Development And Performance Evaluation Of An Fufu Making Machine

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***Abstract*— This study investigates the influence of initial water content, cooking time, torque, power consumption, and stirring rate on the automated processing of fufu. Understanding these parameters is crucial for optimizing machine performance and energy efficiency. Experimental data showed that as cooking time increased from 5 to 30 minutes, the initial water content decreased from 65% to 40%, significantly affecting power and torque requirements. Torque increased from 4.5 Nm at 65% water content to 9.5 Nm at 40%, indicating that as moisture content decreased, the viscosity of the fufu mixture increased, making stirring more difficult. Similarly, power consumption rose from 110 W at 65% water content to 195 W at 40%, showing that lower moisture levels require more energy to sustain mixing. The stirring rate decreased from 60 rpm at the start to 38 rpm after 25 minutes, reflecting the increasing resistance due to starch gelatinization. The relationships among these parameters indicate that lower water content leads to higher energy consumption and mechanical load. Maintaining an initial water content of 55%–60% can balance energy efficiency and cooking consistency. The findings highlight the need for an automated control system that adjusts stirring speed dynamically based on real-time torque feedback to optimize performance. To improve efficiency, future designs should incorporate variable-speed motors, real-time moisture sensors, and optimized heating mechanisms. These improvements will enhance automation, reduce energy costs, and improve the consistency of fufu processing.**

Keywords— Fufu Making Machine, Stirring Speed, Cooking Time, Moisture Content, Fermentation, Mechanized Fufu Processing

1. Introduction

Fufu is a traditional fermented cassava consumed in southern, western, and eastern Nigeria and in other West African countries (Rosales-soto et al., 2016). Cassava (Manihot esculent crantz) is a dicotyledonous plant which originated from Latin America and has been cultivated in other parts of the world. It is an important staple food crop for millions of people in the tropics. Cassava roots are normally processed before consumption. Various fermented cassava products are available, this include garri, Fufu, lafun etc. (Oyewole, 1992).

Fermentation of cassava for Fufu production entails peeling, washing and soaking submerge of cassava tubers in water for 3 - 4 days. The retted cassava tubers use this time to get softened. The softened pulpy mass is then disintegrated in water and passed through a coarse sieve. This separates the fiber from starch which is allowed to sediment then the water is decanted. It is then packed into cloth bags and excess water is squeezed out. The resulted excess meal is white and crumbly which is usually cooked before being eaten (Ihekoronye and Ngoddy, 1985). It is ranked next to gari as an indigenous fermented food in the southern part of Nigeria (Egwim et al., 2013). The preference for fufu as a staple food is gradually developing in West Africa (Johnson et al., 2006). The variations in fufu processing methods and differences in the biophysical traits of the varieties may change the texture and sensory properties of cooked dough (Chijioke, et al., 2021).

Studies also show most preferred characteristics of fufu as mouldability, drawability and colour. At the raw material level, important quality characteristics for all users (women, men and youth) include; smooth skin, heavy weight, and white colour. Important processing characteristics were easy to ferment, easy to peel, high mash yield, and white/cream colour. Poor quality characteristics indicated by the respondents during processing include: bad colour, light weight, fibrous/burnt cassava root, high moisture content, black lines on the body of the product, too soft, sticks to the hand, not easy to mould, not well cooked, and bad odour (Madu et al, 2022).

Fufu is reconstituted by stirring in boiling water to form a dough and eaten with flavoured sauces (Pelczar et al., 1993). The single problem associated with fufu consumption is the high offensive odour associated with it. The products of the breakdown of cyanogenic glucoside give-off this offensive odour and at the same time reduced the compound to safe level by traditional method of processing and preparing cassava for consumption by fermentation (Okafor, 1998).

The process of producing Fufu is tedious and cumbersome, especially when processed in commercial quantity. There is also a concern about the hygiene in the production process – whereby sweat and other forms of waste from the body of the operator might contaminate the product. According, over the years, studies have been made to develop mechanized fufu processing machine. This is also the focus in this work.

2. Methodology

The fufu making machine comprised several components such as the stirring blade, the electric drive unit, band heater unit, temperature control, and the cooking cylinder. Some of the detailed design calculations presented concerns the determination of the volume of Fufu to be prepared and the determination of the permissible mass of cassava mash to be charged into the cooking chamber. The summary of the machine fabrication is presented.

2.1 Determination of the volume of Fufu to be prepared

The volume of Fufu to be prepared is denoted as Vc and it is given as;

$$Vc = \pi r^2 h \quad (1)$$

Where the diameter of the cooking cylinder is denoted as D and the height of the cooking chamber is denoted as h, while the radius, r of the cooking chamber is given as r = $D/2$. The volume of the cassava mash, Vm is as follows:

$$Vm = 2/3\, Vc \quad (2)$$

Where $V\ m$ denotes the volume of mash in the cylinder while denotes volume of the frying chamber.

2.2 The permissible mass of cassava mash to be charged into the cooking chamber.

Two-third of the total mas of the cylinder was adopted.Therefore,

$$Mc = 2/3 \times mc \quad (3)$$

Heat (Q) generated for the drying is determined as follows;

$$Heat\ Q = MC\Delta T \quad (4)$$

Where, M denotes the mass of cassava mash in the cylinder and C denotes the specific heat capacity of mash = 1.598$J/kg^{o}C$ (FAO, 2000). Using Fourier's law of heat conduction,

$$Q = KA(T2 - T1)\, L \quad (5)$$

Where, K denotes the thermal conductivity of mash = 0.2. A denotes the surface area of the cooking cylinder. Area of the mash in cylinder is derived from the area of a cylinder. Thus,

$$A = 2\pi rh + 2\pi r^2 \quad (6)$$

2.3 Determination of the power required to turn the Fufu

$$\text{Power, } P = W\,t \quad (7)$$

where, W denotes the work done, and t denotes the time. Then, torque (T) is given as;

$$F = T\,r \quad (8)$$

In angular displacement, v = ω× r, therefore,

$$\text{P} = T\,r \times \omega.\, r = \omega.\, T \quad (9)$$

The torque can be obtained from the following relationship.

$$T\,J = \tau\, R = G\theta\, L \quad (10)$$

Where, T denotes the Torque, Ɵ denotes the Angle of twist, G denotes the Modulus of rigidity of shaft, L denotes the length of shaft, and J denotes the Polar moment.

$$T = JG\theta/L \quad (11)$$

$$J = \pi d^4/32 \quad (12)$$

2.4 Fabrication and Performance Evaluation of the Machine

Standard manufacturing processes such as marking out, cutting and welding were applied in the production of the machine. Marking out was done using the dimensions and geometry presented in the working drawing. Again, the machine was assessed for its efficiency based on how much time it takes to complete a cooking process. For this purpose, a timer was used. It was operated at various speeds to ascertain the effect of stirring speed on the production time and physically-examined homogeneity. This information was compared to what is obtainable in manual production.

3. Results and discussion

The graph showing the power consumption plotted against initial water content is shown in Figure 1. The relationship between the initial water content and power consumption further reinforces the importance of proper hydration levels in the process. As expected, power consumption increases as initial water content decreases. The increase in power consumption is attributed to the fact that a thicker mixture requires more motor effort to maintain the required stirring rate. This trend is similar to findings in extrusion cooking processes studied by Mestres and Rouau (1997), where lower moisture content led to higher energy requirements due to increased shear resistance. The practical implication of this observation is that machines designed for fufu processing should have adjustable speed and torque settings to accommodate variations in water content. Additionally, energy efficiency could be improved by incorporating an automated water injection system that adjusts moisture levels in real time based on torque feedback.

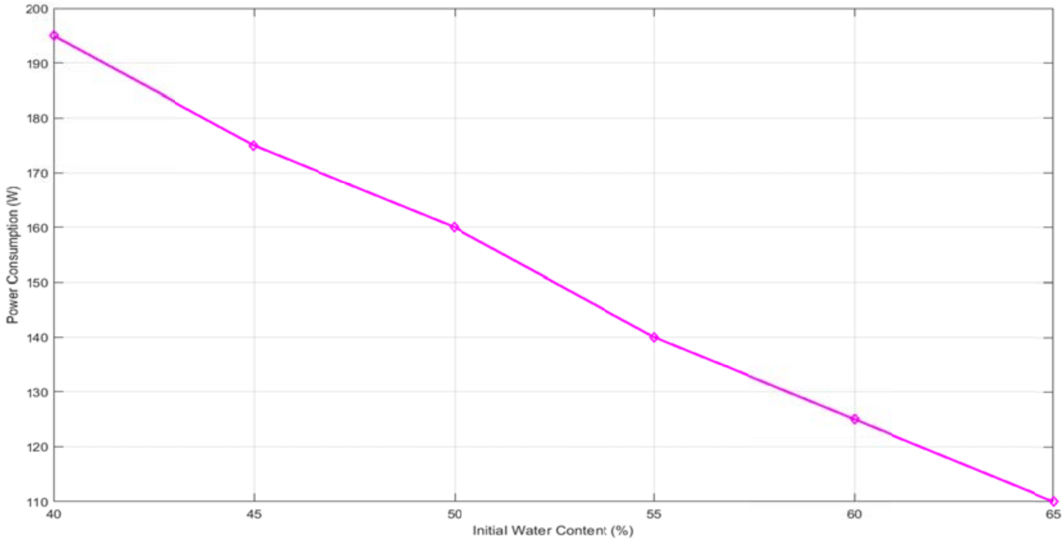

Figure 1: Plot showing the power consumption plotted against initial water content

The 3D surface plot showing the torque plotted against cooking time and initial water content is presented in Figure 2. The graph showing the torque plotted against initial water content is presented in Figure 3 while the graph showing the torque plotted against initial water content is presented in Figure 4. The 3D surface plot depicting the relationship between cooking time, initial water content, and torque provides valuable insights into how these variables interact. As cooking time increases, torque also increases, but this effect is more pronounced for mixtures with lower initial water content. This suggests that starting with an optimal water content can significantly reduce the mechanical load required during the later stages of cooking. The findings align with the work of Zuo *et al*. (2019), who observed similar trends in starch-based food processing, where gelatinization and thickening effects became more dominant at later stages of heating. Understanding this interaction is crucial for optimizing the design of fufu-processing machines. A system that dynamically adjusts stirring speed based on real-time torque feedback could help maintain efficiency while preventing excessive motor load.

From a practical standpoint, these findings highlight the need to balance the initial water content to achieve optimal processing conditions. If the water content is too high, cooking time may increase due to the additional energy required to evaporate excess moisture. Conversely, if the water content is too low, the machine will require higher torque and power consumption to maintain stirring, leading to inefficiencies and potential mechanical strain. The optimal initial water content should be carefully selected to balance ease of mixing, energy efficiency, and cooking time. Furthermore, real-time monitoring of torque and viscosity during processing can provide valuable feedback for automated control systems to improve performance.

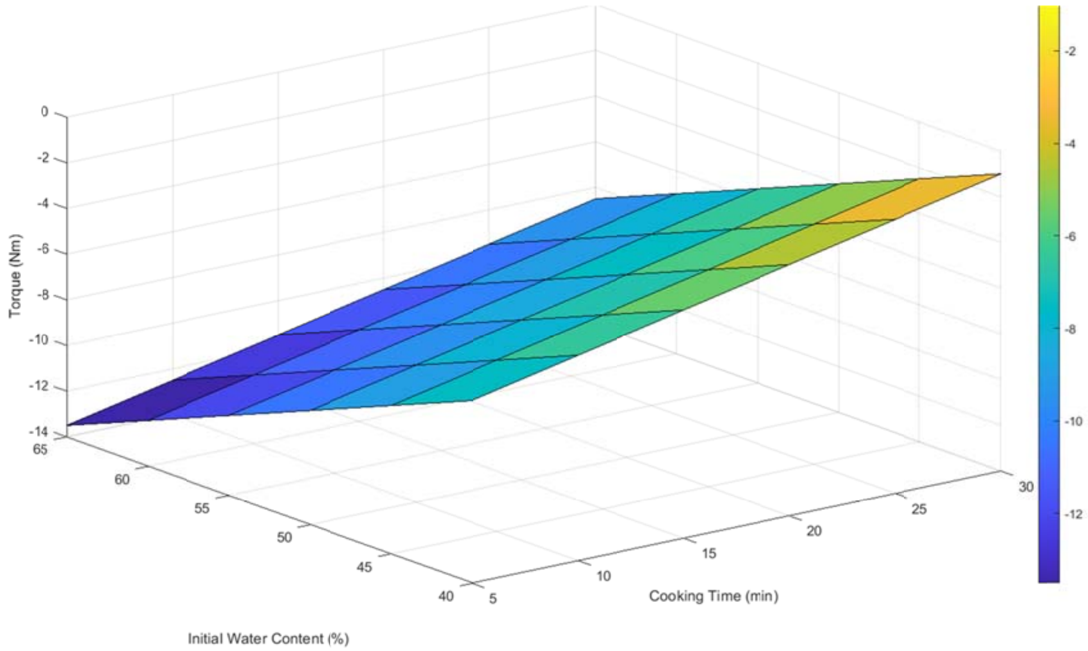

Figure 2: Surface Plot showing the torque plotted against cooking time and initial water content

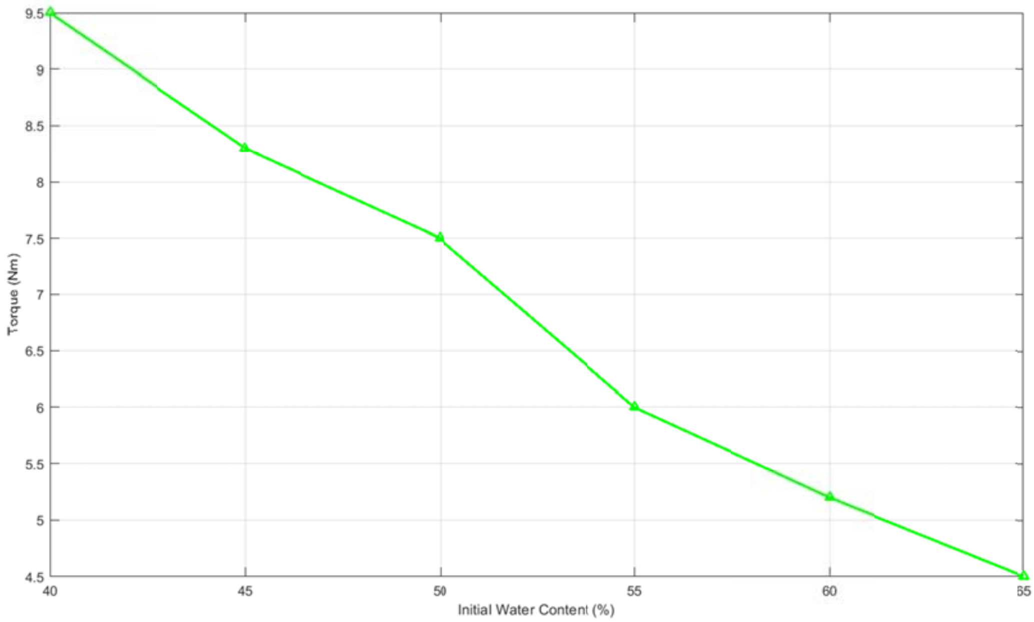

Figure 3: Plot showing the torque plotted against initial water content

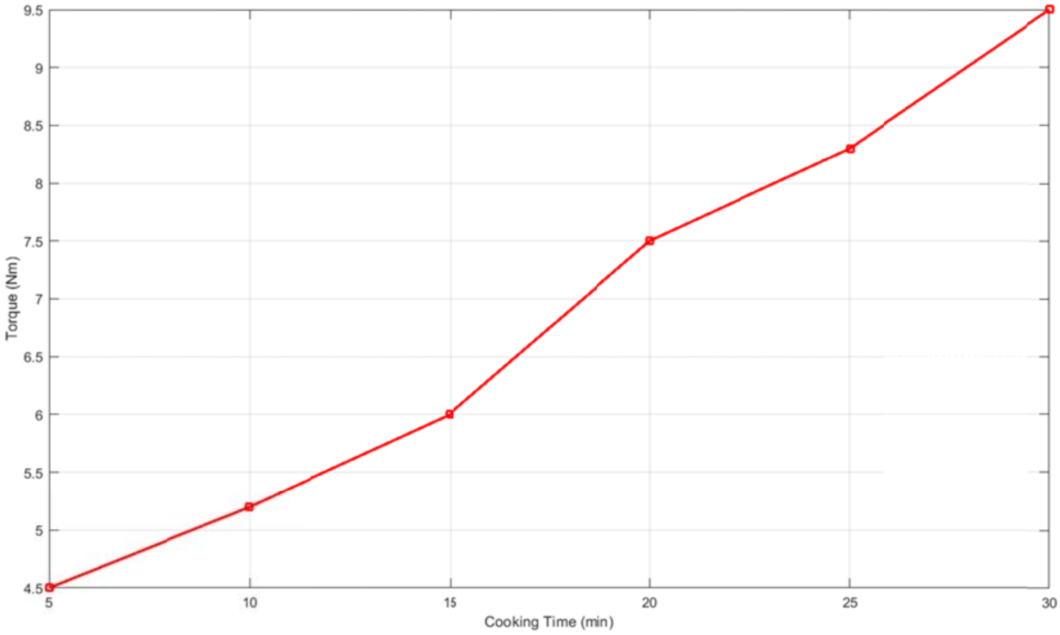

Figure 4: Plot showing the torque plotted against cooking time

Also, the graph showing the initial water content plotted against cooking time is presented in Figure 5 while the graph showing the stirring rate plotted against cooking time is presented in Figure 6. As shown in the graph of Figure 6, the stirring rate gradually decreases over time. At the start of the process, the fufu mixture has a relatively low viscosity due to the high initial water content (as shown in Figure 5), allowing for faster mixing at a high RPM. However, as cooking progresses, the starch gelatinizes, leading to a thicker consistency that resists motion. The increased resistance causes a reduction in the stirring rate since the motor encounters more load. This trend aligns with studies by Afoakwa *et al.* (2010), who reported that starch-based food systems exhibit increasing shear resistance during gelatinization. As a result, the stirring mechanism must compensate by reducing speed to avoid excessive energy consumption or mechanical strain. This also suggests that an adaptive control system could be beneficial, where the stirring rate automatically adjusts based on real-time viscosity feedback.

The relationship between cooking time and initial water content follows a predictable pattern, where the initial water content decreases progressively from 65% to 40% as cooking progresses from 5 to 30 minutes. This reduction affects the physical and mechanical properties of the fufu mixture, as confirmed by the corresponding increase in torque and power consumption.

The torque required to stir the mixture increased from 4.5 Nm at 65% water content to 9.5 Nm at 40%. This demonstrates that as moisture content decreases, the viscosity of the mixture rises, increasing mechanical resistance. Similar findings have been reported in studies on starch-based food rheology, where gelatinization and water absorption lead to increased shear resistance (Afoakwa et al., 2010). The higher torque requirements at lower initial water content highlight the importance of precise hydration control at the beginning of the process.

A similar trend was observed in power consumption, which increased from 110 W at 65% water content to 195 W at 40%. This aligns with findings in extrusion cooking studies, where lower moisture levels lead to higher mechanical resistance and energy demands (Mestres & Rouau, 1997). The implication is that maintaining an optimal initial water content can reduce energy consumption and extend the lifespan of the stirring mechanism by preventing excessive load on the motor.

The data also show a direct relationship between cooking time and torque. At the beginning (5 minutes), the torque requirement was 4.5 Nm, but as cooking continued to 30 minutes, it reached 9.5 Nm. This increase is due to starch gelatinization, which thickens the mixture and makes it harder to stir. As a result, the stirring rate declined from 60 rpm at the start to 38 rpm at 25 minutes. The reduced stirring rate indicates that the motor compensates for the increased viscosity by slowing down, a feature that should be integrated into automated fufu-processing machines to optimize performance.

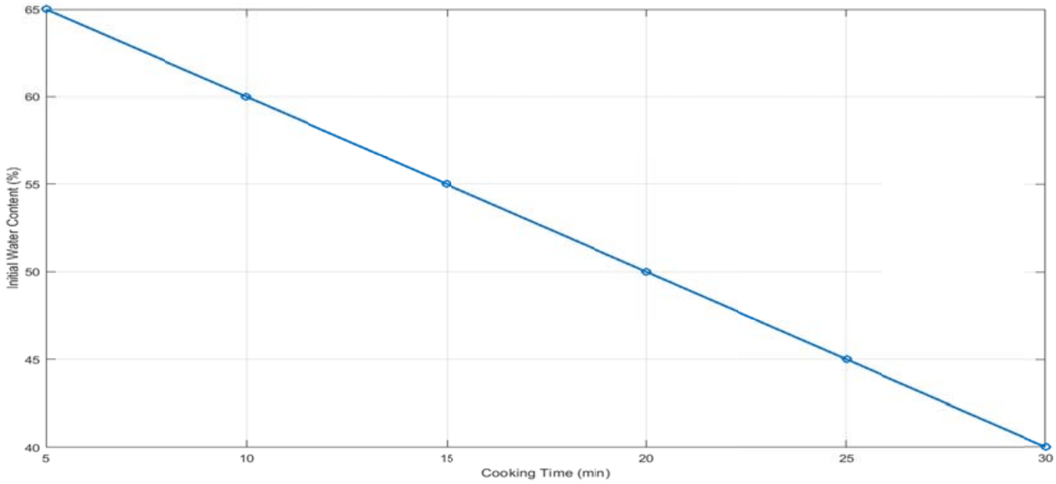

Figure 5: Plot showing the initial water content plotted against cooking time

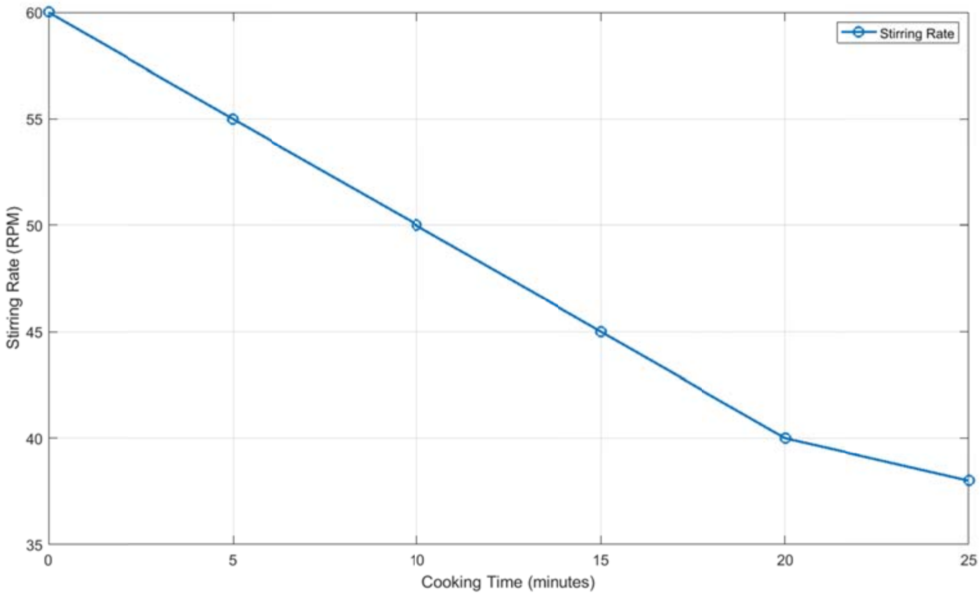

Figure 6: Plot showing the Stirring rate plotted against Cooking Time

4. Conclusion

This study analyzed the key parameters affecting the automated processing of fufu, focusing on initial water content, cooking time, torque, power consumption, and stirring rate. The study demonstrated that initial water content plays a crucial role in the mechanical and energy requirements of fufu processing. Lower initial water content resulted in significantly higher torque and power consumption compared to higher water content which required only small torque and small power consumption respectively. The cooking process also showed a decrease in stirring rate after some minutes due to increase in viscosity. These findings emphasize the need for precise moisture control at the start of processing to optimize efficiency. An automated fufu-processing machine with dynamic stirring adjustments based on real-time torque and viscosity monitoring would significantly improve energy efficiency, reduce mechanical wear, and enhance the consistency of fufu production.

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