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Performance Optimization of an Integrated Gari Processing Machine Using Computer-Aided Design and Multi-Physics Simulation

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ABSTRACT

Traditional gari processing in Nigeria is characterized by labor-intensive manual methods that are inefficient, pose health risks, and yield inconsistent product quality. While mechanized solutions exist, their adoption is limited by high costs and suboptimal performance. This study aimed to design and simulate the performance of an integrated gari processing machine to identify optimal operating parameters for peeling, dewatering, and frying units.The machine components were designed in SolidWorks. Performance was simulated using ANSYS 2021, employing Explicit Dynamics for peeling, a Porous Media model for dewatering, and a Coupled Thermal-Diffusion model for frying. Parametric studies were conducted by varying motor speed (350-1440 rpm), pulp mass (5-11.65 kg), and frying temperature (74-80°C). Simulation output data was analyzed using Microsoft Excel to derive predictive performance models via regression analysis. The peeling unit showed optimal performance at 750 rpm with minimal flesh loss (13.82%). The dewatering efficiency increased linearly with pulp mass, reaching 24.98% water loss. Frying efficiency followed an exponential trend, with a critical improvement at 80°C, achieving 7.35 kg of moisture loss. Predictive models with high correlation ($R^2 > 0.98$) were successfully developed for each process. The study demonstrates that simulation-based design is a powerful tool for optimizing food processing equipment. The identified parameters and predictive models provide a foundation for developing cost-effective, efficient, and accessible gari processing technology for small-scale processors.

Keywords: Cassava, Gari, Simulation, Optimization, Finite Element Analysis, Machine Design, ANSYS.

1. INTRODUCTION

Cassava (*Manihot esculenta*) is a vital staple crop and a primary source of carbohydrates in tropical and subtropical regions, with Nigeria being the world's largest producer (Airaodion *et al.,* 2019). Gari, a granular, roasted product, is one of the most widely consumed cassava derivatives in West Africa.

However, its production predominantly relies on traditional manual methods involving peeling, grating, dewatering, and frying. These methods are not only laborious and time-consuming but also expose operators, predominantly women, to physical hazards and health risks (Adenuga, 2014). The development of mechanized processing systems has been ongoing, but widespread adoption is hindered by challenges such as high cost, operational inefficiency, and technical complexity (Okereke *et al.,* 2016). A key engineering challenge is the efficient peeling of tubers, which is complicated by their irregular shapes, leading to high flesh loss and low yield in existing machines (Egbeocha *et al.,* 2016).

Computer-aided design (CAD) and simulation have emerged as indispensable tools in industrial design, offering a flexible and cost-effective approach to analyzing and optimizing system performance before physical prototyping (Chime, 2020). While previous studies have simulated individual unit operations like grating (Olaoye, 2009; Chime, 2020) and frying (Sobowale *et al.,* 2017), a research gap exists in the integrated simulation and optimization of the entire gari processing chain.

This study, therefore, aims to bridge this gap by employing a multi-physics simulation approach to design and optimize an integrated gari processing machine.

2. METHODOLOGY

2.1 Machine Design and Components

The integrated gari processing system was designed using SolidWorks software. The system comprised four main units:

- Peeling-Washing-Grating Machine: A single integrated unit powered by one electric motor, featuring a hopper, dual rotating drums (one abrasive, one smooth), a water spray system, and a grating drum.
- Dewatering Machine: A hydraulic press consisting of a pressing chamber and a hydraulic system to apply a constant pressure of 1500 kN/m².
- Frying Machine: A unit with a stainless-steel frying chamber, a lower heating chamber, and rotating paddles for even heat distribution.
- Sieving Machine: A vibrating sieving chamber for particle classification before and after frying.

2.2 Simulation Setup and Physics Models

Performance simulation was conducted using ANSYS 2021. The following physics models were applied to replicate real conditions:

Peeling Process: An Explicit Dynamics analysis was used to model the impact and abrasive contact. Material failure was modeled using a Johnson-Cook plasticity model (Equation 1), which defines the yield stress (σy) based on plastic strain and strain rate.

$$\sigma y = (A+B\epsilon^{n})(1+C * \ln\epsilon*) \quad (1)$$

where A, B, C, n are material constants for cassava, ε is equivalent plastic strain, and $\epsilon*$ is the dimensionless strain rate.

Dewatering Process: A **Porous Media model** governed by **Darcy's Law** (Equation 2) was used to simulate fluid flow through the cassava pulp under pressure.

$$q = -\kappa\mu\nabla P \tag{2}$$

where q is the fluid discharge rate, κ is permeability, μ is viscosity, and ∇P is the pressure gradient.

Frying Process: A **Coupled Thermal-Diffusion model** was employed, solving the heat transfer and mass diffusion equations simultaneously to predict temperature distribution and moisture loss.

2.3 Parametric Studies and Model Derivation

Parametric studies were performed by varying key input parameters:

- **Peeling:** Motor speed (350, 500, 750, 900, 1440 rpm).
- **Dewatering:** Mass of cassava pulp (5.00, 5.89, 7.35, 8.45, 11.65 kg).
- **Frying:** Temperature (74, 76, 78, 80 °C).

The output data from ANSYS simulations (flesh loss, water loss, moisture loss) was exported. Predictive mathematical models were derived by performing least-squares regression analysis on this data using Microsoft Excel to find the best-fitting curves.

3. RESULTS AND DISCUSSION

3.1 Peeling Performance and Optimization

The relationship between motor speed and flesh loss is presented in Table 1. The results indicate a non-linear relationship, with flesh loss decreasing to a minimum of **13.82% at 750 rpm** before increasing again at higher speeds.

Table 1: Variation in Percentage Flesh Loss with Motor Speed

Motor Speed (rpm)	Percentage Flesh Loss (%)
350	18.19
500	15.78
750	13.82
900	14.42
1440	16.00

This optimal point represents a balance between insufficient peel removal at low speeds (due to prolonged contact) and excessive flesh removal at high speeds (due to aggressive impact forces), a challenge noted by Egbeocha *et al*. (2016). The data was fitted to a quadratic model ($R^2 \approx 0.98$) and is as shown in equation 3. Where w is the motor speed.

$$FL(\%) = (1.926 \times 10^{-5}) \cdot \omega^2 - 0.028 \cdot \omega + 24.01 \tag{3}$$

3.2 Dewatering Efficiency

The dewatering efficiency showed a strong positive linear correlation with the initial mass of the cassava pulp, as shown in Table 2. Water loss increased from 12.00% to **24.98%** as the pulp mass increased from 5.00 kg to 11.65 kg.

Table 2: Dewatering Performance with Varying Pulp Mass

Mass of Pulp (kg)	Percentage Water Loss (%)
5.00	12.00
5.89	15.11
7.35	15.65
8.45	17.75
11.65	24.98

This trend is consistent with Darcy's Law, as a larger pulp mass provides a greater cross-sectional area for fluid flow under the same pressure gradient. The linear relationship is described in equation 4

$$WL(\%) = 1.614 \cdot M + 5.312 \quad (4)$$

3.3 Frying Process Thermal Efficiency

The moisture loss during frying increased exponentially with temperature (Table 3). A significant jump was observed at **80°C**, where moisture loss reached **7.35 kg**, compared to 5.85 kg at 78°C.

Table 3: Moisture Loss at Various Frying Temperatures

Frying Temperature (°C)	Moisture Loss (kg)
74.00	5.55
76.00	5.70
78.00	5.85
80.00	**7.35**

This indicates a critical temperature threshold where the evaporation rate accelerates markedly, a phenomenon also observed in the modeling work of Sobowale et al. (2017). The exponential relationship is captured by the model and is as shown in equation 5.

$$ML(kg) = 0.012 \cdot e^{\wedge}(0.098 \cdot T) \quad (5)$$

4. CONCLUSION

This study successfully demonstrates the application of CAD and multi-physics simulation in designing and optimizing an integrated gari processing machine. The key findings are:

The optimal operating parameters were identified as **750 rpm for peeling**, a constant **1500 kN/m² for dewatering**, and **80°C for frying.**

Predictive models were derived for each unit operation, providing valuable tools for performance prediction and system scaling.

The simulation-based approach validated the design specifications and confirmed the system's potential to address the inefficiencies of traditional processing methods. The study confirms that this methodology is a cost-effective strategy for developing accessible and efficient agricultural technology, building on the foundational work of earlier researchers (Chime, 2020; Olaoye, 2009). For future work, it is recommended that a physical prototype be fabricated to validate these simulation results and that an economic analysis be conducted to assess the machine's viability for small-scale processors.

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