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PERFORMANCE EVALUATION OF A MOTORIZED GINGER RHIZOMES PEELING MACHINE

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Abstract: A 5kg motorized Ginger rhizome (*Zingiber Officinale Roscoe*) peeling machine was designed, developed and tested. Three moisture contents (70%, 75% and 80% wb), three feed rates (54 kg/h, 68 kg/h and 73 kg/h) and three peeling speeds (230 rpm, 270 rpm and 300 rpm) were used for the performance evaluation of the machine. A $3 \times 3 \times 3$ factorial experiment in a randomized complete block design (RCBD); replicated two times was used to study the effects and interactions of the three factors (moisture content, feed rates and peeling speed) on the performance parameters (peeling efficiency, peeling capacity and percent damage). Relationship between performance parameters and the influencing factors were determined using multilevel factorial design and response surface methodology for the graphical analyses. The study showed that peeling efficiency increased from 82.3% to 88.5% with an increase in moisture content from 70% to 80%, a decrease in feed rate from 73 kg/h to 54 kg/h and an increase in peeling speed from 230 rpm to 300 rpm. Peeling capacity increased from 2.4 kg/h to 11.64 kg/h with an increase in moisture content from 70% to 80%, a decrease in feed rate from 73 kg/h to 54 kg/h and an increase in peeling speed from 230 rpm to 300 rpm. Percent damage increased from 6.3% to 14.4% with a decrease in moisture content from 80% to 70%, an increase in feed rate from 54 kg/h to 73 kg/h and an increase in peeling speed from 230 rpm to 300 rpm. The analysis of variance (ANOVA) result showed that the interaction of moisture content, feed rate and peeling speed had significant effect on peeling efficiency, peeling capacity and percent damage at $p < 0.05$ level. For a maximum peeling efficiency, peeling capacity and minimum percent damage, an optimum moisture content of 75%, feed rate of 68 kg/h and peeling speed of 270 rpm were recommended for use.

Key words: Ginger rhizomes, performance evaluation, peeling capacity, peeling efficiency.

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INTRODUCTION

Peeling of Ginger (*Zingiber Officinale Roscoe*) is an important unit operation where fully matured rhizomes are scraped with bamboo-splits having pointed ends, to remove the outer skin before drying to accelerate the drying process [1]. Although Ginger cultivation in Nigeria started in 1927 [2]. Peeling which is one of the unit operations in its local processing is still being done predominantly by traditional method (manual scraping with knife) which is labour intensive, full of drudgery and it equally exposes the hand to injury. Primary processing of Ginger rhizomes involves operations such as washing, slicing/splitting/peeling and drying [3]. Dried Ginger is produced from mature rhizome, since the flavour and aroma become much stronger as the rhizome matures. Rhizomes of dried Ginger may be left whole, peeled, split or sliced into smaller pieces to speed up drying [4]. Deep scraping with knife needs to be avoided to prevent damage to oil-bearing cells present just beneath the outer skin. Excessive peeling results in reduction of essential oil content in dried product [4]. Few industries that process Ginger in the country make use of imported machinery due to non-availability of simple locally developed machines for its processing and this has adversely affected the production and marketing of Ginger in Nigeria, in spite of its great economic potentials.

[1] developed a concentric drum brush type Ginger peeler with a capacity to peel 7 kg per batch. The optimum operating conditions for peeling Ginger were obtained at drum load of 7 kg, for inner drum speed of 45 rpm, outer drum speed of 20 rpm and for a peeling duration of 15 minutes. The peeling efficiency was 61% and the corresponding material loss was 5.33%. A brush type Ginger peeling machine with two continuous brush belts moving vertically in opposite direction was reported by [5]. The maximum peeling efficiency obtained for the brush type Ginger peeling machine was 84.3% at a belt speed of 85 rpm having a belt spacing of 1 cm. [6] reported the development of an abrasive brush type Ginger peeling machine consisting of two continuous vertical belts provided with 32-gauge steel wire brush, 2 cm long and having a peeling zone of 135 cm, had a maximum peeling efficiency of 85%.

Despite all the developments relating to Ginger peeling machine, the farmers still fall back to the manual method of peeling. In recognition of the constraints imposed by manual method of peeling Ginger, there is need to develop a motorized Ginger peeling machine that will be developed locally. This study therefore reports on the performance evaluation of a locally developed motorized Ginger rhizomes peeling machine.

MATERIALS AND METHODS

The study was conducted at the Postharvest Technology Laboratory, Department of Agricultural and Bioresources Engineering, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria.

Description of Developed Ginger Rhizome Peeling Machine

The motorized Ginger peeling machine consist of the following components: frame, feeding unit, pulley and belt drive, shoe pad, arm, shaft, crank shaft, cranking mechanism, discharge chute and gate. Figures 1 and 2 shows the pictorial and isometric views of the developed motorized Ginger rhizomes peeling machine.

Fig. 1. Developed Ginger rhizomes peeling machine

Fig. 2. Isometric view of the developed ginger rhizomes peeling machine Legend: A-Puley, B-Puley shaft, C-Connecting rod, D-Frame, E-Discharge shute, F-Hopper, G-Shoe pad shaft, H- Discharge gate

Frame

The frame holds all the components of the Ginger peeling device. It is designed to withstand torsional and vibrational forces. It has a length of 800 mm, width of 400 mm and a height of 830 mm.

Feeding unit (Hopper)

The hopper feeds the Ginger rhizomes into the peeling chamber where rhizomes are subjected to abrasive force from the abrasive shoe pad through the shaft rotation. It has a dimension of 300 mm by 230 mm and inclined at an angle of 40° .

Pulley and belt drive

The pulleys which have diameter sizes of 85 mm, 250 mm and 300 mm transmits the mechanical energy from the shaft of the combustion engine to the shaft of the Ginger rhizome peeler.

Shoe pad

This is a not machine component that comes into direct contact with the Ginger rhizomes and provides the frictional force for peeling. The shoe pad (362 mm by 118 mm) is made-up of wire gauze material which has a rough surface. This material is attached to a flat bar using bolts and nuts for ease of replacement.

Arm

The arm is the component of the machine which carries the shoe pad for the peeling. It is joined to the shaft by welding. It has a hollow pipe which is welded to the shaft and then a solid part which slides inside the hollow pipe in order to alter the clearance. The solid arm (200 mm length and 10 mm diameter) is held firmly to the hollow pipe by screw after adjusting to the suitable clearance. The adjustment is to accommodate for the variation in the sizes of the Ginger rhizomes.

Shaft

The shaft of the Ginger rhizome peeling machine which has a length of 620 mm and a diameter of 25 mm transmits the mechanical energy that will be transmitted from the combustion engine through the pulley and belt drive system to the oscillating shoe pad.

Connecting rod

This transmits rotary motion given to the shaft by the motor to oscillating motion of the shoe pad which has a length of 480 mm and diameter of 15 mm.

Discharge chute

Discharge chute is an extension of the peeling unit whereby the peels of the Ginger rhizomes are discharged under gravity as they are being peeled. It has a dimension of 115 mm length, 300 mm width and an angle of inclination of 65° .

Discharge gate

The discharge gate is a casing of 80 mm length and 305 mm width covering the peeling chamber which is inclined at an angle of 46° so that during the peeling operation the rhizomes do not splatter, rather its being opened after the operation for collection of the peeled Ginger rhizomes.

Working Principle of the Developed Ginger Peeling Machine

The kinematics upon which the machine works is the principle of quadric-crank mechanism. This principle converts rotary motion to oscillatory motion, whereas the force application for peeling uses the principle of attrition or shearing force principle. The shoe pad which comes in contact with the Ginger has conical projection on its surface. The machine prime mover is a 2.25 kW petrol internal combustion engine. The shoe pad is attached to an adjustable arm which is then attached to the shaft. The shaft is connected to the cranking mechanism through a connecting rod. As the pulley makes a rotary motion, this motion is converted to the oscillatory motion of the shaft, the arm and the shoe pad which are attached rigidly together. The shoe pad and the peeling chamber have a clearance which depends on the geometric mean diameter of the Ginger rhizomes. As the rhizomes are trapped in between the abrasive shoe pad and the abrasive peeling chamber; and the shoe pad performs an oscillating motion, the rhizomes are being peeled due to the friction between the Ginger and the abrasive surface of peeling chamber; Ginger and abrasive surface of the shoe pad and as well friction among the rhizomes. The peels fall through the openings on the peeling chamber through the discharge chute while the peeled Ginger rhizomes are collected from the discharge gate.

Experimental Procedure

Ginger rhizomes used for this study was sourced from Ntigha market in Isialangwa Local Government Area of Abia State, Nigeria. The rhizomes were cleaned and prepared ready for peeling. The machine was set into operation and allowed for 2 minutes before a known weight of Ginger rhizomes were fed into the peeling chamber through the hopper. The time taken together with the peeling shaft speed were noted and recorded. The peeled Ginger and peels were collected and weighed independently. The feed rate and moisture content were also determined. Each test carried out was replicated two times and at three levels of speed, moisture content and feed rate. The peeling speed, feed rate and moisture content were taken as independent parameters for this study. Three levels of peeling speed termed S_1 , S_2 and S_3 (230, 270 and 300 rpm) were chosen in order to determine the optimum speed required for peeling Ginger rhizomes. Three levels of feed rate were also taken as F_1 , F_2 and F_3 (54, 68 and 73 kg/h). Also, three levels of moisture content were taken as M_1 , M_2 and M_3 (70, 75 and 80% wb). These parameters gave a $3 \times 3 \times 3$ factorial experiment replicated two times. This gave a total of 27 treatment combinations and 54 numbers of observations. The values obtained were used to calculate the performance parameters.

Performance Evaluation Parameters

The performance evaluation carried out on the developed Ginger peeling machine was assessed using the following parameters given by [6]:

$$F_R = \frac{Q_f}{t} \quad \dots\dots\dots (1)$$

Where,

F_R = feed rate (kg/h)

Q_f = mass of Ginger rhizomes fed into the machine (kg)

t = time to finish the feeding (h)

$$\eta_p = \frac{(W_{sf} - W_{sm})}{W_{sf}} \times 100\% \quad \dots\dots\dots (2)$$

Where,

η_p = peeling efficiency of Ginger peeler (%)

W_{sf} = weight of skin on fresh Ginger (kg)

W_{sm} = weight of skin removed by hand trimming after mechanical peeling (kg)

$$C_p = \frac{Q_t}{t} \quad \dots\dots\dots (3)$$

Where,

C_p = peeling capacity (kg/h)

Q_t = mass of Ginger rhizome peeled (kg)

t = time taken for peeling (h)

$$P_d = \frac{(W_1 - W_{sf}) - (W_2 - W_{sm})}{W_1} \times 100\% \quad \dots\dots\dots (4)$$

Where,

P_d = damage of Ginger (%)

W_1 = total weight of Ginger before peeling (kg)

W_2 = total weight of Ginger after mechanical peeling (kg)

W_{sf} = weight of skin on fresh Ginger (kg)

W_{sm} = weight of skin removed by hand trimming after mechanical peeling (kg)

Statistical analysis

Data obtained during performance evaluation of the machine were subjected to the Analysis of Variance (ANOVA) for the test of significance of experimental factors and their interactions. ANOVA for each factor was done using Minitab version 17.0 software package and a significance level of ($P < 0.05$) was used for all the analyses. Relationship between performance parameters and the influencing factors were determined using multilevel factorial design and response surface methodology for the graphical analyses.

RESULTS AND DISCUSSION

Effect of Interaction of Experimental Factors on Peeling Efficiency

Peeling efficiency as shown in Fig. 3 increased from 82.9% to 88.5% with an increase in feed rate and decrease in moisture content. According to Fig. 4, peeling efficiency increased from 82.3% to 87.8% with a decrease in moisture content and an increase in peeling speed which could be as a result of the increased friction between the rhizomes. [1] reported a maximum Ginger peeling efficiency of 62.86% when the outer drum speed was 25 rpm, the inner drum speed was 45 rpm and the peeling duration was 15 minutes at a constant drum load of 6 kg of Ginger. Also, the peeling efficiency decreased from 88.2% to 84.2% with an increase in feed rate and a decrease in peeling speed as shown in Fig. 5. There was significant effect in the interaction of moisture content, feed rate and peeling speed on peeling efficiency at $p < 0.05$ level as presented in Table 1. [5] reported a maximum peeling efficiency of 84.3% in a vertical brush type Ginger peeling machine when the belt speed was 85 rpm at belt spacing was 1 cm. [7] reported that during abrasive peeling of potatoes in an abrasive drum type peeler, peeling efficiency increased with time. Similarly, peeling efficiency also increased with the increase in drum speed. This agrees with this study.

Fig. 3. Surface plot of interaction of moisture content and feed rate on peeling efficiency

Fig. 4. Surface plot of interaction of moisture content and peeling speed on peeling efficiency

Fig. 5. Surface plot of interaction of feed rate and peeling speed on peeling efficiency

Tab 1. ANOVA for the effects of moisture content, feed rate and peeling speed on peeling efficiency

Source of Variation	DF	SS	MS	F-value	P-value
MC	2	8.61	4.31	2.07	0.1458 ^{NS}
FR	2	18.32	9.16	4.40	0.02218 ^{NS}
PS	2	4.60	2.30	1.11	0.3441 ^{NS}
MC*FR	4	11.85	2.96	1.42	0.2542 ^{NS}
MC*PS	4	7.27	1.82	0.88	0.4889 ^{NS}
FR*PS	4	7.97	1.99	0.96	0.4453 ^{NS}
MC*FR*PS	8	41.72	5.22	2.51	0.03507 ^S
Error	27	56.06	2.08		
Total	53	156.71			

Keynote:

MC - Moisture content; FR - Feed rate; PS - Peeling speed; DF- Degree of freedom; SS - Sum of squares; MS - Mean of squares; S - Significant; NS - Not significant

Effect of Interaction of Experimental Factors on Peeling Capacity

Figure 6 showed that the peeling capacity increased from 9 kg/h to 10.9 kg/h with an increase in feed rate and a decrease in moisture content. The peeling capacity as well decreased from 7.2 kg/h to 2.4 kg/h with a decrease in moisture content and a decrease in peeling speed (Fig. 7) which was due to a decrease in friction among the rhizomes. Also, peeling capacity increased from 3.2 kg/h to 9.8 kg/h with an increase in peeling speed and decrease in feed rate (Fig. 8) which was due to the amount of Ginger fed into the machine and also increase in friction due to increase in speed. In Table 2, the analysis of variance (ANOVA) showed that the interaction of moisture content, feed rate and peeling speed had a highly significant difference on peeling capacity at $p < 0.05$ level. [8] reported that the average throughput capacity of cocoa yam peeling machine was highest (112.92 kg/h) at the operational speed of 933 rpm which was the most efficient for the operation of the machine.

Fig. 6. Surface plot of interaction of moisture content and feed rate on peeling capacity

Fig. 7. Surface plot of interaction of moisture content and peeling speed on peeling capacity

Fig. 8. Surface plot of interaction of feed rate and peeling speed on peeling capacity

Tab 2. ANOVA for the effects of moisture content, feed rate and peeling speed on peeling capacity

Source of Variation	DF	SS	MS	F-value	P-value
MC	2	0.60	0.30	115.38	0.00001 ^S
FR	2	305.76	152.88	58800	0.00001 ^S
PS	2	0.18	0.09	34.62	0.00001 ^S
MC*FR	4	0.58	0.145	55.78	0.00001 ^S
MC*PS	4	0.11	0.0275	10.58	0.00001 ^S
FR*PS	4	0.10	0.025	9.62	0.00001 ^S
MC*FR*PS	8	0.15	0.0188	7.23	0.00001 ^S
Error	27	0.07	0.0026		
Total	53	307.63			

Keynote:

MC - Moisture content; FR - Feed rate; PS - Peeling speed; DF- Degree of freedom;
 SS - Sum of squares; MS - Mean of squares; S - Significant; NS - Not significant

The percent damage increased from 7.5% to 13.5% with an increase in moisture content and increase in feed rate as shown in Fig. 9. [1] observed a maximum material loss of Ginger at 6.15% when the outer drum speed was 25rpm, inner drum speed of 45 rpm and peeling duration of 15 minutes when the drum load was constant at 6 kg of Ginger.

At same time, the percent damage increased from 6.3% to 3.4% with an increase in peeling speed and increase in moisture content as shown in Fig. 10. [5] reported a substantial increase of flesh loss of Ginger when the speed was increased from 65 to 85 rpm.

Also, percent damage decreased from 14.4% to 6.9 % with a decrease in feed rate and a decrease in peeling speed as shown in Fig. 11. [6] reported a material loss of 3.27% in an abrasive brush type Ginger peeling machine when the peeling efficiency was 85.56%.

In Table 3, the analysis of variance (ANOVA) proved that the interaction of moisture content, feed rate and peeling speed had significant effect on percent damage at $p < 0.05$ level.

Fig. 9. Surface plot of interaction of moisture content and feed rate on percent damage

Fig. 10. Surface plot of interaction of moisture content and peeling speed on percent damage

Fig. 11. Surface plot of interaction of feed rate and peeling speed on percent damage

Tab 3. ANOVA for the effects of moisture content, feed rate and peeling speed on percent damage

Source of Variation	DF	SS	MS	F-value	P-value
MC	2	84.94	42.47	151.68	0.00001 ^S
FR	2	291.34	145.67	520.25	0.00001 ^S
PS	2	3.74	1.87	6.68	0.0044 ^S
MC*FR	4	104.84	26.21	93.61	0.00001 ^S
MC*PS	4	4.99	1.25	4.46	0.00676 ^S
FR*PS	4	3.60	0.90	3.21	0.02802 ^S
MC*FR*PS	8	14.06	1.76	6.29	0.00013 ^S
Error	27	7.58	0.28		
Total	53	526.20			

Keynote:

MC - Moisture content; FR - Feed rate; PS - Peeling speed; DF- Degree of freedom;
SS - Sum of squares; MS - Mean of squares; S - Significant; NS - Not significant

CONCLUSIONS AND RECOMMENDATION

Conclusions

The following conclusions can be drawn based on the results of this study:

1. A motorized Ginger rhizomes peeling machine made from readily available materials was designed and developed. The machine is cheap and within the buying capacity of local farmers.
2. Peeling efficiency increased from 82.3% to 88.5% with an increase in moisture content from 70% to 80%, a decrease in feed rate from 73 kg/h to 54 kg/h and an increase in peeling speed from 230 rpm to 300 rpm.
3. Peeling capacity increased from 2.4 kg/h to 1.64 kg/h with an increase in moisture content from 70% to 80%, a decrease in feed rate from 73 kg/h to 54 kg/h and an increase in peeling speed from 230 rpm to 300 rpm.
4. Percent damage increased from 6.3% to 14.4% with a decrease in moisture content from 80% to 70%, an increase in feed rate from 54 kg/h to 73 kg/h and an increase in peeling speed from 230 rpm to 300 rpm.
5. The interaction of moisture content, feed rate and peeling speed had significant effect on peeling efficiency, peeling capacity and percent damage at $p < 0.05$ level.

Recommendation

For a maximum peeling efficiency, peeling capacity and minimum percent damage, an optimum moisture content of 75%, feed rate of 67 kg/h and peeling speed of 270 rpm were recommended for use.

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OCENA PERFORMANSI MAŠINE SA MOTOROM ZA LJUŠTANJE GINGER KORENA

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Sažetak: Dizajnirana, razvijena i testirana mašina sa motorom za ljuštenje korena đumbira u količini od 5 kg (Ginger) (*Zingiber Officinale Roscoe*).

Ispitivanje obuhvatilo tri vrednosti: sadržaja vlage (70%, 75% i 80% wb), brzine dodavanja (54 kg/h, 68 kg/h i 73 kg/h) i broja obrtaja rotora sa sečivom za ljuštenje korena (230 o/min, 270 o/min i 300 o/min), za ocenu performansi mašine. Trofaktorski eksperiment (3×3×3), sistem randomizovani kompletni blok dizajn (SRKBD) sa dva ponavljanja, korišćen za proučavanje efekata i interakcija tri faktora (sadržaj vlage, brzina uvlačenja krtle i brzina ljuštenja) na parametre performansi (efikasnost, kapacitet i % oštećenja) Ginger korena. Odnos između parametara performansi i faktora uticaja utvrđen je korišćenjem višefaktorskog dizajna i metode određene površine za grafičke analize.

Studija je pokazala da se efikasnost ljuštenja korena đumbira povećala sa 82,3% na 88,5% sa promenom sadržaja vlage sa 70% na 80%, smanjenjem brzine punjenja od 73 kg/h na 54 kg/h i povećanjem broja obrtaja rotora za ljuštenje od 230 o/min na 300 o/min.

Kapacitet ljuštenja korena je povećan od 2,4 kg/h na 11,64 kg/h uz povećanje sadržaja vlage od 70% na 80%, smanjenjem količine punjenja prijemnog koša od 73 kg/h na 54 kg/h i povećanjem brzine rotora za ljuštenje od 230 o/min na 300 rpm.

Oštećenje (%) korena đumbira (Ginger) je povećano sa 6,3% na 14,4% sa smanjenjem sadržaja vlage od 80% na 70% i sa povećanjem brzine dodavanja (punjenje) masom korena sa 54 kg/h na 73 kg/h, i povećanjem broja obrtaja rotora sa sečivom za ljuštenje Ginger korena od 230 o/min na 300 o/min.

Rezultat analize varijanse (ANOVA, softverski paket Minitab, ver. 17.0) pokazuje da interakcija faktora: sadržaj vlage, brzina uvlačenja i brzina ljuštenja ima značajan uticaj na efikasnost ljuštenja, kapacitet ljuštenja i procenat oštećenja Ginger korena (đumbira) na nivou tačnosti $p < 0,05$.

Za maksimalnu efikasnost ljuštenja, kapacitet ljuštenja i minimalni procenat oštećenja, preporučeni su: optimalni sadržaj vlage 75%, brzina uvlačenja mase korena đumbira 68 kg/h i broj obrtaja rotora sa sečivom za ljuštenje Ginger (đumbir) korena (*Zingiber Officinale Roscoe*) od 270 o/min.

Ključne reči: Ginger koren, procena performansi, kapacitet ljuštenja, efikasnost ljuštenja.

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