Forth)	6	P120.00
		Total	P2,704.00	

Because of the high costs and need for technological infrastructure, access to technologies is still restricted, impeding the expansion of

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the nation's cassava chip sector. Although manual processing takes much time and labor, most farmers need automated or other advanced processing techniques. This is because individual smallholders need help to afford the more advanced techniques requiring motorized equipment (Abass et al., 2018). The table presents a detailed breakdown of the total cost involved in the innovation and design of the Manihot esculenta (Cassava) dryer, highlighting the financial investment required for its development. This cost estimate includes all necessary components, materials, and labor for constructing the prototype.

Electrical Consumption

Table 9. *Electrical Consumption*

Trial	*Current (I) (A)*	*Voltage (V) (V)*	*Resistance (R) (Ω)*	*Electric Power Input (P_input) (W)*	*Electric Power Output (P_output) (W)*	*Power Loss (P_loss) (W)*	*Efficiency (%)*
1 hour	4.77 I	230V	48.218 Ω	1097.1 W	767.97 W	109.099W	70%
2 hours	4.77 I	230V	48.218 Ω	2194.2 W	1535.94 W	109.099W	70%
3 hours	4.77 I	230V	48.218 Ω	3291.3 W	2303.91 W	109.099W	70%
4 hours	4.77 I	230V	48.218 Ω	4388.4 W	3071.88 W	109.099W	70%
Average:	4.77 I	230V	48.218 Ω	2742.75 W	1919. 925W	109.099W	70%

Table 10. *Total Consumption per Hour*

Trial	*Electric Power Input (P_input) (kWh)*	*Electric Power Output (P_output) (kWh)*	*Power Loss (P_loss) (kWh)*	*Rates Per Hour*	*Cost per Hour*
1 hour	1.0971 kWh	0.76797 kWh	0.109099 kWh	₱ 5.6557/kWh	₱ 6.20
2 hours	2.1942 kWh	1.53594 kWh	0.109099 kWh	₱ 5.6557/kWh	₱ 12.41
3 hours	3.2913 kWh	2.30391 kWh	0.109099 kWh	₱ 5.6557/kWh	₱ 18.61
4 hours	4.3884 kWh	3.07188 kWh	0.109099 kWh	₱ 5.6557/kWh	₱ 24.82
Average:	2.74275 kWh	1.919925 kWh	0.109099 kWh	₱ 5.6557/kWh	₱ 15.51

Furthermore, the efficient management of electrical consumption in household and industrial appliances, particularly dryers, plays a crucial role in optimizing energy use and reducing costs. Dryers typically operate within a power range of 1,800 to 5,000 watts, depending on the model and efficiency (Solar Switch Philippines, 2023). While these appliances contribute to overall electricity expenses, advancements in energy-efficient technology help minimize costs for households and industries that extensively rely on drying systems. Research shows that conventional dryers account for approximately 3% of total household energy consumption, equivalent to an estimated 814 kWh per year (SolarNRG Philippines, 2023).

In the Philippine setting, this corresponds to an annual cost of around ₱2,400, assuming an electricity rate of ₱2.96 per kWh. These figures emphasize the significance of enhancing dryer efficiency to optimize energy use and reduce waste. Given that many Filipino households still prefer traditional drying methods like sun-drying due to affordability, exploring ways to balance energy consumption with drying efficiency remains essential.

Similarly, cassava drying machines demonstrate varying power requirements based on their design and capacity. A typical mechanical cassava dryer operates at approximately 4.8 kWh per cycle, depending on its specifications and settings. Energy costs associated with cassava drying also vary depending on the type of dryer used. Studies highlight that a fixed-bed dryer maintains a cost-effective energy consumption rate, averaging USD 0.004 per kilogram of dried cassava grits. Converting this cost to Philippine pesos (PHP) using the average exchange rate for January 2025—approximately ₱58.464 per USD—further underscores the economic viability of cassava drying (Precoppe et al., 2020).

Moreover, electrical consumption measurements were conducted to evaluate the energy efficiency and cost-effectiveness of CrispCassa. The trials, carried out over different durations, analyzed energy input, useful output, power loss, and cost per hour of operation, offering valuable insights into the system's efficiency. The electricity rate used for cost computation is based on the standard rate of Bukidnon Second Electric Cooperative, Inc. (BUSECO), which is ₱5.6557 per kWh.

Trial 1: In the first hour, the dryer consumes 1.0971 kWh of electrical energy but only produces 0.76797 kWh of useful output. This means that some of the input energy is lost, exactly 0.109099 kWh. This power loss could be due to transmission inefficiencies, heat dissipation, or system resistance. Despite the loss, the operation cost for one hour is computed using the usual power rate of ₱5.6557 per kWh, yielding a total cost of ₱6.20.

Trial 2: When the dryer operates for two hours straight, the power input totals 2.1942 kWh, while the output energy rises to 1.53594 kWh. Interestingly, the power loss remains constant at 0.109099 kWh, demonstrating that the inefficiency does not increase in direct proportion to the input power. Instead, it looks to be a very consistent loss per hour. The cost of electricity has doubled to ₱12.41, indicating that billing is precisely proportionate to input power use.

Trial 3: Extending the experiment for three hours yields a total power input of 3.2913 kWh and a comparable output of 2.30391 kWh. Again, the power loss remains constant at 0.109099 kWh, confirming that the system has a fixed inefficiency per hour. At this level, the total cost increases to ₱18.61, consistent with the pattern of rising power demand and cost.

Trial 4: By the fourth hour, the total power input has reached 4.3884 kWh, while the output has increased to 3.07188 kWh. The power loss remains constant at 0.109099 kWh, indicating a consistent hourly system inefficiency that does not vary depending on the period of operation. The total cost for four hours of consumption is ₱24.82, following the trend of proportionate cost scaling.

Structure

Table 11. *Overall Structure of the automated dryer (Pre-test)*

Overall Structure of the CrispCassa Dryer of Pre-test	
Length	21 inches
Width	10.7 inches
Height	21.2 inches
Total Area	1793.48 square inches

Table 12. *Overall Structure of the automated dryer (Post-test)*

Overall Structure of the CrispCassa Dryer of Post-test	
Length	24 inches
Width	10.7 inches
Height	21.2 inches
Total Area	1984.88 square inches

The table highlights the dimensions of the overall structure of the automated dryer, providing critical information about its size and surface area. The dryer has a length of 21 inches during the pre-test and 24 inches during the enhancement of the post-test, a width of 10.7 inches, and a height of 21.2 inches giving it a compact yet sturdy form suitable for industrial use.

These dimensions result in a total surface area of 1793.48 square inches during the pre-test and 84.88 square inches during the post-test, reflecting the dryer's total outer surface. This surface area is an essential factor, as it indicates the material requirements for construction and can also impact factors like heat distribution during drying. Effective drying requires consistent airflow and heat dispersion, which a well-designed structure ensures. Uneven drying caused by poor airflow may lower the final product's quality (Ron Marshall, 2014).

Power Source

Table 13.

Power Source of the Manihot esculenta (Cassava) Dryer		
Materials	Voltage	Power Supply
AC Motor	220V	Direct Current
Heating Element	220V	Direct Current
Digital Temperature Controller	220V	Direct Current
Heatsink	12V	Direct Current

The table outlines the various electrical components of the automated cassava dryer, detailing their corresponding voltage requirements and power sources. Power devices can experience damage or total failure when exposed to excessive currents caused by external disturbances like A.C. line transients, mechanical overloads, misfiring, or inverter shoot-throughs. These events can lead to currents several times higher than the system's rated capacity flowing through the electrical drive. While electrical machines are generally robust and can tolerate high currents for relatively more extended periods (ranging from milliseconds to seconds, depending on the machine's size), such conditions pose significant risks to their integrity (Short Circuit Detection and Fault Current Limiting Method for I.G.B.T.S., 2020).

The key components, including the A.C. motor, heating element, digital temperature controller, and heatsink, all operate at 220V, powered by direct current (D.C.). These high-voltage components are essential for the core functions of the dryer, such as rotating the drying chamber, generating heat, and regulating temperature, ensuring the system operates efficiently.

Additionally, the heatsink, which functions as a cooling fan to prevent overheating, operates at 12V D.C., ensuring safe and steady airflow during drying. The heatsink's lower voltage is designed to manage the temperature while minimizing energy consumption efficiently. By specifying the voltage requirements and the current, this table helps illustrate how each component is powered and interconnected, highlighting the energy requirements for optimal performance in the cassava drying process. This detailed information also ensures proper electrical setup and safety during operation.

Manihot esculenta (Cassava)

Mass and Duration of Trials

Table 14. *Mass and Duration of Trials (Pre-test)*

Duration of Trials during Pre-test		
No. of Trials	*Initial Mass*	*Time*
Trial 1	250 g	1 hour
Trial 2	250 g	2 hours
Trial 3	250 g	3 hours
Trial 4	250 g	4 hours

Table 15. *Mass and Duration of Trials (Post-test)*

Duration of Trials during Post-test		
No. of Trials	*Initial Mass*	*Time*
Trial 1	250 g	1 hour
Trial 2	250 g	2 hours
Trial 3	250 g	3 hours
Trial 4	250 g	4 hours

The table illustrates the varying durations of each trial and the corresponding initial masses used in the automated cassava drying process. In Trial 1, the initial mass of 250 g is subjected to a drying process for 1 hour. Similarly, Trial 2 maintains the initial mass of 250 g but extends the drying period to 2 hours. Trial 3 begins with 250 g but undergoes drying for 3 hours. This systematic variation in drying times across the trials is designed to assess the impact of different drying durations on the cassava's moisture content. Lastly, Trial 4 has an initial mass of 250 g and is subjected to drying in 4 hours. By comparing the results from these trials, researchers can determine how effectively the automated dryer removes moisture over time, providing insights into the optimal drying time for maximum efficiency.

Moisture Content

Table 16. *Moisture content of the Trial (Pre-test)*

Moisture Content of Each Trial during Pre-test					
No. of Trials	*Duration*	*Initial Weight*	*Final Weight*	*% Moisture of Water Removed*	*% Moisture of Cassava*
Trial 1	1 hour	250 g	230 g	8%	92%
Trial 2	2 hours	250 g	210 g	16%	84%
Trial 3	3 hours	250 g	200 g	20%	80%
Trial 4	4 hours	250 g	190	24%	76%

Table 17. *Moisture content of the Trial (Post-test)*

Moisture Content of Each Trial during Post-test					
No. of Trials	*Duration*	*Initial Weight*	*Final Weight*	*% Moisture of Water Removed*	*% Moisture of Cassava*
Trial 1	1 hour	250 g	130 g	60%	40%
Trial 2	2 hours	250 g	80 g	84.8%	15.2%
Trial 3	3 hours	250 g	70 g	88.7%	11.3%
Trial 4	4 hours	250 g	65 g	89.2%	10.8%

According to Lynch (2023), moisture content is solved through the formula: Moisture Content (%) = $[(W1 – W2) / W1] \times 100$

Additionally, the researchers did moisture analysis on post-test Trials 2, 3, and 4 since these samples have the standard moisture content a flour moisture meter can read without error. According to Pechaporn et al. (2017), dry cassava chips must meet a moisture content of 14–17% as a requirement to be marketed. To support this, Polcas Agritrade Corporation, located in Damilag Manolo Fortich, Bukidnon, stated that a percentage of moisture above 14% falls under Class B or Cassava's standard market moisture content. Percent moisture below 14% falls under Class A, the high-quality grade of cassava that meets specific standards in size, appearance, and processing. Table 10 demonstrates the mass reduction of cassava after undergoing the drying process in the automated dryer. In pre-test Trial 1, the mass decreased from 250 g to 230 g, resulting in an 8% reduction in moisture content, leaving 92% moisture in the cassava. Pre-test Trial 2 saw a more significant decrease in mass, from 250 g to 210 g, indicating that 16% of the moisture was removed. In Pre-test Trial 3, the mass dropped from 250 g to 200 g, removing 20% of the water content and leaving 80% moisture remaining in the cassava. During Pre-test Trial 4, the mass decreased from 250 g to 55 g, having 78% percent of the water removed and retaining 22% in the cassava.

Moreover, in post-test Trial 1, the mass of cassava decreased from 250 grams to 130 grams, with 48% moisture removed. However, Polcas Agritrade Corporation detected an error, indicating that despite the recorded reduction in moisture, a substantial amount remained within the cassava. This error suggests that the drying process may have needed to have been fully optimized during this trial, as the internal moisture content was higher than expected. In post-test Trial 2, 84.8% of the water was successfully removed from the cassava, leaving only 15.2% moisture. This significant reduction in moisture content indicated that the drying process had significantly improved compared to previous trials. Polcas Agritrade Corporation, a trusted authority in agricultural product quality, recognized this result as meeting the market quality standards set to ensure cassava's suitability for commercial distribution and processing. In post-test Trial 3, the cassava's mass dropped from 250 to 70 grams, achieving a moisture content of 11.3%. Finally, in post-test Trial 4, the mass decreased from 250 grams to 65 grams, removing 89.2% of moisture and leaving a final moisture content of 10.8%. The corporation classified the results from Trials 3 and 4 as Class A cassava, indicating that the product met the highest industry standards for quality. Class A cassava typically has superior texture, moisture balance, and readiness for various processing and consumption methods. The reduced moisture content in Trials 3 and 4 made the cassava more suitable for long-term storage and transport. It enhanced its value in the marketplace, as it met the highest quality criteria.

Problem 2. What will be the efficiency of the automated Manihot esculenta (Cassava) dryer in the following duration: 1 hour, 2 hours, 3 hours, 4 hours

Table 18. *Pre-test Trial 1 in 53°C-59°C*

Number of Trials	*Trial 1*
Duration (hours)	1 hr.
Initial Mass (g)	250 g
Final Mass (g)	230 g
Water Removed (g)	20 g

Table 19. *Post-test Trial 1 in 97°C-107°C*

Number of Trials	*Trial 1*
Duration (hours)	1 hr.
Initial Mass (g)	250 g
Final Mass (g)	130 g
Water Removed (g)	120 g

In the first pre-test trial of the dryer, the sample's initial mass of 250 grams decreased by 20 grams after one hour, indicating successful moisture removal from the surface. The result is consistent with established cassava drying patterns at 53°C and 59°C, where significant surface moisture is lost during the early drying stages. Studies have shown that moisture content can decrease by more than 20% within the first hour under similar conditions. Still, the drying rate typically slows as moisture from the inner layers becomes more challenging to extract (Ijala et al., 2017). The physical changes observed in the cassava, such as surface hardening and possible discoloration, reflect the process, where moisture diffusion from the core limits further drying. This highlights the initial effectiveness of the dryer, though extended drying times may be necessary to ensure complete moisture extraction and optimal efficiency (Mujaffar & Lalla 2020).

Moreover, in Figure 19, the post-test results of the prototype cassava dryer demonstrate its effectiveness in removing moisture from cassava. In a one-hour trial at a temperature range of 97-107 degrees, 120 grams of water were successfully removed from an initial sample of 250 grams. This represents a significant reduction in moisture content, indicating the dryer's potential for preserving cassava and improving its shelf life. This result aligns with findings from several cassava drying studies, where optimal drying methods, such as oven drying, significantly reduce moisture content. For example, research on cassava chips has shown that drying at controlled temperatures can effectively lower the moisture content, improving drying efficiency and product stability. Drying techniques, like oven drying, are preferred over conventional sun drying because they ensure uniform drying and reduce drying time. Oven-dried cassava typically retains better quality and has reduced moisture content, vital for extending shelf life and preventing spoilage (Okeke et al., 2023).

Table 20. *Pre-test Trial 2 in 53°C-59°C*

Number of Trials	*Trial 2*
Duration (hours)	2 hrs.
Initial Mass (g)	250 g
Final Mass (g)	210 g
Water Removed (g)	40 g

Table 21. *Post-test Trial 2 in 97°C-107°C*

Number of Trials	*Trial 2*
Duration (hours)	2 hrs.
Initial Mass (g)	250 g
Final Mass (g)	80 g
Water Removed (g)	170 g

In the second pre-test trial, the cassava's initial mass was 250 grams, and after 2 hours of drying, it was reduced to 210 grams, signifying a loss of 40 grams of moisture. This represents an increase in efficiency compared to the first trial. The improvement is likely due to better heat distribution and airflow within the dryer, which are crucial for optimizing the drying process. According to a study on cassava drying, moisture content levels ranging from 8.9% to 12.1% are essential for maintaining the quality and usability of cassava products (Precoppe et al., 2020). Another study highlights that performing and showing consistent airflow and temperature regulation is critical for reducing microbial contamination and achieving optimal drying rates (Menya et al., 2020).

For post-test trial 2, the cassava drying process over 2 hours led to an initial mass of 250 grams reduced to 80 grams, removing 170 grams of water and extending the drying time by an additional hour allowed for a more thorough moisture extraction than Trial 2 Pre-test. The removal of 170 grams of water (68% of the initial mass) demonstrates a higher efficiency in moisture reduction over a more extended drying period. The temperature range employed in the trial is critical for optimal drying. This temperature range falls within the optimal range for cassava drying, ensuring rapid moisture removal while minimizing the risk of nutrient loss or degradation of the product's quality. This is supported by recent research exploring innovative approaches to cassava drying, emphasizing the importance of energy efficiency, product quality, and predictive modeling tools.

Furthermore, recent studies have highlighted the potential of hybrid solar-thermal drying systems for cassava chips, achieving significantly faster drying rates than conventional sun drying methods. For example, a study by Akinnusi et al. (2022) found that a hybrid solar-thermal dryer for cassava chips achieved a drying rate of 0.035 kg water/m2/hour, significantly faster than conventional sun drying methods. While the prototype dryer shows promising results, further research and development are necessary to optimize its performance and address potential limitations.

Table 22. *Pre-test Trial 3 in 53°C-59°C*

Number of Trials	*Trial 3*
Duration (hours)	3 hrs.
Initial Mass (g)	250 g
Final Mass (g)	200 g
Water Removed (g)	50 g

Table 23. *Post-test Trial 3 in 97°C-107°C*

Number of Trials	*Trial 3*
Duration (hours)	3 hrs.
Initial Mass (g)	250 g
Final Mass (g)	70 g
Water Removed (g)	180 g

In the third pre-test trial, the cassava dryer demonstrated increased moisture extraction efficiency over a 3-hour drying period. The cassava's mass decreased by 50 grams, showing an enhanced ability to remove moisture compared to earlier trials. The prolonged drying time, combined with optimized airflow and consistent heat distribution, helped improve the cassava's physical condition, which is vital for ensuring high-quality cassava. Studies suggest that drying cassava under controlled conditions improves starch properties, including enhanced paste viscosity, reduced breakdown, and improved gelatinization temperatures. These changes are critical for producing cassava with desirable qualities for industrial and food applications, such as increased swelling power and reduced susceptibility to enzymatic hydrolysis, which affects starch stability during processing (Piyachomkwan et al., 2017). Another finding has stated that maintaining appropriate moisture levels in dried cassava is essential for preserving its quality and ensuring desirable qualities like reduced microbial contamination and optimal physical characteristics (Nainggolan et al., 2024).

On the other hand, trial three post-test demonstrates a substantial water removal of 180 grams from an initial mass of 250 grams, resulting in a final mass of 70 grams. This translates to a 72% reduction in moisture content within three hours. This high drying efficiency, even exceeding the results of the Trial 2 Post-test, suggests the prototype dryer can significantly reduce moisture content within a relatively short timeframe. The extended drying time in the Trial 3 Post-test, compared to the Trial 3 Pre-test, has resulted in a slightly higher water removal rate. This suggests that the dryer's performance is not only influenced by the temperature but also by the duration of the drying process. The longer the drying period, the more moisture can be removed, potentially leading to a more desirable final product with a lower moisture content. Several studies have investigated the effectiveness of different cassava drying technologies, providing valuable insights for comparison. A study on the drying kinetics of cassava chips using a solar dryer found that the drying time significantly impacted the final moisture content of the chips (Yin et al., 2020). The study concluded that longer drying times resulted in lower moisture content, aligning with the observations from Trial 3.

Table 24. *Pre-test Trial 4 in 53°C-59°C*

Number of Trials	*Trial 4*
Duration (hours)	4 hrs.
Initial Mass (g)	250 g
Final Mass (g)	190 g
Water Removed (g)	60 g

Table 25. *Post-test Trial 4 in 97°C-107°C*

Number of Trials	*Trial 4*
Duration (hours)	4 hrs.
Initial Mass (g)	250 g
Final Mass (g)	65 g
Water Removed (g)	185 g

In Trial 4, the automated Manihot esculenta (Cassava) dryer was tested for 4 hours. The initial mass of the cassava was 250 grams, and after the drying process, the final mass recorded was 190 grams. This indicates that 60 grams of water were successfully removed during the drying period. Water removal efficiency in this trial is consistent with previous trials, which shows the dryer's ability to reduce moisture content. According to recent studies, optimal drying conditions are crucial to maintaining cassava's quality and moisture content. For example, research by Adepoju and Oyewole (2019) found that drying cassava at controlled temperatures between 60°C to 70°C for 3 to 5 hours leads to better moisture reduction and preservation of the starch content. Similarly, a study by Wang et al. (2022) highlighted that drying cassava under mechanical conditions resulted in 30% to 40% moisture content after 3 hours, which aligns with the efficiency observed in this trial.

Lastly, for Post-Test Trial 4, the cassava drying process removed 185 grams of water from an initial mass of 250 grams, leaving a final mass of 65 grams after 4 hours. This shows a highly efficient moisture extraction, removing 74% of the cassava's original mass, which is an excellent result for a more extended drying period. The substantial water loss suggests that the drying conditions were optimal in this trial, likely achieving near-complete moisture reduction within the allotted time. The significant reduction in moisture content strongly indicates that the extended drying time effectively targeted both surface moisture and more tightly bound water within the cassava tuber. Research indicates that longer drying times can result in more efficient moisture removal, especially when drying temperatures and airflow are adequately controlled. Achieving a final mass of 65 grams from an initial 250 grams aligns with the moisture content range required for long-term storage of cassava products, ideally around 10-14%, to inhibit microbial activity and enhance shelf life. A recent study by Rakotonirainy et al. (2020) discusses the importance of prolonged drying to achieve low moisture content in cassava. This highlights the critical role of temperature control and airflow in ensuring uniform drying, particularly during the later stages of the process when water diffusion from within the tuber slows down. Moreover, Nwakuba et al. (2022) explored the effectiveness of hot air drying on cassava, finding that controlled drying at temperatures between 60–80°C can drastically reduce moisture levels, similar to the results observed in this trial. This study emphasizes that achieving such moisture reduction within 4 hours reflects efficient drying conditions, particularly when optimizing storage and quality.

Problem 3. Will there be a significant difference between the different durations of post-test trials—Trial 1, Trial 2, Trial 3, and Trial 4?

Table 26. *ANOVA Test*

Testing Variables	SS	df	MS	F	P-value
Between Groups	19608.919	2	9804.460	33.063	0.000
Within Groups	2668.866	9	296.541		
Total	22277.786	11			

ONE-WAY ANOVA TEST: If P<0.05, Reject null hypothesis

The evaluation of the variables—final weight, moisture removed, and moisture content of cassava—produced a p-value of 0.000, significantly below the established significance level of 0.05. Consequently, the null hypothesis is rejected since the p-value is less than 0.05. This outcome indicates statistically significant differences among the trials concerning the final weight, moisture removed, and moisture content of the cassava. The rejection of the null hypothesis affirms that the variations observed in the drying process are not attributable to random chance but reflect meaningful differences from the tested drying conditions. Thus, the results suggest that the drying methods employed had a substantial and measurable impact on the cassava's drying efficiency and moisture content. This underscores the importance of selecting appropriate drying techniques to optimize product quality in cassava processing.

Previous studies have corroborated these findings, suggesting that shorter drying durations at higher temperatures can reduce energy costs while maintaining product quality (E. Nainggolan et al., 2019). For instance, studies have shown that optimal drying temperatures (e.g., around 100 °C) yield better quality cassava chips with desirable texture and color than lower temperatures (A. Onokwai et al., 2020). The drying temperature also affects the physicochemical properties of cassava starch. Research indicates that water binding capacity and paste clarity improve as the drying temperature increases while swelling power and solubility decrease. This alteration in properties is significant for applications in food processing where starch functionality is critical (J. Igbeka et. al., 2010).

Problem 4. Will there be a significant difference between the pre-testing and post-testing results of the automated Manihot esculenta (Cassava) dryer?

Table 27. *T-Test*

Paired Sample T- Test

	Paired Differences				
	Mean	Std.Deviation	t-value	df	p-value
Pair 1 Test-Temperature	-77.5000	24.054	-9.113	7	0.000
Pair 2 Test-Final Moisture Content	-57.250	27.948	-5.794	7	0.001
Pair 3 Test-Final Weight	-146.000	68.433	-6.034	7	0.001

Paired T-test: If P<0.05, reject null hypothesis

The paired t-test analysis at a significance level of 0.05 ($p < 0.05$) reveals statistically significant differences across all three measured pairs, underscoring the automated dryer's advantages over conventional sun-drying methods. Pair 1 focused on temperature control, and a p-value of 0.000 led to rejecting the null hypothesis, demonstrating a substantial improvement in temperature regulation. With a mean difference of -77.5 and a t-value of -9.113, this result highlights the automated dryer's capability to maintain consistent, optimal temperatures, a key factor for efficient cassava drying. Similarly, Pair 2, concerning final moisture content, shows a p-value of 0.001, prompting the rejection of the null hypothesis. The observed mean difference of -57.25 and t-value of -5.794 suggest a significant reduction in moisture content, which is critical for producing high-quality dried cassava with reduced spoilage risks.

In Pair 3, related to final weight, the automated dryer achieved a p-value of 0.001, supporting the rejection of the null hypothesis and indicating a statistically significant reduction in cassava weight post-drying. With a mean difference of -146.0 and a t-value of -6.034, this finding confirms that the automated dryer achieves an effective drying process, resulting in consistently lighter, thoroughly dried cassava than sun-drying. Collectively, these results validate the automated dryer's efficiency in controlling temperature, reducing moisture content, and ensuring optimal weight loss, ultimately meeting the project's objectives of enhancing cassava drying outcomes and providing a reliable, environmentally independent drying solution. Drying temperature plays a crucial role in determining the efficiency of moisture removal from cassava (N. Aviara, 2020). Higher temperatures generally lead to faster drying rates, which can improve the quality of the dried product by preserving flavors, colors, and nutritional values (D. Nury, 2023). In summary, both drying temperature and duration are critical parameters in the drying process of cassava. They significantly affect moisture content; balancing temperature and time enhances product quality and contributes to efficient energy use during processing.

Problem 5. What is the comparative advantage of the Automated Manihot esculenta (Cassava) Dryer in relation to conventional commercial cassava drying methods?

Table 28. Comparison of the Conventional Drying and Prototype Dryer

Cassava from CrispCassa Prototype (Weight)								
	Initial Weight	*Number of hours*						
		1	*2*	*3*	*4*	*Final Weight*	*Total Weight Loss*	*Moisture Content*
Manihot esculenta (Cassava)	250g	130g	80g	70g	65g	65g	185g	10.8%
Cassava from Conventional Sun Drying (Weight)								
	Initial Weight	Number of hours						
		1	2	3	4	Final Weight	Total Weight Loss	Moisture Content
Manihot esculenta (Cassava)	250g	230g	200g	190g	180g	180g	70g	28%

A study by Okeke et al. (2023) investigated the effects of drying temperatures and times on the drying rates, moisture content, and cyanide levels of five different species of cassava chips, comparing two drying technologies: oven drying and sun drying. The results indicated that oven drying significantly outperformed sun drying in terms of drying rates. Sun drying, while a common practice among farmers, has several limitations. It depends on weather conditions, requiring a prolonged drying period ranging from 2 to 6 days. Additionally, this method exposes cassava chips to the elements, making them susceptible to insect and pest attacks. Another critical drawback of sun drying is its low efficiency; the reflective surfaces of the white chips can further impede effective moisture removal, slowing the drying process.

Additionally, a local farmer from Lunocan, Manolo Fortich, Bukidnon, stated that conventional sun-drying lasts 7-8 days. In contrast, the automated Manihot esculenta (Cassava) dryer provides a more effective solution. It can dry cassava chips efficiently within four hours, significantly reducing the drying duration compared to sun drying. This efficient drying process minimizes exposure to environmental factors, reducing the risk of pest infestations and ensuring higher product quality. Moreover, the controlled environment of the automated dryer allows for consistent heat application and airflow, leading to uniform drying and improved moisture content management. Overall, the CrispCassa, or the automated cassava dryer, represents a significant advancement over conventional sun drying methods, offering enhanced efficiency, reduced drying times, and better protection against contamination, ultimately supporting higher-quality cassava chip production.

Conclusions

The CrispCassa has proven to be a feasible solution for smallholder farmers, offering an efficient and scalable technology to meet the growing demand for cassava. The results indicate significant enhancements in moisture removal efficiency, with optimal levels achieved within 4 hours of operation. Moisture content analysis confirmed substantial improvements, as statistical tests, including t-tests and ANOVA, demonstrated significant differences in moisture content and final weight compared to conventional drying methods, underscoring the dryer's effectiveness in improving product quality.

Based on the result of the study, the following recommendations are made:

A weighing sensor connected to the Arduino system should be integrated into the drying chamber. This would enable a real-time monitoring of the cassava's weight during drying, providing immediate data on moisture loss. Such an addition would allow for more precise control over the drying cycle, stopping the process once the desired moisture level is achieved without manual intervention.

To enhance accessibility when retrieving cassava after drying, the automated cassava dryer could feature removable trays or baskets equipped with handles. This design would allow for effortless lifting of the dried cassava once the drying process is complete, simplifying the retrieval process and minimizing the risk of spills or damage to the product.

Solar power should be incorporated into the automated cassava dryer to improve energy efficiency and sustainability significantly. This approach would provide a viable solution for reducing reliance on conventional power sources. Utilizing solar energy would lower the carbon footprint associated with traditional energy sources, aligning with eco-friendly agricultural practices.

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