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DEVELOPMENT OF DOUGH KNEADING MACHINE FOR SMALL AND MEDIUM-SIZED ENTERPRISES

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Abstract:

This work focuses on the development of a motor-powered dough-kneading machine for small to medium-scale businesses to aid in the efficient production of their edible products. The work was carried out at the Department of Mechanical Engineering, Adeleke University, Ede, Osun State. The machine employs upper and lower electric motors configured to rotate in opposite directions on the same axis for an efficient kneading process. The design analysis was carried out in line with the defined specifications, which were followed by fabrication and evaluation. The result showed a kneading torque of 128 Nm at an average kneading power and speed of 1.37 kW and 102.02 rpm, respectively. The dough volume per batch and the mixing bowl volume were 0.00397 and 0.00512 m^3. The capacity and efficiency of the machine were estimated to be 0.87 kg/min and 90.65%. The performance showed that the dough-kneading machine is efficient and can be produced in mass to meet the market demands of small and medium-scale businesses.

Keywords: dough; production sustainability; kneading; flour; beater.

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1. Introduction

The major ingredient in dough production is flour, characterized as finely ground cereal grains or other starchy components of plants, integral to various food products and particularly vital in baked goods such as bread (Cappelli et al., 2021, 2022; Venturi et al., 2022). Flour-based foods serve as a fundamental source of energy and essential nutrients, encompassing proteins, fiber, vitamins, and more, rendering them well-suited for dietary consumption (Agrawal et al., 2017; Okonkwo, 2014; Olivier & Allen, 1992). The combination of flour, water, air, and other crucial constituents achieved through the kneading process produces gluten via mechanical operation (Agrawal et al., 2017; Cappelli et al., 2018; Cappelli & Cini, 2021; Venturi et al., 2022). These constitute the foundation of conventional dough preparation. Consequently, kneading stands as a cornerstone operation within the dough-processing industry, where the mixture and aeration of flour, water, and other ingredients are achieved through mechanical work, as depicted in Equation (1) (Gras et al., 2000; Nobyleong, 2017; Wilson et al., 2001; Zheng et al., 2000). In essence, the creation of high-quality dough necessitates the input of sufficient energy, applied in the appropriate sequence during the kneading process.

$$\text{Flour} + \text{Water} + \text{Air} + \text{Energy (work)} \rightarrow \text{Dough} \quad (1)$$

In the realm of kneading machines across various tiers of research, Orelaja et al. (2020) reported the development of an enhanced industrial dough mixer, boasting an efficiency rate of 86.7% and a mixing rate of 130 kg/h per batch, rendering it suitable for small and medium-scale enterprises. Furthermore, Hwang and Gunasekaran (2001) explored the influence of mixing duration on flour composition, encompassing mixer type and speed within dough production. Owolabi et al. (2017) contributed to this field by introducing a small-scale motorized dough-kneading machine featuring rollers, conveyor belts, gears, a work table, a variable electric motor, and a supporting frame. Owolabi et al. (2017) design exhibited a kneading efficiency of 87%, an optimal kneading time of 14 seconds and a rate of 38.57 kg/h. However, despite these advancements, existing kneading machines have encountered shortcomings in terms of cost, ease of operation, and maintenance, thereby limiting their feasibility for small to medium business owners. Many of these machines either exhibit complexity in operation and handling or fail to deliver effective kneading for homogeneous, gluten-rich, and pliable dough. Consequently, a significant portion of business owners still rely on a rudimentary manual kneading process, necessitating substantial time and energy input before achieving the desired dough consistency. This manual approach also exposes the dough to unsanitary environmental conditions, including the risk of harmful

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microorganisms that can contribute to various diseases. Furthermore, the bulkiness, substantial floor space requirements, and lack of mobility associated with some kneading machines pose a challenge for entrepreneurs who engage in the sale of daily dough products. Notably, roller kneading machine types are likely to impart excessive mechanical energy and shear forces onto the dough. Therefore, this leads to the breakdown of stable molecular interactions among gluten-forming proteins such as disulfide bonds thereby causing the depolymerization of large gluten aggregates (Weegels et al., 1996).

This study endeavors to address the challenges and limitations faced by small-scale dough businesses in both rural and urban Nigeria by developing an affordable and user-friendly spiral mixer dough-kneading machine. Notably, this research stands out for its emphasis on affordability, simplicity of operation, and mobility, catering to entrepreneurs of varying technical expertise. The commitment to ensuring the production of high-quality, homogeneous, and gluten-rich dough is a distinct novelty, setting it apart from existing machines. Furthermore, the study conducts a context-specific case study in Ede, Osun State, Nigeria, recognizing the importance of tailoring solutions to regional needs. The primary objectives include the design, fabrication, and evaluation of the machine's average capacity, with a specific focus on assessing kneading machine mass and speed efficiencies. This multifaceted approach holds great promise for transforming the dough-processing industry and meeting the critical demands of small-scale businesses in Nigeria.

2. Methodology

2.1. Overview Description and Working Principle of the Machine

The machine was designed according to the design concept. The machine is to make homogenous gluten dough using whole wheat or other flours with other compositions of ingredients. The machine has two-speed reduction gearing electric motors at the upper and lower sides of the frame, whose speeds are 110.5 and 70.42 rpm, respectively. The spiral kneader is attached to the upper motor, which rotates when powered and performs the mixing operation, while the lower motor is facilitated through different mechanisms to hold and rotate the mixing bowl in the opposite direction to the spiral beater. The mixing bowl contains various ingredients for dough formation.

2.2. Design Factors and Materials Selection

The following factors were used in the design analysis based on the properties of the materials and components used in the calculations:

i. The acceleration due to gravity is 9.81 kg/m^2.
ii. The density of the stainless steel is 7500 kg/m^3.
iii. The density of the mild steel is 7850 kg/m^3.
iv. The volume of the ingredient to be mixed should be less than the total volume of the mixing bowl (around 70% of the volume of the mixing bowl).

Materials required for the development of the dough-kneading machine are sourced locally and selected based on availability, inertness to food products, and cost. These materials were selected because of their good physical properties, such as resistance to corrosion, weight, weldability, strength, machineability, toughness, hardness, etc. The procured upper and lower motors have speed reduction gears to maintain consistency when kneading the dough. Table 1 shows the list of materials.

Table 1: Major components and materials.

S/N	Components	Material	Fabrication method
1.	Frame	Mild steel	Cutting and welding
2.	Mixing bowl	Aluminium	Procured (based on the designed parameters)
3.	Upper Electric motor	-	Purchased
4	Lower Electric motor	-	Purchased
5	Stirrer	Stainless steel	Bending

2.3. Design Consideration

2.3.1. Electric Motor Power Requirement

The power that supplies mechanical energy to the machine is provided by the electric motor, whose specifications are selected based on need. Consideration is given to selecting an electric motor that can supply adequate torque for the kneading process. In selecting the motor, analysis is carried out to ensure that the motor power output is less than the rated power on the nameplate to avoid overloading and damage (E4U, 2022; USDE, 2014).

The power requirement of the electric motor was sized after considering the following factors: the electrical power input (P_{in}), the motor power output (P_{out}); and the power rating in the nameplate (P_{rated}).

i. Electrical power input

The electric power input of the motor is given by

$$P_{in}=(IVf_p)/1000 \rightarrow \text{for single phase motor} \quad (2)$$

(E4U, 2022; FP, 2008; McCoy & John, 1996; Shaikh et al., 2022; USDE, 2014).

Where V is the voltage = 220-240 V (Nigerian-rated voltage). Other motor parameters are chosen according to the specifications for a single-phase, 50Hz, 2hp motor is current, and f_p is the power factor. Therefore, the values taken are: I = 12 A, f_p = 0.7, η_{motor} = 80%. The power input and output of the motor are estimated from Equations 2 and 3.

$$P_{out}=(\eta_{motor}\ P_{in})/100 \quad (3)$$

Since the power output (P_{out}) of the motor is less than the rated power (P_{rated}) on the nameplate (2hp or 1.49 kW), it shows that the motor is saved to use for the intended purpose and cannot be overloaded.

$$P_{out}<P_{rated}$$

2.3.2. Torque Required for the Kneading Dough

Adequate torque is required for the kneading process. The torque, which the electric motor must develop for the kneading process, is defined according to Equation (4) (Khurmi & Gupta, 2005).

$$T_m=(60P_{out})/(2\pi N_m) \quad (4)$$

Where N_m is the average speed in rpm required for kneading. The mixing and kneading speed for dough production should not be too high (Owolabi et al., 2017). The speed selected is 110 rpm (Orelaja et al., 2020). P_{out} is the power output of the motor, 1.48 kW.

2.3.3. Design of the Dough Mixing Bowl

The circumference and the height of the mixing bowls were considered to determine the optimum capacity of the dough the mixing bowl can contain, kneading time, kneading efficiency, and kneading capacity of the mixer (i.e., the spiral) per operation. The basin should be able to accommodate an effective mechanical kneading process for gluten and pliable dough. Therefore, the actual volume of the mixing bowl was designed by taking into consideration clearance for mechanical mixing. The basin capable of kneading 5 kg per batch of dough is considered, according to Equation (5). According to Orelaja et al. (2020), the average apparent density of dough is 1258 kg/m^3. Now, (Orelaja et al., 2020).

i. The volume of the dough

$$V_{dough}=m_{dough}/\rho_{dough} \quad (5)$$

ii. The volume of the mixing bowl

The final volume of the mixing bowl having taken into consideration the clearance is designed using Equation (6) (Orelaja et al., 2020).

$$V_{bowl}=V_{dough}+(30\%\ V_{dough}) \quad (6)$$

iii. Height of the mixing bowl

A bowl with a diameter of 0.3 m is considered. The height of the mixing bowl is calculated using the relationship in Equation (7).

$$h_{bw}=(4V_{bowl})/(\pi d_{bw}^2) \quad (7)$$

iv. The thickness of the mixing bowl

The determination of the mixing bowl's thickness was conducted through the application of the circumferential or hoop stress equation (Agrawal et al., 2017; Khurmi & Gupta, 2005; Okafor, 2015). Given that the bowl is configured as a thin-walled open cylinder, it is susceptible to internal pressure, the excessive presence of which may lead to the rupture of the mixing bowl's walls. The specific calculation of the mixing bowl's thickness is derived from the relationship presented in Equation (8).

$$t=Pd/(2\sigma_t) \quad (8)$$

Where P is the intensity of the combined internal pressure from both the weight of the gluten mixture and the centrifugal action caused by the rotation of the gluten mixture. is the circumferential hoop stress on the thin wall of the mixing bowl. $\sigma_t \leq 5$ MPa for this design, the mixing bowl is a thin wall, so the value considered is 0.1 MPa.

i. The Total Internal Pressure

$$P=(\rho g h_{bw})+(m_d\, \omega^2\, rA) \quad (9)$$

Where h_{bw} is the height of the mixing bowl, A is the area on which the centrifugal force acts as a result of dough mixing and ω is the angular velocity of the lower motor (Equation 10).

$$\omega=(2\pi N_{Lm})/60 \quad (10)$$

2.3.4. Design of the Design of the Spiral Beater

The spiral beater employed in this study adopts the configuration of an open-coiled helical spring with gaps present between consecutive turns of the wire. This choice was made due to its capability to effectively mix ingredients, endure static and infrequently varying loads, enhance dough ductility, and ensure the production of homogeneous gluten within the dough. It's worth noting that this application is confined to mixing tasks and does not extend to the complex functions associated with conventional helical springs, such as axial loading. The spiral beater is designed for light-service applications, with the lower portion coiled into a spiral shape and cold-formed to optimize its strength (Khurmi & Gupta, 2005; Sunmonu et al., 2021). Stainless steel was selected as the material for the spiral beater due to its superior corrosion resistance, non-reactivity with food materials, and robustness, all crucial attributes for effective kneading operations. The diameter of the beater rod was determined based on considerations of the twisting moment (T), ensuring it can withstand lateral loads exerted by the mixing materials. For the purposes of this analysis, any deflection in the beater rod was disregarded, as the magnitude of load required to induce deflection in the material would be several hundred kilograms (Khurmi & Gupta, 2005). Equation (11) was employed to calculate the appropriate diameter of the beater rod.

$$d=\sqrt[3]{\frac{16T_m}{\pi\tau}}=\left(\frac{16T_m}{\pi\tau}\right)^{\frac{1}{3}} \quad (11)$$

Where T_m is Torque for the kneading operation, τ is maximum shear stress in the spring materials for stainless-steel. Since the value for light service application is 437.5 MPa (Khurmi & Gupta, 2005; Sunmonu et al., 2021), the diameter of the beater rod (d) can be determined.

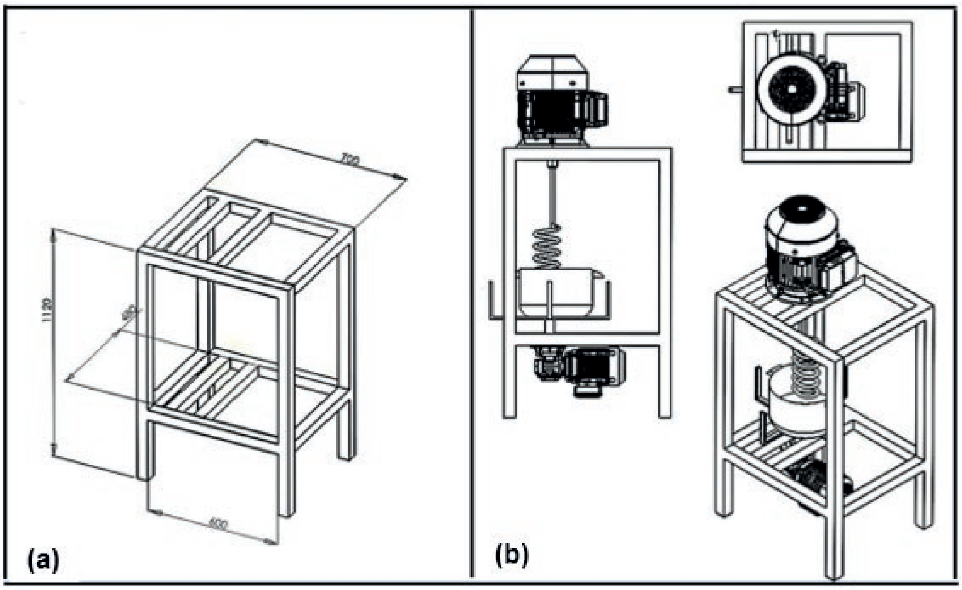
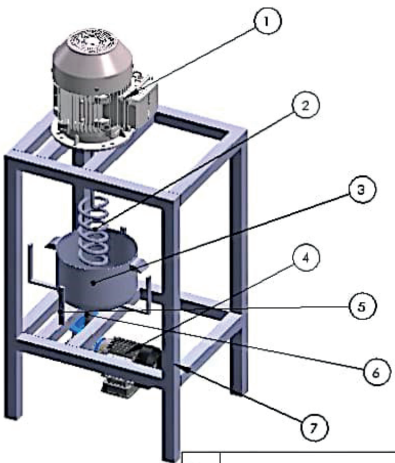


Figure 1: The frame structure (a) and complete machine design (b).

2.3.5. Design Diagrams

The machine's design diagrams were made following a comprehensive design analysis, and necessary adjustments were incorporated where deemed essential. Employing advanced 3-D software (Solidworks 2017), the complete array of components comprising the dough kneading machine was systematically designed. Detailed representations of these design diagrams are visually presented in Figures (1) and (2).



S/N	component
1	UPPER MOTOR
2	SPIRAL BEATER
3	MIXING BOWL
4	LOWER MOTOR
5	BOWL CLAW
6	MOTOR SHAFT
7	FRAME

Figure 2: The part lists of the modeled design.

3. Experimental Results

3.1. Performance Evaluation of the Dough Kneading Machine

This work did not only focus on the mixing capacity but also on the hygienic, smoothness, pliability, and ductility nature of dough produced within a specified time, which all influence the quality of the end edible end products. Therefore, the developed machine was subjected to tests to evaluate its performance for the intended design purpose and objectives. The evaluation was carried out at the Central Workshop, Department of Mechanical Engineering, Adeleke University, Ede. A different recipe for the dough preparation was formulated under an ambient temperature of 27 °C and 56% average relative humidity except for water which was determined experimentally (Zounis & Quai, 1997).

3.2. Dough Preparation

The recipe for the dough was prepared after consulting the food chemists in the Department of Chemistry at Adeleke University and following the standard kinds of literature on the methods of dough preparation. However, the amount of water that formed the dough in each case was determined by the experiment. The mass (kg) of the ingredients for the dough and the composition of the recipe preparation are shown in Table 2. The percentage (%) compositions in the table were in terms of the mass of flour used in each run of the experiment (x kg of flour in each case).

Table 2: Compositions of the dough ingredients for machine evaluation.

S/N Type	1	2	3	4	5	6
Recipe	Sugar (M_{su})	Salt (M_{st})	Veg. oil (M_{vo})	Margarine (M_{mag})	Milk (M_{mk})	Yeast (M_{by})
Composition (%)	13.5	1.60	1.65	3.30%	3.00	1.25

Ten different experiments in total were run on the machine. The experiment began by measuring the speed of the beater at no load and recording it, then putting 0.5 kg of flour into the mixing bowl. This was followed by the addition of masses of other constituents according to the percentage composition of flour, as shown in Table 2. The machine was powered to start, and while the beater started mixing, the water was gradually added to the mixture in the mixing bowl until a smooth dough was formed. The shear and extensional properties during the mechanical dough development, which were the most important parameters, were monitored according to the method provided by Okafor (2015) because they affect the dough's resistance to deformation. The final speed of the beater was taken at the point of the smooth dough with a tachometer, and the machine was stopped. The mass of the dough was taken, and the mass of water that formed the dough was estimated. This process was repeated by increasing the mass of flour by 0.5 kg and adding other constituents by % composition. Figure 3 shows a sample of the formed dough.

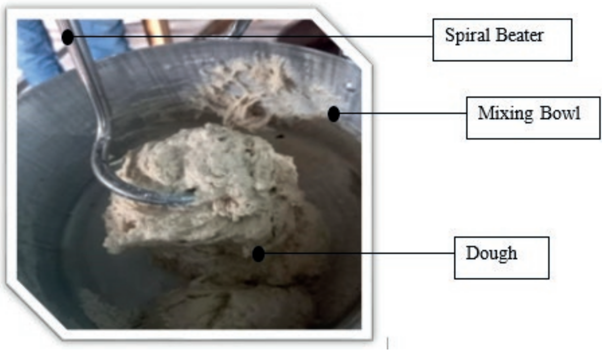


Figure 3: Image of the produced dough.

3.3. Capacity of the Machine

The capacity of the machine is the amount of dough in kg the machine can knead successfully in a given time (minutes). It was determined at each run of the experiment using Equation (12).

$$Cp = \frac{\text{Mass of Dough (kg)}}{\text{Time taken (minutes)}} \text{ (kg/min)} \qquad (12)$$

3.4. Efficiency of the Machine

Efficiency is the ratio of output power or quantity to the input power or quantity. The efficiency of the machine in each run of the experiment was determined by two methods, as follows:

3.4.1. Efficiency of the Machine by Mass Ratio

Equation (13) estimated the efficiency of the machine on a mass basis. While Equation (14) estimated the efficiency of the machine on a speed basis.

$$\%_m = \frac{\text{Mass of Dough (kg)}}{\text{Mass of all the ingredients (kg)}} \times 100 \qquad (13)$$

$$\%_{rpm} = \frac{\text{Beater final speed during dough formation}}{\text{Beater initial speed at no load}} \times 100 \qquad (14)$$

4. Results and Discussion

The overview of the results of the design considerations is presented in Table 3.

Table 3: Results of the design consideration.

S/N	Parameter	Value	Unit
1	Electric power Input of Motor (P_{in})	1.85	kW
2	Beater or motor power output (P_{out})	1.48	kW
3	Kneading torque required (T_m)	128	Nm
4	Average speed (N_{AV})	102.02	rpm
5	The volume of dough (V_{dough})	0.00397	m^3
6	The volume of the mixing bowl (V_{bowl})	0.005161	m^3
7	Height of mixing bowl (h_{bw})	0.073	m
8	The thickness of the mixing bowl (t)	1.3556×10^{-3}	m
9	Diameter of spiral beater coil (d)	0.0114	m
10	Maximum deflection in spiral beater coil (δ_{max})	0.07	m

4.1. Power Input and Motor Power Output of the rotating Spindle or Beater

Table 3 summarizes the results of the design considerations for the machine. The electrical power input (P_{in}) for the single-phase motor and beater power output (P_{out}) were 1.85 and 1.48 kW, respectively. These values ensured that the power output from the rotating spindle of the motors at full load fastened to the beater was less than the electrical power input supplied by the voltage. This is good for the safety of the machine motor from any form of overheating and damage (McCoy & John, 1996; Orelaja et al., 2020; Todd, 2001).

4.2. Kneading Torque and Average Power Developed by the Machine

The kneading torque obtained was approximately 128 Nm. This magnitude is adequate to provide enough rotation for hydrated dough recipes in the mixing bowl, especially at the point of dough formation, where the characteristics of ductility, smoothness, tenacity, and extensibility of the dough tend to demand more work output from the motor, thereby impinging on the beater shaft rotation and causing reduced torque and power. The kneading torque obtained was higher than most of the values observed from the literature consulted, which are around 50–80 Nm (Ajibola & Ibrahim, 2020; Chikelu et al., 2015; Owolabi et al., 2017). This makes the machine less susceptible to mechanical damage and enhances its efficiency at processing dough in a shorter amount of time. The average power (P_{AV}) developed by the machine was estimated from Equation (16) (Sunmonu et al., 2021).

$$P_{AV} = \frac{2\pi N_{AV} T_m}{60} \approx 1.37 \text{ kW} \qquad (15)$$

4.3. The Volumes of the Dough and Mixing Bowl, and the Height of the Mixing Bowl

The V_{dough} and V_{bowl} were estimated at 0.00397 and 0.005161 m^3 respectively. The estimated volume of the dough was below the total volume of the mixing bowl to allow adequate clearance space for the mixing and to avoid excessive clogging. Clogging can cause excessive power and torque requirements from the motor and then damage the motor coil (Khurmi & Gupta, 2005; Sunmonu et al., 2021). The height of the mixing bowl obtained was 0.073 m. This value is adequate to support each batch production of the dough for the machine design.

4.4. The Thickness of the Mixing Bowl

The obtained value was 1.3556×10^{-3} m or 0.0013556 m (≈1.4 mm). Sunmonu et al. (2021) designed the pulley-powered dough-kneading machine whose mixing bowl was made of the same material but whose thickness was around 0.0017 m for 10 kg of dough production per batch. Ajibola and Ibrahim (2020), has a mixing bowl thickness of 0.0016 m. The developed machine in this study has a comparable thickness to dough mass (kg) production per batch. This thickness tends to withstand the internal pressure created by the mixing constituents and avoid rupture. Moreover, the mixing technique of the spiral beater allows the machine to accommodate more dough capacity beyond 5.0 kg per batch to 7.5 kg per batch.

4.5. The Diameter of the Spiral Beater

The designed beater diameter was 0.0114 m (11.4 mm). The kneading end of the beater was made up of three (3) coils for more quick aeration of the dough and to accelerate dough formation at a lesser time in comparison to other kneading machines of the same capacity. Both the beater diameter and maximum deflection were carefully estimated to withstand the kneading processes, especially during the increased torque requirements due to more dough ductility and other resistive parameters at the point of dough formation.

4.6. Results of the Performance Evaluation of the Machine

The results of the performance evaluation of the developed machine are presented in Table 4.

4.6.1. Variation of the machine capacity and water with mass of the dough

Figure 4 shows how the capacity of the machine and hydration level change with the amount of dough formed in kg. The capacity of both the machine and the hydration level (water) increase as the mass of the dough increases. These relationships are almost linear in both cases. The capacity increases to the point of maximum at 1.19 kg/min, as shown in Figure 4. Beyond this maximum point, there is a sharp decline in capacity while the mass of the dough increases. This decline could be attributed to the increased power required to knead the dough due to improved ductility over time as more water is added against the power supplied by the motor (Dahiru et al., 2007; Owolabi et al., 2017). The increase in water demand as the mass of dough increases allows adequate hydration of the protein formation. These support the gluten to relax and unwind and therefore help to build the network of gas produced by dough fermentation (Cauvain, 2015; Gareth, 2020; Zheng et al., 2000).

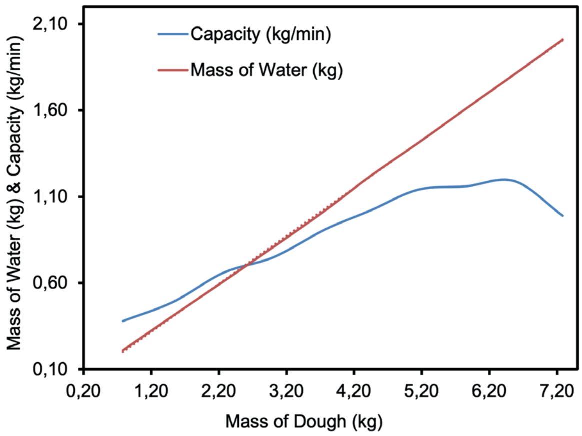


Figure 4: The variation of capacity and hydration level with the mass of dough.

However, a few of these water molecules dried up before the full dough formation, which increased according to the M_{dough} produced as shown in Figure 5. This hydration loss can be attributed to the aeration process, and the effect can be seen as the M_{dough} which is less than the total mass recipes used for the dough production (Cauvain, 2015; Gareth, 2020; MacRitchie, 2010; Nobyleong,

Table 4: Performance evaluation results.

S/N	Mass of Dough (M_d)	Capacity (kg/min)	Mass of Water for dough formation (M_w)	Efficiency by Mass (%)	Efficiency by speed (%)
1	0.78	0.38	0.21	92.20	96.47
2	1.52	0.49	0.41	92.01	94.30
3	2.27	0.66	0.61	91.61	93.94
4	3.01	0.75	0.81	91.35	93.23
5	3.77	0.91	1.02	91.26	91.67
6	4.44	1.02	1.22	89.93	91.40
7	5.14	1.14	1.41	89.81	91.19
8	5.85	1.16	1.61	89.46	90.53
9	6.57	1.19	1.83	89.45	90.40
10	7.28	0.99	2.01	89.42	90.15

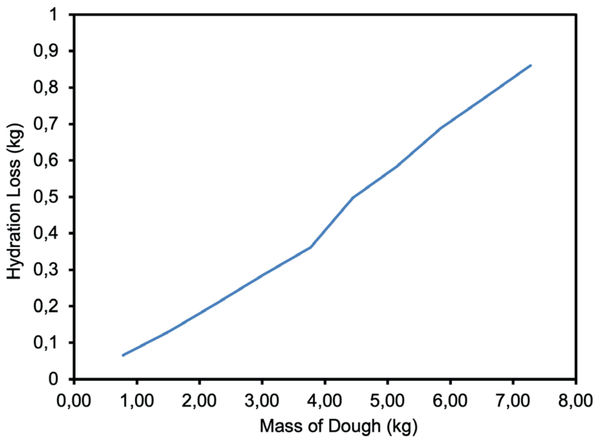


Figure 5: Hydration loss variation with dough formation.

2017). The obtained R^2 showed that the variation in the mass of the dough could account for about 82.7%, 99.99%, and 99.28% of the variation in the machine's capacity, the mass of water added, and hydration loss dough (O. M. John, 2012; O. R. John et al., 1998).

4.6.2. Efficiencies of the kneading machine

The efficiencies of the machine are presented in Figure 6. The efficiencies of the machine in both cases decrease with an increase in the mass of the dough due to increased loading and more power consumption. The obtained R^2 values are 91.3% and 92.5% for the speed-to-speed ratio and mass-to-mass ratio efficiencies, respectively. This shows that, even though the consideration of the speed ratio of the machine gives a higher efficiency than the mass ratio, the variation in efficiency by mass ratio can be more explained than the variation in efficiency by speed ratio. Except at the point where the mass of the dough was 3.77 kg, at which the two efficiencies are almost at equilibrium. Therefore, it is more suitable to analyze the efficiency of the machine by mass ratio. Finally, the result also showed that the overall average speed of the beater was 102.02 rpm, during which the capacity, speed ratio efficiency, and mass ratio efficiency of the machine were 0.87 kg/min, 92.33%, and 90.65%, respectively. The dough-kneading machine is efficient and can be produced for small and medium-scale businesses or entrepreneurs to aid the efficient and continuous production of their doughs, which can be used for different flour-based products (Irving & Saxton, 1967).

4.6.3. Variation of the Torque with the Time for Dough Formation

The presented results also reveal a distinct and notable correlation between mixing time and torque during the process of dough preparation. The torque values exhibit a consistent increase, ranging from 10.41 Nm to 48.59 Nm, as the mixing time progresses from 2.05 to 7.33 minutes, a phenomenon depicted in Figure 7. This observation strongly implies that prolonged mixing durations result in heightened torque requirements, indicating an ongoing process of gluten formation and dough development. Moreover, it is noted that torque exhibited a corresponding increase with the variation in dough mass, which ranged from 0.846 kg to 8.141 kg. This suggests that factors such as ingredient proportions or hydration levels may exert an influential role in shaping dough characteristics. These findings have practical significance for a wide range of applications, including small-scale businesses and industries such as baking and food processing. This relationship can enable the optimization of manufacturing processes and the determination of ideal mixing durations to achieve the desired dough consistency.

The presented results not only shed light on the relationship between mixing time, torque, and dough characteristics but also in the context of energy consumption in dough preparation processes. As observed, the torque increases with extended mixing times, which implies ongoing gluten formation and dough development. This increase in torque corresponds to higher energy consumption, as more energy is required to sustain the mixing process. It is evident that energy consumption is closely tied to the amount of dough mass obtained per hour, as both parameters are influenced by the mixing time. As mixing time increases, more dough mass can be processed per hour, but this also entails higher energy consumption due to the elevated torque requirements. These findings are pertinent

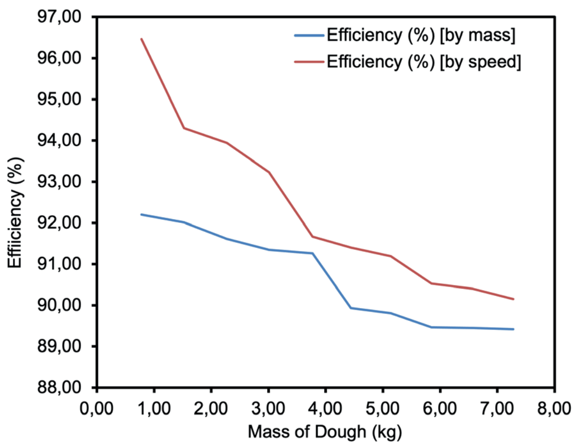


Figure 6: Efficiencies of the Machine by Mass and Speed.

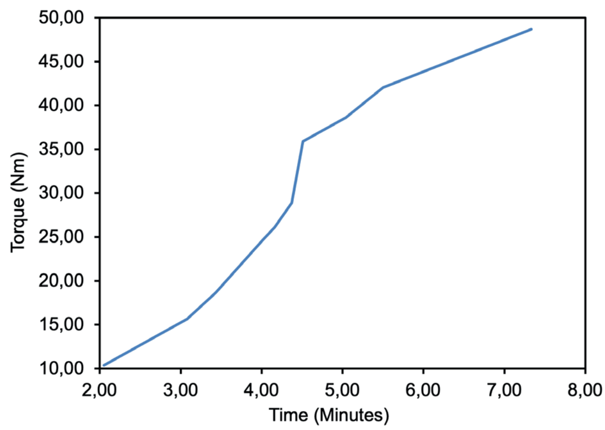


Figure 7: Torque Developed by the Machine Over Time.

for baking and food processing, as they highlight the need for optimizing energy efficiency alongside dough consistency.

5. Conclusion

This study carried out the development of dough-kneading machines to address the production needs of small and medium-scale businesses in Ede Town, Osun State, Nigeria. Two motors powered the kneading operation of the machine, and the beater was attached to the upper motor. The design was carried out, and the components were mounted on the steel frame. In the design concept, the study considered the selection of materials that are suitable for dough production to avoid food contamination. The fabrication and assembly of the machine were made according to the design concept by welding, coupling, and polishing the sharp edges to avoid accidents. Following the principle of hygiene, the machine was painted for the smooth production of dough and to avoid corrosion. The quality of the produced dough was assessed using the method provided by Zheng et al. (2000). The kneading torque was 128 Nm, while the volume of dough per batch and the volume of the mixing bowl were 0.00397 and 0.00512 m^3 respectively. The results showed that the average power and speed of the beater needed to knead the dough were 1.37 kW and 102.02 rpm. While the capacity, speed ratio efficiency, and mass ratio efficiency are 0.87 kg/min, 92.33%, and 90.65%, respectively. The dough-kneading machine is easy to move around, has limited movable parts, and is efficient. It is suitable and can be produced for small and medium-scale enterprises.

Future research can also aim at exploring a broader range of mixing times and dough compositions in order to improve the comprehension of ideal mixing durations. Furthermore, the establishment of standardized experimental procedures is of utmost importance to guarantee data consistency and reproducibility in forthcoming experiments. More studies are needed in this area to explore ways to minimize energy consumption while achieving the desired dough characteristics. This can be achieved through adjustments in mixing time, equipment efficiency, or other process variables. Moreover, standardizing procedures and factors such as ingredient proportions and hydration levels can further refine the relationship between energy consumption and dough mass production. Thereby facilitating more sustainable and efficient dough manufacturing practices.

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