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Performance Evaluation of a Portable Ginger Slicing Machine

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Authors' contributions

This work was carried out in collaboration among all authors. Authors IA, DDY and USM designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors AZ and JKA managed the analyses of the study. Authors ZUB and KAH managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The study aimed at evaluating the functional performance of a developed portable ginger rhizomes slicing machine. The study was conducted at various levels of impeller speed, impeller gang and slicing compartment in the Department of Agricultural and Bioresources Engineering, Ahmadu Bello University, Zaria, Nigeria between April 2018 and June 2018. A $5 \times 4 \times 2$ factorial experiment in a Completely Randomized Design (CRD) was used. The indices for the performance evaluation were the Slicing Efficiency and Throughput Capacity. The machine was powered by one horse power petrol engine and ginger moisture content of 77.44%. Data collected were subjected to statistical analysis using Analysis of Variance (ANOVA) to test the significance level of the experimental factors and their interactions; and those found significant were further subjected to Duncan Multiple Range Test (DMRT) for mean separations at (P = .05), respectively. The results showed that, the ANOVA for all the factors evaluated and their interactions on Slicing Efficiency

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were highly significant at (P ≤ .01). However, the ANOVA for the factors evaluated on Throughput capacity were highly significant but interaction between type of compartment and speed of impeller was not significant at (P =.05). The mean Slicing Efficiencies for the cushion and spring compartments were: 63.5 and 50% while the mean Throughput Capacities were: 58.32 and 6.32 kg/h, respectively.

Keywords: Evaluation; DMRT; ginger slicing; spring and cushion compartments.

1. INTRODUCTION

Ginger (*Zingiber officinale* Roscoe) is a root crop grown in many parts of the world (India, China, Indonesia, Nigeria, Brazil, Philippines and Thailand). [1] and [2] reported that, India is the largest producer of ginger in the World with a production of1,109,000 metric tonnes/year and Japan is the largest importer in the World. However, Nigeria is the fourth producer in the world and largest producer in Africa with a production of 522,964 metric tonnes/year. The crop is an important source of foreign exchange for Nigeria [3]. It can be used in pharmaceutical, bakery, culinary, cosmetic preparation and soft drink in beverage industries [4]. As reported by [5], ginger has a moisture content of 80 - 85% wet basis when freshly harvested and 10 - 12% moisture content dry basis for storage. It can be consumed fresh or dried [6]. The plant is grown in different parts of Nigeria such as Kaduna, Nasarawa, Sokoto, Zamfara, Akwa Ibom, Oyo, Abia and Lagos States, Kaduna being the largest [7].

Ginger enters the international markets as fresh, preserved or dried forms. However, the most important commercial form is the dried ginger (split or whole) [8]. Report by [9], stated that demand for dry ginger locally and internationally is increasing by the day. Slicing longitudinally is to enable maximum surface exposure for quick and uniform drying thereby retaining the aroma, flavour and pungency which are the qualities requirements in ginger trade [4]. Traditional method of slicing is the most practiced. It involves use of kitchen knife which has different edge directions, the moisture content and the cross sectional area has significant influence over the cutting energy. Slicing 14 - 15 kg of ginger takes about 5 man- hours which is relatively time consuming thus manual slicing of ginger becomes cumbersome and cannot meet the demands and hence, the need for mechanizing ginger production particularly, it's processing. The aim of this study therefore is to evaluate the functional performance of a developed portable ginger rhizomes longitudinally slicing machine.

2. MATERIALS AND METHODS

The study was conducted in the Processing Laboratory, Department of Agricultural and Bioresources Engineering, Ahmadu Bello University, Zaria, Nigeria between April 2018 and June 2018.

2.1 Description of the Developed Portable Ginger Slicing Machine

The developed ginger slicing machine consists of the following components: frame, hoppers, slicing units, and power transmission unit as in Fig.1.

2.1.1 Frame

The machine has trapezoidal shape with parallel sides of $600\ mm$ and $960\ mm,$ and height of $300\ mm$. The frame was fabricated with $30\ mm \times 30\ mm \times 3mm$ angle iron. Mounted on the frame are bearings, shaft, slicing units, hoppers and a prime mover.

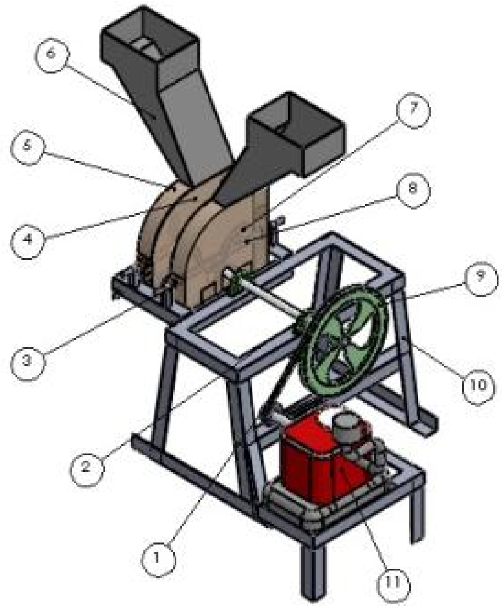
2.1.2 Hopper

The hoppers are rectangular in cross section and made from 3 mm mild steel sheets. They had $190\ mm \times 150\ mm \times 65\ mm$ dimensions as length, breath and width with an inclination of 42º.

2.1.3 Slicing units

The chamber is composed of two types of slicing chambers, spring and cushion compartments to accommodate the irregular thickness of ginger rhizomes. The slicing chambers have cross sections of $300mm \times 300mm$ and widths of $50\ mm$. The widths of the chambers were to accommodate all thickness of ginger. It compresses/deflects when a bigger size is fed into the chamber.

The cutting blades (saw blade) are sharpened at one side and were positioned at a tension through adjustable screw and bolt to prevent



S/N	PART DESCRIPTION
1.	BELT
2.	BEARING
3.	KNIFE GUIDE
4.	SLICING CHAMBER INNER COVER
5.	SLICING CHAMBER INNER COVER
6.	HOPPER
7.	IMPELLER
8.	KNIFE
9.	PULLEY
10.	STAND/FRAME
11.	PRIME MOVER

Fig. 1. Isometric view of a portable ginger slicing machine

Fig. 2. The pictorial view of the portable ginger slicing machine

distortion during operation. It has overall dimensions of $400\ mm \times 30\ mm \times 1.6\ mm$.

Impeller of $145\ mm \times 20\ mm \times 5\ mm$ cross section were fabricated and keyed to a rotating shaft. The impellers were curved and spaced equally at 7 *mm* across the cutting blades lateral cross sections and along the shaft's longitudinal axis to avoid obstruction.

2.1.4 Power transmission unit

The V- belt and pulley assembly were used to transmit the power from the prime mover to the slicing chambers at different levels of impeller speeds. The prime mover is mounted on a frame slit to facilitate adjustment of the belt tension.

2.2 Principle of Operation

The machine was operated by one horse power petrol engine through a V-belt as in Fig. 2. The ginger rhizomes were washed to remove all the soil particles. Each rhizome sample was prepared by cutting off the fingers from the interconnecting tangled clumps [10,11]. The ginger rhizome was fed manually into the hopper. It slides down to the slicing chamber to meet rotating impeller. The centrifugal force of rotating impeller forced the fallen ginger rhizome on a thin-sharp stationary cutter to accomplish the slicing process. The sliced ginger rhizome was discharged through the outlet directly below by gravity and it was collected in a container.

2.3 Instrumentation

The instruments used for measuring mass, shaft speed and time were: Mettler Model (PN20001) top loading balance with capacity of 2 kg and accuracy of 0.1 g; Lutron Digital Photo Tachometer that can measure a range of 0.5 to 100,000 rpm and accuracy of 0.05% + 1 digit and digital stop watch.

2.4 Experimental Procedure

Fresh ginger rhizome was purchased from local market Sabon Gari, Zaria, Kaduna State Nigeria. The constructed ginger slicing machine was evaluated based on Slicing Efficiency and Throughput Capacity. Equal weights of 500 g were used for the experiment for the respective slicing units (spring and cushion compartments). The collected sliced ginger were separated and weighed to determine the Slicing Efficiency. Times for slicing were recorded for each experiment to determine the Throughput Capacity of the machine. The impeller speed was varied at five levels (250, 300, 350, 400 and 450 rpm) and also, the number of impeller varied from one to four (one, two, three and four gang arrangements). The experimental procedures were repeated three times (three replications). The pictorial views of unsliced and sliced ginger as in Figs. 3 and 4.

2.5 Statistical Analysis

The speed of impeller, number of impeller, type of compartment and crop variety were taken as independent parameters for the study. The parameters were arranged in $5 \times 4 \times 2 \times 1$ factorial experiment fitted into Completely Randomized Design (CRD). This gave a total of 60 treatments. The experiment was repeated three times giving a total of 120 treatments. In each slicing compartment, the experiment was ran 20 times (as in Table 1) and repeated to give 60 runs.

Fig. 3. The pictorial view of unsliced ginger

Fig. 4. The pictorial view of sliced ginger

Data from the performance evaluation was subjected to statistical analysis using Analysis of Variance (ANOVA) to test the significance of experimental factors and their interactions. Mean separation with observed significant differences was compared using Duncan's Multiple Range Tests (DMRT) using SAS 9.13 portable package. The ANOVA was computed at probability level of 5% (P=.05).

Table 1. Layout of the randomization (5x4)

S_5N_1	S_2N_1	S_1N_1	S_1N_2
S_4N_2	S_3N_2	S_2N_2	S_5N_3
S_3N_3	S_4N_3	S_5N_2	S_3N_4
S_2N_4	S_4N_4	S_3N_1	S_1N_3
S_5N_4	S_2N_3	S_4N_1	S_1N_4

2.6 Performance Indicators

The performance evaluation of the machine was based on Slicing Efficiency and throughput capacity.

2.6.1 Determination of slicing efficiency

The Slicing Efficiency is the ratio of effective capacity to theoretical capacity expressed in percentage. The Slicing Efficiency was determined as given by many researchers [11,4,12,13] in Equation (1):

$$SE(\%) = \frac{Q_{CS}}{Q_{CO}} \times 100 \quad (1)$$

Where:

SE = Slicing Efficiency, %
Q_{CS} = Total quantity of ginger completely sliced, g
Q_{CO} = Total quantity of ginger collected at outlet, g

2.6.2 Determination of throughput capacity

The Throughput Capacity of the machine is the ratio of the mass/weight/quantity of ginger that can be sliced per time. Throughput Capacity was determined as given by many researchers [11,4,12,13] in Equation (2):

$$OC(g/sec) = \frac{Q_{CO}}{t} \quad (2)$$

Where:

OC = Throughput Capacity, g/sec
Q_{CO} = Total quantity of ginger collected at outlet, g
t = Time taken to complete splitting, second

3. RESULTS AND DISCUSSION

The results of the performance evaluation (Slicing Efficiency and Throughput Capacity) of the developed portable ginger slicing machine are shown in Tables 2, 3, 4 and 5.

The Analysis of Variance (ANOVA) of effect of type of compartment, number of impeller and speed of impeller on Slicing Efficiency is shown in Table 2. It indicated that all the factors evaluated and their interactions were highly significant at ($P \leq .01$).

The results of interaction of type of compartment, number of impeller and speed of impeller on Slicing Efficiency are shown in Table 3. The combination do not have definite pattern. The highest mean Slicing Efficiency recorded with cushion compartment was 63.5% at 350 rpm speed of impeller and one impeller gang. However, the highest mean recorded with spring compartment was 50% at the same conditions. This is because of the friction at the surface of the cushion material which enabled it held the ginger rhizome tightly before accomplishing the slicing. The lowest mean Slicing Efficiency of 30.7 and 27.2% was observed with cushion and spring compartments at the same speed of impeller for four and two impeller gangs, respectively. The Slicing Efficiency obtained is within the range reported as mean Slicing Efficiency of ginger slicing machine by many researchers [14,15,11,8].

The ANOVA of effect of type of compartment, number of impeller and speed of impeller on Throughput capacity is shown in Table 4. It indicated that all the parameters and but interactions between type of compartment and speed of impeller was not significant at P = .05.

Table 2. Analysis of variance (ANOVA) results for slicing efficiency

Source of variations	DF	SS	Mean square	F Value	Pr > F
C	1	4869.51	4869.51	230.94	<.0001**
N	3	2861.78	953.92	45.24	<.0001**
S	4	4263.55	1065.88	50.55	<.0001**
C×N	3	1839.46	613.15	29.08	<.0001**
C×S	4	1094.19	273.54	12.97	<.0001**
N×S	12	3604.13	300.34	14.24	<.0001**
C×N×S	12	1903.18	158.59	7.52	<.0001**
Error	39	3373.66	21.08		
Corrected Total	119	25136.92			

**= Significant at (P=.05), **= Highly Significant at (P<.01) and NS= Not significant; Type of compartment, C, Number of impeller, N, Speed of impeller, S*

Table 3. Interaction of type of compartment, number of impeller and speed of impeller on slicing efficiency

Treatment	Mean slicing efficiency (%)	Mean ranking	Treatment	Mean slicing efficiency (%)	Mean ranking
Cushion compartment, c_1			**Spring compartment, C_2**		
$S_3N_1C_1$	63.5	a	$S_3N_1C_2$	50.0	d-g
$S_1N_2C_1$	60.6	ab	$S_4N_2C_2$	49.8	efg
$S_1N_4C_1$	60.4	ab	$S_1N_1C_2$	49.7	efg
$S_1N_1C_1$	59.2	ab	$S_1N_4C_2$	46.5	f-k
$S_3N_2C_1$	58.2	abc	$S_2N_2C_2$	44.7	g-l
$S_2N_3C_1$	57.5	bc	$S_2N_3C_2$	44.6	g-l
$S_1N_3C_1$	56.0	bcd	$S_1N_2C_2$	42.8	i-n
$S_4N_2C_1$	53.2	cde	$S_2N_1C_2$	42.1	k-o
$S_2N_1C_1$	52.6	c-f	$S_2N_4C_2$	41.9	k-o
$S_2N_2C_1$	49.1	e-h	$S_3N_4C_2$	39.2	l-p
$S_4N_1C_1$	48.5	e-i	$S_4N_1C_2$	38.1	m-p
$S_3N_3C_1$	48.3	e-i	$S_5N_2C_2$	38.1	m-p
$S_4N_3C_1$	47.2	e-k	$S_5N_1C_2$	38.0	m-p
$S_5N_2C_1$	43.8	g-m	$S_4N_4C_2$	36.3	o-q
$S_5N_1C_1$	43.4	h-n	$S_1N_3C_2$	35.2	pq
$S_5N_3C_1$	42.3	j-o	$S_3N_3C_2$	34.5	pq
$S_4N_4C_1$	37.5	n-p	$S_5N_4C_2$	34.1	pq
$S_2N_4C_1$	34.9	pq	$S_5N_3C_2$	34.0	pq
$S_4N_5C_1$	33.1	pq	$S_4N_3C_2$	33.0	pq
$S_3N_4C_1$	30.7	qr	$S_3N_2C_2$	27.2	r

Means followed by same letter(s) on the same column and row are not different statistically at P=.05 using DMRT; S= impeller speed, N= number of impeller, C1=cushion compartment, C2= spring compartment

Table 4. ANOVA results for mean throughput capacity

Source of variation	DF	Sum of squares	Mean square	F Value	Pr > F
C	1	125.80	125.80	17.43	<.0001**
N	3	638.37	212.79	29.49	<.0001**
S	4	551.89	137.97	19.12	<.0001**
C×N	3	177.35	59.11	8.19	<.0001**
C×S	4	65.03	16.25	2.25	0.0657^{NS}
N×S	12	861.81	71.81	9.95	<.0001**
C×N×S	12	260.77	21.73	3.01	0.0008**
Error	39	1154.70	7.21		
Corrected total	119	3985.37			

**= Significant at (P=.05), **= Highly Significant at (P<.01) and NS= Not significant*

The results of the variation on Throughput Capacity in type of compartment, different number of impeller gangs and speed of impellers is shown in Table 5. The combination do not have definite pattern. The highest mean Throughput Capacity was obtained as 26.3 g/sec (94.68 kg/h) at 300 rpm for one impeller gang with spring compartment and 24.9 g/sec (89.64 kg/h) at 300 rpm for one impeller gang with cushion compartment, respectively. This is because, ginger rhizome slides with relatively low resistance with spring compartment than cushion compartment. The machine Throughput Capacity obtained was similar to many researchers [4,13, 11] ginger slicing machines. The difference in results obtained by [11] may be due to the thickness of the knife used.

Table 5. Interaction between type of compartment, number of impeller and speed of impeller on throughput capacity

Treatment	Mean throughput capacity (g/sec)	Mean ranking	Treatment	Mean throughput capacity (g/sec)	Mean ranking
Cushion compartment, C_1			**Spring compartment, C_2**		
$S_2N_1C_1$	24.9	ab	$S_2N_1C_2$	26.3	a
$S_1N_1C_1$	20.7	cde	$S_1N_4C_2$	22.5	bc
$S_1N_2C_1$	19.7	c-g	$S_5N_3C_2$	21.3	cd
$S_4N_1C_1$	18.4	d-i	$S_1N_1C_2$	20.4	cde
$S_4N_2C_1$	17.9	d-j	$S_1N_2C_2$	20.0	c-f
$S_1N_4C_1$	16.2	g-l	$S_2N_4C_2$	19.4	c-g
$S_3N_1C_1$	16.2	g-l	$S_3N_4C_2$	18.8	d-h
$S_2N_4C_1$	15.7	h-l	$S_3N_1C_2$	18.7	d-h
$S_5N_2C_1$	15.5	h-l	$S_2N_2C_2$	18.4	d-i
$S_5N_1C_1$	15.4	h-l	$S_4N_1C_2$	17.2	e-k
$S_3N_2C_1$	15.3	h-l	$S_1N_3C_2$	16.6	f-l
$S_3N_4C_1$	15.3	h-l	$S_4N_2C_2$	16.6	f-l
$S_2N_2C_1$	14.7	i-n	$S_5N_1C_2$	16.1	g-l
$S_2N_3C_1$	14.6	i-n	$S_4N_4C_2$	15.2	h-m
$S_4N_3C_1$	14.6	i-n	$S_5N_4C_2$	15.2	h-m
$S_3N_3C_1$	14.0	k-n	$S_4N_3C_2$	14.8	i-n
$S_1N_3C_1$	13.4	k-n	$S_3N_3C_2$	14.3	j-n
$S_4N_4C_1$	13.2	lmn	$S_2N_3C_2$	13.6	k-n
$S_5N_3C_1$	13.1	lmn	$S_5N_2C_2$	12.9	lmn
$S_5N_4C_1$	11.5	mn	$S_4N_2C_2$	11.3	n

Means followed by same letter(s) on the same column and row are not different statistically at P=.05 using DMRT

4. CONCLUSION

The performance evaluation (Slicing Efficiency and Throughput Capacity) of a portable ginger slicing machine was carried out. At ginger moisture content of 77.44% wet basis, and at operating speed of 350 rpm, the machine has an average Slicing Efficiency and Throughput Capacity of 63.5 %, 58.32 kg/h, and 50 % and 67.32 kg/h for cushion and spring compartments, respectively.

COMPETING INTERESTS

Authors have declared that no competing interests exist compartment. The machine Throughput Capacity obtained was similar to [4], [13], and [11] ginger slicing machines. The difference in results obtained by [11] may be due to the thickness of the knife used.

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