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Vol. 10(37), pp. 3662-3670, 10 September, 2015
DOI: 10.5897/AJAR2015.9928
Article Number: F4242D455294
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Performance evaluation of a motorized ginger juice expression machine

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Received 19 May, 2015; Accepted 21 August, 2015

Ginger juice obtained from mechanical expression of fresh ginger rhizomes offers a value-added ginger product which increases market opportunity for farmers. In this study, the performance of a developed motorized ginger juice expression machine was evaluated to determine the effects of moisture content of ginger and screw shaft speed on the expression efficiency, juice yield, expression loss and throughput capacity. Three levels of moisture content (84, 79 and 72%) (wet basis) and three levels of screw shaft speed (420, 472 and 660 rpm) at two replications were used for the study. A 3 × 3 factorial experiment in a completely randomized experimental design was used. Data for the performance evaluation were subjected to analysis of variance for test of significance of the experimental factors and their interactions. The result showed that mean expression efficiency decreased with increase in screw shaft speed and with decrease in moisture content for the speed and moisture content range studied. The highest expression efficiency of 91.62% and juice yield of 61.28% were obtained at screw shaft speed of 420 rpm and at 72% moisture content (wb). The mean juice yield decreased with an increase in screw shaft speed and with a decrease in moisture content of ginger considered. The lowest expression loss of 11.69% was obtained at 472 rpm and 72% moisture content. The machine had highest throughput capacity of 9.47 kg/h at 420 rpm. Analysis of variance (ANOVA) results showed no significant effect of moisture content levels considered, speed and their interactions on all the performance indicators of the machine at P<0.05.

Key words: Expression, moisture content, ginger juice, expression efficiency, expression loss, juice yield.

INTRODUCTION

Ginger (*Zingiber officinale roscoe)* is valued for its essential oils, mainly oleoresin and gingerol, used in the pharmaceutical, bakery and soft drink beverage industries as well as culinary and cosmetics preparation. Percentage composition of volatile oil and non-volatile extract of ginger from Nigeria was given as 2.5 and 6.5%, respectively (Ravindran and Nirmal, 2005). Nigeria's ginger is highly valued for its aroma, pungency, high oil and oleoresin content (Yiljep et al., 2005). However, it has been observed that the quality of its dried ginger has been declining, due to low level of mechanization of ginger production and processing (Onu and Okafor, 2002), with attendant mould growth and loss of some important ginger qualities, as a result of which Nigerian

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ginger attracts the cheapest price in the world market.

Research carried out by Endrais and Asfaw (2011) showed that there is low percentage of oleoresin content per unit volume of ginger as a result of extended harvest, long storage period, over drying and/or re-drying due to dampness. Similarly, Eze and Agbo (2011) reported that drying ginger at a higher temperature appears to denature its protein and alters its organoleptic attributes through loss of its aroma and colour. The deterioration of active ingredients in dried ginger reduces its economic value and utilization in the industries. The bulk of ginger produced in Nigeria is often exported in processed form as split-dried ginger, dried ginger powder and extracts.

Fresh ginger rhizomes can be processed to ginger juice using chemical (extraction) or mechanical (expression) method. The chemical extraction method requires the use of organic solvents to recover oil from products (Ibrahim and Onwualu, 2005). This method of processing ginger is not generally adopted by farmers due to the high cost and complexity of the equipment used in the extraction. The ginger extract obtained from this process usually has some elements of impurity resulting from dissolved chemicals used in the extraction. The wet extraction process otherwise known as hot water or steam extraction used traditionally by women in rural communities for processing varieties of oil-bearing biological materials (Olaniyan, 2010), falls short of standard especially in quality. The traditional method used in expressing ginger juice is usually a manual process and involves pounding with mortar and pestle and hand pressing. This process is inefficient, unhygienic and tedious. These have affected the quality and quantity of ginger extract available in the market in Nigeria. Ginger juice obtained from mechanical expression of pulverized ginger rhizomes offers a value added ginger product which will increase market opportunity for farmers.

Lewis (1990) published that the efficiency of expression processes is determined by the yield and solids content of the liquid obtained. Some of the factors that influence the rate of expression include: Maturity and growth conditions of the raw material, extent of disruption of cell structure, rate of increase in pressure, resistance of the solids to mechanical deformation, time of pressing, the maximum pressure applied, the temperatures of the solids and liquid, and viscosity of the expressed liquid (Fellows, 1990). The effect of particle size, moisture content, heating temperature, heating time, applied pressure, and duration of pressing on the yield and quality of mechanically expressed oil from different crops have been investigated by researchers (Fasina and Ajibola, 1989; Tunde-Akintunde et al., 2001; Olaniyan, 2010). Results showed that these factors had significant influence on the oil yield.

In order to reduce the amount of loss of oleoresin and volatile oil in ginger during processing due to drying and long time storage, a motorized ginger juice expression machine aimed at processing ginger at the shortest possible time after harvest, as well as increasing the retention level of the active ingredients in ginger, was developed. The objective of this work is to evaluate the performance of a developed motorized ginger juice expression machine to determine the effects of moisture content of ginger and screw shaft speed on the expression efficiency, juice yield, expression loss and throughput capacity.

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 the motorized ginger juice expression machine

The developed motorized ginger juice expression machine (GJEM) consists of the following major components: Feeding unit, pulverizing unit, juice expression unit, juice drainage point (outlet), waste outlet, frame and power transmission system (Figure 1).

Frame

The two design factors considered in determining the material required for the frame are weight and strength. The frame was constructed with 38 mm × 38 mm × 3 mm mild steel angle iron. The frame provides firm support for the entire assembly. Based on anthropometric data of male and female agricultural workers in southern Nigeria reported by Onuoha et al. (2012), the overall dimension of the frame was chosen as 610 mm × 390 mm × 790 mm.

Feeding unit

The hopper is a stationary part mounted onto the machine which forms the feeding chute through which sliced ginger rhizomes are fed into the pulverizing unit by gravity. The passage hole (85 × 55 mm) of the hopper was large enough to prevent choking of the product. The hopper is made of stainless steel and is rectangular pyramid in shape.

Pulverizing unit

The pulverizing unit consists of a shaft with a screw conveyor and two attrition plates. One of the attrition plates is fixed on a stationary horizontally-placed small cylindrical drum, while the other is adjustable to allow the passage of the various sizes of the sliced ginger rhizomes. As the shaft rotates in the drum, it pulverizes the whole ginger rhizomes into smaller sizes and they are conveyed by gravity to the position where it enters the expression unit through the lower hopper. The pulverizer is made of stainless steel to avoid any reaction with the juice.

Ginger juice expression unit

The ginger juice expression unit consists of a tapered cylindrical barrel which covers a perforated tapered cylindrical drum that

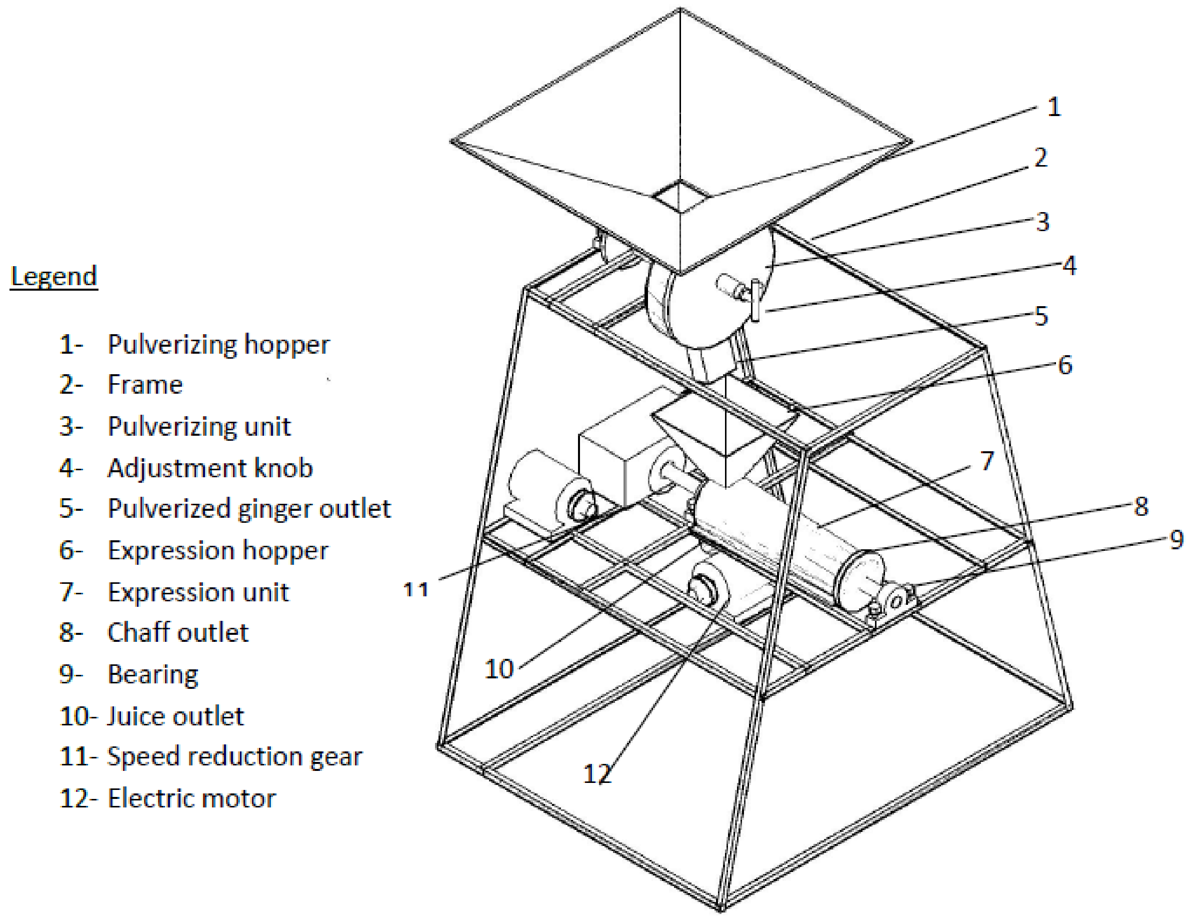

Figure 1. Isometric view of the developed motorized ginger juice expression machine.

houses a screw shaft. The screw shaft is the main component of the juice expression unit. The screw shaft is a stainless shaft with a tapered helical screw of variable pitch. The pitch of the screw flights gradually decreases towards the discharge end, to increase the pressure on the pulverized ginger rhizomes as it is carried through the barrel. The barrel is perforated to allow expressed juice to escape. The diameter of the perforation is about 1 mm. The pressed ginger residue (chaff) passes through the waste discharge point in the barrel outlet.

Power transmission system

The power transmission system comprises the prime mover (electric motor), shaft, speed reduction gear, pulleys and belt. The power was provided by a 2 hp, 1400 rpm and 1 hp, 1430 rpm electric motors. The V-belts and pulley assembly were used to transmit the power to the pulverizing and expression units at a speed of 646 and 240 rpm, respectively. The prime movers were mounted on a slotted plate on the frame to facilitate adjustment of the belt tension.

Working principle of the developed GJEM

The GJEM performs two distinct unit operations simultaneously, size reduction and separation processes. The ginger rhizomes are fed into the pulverizer through the hopper. The ginger rhizomes are comminuted by shearing and rubbing at the pulverizing unit. The screw shaft of the expression unit crushes, presses and conveys the product that comes from the pulverizing unit in such a way that juice is squeezed out of the pulverized rhizomes. The expression is actually achieved by the action of the screw shaft in squeezing the pulverized ginger rhizomes against each other and on the surface of the screw and perforated cylindrical barrel along the line of travel. The juice expressed is drained through the juice channel into the juice outlet from where it is collected while the residual waste is collected at the waste outlet. The picture of the developed GJEM is shown in Figure 2.

Experimental design for performance evaluation

The moisture content and speed of expression were taken as independent parameters for the study. The moisture content of the ginger rhizomes was selected at three levels (84, 79 and 72% wb). The first level was defined after soaking in clean water for two days from the time of purchase. The second level was defined at the period of purchase, while third level was defined after sun drying for one day. The rotational speed of the expression shaft was varied from 420 to 660 rpm at three levels (420, 472 and 660 rpm) using a triple groove pulley of different diameter in order to determine the optimum speed required in expressing ginger juices.

These parameters gave a 3 × 3 factorial experiment fitted into a complete randomized design (CRD). This gave a total of 9 treatments. The experiment was repeated twice giving a total of 18

Figure 2. The developed motorized ginger juice expression machine.

experimental runs.

Experimental procedures

Fresh ginger rhizomes were obtained from a local market in Umuahia, Abia state. Nigeria. Umuahia lies on latitude 5° 32' N and longitude 7° 29' E. The ginger rhizomes were washed, sliced and prepared ready for juice expression. The machine was set into operation and known weights of sliced ginger rhizomes were fed into the pulverizer where they were pulverized and transferred into the expression unit. The feeding time and expression shaft speed were recorded.

The juice expressed and residual waste were collected and weighed separately. The values obtained were used to calculate the juice yield, expression efficiency and expression loss. Also moisture content of the ginger rhizomes was determined. Each of the tests was done at three levels of moisture content and three expression shaft speeds in two replications.

Performance indicators

The performance of the machine was evaluated based on the following performance indicators:

1. Throughput capacity (C_T)
2. Expression efficiency (J_E)
3. Juice yield (J_y)
4. Expression loss (E_L)

Throughput capacity (C_T) was calculated from Equation 1, while J_E, J_y and E_L were calculated using Equations 2, 3 and 4 as given by Olaniyan and Oje (2011).

$$C_T = \frac{Q_o}{t} \quad (1)$$

$$J_E = \frac{100\,W_{JE}}{xW_{fs}}\ \% \quad (2)$$

$$J_y = \frac{100\,W_{JE}}{W_{JE} + W_{RW}}\ \% \quad (3)$$

$$E_L = \frac{100\left[W_{fs} - \left(W_{JE} + W_{RW}\right)\right]}{W_{FS}}\ \% \quad (4)$$

Where, Q_o = Total quantity of ginger collected at the outlet (g); t = time taken to complete expression (s); W_{JE} = weight of juice expressed (g); W_{RW}= weight of residual waste (g); W_{fs} = weight of feed sample (g), and x = juice content of ginger in decimal.

RESULTS AND DISCUSSION

Effect of moisture content

The results of effect of moisture content on expression efficiency are presented in Figure 3. The 84% moisture content corresponds to highest mean expression efficiency of 83.12%. This was followed by 79% moisture content with expression efficiency of 78.78%. The lowest mean expression efficiency (76.24%) was however recorded at 72% moisture content. Expression efficiency increases with increasing moisture content between 72 and 84% range studied. From Figure 4, expression efficiency at 84% moisture content increased from 81.32% at 420 rpm to 88.82% at 472 rpm, and then decreased to 79.23% at 660 rpm. At 79% moisture content, the expression efficiency decreased from 88.13% at 420 rpm to 69.19% at 660 rpm. High water content in ginger accounts for high amount of juice yield and increasing expression efficiency. The lowest (47.89%) and highest (57.72%) mean juice yield were obtained at 72 and 84% moisture content respectively as shown in Figure 3 . The result is in conformity with reports of previous studies which recorded that in oil or juice expression using screw press, increase in moisture content leads to increase in juice yield for crambe seed (Singh et al., 2002); and flaked seed of *cuphea* (Evangelista and Cermak, 2007). This may be due to the increase in the water content. It was observed that the highest mean expression loss of 25.5% was at 79% moisture content. Mean expression loss varies directly with moisture content of the ginger rhizomes. Analysis of variance (ANOVA) showed that moisture content and interactions of speed had no significant effect on the performance indicators at $P< 0.05$ level at the moisture content levels considered (Table 1).

Effect of screw shaft speed

It was observed that expression efficiency generally decreased with increase in screw shaft speed. Figure 5 showed that the expression efficiency was highest (87.0%) at 420 rpm and decreased to 70.47% at 660 rpm. Kolawole et al*.* (2012) observed that the higher the machine speeds, the lower the machine efficiency. Their finding agrees with the relationship between the mean expression efficiency and screw shaft speed recorded in this study. The decrease in expression efficiency with increase in screw shaft speed within the study range can be attributed to the high rate of conveyance of the pulverized ginger by the screw conveyor which results to a short residence time of the pulverized ginger fed in the expression barrel.

The mean juice yield at 420, 472 and 660 rpm were 57.8, 53.1 and 48.47%, respectively (Figure 5). Effect of the interaction of moisture content and screw shaft speed (Figure 6) revealed that speed varies inversely with the juice yield except at 84.03% moisture content. Juice yield at 84% moisture content increased from 55.73% at 420 rpm to 61.25% at 472 rpm, and decreased to 56.18% at 660 rpm. Deli et al. (2011) observed that the percentage of oil yield from *Nigella sativa* L seeds decreased with the increase on the rotational speed of machine, which is in consonance with the result obtained from ginger in this study. The effect of different speeds on the percentage of juice yield is related with the duration of pressing process. Slow speed would probably extend the pressing process and result in increase of temperature during the process (Evangelista and Cermak, 2007).

At 72% moisture content in Figure 7, the mean expression loss decreased with speed from 12.8 to 11.68% and increased rapidly from 11.68 to 19.96% as speed increased from 472 to 660 rpm. This indicates that for minimal loss, the machine is better operated at 472 rpm and lowest moisture content (72%) for the speed range tested. The mean machine losses of sugar cane juice extractor reported by Olaoye and Oyelade (2012) decreased with the speed of operation which was also observed in the ginger juice expression machine within the speed of 420 to 472 rpm. From Figure 8, results showed that the highest mean throughput capacity of 9.47 kg/h was observed at the speed of 420 rpm. This was followed by a mean throughput capacity of 7.81 kg/h at 660 rpm. The minimum throughput capacity of 5.22 kg/h was observed at 472 rpm.

No significant effect of screw shaft speed and interactions of moisture content on the performance indicators recorded in this study (Tables 2 and 3) was due to probably close range of values (72- 84%) of

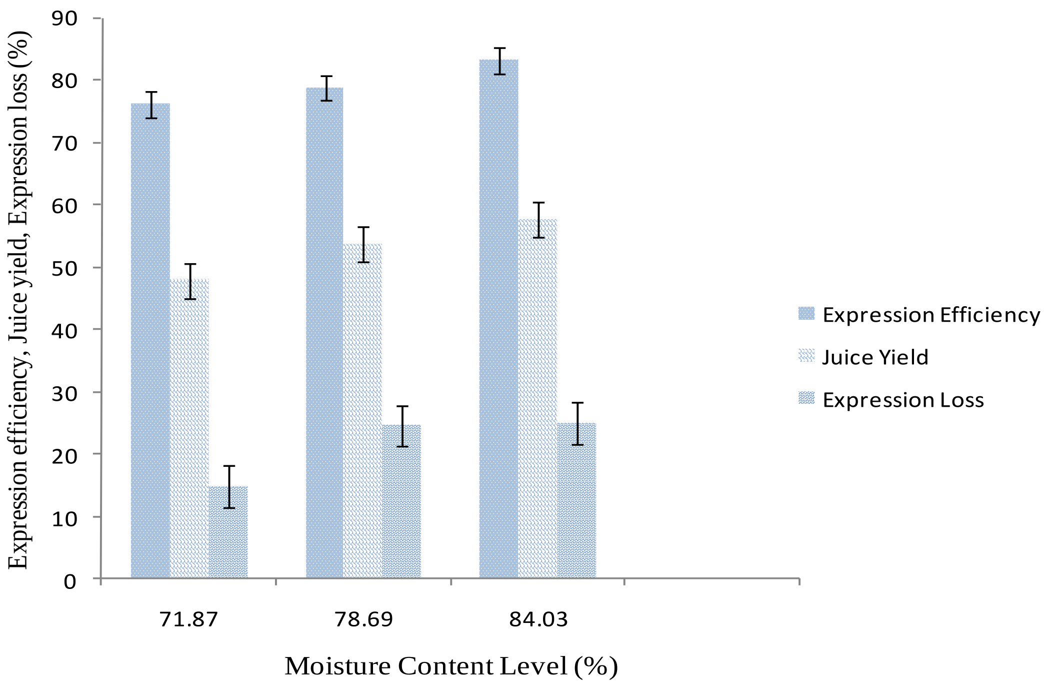

Figure 3. Effect of moisture content on expression efficiency, juice yield and expression loss. Data points are means (±SE) of the replicates.

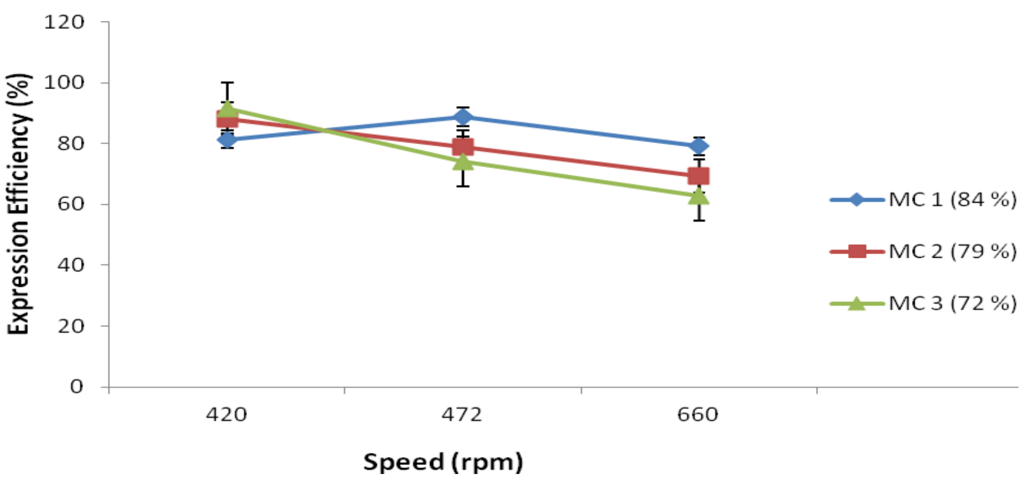

Figure 4. Effect of speed on expression efficiency at different moisture content. MC = moisture content. Data points are means (±SE) of the replicates

Table 1. Analysis of variance (ANOVA) for expression efficiency.

Source of variation	d.f.	s.s.	m.s.	v. r.	F< pr.
Moisture	2	145.4	72.7	0.47	0.640*ns
Speed	2	835.8	417.9	2.70	0.121*ns
Moisture speed	4	457.5	114.4	0.74	0.589*ns
Residual	9	1395.5	155.1		
Total	17	2834.1			

*ns = Not Significant at 5% probability level.

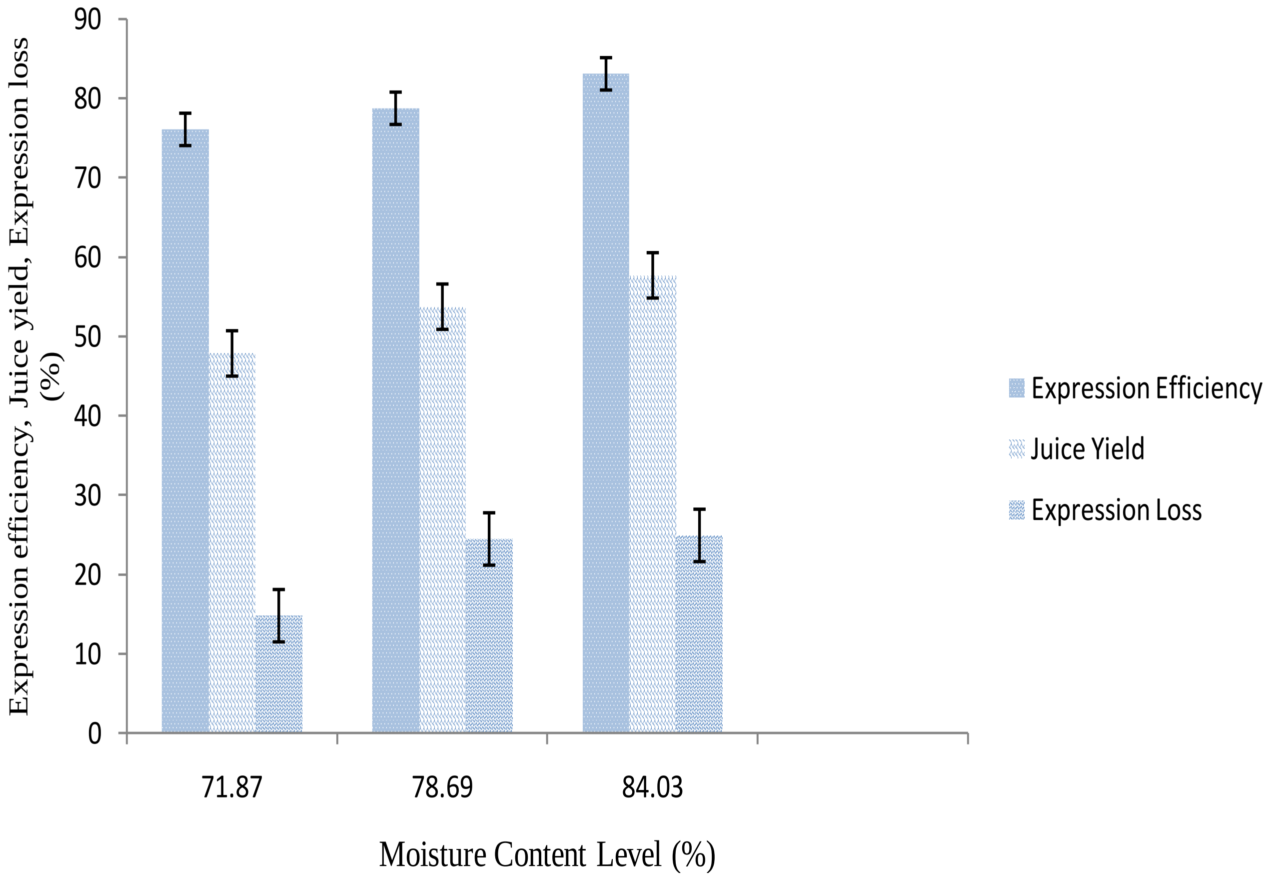

Figure 5. Effect of screw shaft speed on expression efficiency, juice yield and expression loss. Data points are means (±SE) of the replicates.

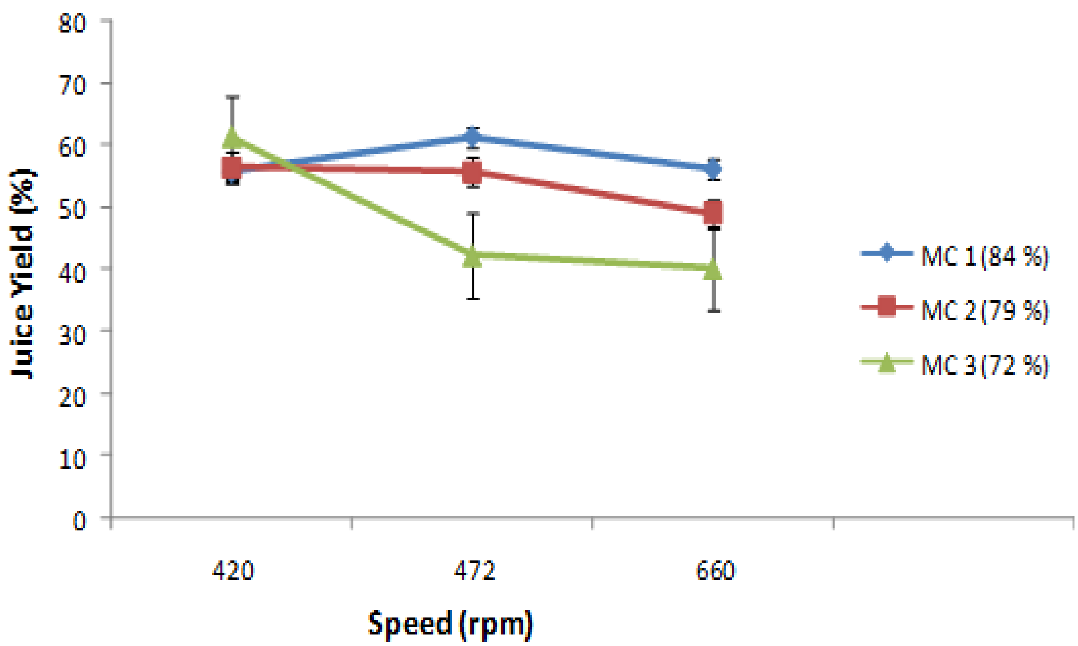

Figure 6. Effect of speed on juice yield at different moisture content. MC = moisture content. Data points are means (± SE) of the replicates.

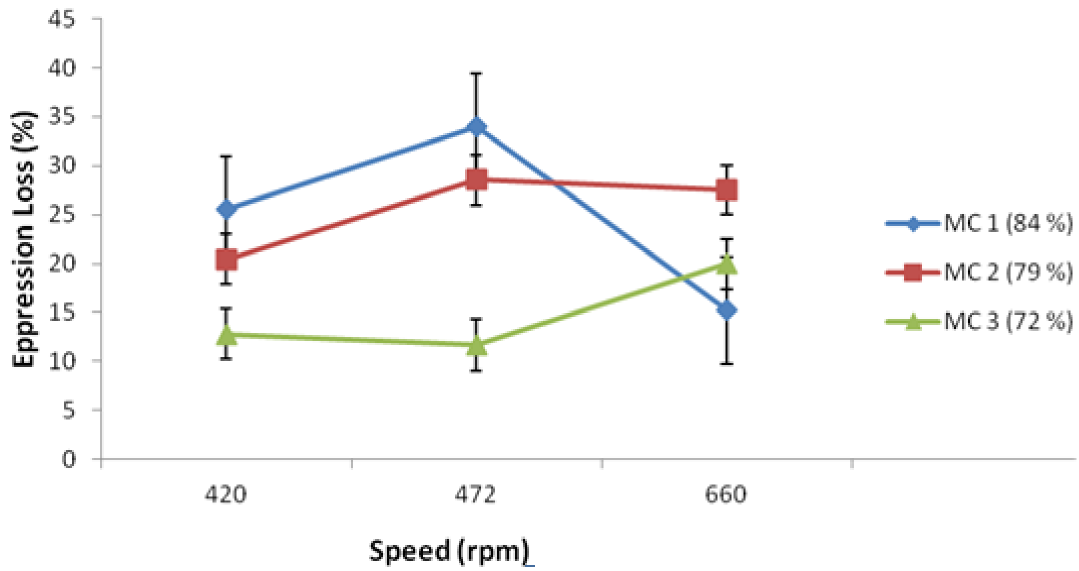

Figure 7. Effect of speed on expression loss at different moisture content**.** MC = moisture content. Data points are means (±SE) of the replicates.

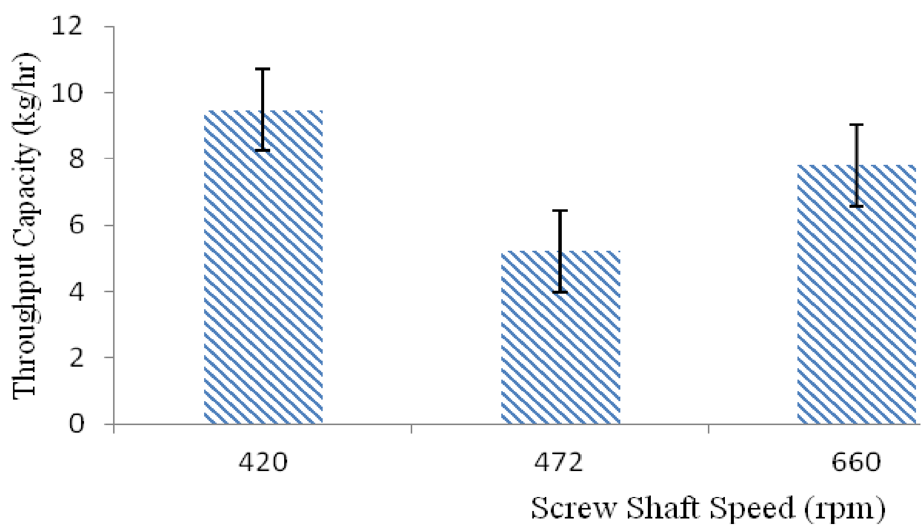

Figure 8. Effect of screw shaft speed on throughput capacity. Data points are means (±SE) of the replicates.

moisture content and speed (420- 660 rpm) used in the test.

Conclusion

The performance of the developed motorized ginger juice expression machine was evaluated, and the following conclusions were drawn:

1. The highest juice yield and expression efficiency of the ginger juice expressing machine can be obtained by operating the machine at lowest possible operational speed and moisture content level. The 420 rpm speed and 72% moisture content level satisfied this condition as was established for the range of speeds and moisture content levels considered in this study.
2. Increase in moisture content level from 72 to 84% led to increase in expression efficiency and juice yield from 76.24 to 83.12% and 47.89 to 57.72%, respectively, while expression loss increased from 14.82 to 25.5% as moisture content level increased from 72 to 79%, and

Table 2. Analysis of variance (ANOVA) for juice yield.

Source of variation	d.f.	s.s.	m.s.	v. r.	F< pr.
Moisture	2	293.87	146.94	3.96	0.059*ns
Speed	2	261.14	130.57	3.52	0.074*ns
Moisture .Speed	4	384.87	96.22	2.59	0.108 *ns
Residual	9	334.27	37.14		
Total	17	1274.15			

*ns = Not Significant at 5% probability level.

Table 3. Analysis of variance (ANOVA) for expression loss

Source of variation	d.f.	s.s.	m.s.	v. r.	F< pr.
Moisture	2	433.41	216.71	3.55	0.073*ns
Speed	2	85.49	42.75	0.70	0.521*ns
Moisture speed	4	427.71	106.93	1.75	0.222*ns
Residual	9	548.70	60.97		
Total	17	1495.32			

*ns = Not Significant at 5% probability level.

then decreased to 24.94 at 84% moisture content level.

3. The mean expression efficiency and mean juice yield decreased with increase in screw shaft speed from 420 to 660 rpm.

4. Moisture content levels considered, screw shaft speed and their interaction had no significant effect on the performance indicators at 5% probability level.

Conflict of Interest

The authors have not declared any conflict of interest.

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