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Establishment and Performance Evaluation of a Small-scale Moringa Leaves Powder Processing Plant in Nigeria

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Abstract

A small-scale dry moringa leaves powder processing plant of 300 kg per day capacity was established in Federal Polytechnic Bida, Niger State, Nigeria. All the machine parts were fabricated in the Institution. The plant is made up of the following sections: leaves washing unit, draining unit, drying, and milling units. All machine parts that will get in direct contact with the moringa leaves were made of stainless steel. The results of testing show that all the proximate compositions of the samples significantly ($p<0.05$) changed with an increase in drying temperatures. The moisture content, crude protein, and fat content of the dried leaves sample decreased with an increase in drying temperature from 34°C to 49°C. While carbohydrate, fibre, and ash content increased significantly ($p<0.05$) with an increase in drying temperature of the moringa leaves samples. The milling efficiency of the hammer mill ranged between 60.39% and 96.83%. The highest milling efficiency of 96.83 was obtained from the interaction between 18 numbers of hammer head assembly, moringa moisture content of 9 %, and speed of 1460 rpm. The milling efficiency increased with an increase in the speed of milling and an increase in the number of hammer head but decreased with an increase in the moisture content of the leaves. In conclusion, dried moringa leaves contained more fat, fibre, protein, and carbohydrate than the fresh leaves. The small-scale Moringa leaves powder processing plant was established at the Federal Polytechnic Bida, Niger State, in October 2017, and the study continued until January 2021, giving a total duration of approximately three years and three months.

Keywords

Establishment; indigenous; leaves; moringa; plant; processing; Nigeria

1. Introduction

Moringa leaves powder is a product obtained from milling dried Moringa oleifera leaves. The leaves of the Moringa oleifera tree are exceptionally nutritious and may be consumed fresh, cooked, or dried. Crucially, the dried leaves retain their nutrient content and are easily converted into a stable leaf powder [1]. Moringa leaf powder is widely used as a food supplement and can be consumed in various ways, such as mixing a teaspoon with juices or beverages, or incorporating it into prepared vegetable dishes or soups. As little as one teaspoon of the leaf powder can provide a broad spectrum of nutrients required by the body. According to [2], a daily administration of 25 g of Moringa

powder to pregnant women can significantly enhance their prenatal nutrition. Beyond plain powder, Moringa is also processed into capsules. No adverse effects from the daily consumption of Moringa leaves and seeds have been reported; furthermore, it offers various health benefits, including reducing cholesterol and triglycerides ("bad" fats), controlling blood sugar, supporting normal energy balance, supplying essential vitamins and minerals, and providing powerful anti-ageing and anti-inflammatory substances, many of which possess anti-cancer properties [3]. The leaves are a strong source of vitamins A, B, and C, and minerals, particularly iron and sulphur-containing amino acids [4]. Fuglie [4] and Anwar, et al. [5] report that the processing of Moringa leaves yields numerous socio-economic and health benefits, notably serving as a source of income for producers and dealers. Moringa oleifera contains more Vitamin A than carrots, more calcium than milk, more iron than spinach, more Vitamin C than oranges, and more potassium than bananas.

Moringa oleifera has attracted increasing scientific attention globally due to its exceptional nutritional density and wide-ranging physiological benefits. According to [6], the leaves, which are commonly processed into powder, contain high levels of quality proteins, essential vitamins such as A, C, and E, and key minerals including calcium, potassium, and iron. The authors further report that the rich profile of phytochemicals present in the leaf powder confers potent antioxidant capacity, which plays a significant role in mitigating oxidative stress and associated chronic diseases. In addition to these nutritional attributes, M. oleifera leaf powder demonstrates notable anti-inflammatory, antimicrobial, antidiabetic, antihypertensive, and lipid-modulating properties, indicating its potential to support immune function, glucose regulation, and cardiovascular health. As such, [6] positions Moringa oleifera leaf powder as a valuable functional food with promising applications in disease prevention and overall health promotion.

Despite the proven benefits, the current indigenous processing methods for Moringa leaves powder have been observed to be physically demanding and deficient in terms of quality and efficiency. Standardised steps or procedures that guarantee hygienic and high-quality production are often lacking. Most locally produced Moringa leaf powders are frequently found to be adulterated due to the poor sanitary quality of the processing environments [5]. Among the challenges faced by Moringa dealers is the poor quality of their products [7]. Consumer attitudes towards locally processed food supplements are generally negative, with these products being perceived as inferior compared to imported alternatives, largely due to concerns over adulteration during processing.

The general production process and packaging of Moringa powder are often rudimentary, making it simple enough to be done at home. Consequently, products are typically poorly labelled or branded. While initial demand for the powder was high, the influx of numerous fake and adulterated products (with similar colour and taste) undermined consumer confidence and suppressed demand. This led some dealers to abandon Moringa powder production in favour of other Moringa products requiring more specialised processing and packaging techniques. According to [7], approximately 82% of dealers and consumers complained about poor processing methods, the absence of standardised production protocols, and inadequate quality control systems. Furthermore, the texture of the product often varies significantly between different processors. Earlier established Moringa processing plants in Nigeria include: Moringa Agro-Tech Ltd in Kaduna: Active since 2015, operating with a capacity of about 2 tonnes per day using cold-press oil extraction and leaf powder milling technologies. Its main shortcoming was limited automation and inadequate quality certification, leaving a gap in meeting international export standards [8]. Grace Moringa Global in Lagos: Established in 2017, processing approximately 1.5 tonnes per day with stainless steel dryers and GMP-certified packaging equipment. However, the company struggled with inconsistent raw material supply, highlighting a gap in sustainable sourcing [9]. Divine Moringa Processing in Enugu: Active from 2018, with a capacity of 1 tonne per day using solar dryers and hammer mills. Despite this, it faced challenges with energy reliability and lacked advanced filtration sy2.3.3 drying chamber.

The Drying stems, leaving a gap in product purity for pharmaceutical applications [10]. The Ogbomosho Moringa Cooperative in Oyo State: Operational since 2019 with a 500 kg per day capacity using manual presses and local milling machines, suffering from low mechanisation and poor packaging standards, creating a gap in competitiveness against industrial-scale processors [11].

Despite Nigeria's growing interest in Moringa processing, the industry remains constrained by limited mechanisation, inadequate quality certification, unsustainable raw material supply chains, unreliable energy sources, insufficient technical specifications for high-value extracts, poor packaging and branding, and a weak linkage between academic research and industrial application, all of which constitute significant barriers to achieving international competitiveness [8-11]. Hence, the design, fabrication, and testing of a complete Moringa leaf powder processing plant capable of producing acceptable, hygienic, and good-quality powder is of immense significance in alleviating some of the shortcomings associated with current production methods. The primary aim of this project was to

establish a 300 kg per day Moringa leaves powder processing plant capable of producing hygienic and high-quality leaf powder. Furthermore, the project aimed to provide a source of avenue for local processors to process their product, serve as a valuable teaching aid, create rural employment opportunities for unemployed youths, and generally contribute to rural development within the state.

2. Methods

2.1 Processing centre layout

The Moringa leaves powder processing plant layout at the Federal Polytechnic Bida has the following four main sections as shown in Figure 1.

1. Washing and cleaning areas: This is the area where the striped leaflets were collected, cleaned to discard diseased and damaged leaves before weighing.

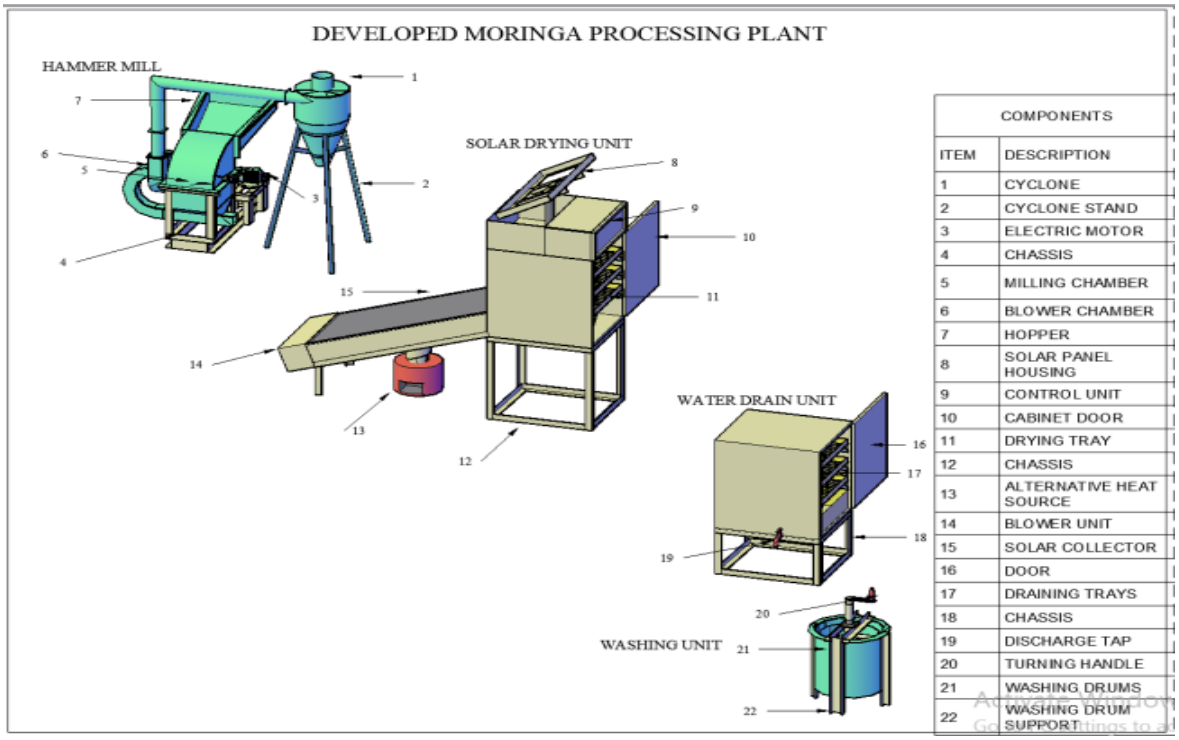

Figure 1. AutoCAD drawing of the processing plant layout.

2. Draining chamber: Draining of excess water from the leaves was carried out by spreading the leaves on perforated trays made with stainless steel inside the draining chamber. The drained water was collected at the water collector and channel out through a hose and valve fixed inside the chamber.

3. Drying Section: This is the section where the drying of the drained leaves takes place. The drying process is achieved using direct solar heating or heat generated from burning of biomass.

4. Milling Section: This is a hammer mill powered by a 15 Hp electric motor. The milling of the dried leaves to powdery form takes place here.

2.2 Production process

The production process of the small scale moringa leaves powder processing plant at Federal Polytechnic Bida is explained in Fig. 2. The leaflets were striped from the leaf petiole and diseased and damaged leaves were discarded. The leaflet was washed using the developed washer with clean potable water to remove dirt; the leaves washed again in 1% saline solution (NaCl) for 5 minutes to remove microbes [12]. The leaves were further washed with 70% ethanol which was followed by twice washing with distilled water. Draining of excess water from the leaves was carried out by spreading the leaves on perforated trays made with stainless steel inside the draining chamber. The leaves were dried to the maximum recommended moisture content of 10% using the automated solar dryer. The

dried leaves were milled and sieved using the developed stainless steel hammer mill. The moringa leaf powder was finally dry to moisture content below 7.5% [12].

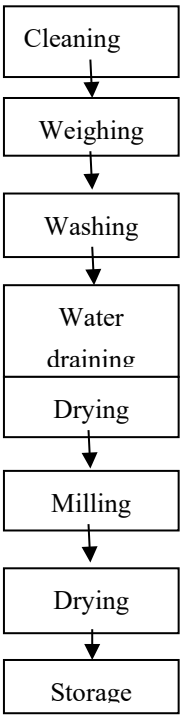

Figure 2. Processing process of the small scale moringa leaves powder processing plant at Federal Polytechnic Bida.

2.3 The plant's components and performance assessment

The following machines and equipment were designed and fabricated by the authors and then installed by the authors in the Agricultural and Bioenvironmental Engineering Department of Federal Polytechnic Bida.

2.3.1 Washing chamber

This unit is made of stainless-steel plate (2 mm) and 2 mm stainless pipe which serves as the stirrer. It is cylindrical in shape with two cylinders, the inner cylinder is perforated with diameter of 0.5 m, while the external cylinder has diameter of 0.6 m. The heights of the two cylinders are 0.9 m each. The washing drum is shown in Figure 3.

Figure 3. Moringa leaves washing equipment.

2.3.2 Draining chamber

This unit is made of stainless-steel materials. It is made up of four trays with dimensions 0.9 m x 0.9 m x 0.8 m each. Two of the trays (trays number 1 and 3) are perforated for draining of water while the other two (trays number 2 and 4) are not perforated and serves as the water collectors. These trays were inclined for easy discharge of water out of the chamber. Each of the water collector trays has a nozzle for discharge of the collected water out of the chamber. It is shown in Figure 4.

Figure 4. Draining chamber showing the trays and water collectors.

2.3.3 Drying chamber

The Drying chamber is made of a stainless-steel plate (1 mm) and galvanize sheet (1 mm) with glass fibre as an isolating material between them. The chamber is made up of 0.9 m x 0.9 x 0.8 m dimension it contains an exhaust outlet portion at the upper part of the door. It is joined with an adjustable solar collector attached to the biomass heating unit (Figures 5 and 6) at the bottom. The drying chamber has an opening of 0.05 m through which pre-heated air coming from the solar collector passes into the drying chamber. The drying trays were made with stainless steel mesh, and space was provided around the trays in order to allow free air circulation within the chamber. The essence of providing this free space is to provide equal drying facility to the entire moringa product inside the drying chamber and thus increase the rate of drying. Two exhaust fans were fixed at the bottom of the drying chamber and covered at the end with a filtering screen. The drying chamber is shown in Figure 7. A temperature sensor capable of sensing temperature differences between 0 ° and 100 ° was fixed inside the chamber. A control system that received a signal from the sensor and actively and deactivate the exhaust fan was also fixed on top of the chamber. The control system is shown in Figure 7.

Figure 5. Hybrid solar and biomass dryer.

Figure 6. Biomass heating unit.

Figure 7. Control system.

2.3.4 Solar collector

The solar collector is a cube in shape with dimensions of 1.6 m x 0.9 x 0.2 m. It is connected to the drying chamber, and it allows the passage of hot air into the drying chamber. The solar collector is made of mild steel of 0.002 m thickness, and it is painted black. At the upper part of the collector, a transparent glass sheet (0.005 m thick) was fixed 0.05 m above the collector. The bottom and sides portions of the collector were fitted with two non-corrosives galvanize iron sheets, and between them a glass fibre of 0.05 m thickness was fixed. At the bottom of the collector, a space of 0.05 m was provided between it and the internal galvanized sheet. This is to allow free circulation of heat generated from the burning of the biomass. The solar collector was designed to be adjustable between the angles of 10 ° to 40 ° based on the latitude of Nigeria, which is between the ranges of 4 ° to 14 ° in order to allow utilization of the solar system anywhere in Nigeria. It was embedded with adjustable legs in front, as shown in Figure 5.

2.3.5 Solar panel

The solar panel used is a 72-watt solar panel, and it is shown in Plate 3. A marine deep-cycle battery that has the advantage of discharging and recharging ability was used. The battery serves as a power accumulator in a case where the solar drying will take place over night in this case it needs to work for almost 18 hours without charging, this call for selection of a large size battery of 18-amp capacity.

2.3.6 Hammer mill

The hammer mill is also made of stainless-steel materials. It has 21 numbers of rectangular beaters and eight numbers of circular beaters. The rectangular beaters are 0.11 m x 0.05 x 0.006 m in dimensions, while the circular beaters have diameters and thickness of 0.22 m x 0.006 m, respectively. The milling chamber has a concave sieve at the bottom. Attached to the base of the machine is extractor fan that extracts the moringa leaves powder and conveyed them out of the machine via the delivery funnel. The machine is powered by 15 hp electric motor with speed of 1460 rpm. The machine is shown in Figure 8.

Figure 8. The Hammer mill.

2.3.7 Mode of operations of the plants

The following procedures were followed to determine the machine performance parameters and moringa leaves powder quality. The green house effects were adopted as the main working principles of this hybrid solar dryer. The sources of heat for the dryers are indirect solar energy and heat generated from heating of Biomass materials. The heat energy from any of the two sources (depend on the one in usage) heat up the fresh air entering from atmosphere through air inlet and is passed through the bottom of the drying chamber and it collects the moisture from moringa leaves and it is exhausted through air outlet. As the air passed into the drying chamber it temperature increases, as the temperature reaches preset 490c the temperature sensor inside the drying chamber sends a signal to the control system which in turns activated the hot air extractor fan situated at the bottom of the drying chamber. The fan blows in filtered air into the chamber which cools the temperature of the chamber. As the temperature decrease to 200c the temperature sensor reactivated again and sends a signal to the control system which in turns deactivated the extractor fan. This process continues automatically. The dried moringa leaves were then fed into the hammer mill which ground them into powder form as shown in Figure 9 below.

Figure 9. Milled moringa powder.

2.4 Performance testing of the plant

Two different experiments were conducted to test the performance of the mini plant. In the first experiment, the performance of the drying section was tested, while in the second experiment, the performance of the milling section was tested.

2.4.1 Testing of the drying unit

In this experiment the moringa leave samples were dried to 10.5 % moisture content at four different temperatures of 34°C, 39°C, 44°C and 49°C using the developed equipment. In each experiment the proximate composition of

the dried sample was determined. Each of the experiment was replicated three times and the average value were determined as presented in Figure 10.

Determination of moringa leaves powder quality: The quality of the moringa leaves powder was determined by evaluating its proximate composition. The analysis carried is as follows.

Proximate Composition: The Proximate composition including moisture, fat, crude protein, ash, and carbohydrate contents of beverage samples, was evaluated at the National Cereal Research Institute, Badeggi, Bida, Niger State, according to [13] and [14].

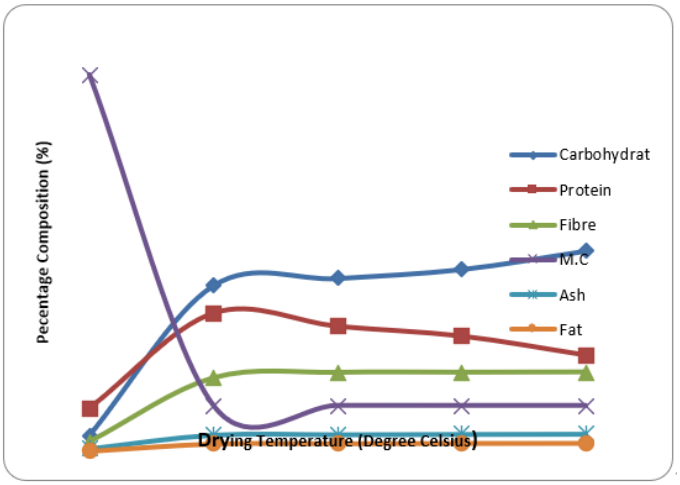

Figure 10. Effect of variation in drying temperature on proximate composition.

2.4.2 Testing of the milling unit

(1) Experimental setup and procedure for developing the design matrix

In this experiment, five levels-three factors (53) central composite rotational design (CCRD) of response surface method (RSM) was used. The factors and their levels are; hammer head of 21- heads, 18- heads, 14- heads, 10-heads and 7- heads assembly, milling speed of 1582 rpm, 1460 rpm, 1360 rpm, 1260 rpm and 1192 rpm, moringa leaves moisture content of 7.9 %, 9%, 10.5% 12% and 13% in order to investigate the milling efficiency of the machine. The experiment consists of 20 experimental runs (2k + 2k + m, where k represents the number of factors independent variables)), involving eight factorial points (23), six axial point (2 x 3), and six replicated centre points at zero level [15] and [16].

(2) Determination of machine milling efficiency

This is the measure of the degree by which the grains are reduced in size and was determined as reported by [17] and [18].

$$M_E = \frac{M_O}{M_I} \text{x } 100 \quad (1)$$

where, M_E is the milling efficiency (%), M_O is the amount of the material passing through the sieve (kg), M_I is the total weight of the material feed into the machine (kg)

3. Results and Discussion

3.1 Effects of variation of drying temperature on proximate composition of the moringa leaves

The proximate composition of the sample was determined, and the result showed that the fresh moringa leaves had a moisture content of 80.22 g/100 g, a fat content of 1.03 g/100 g, a protein content of 9.95 g/100 g, a fibre content of 2.9 g/100 g, and ash and carbohydrate contents of 1.59 and 4.31 g/100 g, respectively. All the samples were dried to almost 10.5% moisture content. The sample dried using indirect solar energy at 34°C had fat content 2.62 g/100 g, protein content of 30.08 g/100 g, fibre content of 16.38 g/100 g, ash and carbohydrate contents of 4.48 and 35.94g/100g respectively. While that dried using the furnace at 49°C had fat content 2.43 g/100 g, protein content of 21.2 g/100 g, fibre content of 17.6 g/100 g, ash and carbohydrate contents of 4.68 and 43.3 g/100 g respectively as shown in Figure 10.

From Figure 3, all the parameters significantly ($p<0.05$) changed with change in drying temperatures. Crude protein of the samples decreased significantly ($p<0.05$) with increased in drying temperature. Samples dried at 34°C had value of 30.08 g/100 g, at 39°C had value of 27.28 g/100 g, 44°C had a value of 25.22 g/100 g, and at 49°C had a value of 21.2 g/100 g. Similar trends were observed for fat content which had values of 1.03 g/100 g for fresh leaves, 2.62 g/100 g at 34°C, 2.6 g/100 g at 39°C, 2.54 g/100 g at 44°C and 2.43 g/100 g at 49°C. The decrease in protein and fat content with a corresponding increase in dying temperature could be a result of denaturation. This result is similar to that reported by [19].

The carbohydrate, fibre and ash content increased significantly ($p<0.05$) with increased in drying temperature of the moringa leaves samples. Samples dried at 34°C had lower carbohydrate content of 35.94g/100 g, fibre content of 16.38 g/100 g, and ash content of 4.48 g/100 g, the values increased significantly to 43.3, 17.6, and 4.68 g/100 g, respectively, when the leaves were dried at 49°C. This is in agreement with the values reported by [20]. [20] and [21], reported that mild drying conditions with lower temperature may improve the product quality but decrease the drying rate.

The result shows that dry leaves are better source of fat, fibre, protein and carbohydrate than the fresh leaves. The trend in change in the proximate composition of the M. oleifera leaves at different drying conditions agrees with the work of [20] and [22].

3.2 Effects of machine parameters on milling efficiency of the hammer mill

The machine parameters investigated in this study include: number of hammer head, speed of milling and moisture content of the moringa leaves, and the response is the milling efficiency. The result of their interaction is presented in Table 1.

Table 1. Effects of interaction between hammer head, moisture content and speed on machine milling efficiency

Std order	Run order	No of Hammer Beaters	Speed of rotation	Moisture content	Milling Efficiency
		Number	Rpm	(%)	(%)
11	1	14	1192	10.5	71.48
19	2	14	1360	10.5	73.18
15	3	14	1360	10.5	73.2
9	4	7	1360	10.5	63.2
6	5	18	1260	12	71.87
20	6	14	1360	10.5	73.2
12	7	14	1528	10.5	79.5
3	8	10	1460	9	72.58
1	9	10	1260	9	67.4
2	10	18	1260	9	85.33
13	11	14	1360	8	79.32
17	12	14	1360	10.5	73.21
18	13	14	1360	10.5	80.19
4	14	18	1460	9	96.83
14	15	14	1360	13	60.39
5	16	10	1260	12	64.18
16	17	14	1360	10.5	73.25
10	18	21	1360	10.5	89.92
7	19	10	1460	12	62.4
8	20	18	1460	12	76.14

3.3 Milling efficiency

From Table 1, the milling efficiency ranged between 60.39% and 96.83%. The highest milling efficiency of 96.83% was obtained from interaction between 18 numbers of hammer head assembly, moringa moisture content of 9% and speed of 1460 rpm while the least efficiency of blending of 60.39% was obtained from interaction between 14 numbers of hammer head assembly, moringa moisture content of 13% and speed of 1360 rpm.

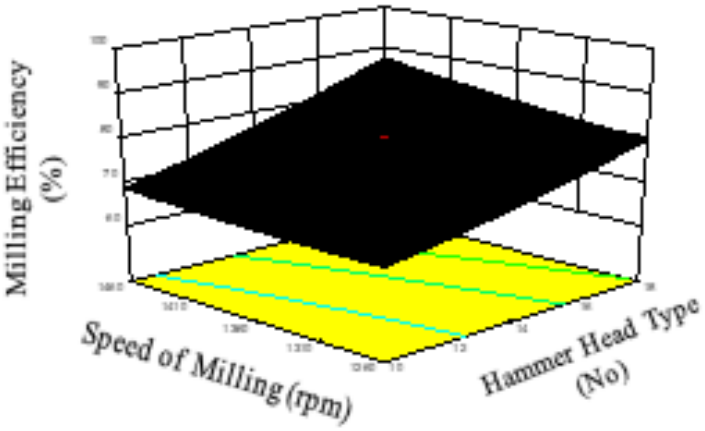

Figure 11. Response surface for milling efficiency with respect to speed and hammer head.

3.4 Relationship between moisture content and speed of milling

The response surface for milling efficiency based on relationship between moisture content and speed of milling is presented in Figure 12. The milling efficiency decreased from 78% to 68% as the moringa leaves moisture content increase from 9% to 12%. This could be a result of an increase in friction and resistance to segregation of the leaves as the moisture content increased. The milling efficiency was also observed to increase from 76% to 84% as the speed increased from 1260 rpm to 1460 rpm. This could be a result of more segregation of the materials with an increase in the speed of milling.

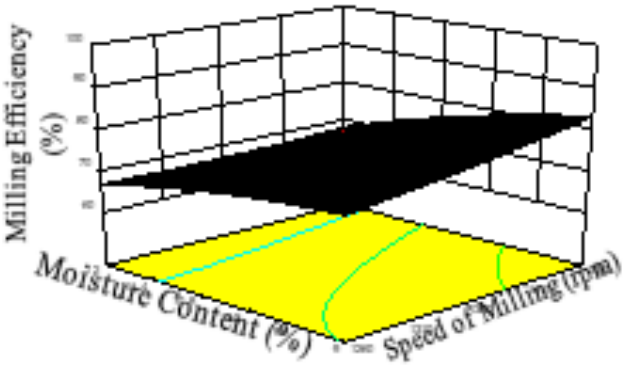

Figure 12. Response surface for milling efficiency with respect to moisture content and speed.

3.5 Relationship between speed of moisture content and hammer head

The response surface for milling efficiency based on the relationship between moisture content and hammer head is presented in Figure 13. The milling efficiency was observed to decrease from 75.5% to 63% with an increase in moisture content from 9% to 12%. This could be a result of an increase in resistance of the leaves to segregation due to their high-water content. The milling efficiency was also observed to increase from 75.5% to 90% with an increase in the number of hammer heads from 10 to 18. This was a result of more contact between the leaves and the hammer head with an increase in the number of heads. This conforms to the result of an earlier study by [24]

were blade design affect segregation of materials.

Optimisation of the machine parameters was carried out using a numeric technique in rsm with the goal of maximising the milling efficiency. It gave the optimum values of 18 number of hammer heads, moisture content of 9%, and speed of 1460 rpm, while the milling efficiency and desirability are 96.34% and 0.988, respectively

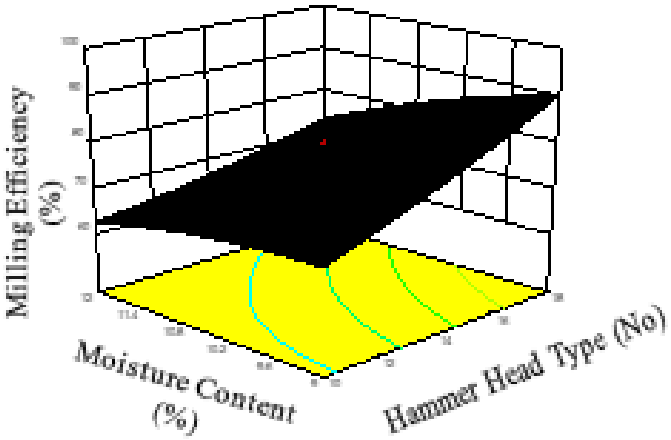

Figure 13. Response surface for milling efficiency with respect to moisture content and number of hammer head.

4. Conclusion

The Federal Polytechnic Bida Moringa Leaf Processing Plant, sponsored by TETFUND, represents the institution's first complete indigenous processing facility, successfully established and developed by the authors following extensive research. The performance evaluation of the unit confirms that low drying temperatures (34°C) are significantly superior for maximising the retention of crude protein and fat in the Moringa powder. Furthermore, machine optimisation revealed that the maximum milling efficiency (96.83%) is achieved at a 9% moisture content, specifically when using 18 hammer beaters operating at 1460 rpm, thereby establishing clear, quantifiable parameters for achieving both optimal product quality and throughput efficiency. The small-scale Moringa leaves powder processing plant demonstrates high economic feasibility in the Nigerian context. The high profit margin (74%) and the rapid estimated payback period (approx. 0.21 years) are primarily driven by the low cost of raw materials and labour relative to the high added-value of the final processed powder. Investing in energy-efficient drying (like solar dryers) is critical to keeping the TOC low and maximizing profitability.

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