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Design, Fabrication and Performance Evaluation of a Multi-Crop Milk Extracting Machine

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ABSTRACT: *A multi-crop milk extractor was designed, constructed and evaluated for performance using soymilk and tigernut milk. The design analysis of the components provided the data that were used in the sizing, fabrication and assembling of the machine. The performance indicators considered were machine grind & strain rate (GSR), grind & strain capacity (GSC) and grind & strain efficiency (GSE). The GSR, were 10.1g/s and 13.57g/s on soybean and tigernut respectively, as compared to traditional method with GSR of 7.2 g/s and 9.6 g/s; GSC, were 18.91l/h and 24.94l/h on soybean and tigernut respectively, as compared with 13.7l/h and 17.95l/h for traditional method of extraction. The GSE, of the multi-crop machine were 89.8% and 85.86% for both soymilk and tigernut milk respectively. The straining efficiencies were 79.72% and 87.14% for soybean and tigernut respectively. In addition, the machine motor's speed (at 900rpm, 1440 rpm and 1840rpm) showed a significant interaction with GST for both Soymilk ($p<0.05$) and tigernut milk ($P< 0.05$) extraction; but showed no significant interaction ($P > 0.05$) with the volume of milk produced for both soymilk and tigernut milk. The machine is simple to operate and maintain, therefore it is recommended for local food processors including micro, small and medium scale processing industries.*
KEYWORDS: performance evaluation, extracting machine, milk extractor, soymilk, tigernut milk

INTRODUCTION

Milk is a necessary requirement in the human diet. Yet, in developing countries like Nigeria, dairy milk and their products are costly, thus limiting consumption. This decrease in the consumption of dairy milk and milk products has stimulated the processing of milk from different seeds and nuts (Udeozor, 2012). Though undervalued in the past, milk from plant sources have been a key ingredient in the diet of African countries (Ukwuru *et al.*, 2011). In a report by Mordi *et al.,* (2010), Soybeans, tiger-nuts, peanuts and cowpea have been identified as potential milk substitutes (Iwuoha & Umunnakwe, 1997; Onweluzo & Owo, 2005).

In the processing of soymilk and tiger-nut milk, it was inferred from reports by Belewu *et al.,* (2005) and Mordi *et al.* (2010) that they have some unit operations in common which include sorting and washing, de-hulling, grinding or wet milling, extraction or straining, pasteurizing, homogenizing (Ogbonna *et al.,* 2013; Udeozor, 2012) amongst others.

The traditional method of processing of vegetable milks (soymilk, tiger-nut milk and others) are either manual or partly mechanized; from conditioning, de-hulling, grinding to straining stages and unit operations, have been found to be stressful, time consuming and prone to contamination. Also, most local processors produce both soymilk and tiger-nut for the sake of customer's preference, and are most times restricted to a batch production per day because of the stressful nature of the wet sieving, thus reducing productivity level (Uwaoma, 2015). For food products like milk, which can be easily contaminated, handlers need to be careful and their processing technology should also help in achieving this hygienic objective (Ukwuru & Ogdobo, 2011). When food is contaminated, food loss is bound to occur (Allam *et al.,* 2016).

The main purpose of the study is to develop a processing machine that will extract milk from vegetable sources (such as soybeans, tiger nuts among others), and to avoid contamination of the product/extract in order to ensure longer shelf life. This research is important, in that, the technology that was developed will replace the manual method of milk extraction from vegetable sources; it will reduce contamination by hands, contamination by other foods substances and insects.

MATERIALS AND METHODS

Design considerations

The engineering properties of the processed fruits that are relevant to the design, development and performance evaluation were considered. The properties include corrosion and hygiene, material selection, efficiency and throughputs, power requirements and overall cost.

Multi-crop Machine Description and Operation

The assembly and exploded views of the multi-crop milk extractor is presented in Figure 1 and 2. The machine consists of four units; the grinding unit, screw press adopted as strainer, power segment and the frame. The grinding unit consist of the hopper, grinding stone, grinding choke and shaft; the strainer consist of the worm shaft, the perforated barrel and the conical restrictor (choke); the power segment consist of the prime mover, belts and pulleys, while the frame serve as a support for the machine on which all other segments were mounted on, including the outlet. Soaked Soya-beans or Tigernuts is fed into the machine through the hopper for wet milling in the grinding unit. The resultant product falls by gravity into the straining chamber through a channel. The worm shaft rotates in the barrel and conveys the milled soybean or tigernut from the feeder section towards the discharge section against a conical restrictor; the pressure generated forced the milk out through the tray while the cake/chaff will be extruded through the tip of the conical restrictor. Pressure was achieved in the machine by the operation of the worm shaft which was designed to have a decreasing pitch; but due to unavailability of computerized numerical control CNC machine, equal pitch was used. Table 1 gives a summary of components specifications from design analysis

Table 1. Summary of components specification from design analysis

SN	Components	Calculated specifications
1	Hopper design	Volume of the Hopper = $0.04m^2$
2	Belt drive design:	Speed of motor = 1,440 rpm, Diameter of motor pulley = 50mm, Speed of grinder' screw shaft = 360 rpm, Diameter of grinder pulley = 200 mm and 50mm Velocity ratio was estimated to be 4 Speed of the strainer shaft = 90 rpm Diameter of strainer pulley = 200mm
3	Weight of pulleys and Belt length	There two pulleys on grinder shaft each weighing 55.83N and 3.49N. The strainer pulley weighed 55.83N The belt lengths were 821mm in both cases.
4	Design of the shafts: Grinder and Strainer shaft	27mm diameter and 300 mm length for grinder 45mm diameter and 1000 mm length for strainer
5	Screw winding (flights)	The strainer shaft will have a total length of 825mm flight winding. Flight height, with and Helix angle were 26 mm, 21mm and 17.3^{o} respectively. The weight of the screw winding was 35N
6	Choke (Pressurized Cone)	Weight of choke is 11.5N
7	Press cage (barrel) design	Volume of barrel is $0.003m^3$ with internal and external diameter of 93 mm and 88 mm respectively.
8	Power requirements	Therefore, a 5 hp single-phase electric motor was selected to drive the machine.
9	Key design for strainer	A key with width, thickness and length of 11mm, 11mm, and 75mm was appropriate
10	Design for shaft bearings	The bearing number 311 was selected. The bearing type is a single row, deep groove, ball bearing and has the following

		parameters; bore (55 mm), width (29 mm) and outside diameter (120 mm).
11	Design of machine frame	A U-channel steel with dimesions 75 × 40 × 4 mm was suitable
12	Flange design	A flat rod of 4mm thickness was used for the flange.

Figure 1. Fabricated multi-crop milk extractor

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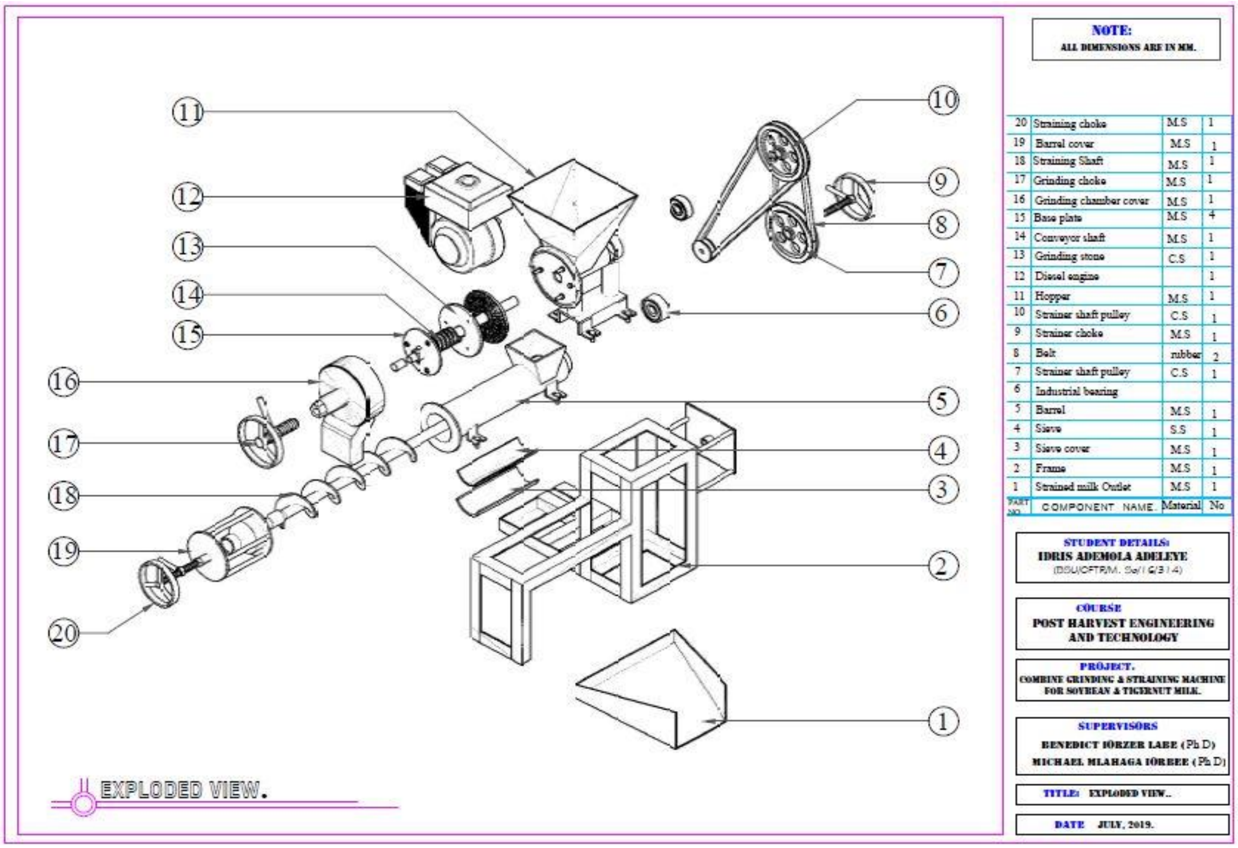

Figure 2. Exploded view of the multi-crop milk extractor designed and fabricator by author

Bill of Engineering Measurement and Evaluation of Production

The cost of producing the extractor is presented in Table 3. This comprises the cost of components bought, cost of materials and parts fabricated and cost of machining and non-machining jobs.

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Table 2. Bill of Engineering Materials and Quantity

COMPONENT	MATERIAL AND SPECIFICATION	QTY	UNIT PRICE (₦)	AMOUNT (₦)
Strained milk outlet	Mild steel; 2mm thick	1	2,000	2,000
Frame	Mild steel; 50 x 50 x 4mm	1	10,000	10,000
Straining shaft	Mild steel; Ø 30mm	1	10,000	10,000
Belts and Pulley system	Pulley: cast iron Belts: Leather	P = 4, B = 2	10,000	10,000
Hopper	Mild steel:2mm sheet	2	2,000	4,000
Grinding stone	Cast iron: 1 pair	1	3,000	3,000
Conveyor shaft	Mild steel: 25mm thick	1	2,000	2,000
Base plate	Mild steel; 3mm thickness	1	2,000	2,000
Grinding choke	Mild steel	1	1,000	1,000
Channel	Mild steel	1	500	500
Perforated barrel	Galvanized steel:Ø 120mm	1	5,000	5,000
Roller bearing	High speed steel	4	250	1,000
Bearing housing	Mild steel	4		500
Straining choke	Mild steel	1		2,000
Sub total				**53,000**
Fuel engine	5hp			20,000
Labor cost				10,000
Miscellaneous				5,000
Grand Total				**₦88,000**

Performance Testing and Evaluation

To test this machine, 40kg each, of Soybeans and tiger-nut was bought from Wurukum market, Makurdi, Benue state; and was weighed into three replicates, each of 0.5kg, 1kg and 2kg respectively. They were soaked in water for three hours and de-hulled. Their masses at point of grinding plus water used in grinding and straining (1:3) were recorded. Till satisfactory grinding and extraction was reached, mass of chaff and volume (mass) milk extracted was also recorded with associated time, t (s), used.

The performance criteria to be evaluated during the test are as follow:

- The throughput - grind and strain capacity, GSC, in litres per second (l/s)
- Throughput - grind and strain rate, GSR, in kilograms per second (Kg/s)
- The grind and strain efficiency, GSE

The time and volume were recorded and tabulated. These criteria were evaluated for both soy milk and tiger nut milk accordingly. This procedure was replicated and repeated at three motor's speed (of 900 rpm, 1440rpm and1850 rpm respectively); with the interaction between factors (machine speed and mass) due to grind & strain time GST, and volume of milk produced. The formulas to be used in evaluating capacities for the Multi-crop extractor were adopted from Fellow (2003) as follows:

$$\text{GSR, Kg/s} = \frac{\textbf{Mass of Sample feed in}}{\textbf{Time taken to completely grind and strain}} \qquad \textbf{Equation 1}$$

$$\text{GSC, l/s} = \frac{\textbf{Volume of milk producced (soymilk/Tigernut milk)}}{\textbf{Time taken to completely grind and strain}} \qquad \textbf{Equation 2}$$

$$\text{GSE, \%} = \frac{\text{Feed out (Mass of chaff+milk)}}{\text{Feed in (Mass of soybean/tigernut+water)}} \times 100 \qquad \textbf{Equation 3}$$

Performance evaluation of traditional method of vegetable milk extraction

This evaluation was carried out in accordance with procedures of Bamishaiye and Bamishaiye (2011) for soybean and Corrales *et al*., (2012) for tigernut. The seeds were soaked for two hours, strained, weighed and taken for grinding. The grinding and straining process had a fixed water addition in a ratio of 1:3 volume of clean water. Straining was done using muslin cloth to obtain the milk (soybean and tigernut milk). Data recorded include grinding time (s), straining time (s), weight of the milk produced (kg), volume of the milk produced (liters) and weight of chaff (kg).

Statistical Analysis

Two-way Analysis of Variance (ANOVA) with repetition (at 5% level of significance; using Microsoft Excel 2010, version 14.0.4734.1000) was used to analyze the interactions between speed, grind & strain time and volume of milk produced.

Results and Discussion

From Table 1, the traditional method showed that tigernut had higher values for grinding rate, GSR, and GSC which may be due to higher seed sizes and tigernut contains more fiber than soybean. Soybean had higher Grind and Strain efficiency (GSE) because every part of the bean can be grinded to produce more milk and thus more milk recovery. For the multi-crop extractor, the machine had higher values of GSR and GSC for tigernut as compared to Soybean. This may be as a result of distinct fiber structure associated with tigernut as compared to soybean.

The machine recorded a high GSE with soybean and this may be as a result easy flow associated with soybean. Every part of soybean seed is a potential for milk production when subjected to continuous grinding which implies a high mass recovery compared to any of the vegetable milk sources. Also, the GSE values indicated a 28% and 22% loss for both soybean and tigernut respectively. During the machine evaluation, close attention was paid to the straining unit and it was observed that the milk had chaff, and the chaff had milk and thus, the straining efficiency was evaluated.

The outputs – both milk and chaff – were further sieved using muslin cloth. The weight from chaff and milk were recorded and evaluated for straining efficiency and for both soymilk and tigernut milk respectively. The result showed that the traditional method had a grinding rate was higher than the value recorded by Akinnuli and Olabanji (2013), which had a grinding rate of 4.151 g/s and a production yield of 33.26 litres per hour. The multi-crop extractor has a grind & strain rate, GSR, less than that of Akinnuli and Olabanji (2013) which recorded 33.26l/h for Soymilk production. The grind & Strain efficiency, GSE, of the multi-crop machine were 89.8% and 85.86% as compared with the traditional method of 86.37% and 83.78% for both soymilk and tigernut milk respectively.

Table 3. Summary of performance evaluation of vegetable milk extraction

		Multicrop exractor		Traditional method	
	Performance evaluated	**Soybean**	**Tigernut**	**Soybean**	**Tigernut**
1.	Grind & strain rate, GSR, g/s	10.19	13.57	12.0	19.9
2.	Grind & strain capacity, GSC, l/h	18.91	24.94	7.2	9.6
3.	Grind & Strain Efficiency, GSE, %	72.17	78.49	13.7	17.95

Table 2 shows the summary of the analysis for straining efficiencies. From this table, the extractor strained Tigernut milk efficiently as compared to Soymilk. Again, this may be due to a clear and bigger fiber structure of Tigernut as compared to that of Soybean.

Table 4. Evaluation results for straining efficiency

SN	Performance evaluated	Soymilk	Tigernut milk
1.	Actual Milk extract from machine (kg)	57.40	45.40
2.	Total Possible Milk Extract (kg)	72.00	52.10
3.	Straining Efficiency (%)	79.72	87.14

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Interaction between factors (motor speed and mass) due to grind & strain time

Interaction between the factors (motor speed and mass) due to Grind &strain time (GST) for soymilk extraction shows that there is a significant difference (P<0.05) in the interaction of the factors due to the GST. This means that the changes in the grind & strain time were as result of changes in speed and mass, and vice versa. The sample and column effect also showed interaction and this implies that the data are too complex to be analyzed. The graph in Figure 3 revealed that there is a significant difference in the interaction of factors due to GST; each plot was distinctive and obvious, although the lines may look alike.

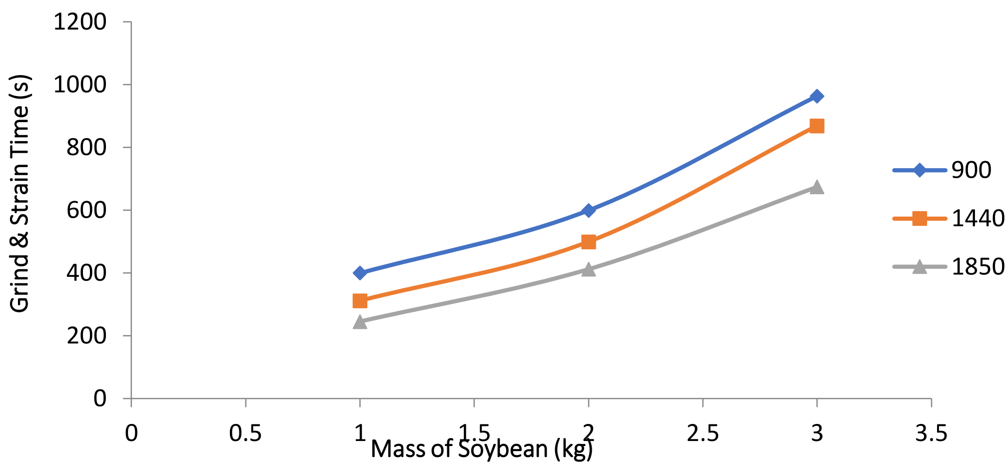

Figure 1. Interaction of Motor speed (rpm) and GST (s) (Soymilk)

Interaction between factors (motor's speed and mass) due Grind & strain time (GST) for Tigernut milk extraction shows that there is a significant difference (P< 0.05) in the interaction of the motor's speed and mass of tigernut processed due to GST. The graph in Figure 4 revealed that there is a difference in the interaction between factors due to GST. The GST and Speed interaction showed no differences (for 900rpm and 1440rpm) at the beginning, up until 1kg, after which their differences became significant.

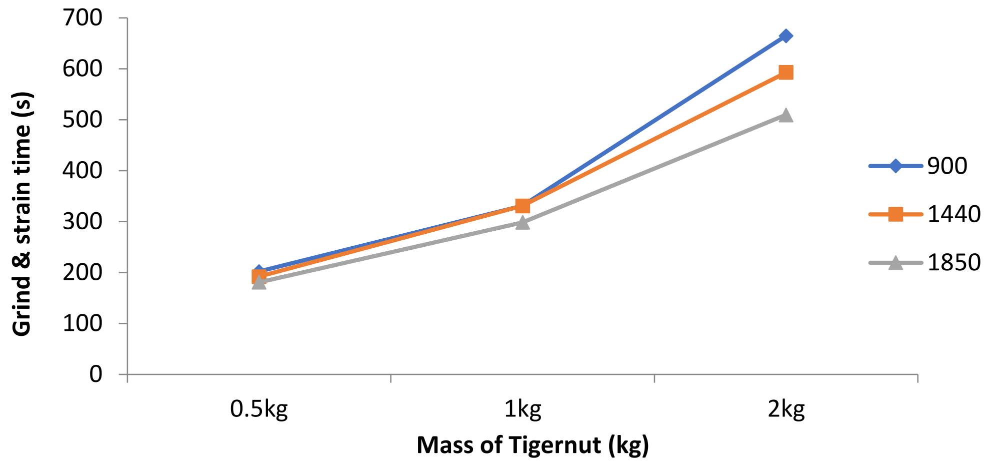

Figure 2. Interaction of Motor speed (rpm) and GST (s) (Tigernut milk)

Interaction between motor speed and mass due to volume of milk extracted

Interaction between the factors (motor speed and mass) due to volume of Soymilk produced, using the multi-crop extractor shows that there is no significant difference in the interaction of factors due to the volume of milk produced ($P > 0.05$). This means that the changes in the volume of milk produced has no linkage or association with changes in motor speed and vice versa. As seen in Figure 5, The graph revealed that there is no significant difference in the interaction between factors subject to volume of milk produced; the lines on the graph were the same. This is because there is a maximum volume of milk that can be extracted from a kilogram of Soybean regardless of speed variation.

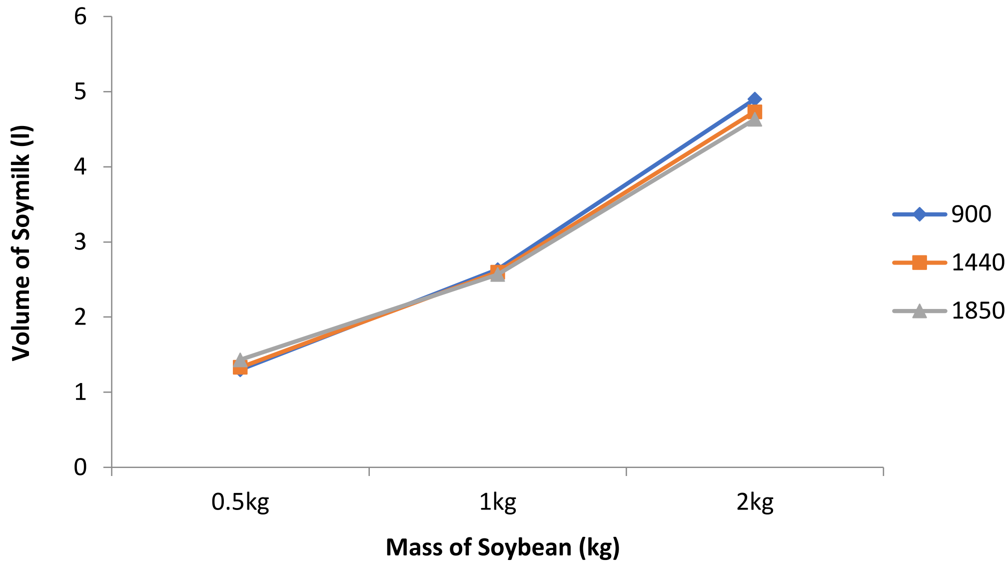

Figure 3. Interaction of Motor speed (rpm) and Volume (l) (Soymilk)

Interaction between factors (motor speed and mass) due to the volume of Tigernut milk produced using the multi-crop extractor showed that there is no significant difference in the interaction between factors due to volume of milk produced ($P > 0.05$). This means that the changes in the volume of milk produced has no linkage or association with changes in motor speed. The graph (figure 6) shows the plot of volume against mass of Soybean at different speed. The graph showed that there is no significant difference in the interaction between factors due to volume of milk produced; they all had the same trace on the graph.

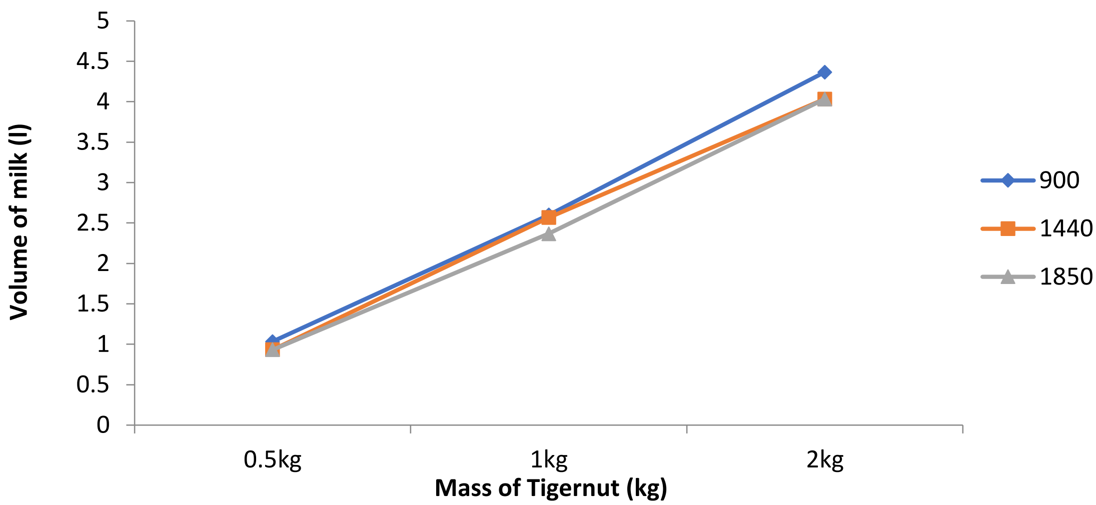

Figure 4. Interaction of Motor speed (rpm) and Volume (l) (Tigernut milk)

Generally, the results showed that there exists a significant difference in interaction between factors due to GST for both soymilk and tigernut milk extraction. The analysis also showed that there is no significant interaction between factors due to volume of milk produced. This means that, regardless of what speed the machine is running, the volume of milk produced has no linkage to it.

CONCLUSIONS

A Multi-crop milk extractor was designed, locally fabricated and tested at Department of Vocational and Technical Education, Benue State University Makurdi, Benue state and in conjunction with Udeeko Engineering Nigeria Limited. The extractor was designed to extract milk based on the principle of compression and shear due to the action of conveyor housing and screw conveyor. Materials used for construction were locally available and cheap. Performance tests showed that the machine was efficient in extracting soymilk and tigernut milk. However, it is recommended that the screw system in the strainer should be replaced with drum and piston system for high pressure delivery.

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