Design and Development of a Ginger Slicer for Small Scale Spice Processors

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Abstract— The objective of this study was to develop a ginger slicer in order to improve the slicing efficiency of the fresh ginger. With the main purpose of high ginger slicing rate, a machine was designed and fabricated for uniform slicing. The machine has a slicing mechanism with a rotary cutting disc and a semi-automated conveyor feeding system. The conveyor feeder consists of a belt and a holding plate to hold the ginger rhizomes while slicing. The slicer disc consists of a chiseled (one side beveled) stainless steel straight blade attached to a SS rotary disc. The machine was evaluated at two different rotary speeds; 400 rpm and 480 rpm respectively for a ginger variety. Slicing efficiency, material loss, machine capacity and the mean thickness of the slices calculated. Moisture content of the ginger was at 71.26% wb during the test. The results showed that the average slicing efficiency, material loss and machine capacity were 87.9%, 2.8% and 71.4 kg/h, respectively at 400 rpm while those were 82.5%, 3.2%, and 81.1 kg/h at 480 rpm. The mean thicknesses of the slices were 9.6 mm and 9.2 mm, at 400 and 480 rpm, respectively. The machine capacity were 7 times higher than the manual method that is10.28 kg/h. The results show that the machine efficiency is higher at lower speed. In addition to ginger, the developed machine could be used for other vegetables like potato and carrot.

Keywords— Ginger Slicing Machine, Machine Capacity, Sliced Ginger, Dry Ginger, Rotational Speed

I. INTRODUCTION

Ginger (Zingiber officinale) is a very popular spice in the world and the cultivation has been spread all over the world. China, India, Nigeria, Nepal, Bangladesh, Japan Thailand, Philippines, Cameroon, Sri Lanka, Korea and Fiji are popular for ginger production [1]. Ginger is used both in fresh form (Green Ginger) and dried form (Dry Ginger). Most of the Asian people use both types with tea in order to enhance the flavor and also for the health benefits [2]. Ginger contains essential oil namely Oleoresin and Geingerol [3]. Due to the special characteristic of these oils, ginger is used in food, (as a spice to flavor curries) beverage, perfume and medicinal industries [4].

Freshly harvested Ginger have 80-85% moisture content and dried to 10 -12% for storage [5]. Ginger is harvested 8-9 months after planting for processing into dried ginger [6]. After harvesting, fresh ginger is subjected to various post-harvest processes such as washing, peeling, killing and either slicing or dicing [7].

Size reduction of ginger is an important unit operation in the dry ginger processing because it reduce the time consumption for drying and energy requirement. Slicing and dicing are the two main pulverizing types which has been practiced for ginger rhizomes. If the ginger is sliced, only 5 to 6 hours are needed to dry in a cross-flow drier, compared to 16 to 18 hours for drying scraped whole ginger using the same equipment and conditions [6, 8]. Most of the time dried sliced ginger is produced for the export market because there is a big demand in the international market for such value added products [9].

Mechanization of slicing procedure is important due to the problems of labor shortage in the industry. Although various types of vegetable slicers are available in the market, due to some drawbacks, those machines cannot be introduced for the ginger slicing. While considering the morphological characteristics of a ringer rhizomes, long and strong fibers can be found in the flesh which can withstand the cutting forces. Jayashee & Visvanathan (2011) have shown that the required cutting force to penetrate the meat of fresh ginger was 31.56N. Vegetable cutters which are available in the market are designed for non-fibrous vegetables such as potato and carrot which require a lesser cutting force. If these cutting machines are used for ginger, the blades may get damaged and has to be replaced frequently. The other major issue is the high cost of these available machines. Small scale industry may not have the capacity to invest on such expensive machines thus they rely on manual labor most of the time.

Daily production varies between 600-800 kg of fresh ginger when the slicing is done manually. The labors use normal kitchen knives which cause injuries due to the hazardous cutting equipment and practices. Also the productivity and the efficiency of the cutting procedure is not at its optimum level. The quality of final products also not uniform due to this manual cutting practices.

Mechanical slicing of ginger can solve the problems associated with the manual labor and transform into commercial production. The objective of this study is to design and develop a cost effective and efficient mechanical solution to slice the fresh ginger with high quality output.

II. METHODOLOGY

Two types of steels were used. Mild steel was used where water is not supposed to be in contact frequently. Stainless steel (SS 304) was used to fabricate the other parts where water is frequently used. Machine parts such as conveyor belt fixing guides and the main frame were made out of mild steel and the rotary disc, conveyor belt holder and cutting blades were fabricated using stainless steel. Conveyor roll shafts was made out of stainless steel due to its special characteristics. Aluminum and timber was used as frame. A flat bed was used where all the machine components could be mounted.

As readymade components a bearing housing was used to mount the rotary disc. A mechanical gear box with a built-in speed controlling mechanism was used to control the speed of the conveyor belt. Two motors were used to drive the system. A mild steel frame was used as the frame of the machine. An endless conveyor was used as the feeding part of the machine.

The Chinese ginger variety was selected for designing the machine. This variety is the most commonly grown in Sri Lanka and gives a higher yield compared to the other varieties.

A. Characterize of ginger rhizomes

Before designing the slicing and dicing machine it is necessary to determine important design parameters of ginger based on morphological characters of ginger. The axial dimensions,
thickness, length and the width were useful in designing the machine. The width and the length of the ginger rhizomes determined the conveyor dimensions and also the width of the cutting blade. The thickness of rhizomes are needed to determine the dimension of the upper holding device on the conveyor belt. A venire caliper was used to determine the axial dimensions with an accuracy of 0.05 mm. Samples of ginger were measured for its weight using an electronic balance with an accuracy of 0.001 kg. To calculate the density of the ginger the water displacement method was used to determine the volumes of ginger rhizomes. Ten samples were used to measure the volume of rhizomes. The volume of ginger is used to calculate the density and determine the dimensions of the conveyor belt, hopper and storage facilities. Density of the ginger was calculated using the volume by mass ratio. The moisture content was determined using the oven dry method in the laboratory. Two samples were placed in an oven and dried for 24 hours at 110˚C and weight of samples before and after were recorded using an electronic balance, with the accuracy of 0.0001 g. The initial moisture content is directly proportional to the cutting force required for the penetration of the ginger flesh.

1) Investigation of manual ginger slicing

Study the operation performance of manual ginger slicing in a spice processing factory. The following data was gathered to characterize the ginger.

- Daily usage of the fresh ginger
- Number of labors and number of working hours
- Average thickness of the manually sliced ginger
- Average manual slicing capacity

\[
\text{Manual Slicing capacity} = \frac{\text{Weight of the sliced ginger}}{\text{Time}} \quad \text{---(1)}
\]

2) Designing of the machine components

Two main functions were identified as conveying and cutting. Then three main parts, frame, conveyor system and rotary knife system were designed. A readymade mild steel table with dimensions of 570 mm x 370 mm x 660 mm used as the frame base (Fig. 1). An 18 mm, 760 mm x 485 mm double side coated plywood sheet was fixed using two iron bars on top of the frame base. A half circle of 200 mm diameter was made in order to collect sliced ginger (Fig. 2).

3) Conveyor belt

An endless conveyor belt was fabricated for the continuous feeding of ginger rhizomes towards the rotary cutting knife. The width of the belt was 95 mm and the length was 863 mm. A rubber mixed food grade belt with a thickness of 1.3 mm was selected. To increase the friction between the ginger and the belt, diamond shaped grips are formed by the manufacture, but it was observed that the friction was not enough to carry the rhizomes smoothly on the conveyor in this experiment. To avoid the slipping on the rubber belt, pusher pins made of stainless steel with the height of 10 mm were designed and fixed on the conveyor belt (Fig. 3).

Mild steel plate was used to mount the rubber conveyor belt on the frame. Four mild steel plates of 15 mm thickness were mounted on another 150 mm x 430 mm mild steel plate using 2.5 mm x 2.5 mm square bars (Fig. 4).

Two holes of 37 mm diameter were machined on the front vertical plates to mount two bearings. On rear plates 90 mm x 30 mm square slots were made to facilitate the horizontal movement of the rear conveyor rollers to adjust the tension of the conveyor belt (Fig. 4).

4) Roller and conveyor belt

Conveyor belt rollers were fabricated using 50 mm diameter aluminum shaft which has a bore of 20 mm. Both rear and front rollers were 97 mm in length. A 20 mm diameter stainless steel shaft was tightly fitted to the front roller. Two bearings were fixed in to the bore of the rear roller, allowing it to rotate on its own axis. On the front wheel a knurling was engraved in order to increase the friction coefficient (µ) between roller and the belt.

A railing was fabricated using a 1.5 mm thick stainless steel sheet to hold the load exerting on the conveyor belt. The ‘U’ shaped railing have the guards on both sides to guide the belt without allowing to moving to sides. The railing was mounted on top of the mild steel plates of the conveyor belt mounter using the holding flanges (Fig. 6).
5) Rotary cutting disc

A straight blade was selected, considering the easiness of the sharpening and the availability [11]. To fabricate the slicer knife, a 1.5 mm thick stainless steel blade was used and it was beveled to a single side (25˚) to optimize the cutting efficiency (Fig. 5). Five tapered holes were drilled on the blade to mount it on the rotary disc. To fabricate the rotary disc, a 10 mm thick stainless steel round plate was used. The diameter of the disc was 290 mm. A slot of 95 mm x 20 mm was cut on the disc in order to facilitate the transfer of the sliced ginger to the other side of the plate. A stainless steel rod with the diameter of 25 mm was used with two bearings at both ends as axial shaft to rotate the rotary disc (Fig 7).

6) Driving mechanism

There were two main necessities to be fulfilled in the driving mechanism of the conveyor belt. First, the conveyor belt has to move very smoothly and at a constant speed in order to achieve a uniform slicing thickness. Secondly, the speed has to be adjusted to control thicknesses of the slices. To achieve these two requirements, a speed reducer was selected coupled with a quarter horse power single phase motor. The speed reducer was a worm type mechanical reducer having the speed ratio of 1:40. Belt and pulleys were used to transfer power from the motor to the drive shaft of the conveyor. Motor rotates at 1440 rpm at no-load and speed reduces to 1300-1350 rpm when loaded. A pulley with a diameter of 20 mm was fixed to the motor shaft and another pulley of 75 mm diameter was attached to the input shaft of the speed reducer. The output shaft of the reducer has a 60 mm pulley that transfers power to another same size pulley on the drive shaft of the conveyor belt. A separate 200 V, geared AC motor was used to drive the rotary disc. The power was transmitted to the rotary disc shaft using a belt and pulleys. A pulley with a diameter of 110 mm was mounted to the motor shaft and a variable size pulley was mounted to the rotary disc shaft. The reason for using a variable size pulley is that to control the rotating speed of the disc at a given time.

B. Operation

The ginger rhizomes were placed on the conveyor belt at the feeding area and rhizomes were push towards the rotary cutting disc at a constant speed by the pusher pins attached to the conveyor belt. The ginger rhizomes were guided by upper holding plate and the conveyor railing to transfer to the cutting edge plate. The slicing mechanism is powered by the rotary slicing blade attached on the rotary disc rotating on a vertical plane. Then with continuous feeding of the rhizomes on the conveyor belt the ginger was sliced and the slices were collected at the other side of the rotary disc through a slot underneath the slicing blade.

C. Performance evaluation

1) Experimental procedure

Ten samples of ginger were weighed and each sample was fed to the machine while the blade runs at various predetermined speeds. The machine capacity was calculated for each replicate using the equation.

\[
\text{Machine Capacity} = \frac{\text{Weight of ginger input}}{\text{time}} \quad -(2)
\]

Collected sliced ginger was weighed to calculate the material loss. The loss of material happens due to the impact forces generated by the rotary cutting disc. Then from the sliced ginger, fully sliced pieces was separated and weighed to get the
slicing efficiency. From each samples twenty five slices were chosen randomly and measured the thickness using a vernier caliper. The material loss and the slicing efficiency was calculated using the equation 03 and 04.

\[
\text{Material Loss} \% = \frac{Q_{\text{in}} - Q_{\text{out}}}{Q_{\text{in}}} \times 100 \quad (3)
\]

\[
\text{Slicing Efficiency} \% = \frac{Q_{\text{out}} - Q_{\text{broken}}}{Q_{\text{out}}} \times 100 \quad (4)
\]

\(Q_{\text{in}} = \) Weight of ginger placed on the conveyor, (g)
\(Q_{\text{out}} = \) Weight of ginger collected at outlet, (g)
\(Q_{\text{broken}} = \) Weight of ginger broken from \(Q_{\text{out}}\), (g)

The rotation speeds of the rotary cutting disc was controlled by using the step pulley which was mounted to the shaft of the rotary disc. Although the rotary disc was rotated in various speeds, the conveyor speed was maintained at a constant level throughout the experiment. Following equation (equation 05) was used to calculate the speeds of the rotary disc for different pulley sizes.

\[N1 \times D1 = N2 \times D2\]  

(5)

Where
\(N1 = \) Speed of the motor pulley (rpm)
\(N2 = \) Speed of the rotary disc (rpm)
\(D1 = \) Diameter of the motor pulley (mm)
\(D2 = \) Diameter of the Step pulley (mm)

### III. RESULTS AND DISCUSSION

#### A. Characterization of Ginger Rhizomes

Morphological characteristics of ginger were shown in Table 1 used for the design of the ginger slicing machine. The density of ginger was 1.09 g/cm³. The average moisture content of the fresh ginger was 71.26% wet basis.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Average Value</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial dimensions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length (cm)</td>
<td>12.15</td>
<td>1.94</td>
</tr>
<tr>
<td>Width (cm)</td>
<td>8.71</td>
<td>1.88</td>
</tr>
<tr>
<td>Thickness (cm)</td>
<td>2.55</td>
<td>0.27</td>
</tr>
<tr>
<td>Fresh weight (g)</td>
<td>65.67</td>
<td>8.23</td>
</tr>
<tr>
<td>Volume (cm³)</td>
<td>60.4</td>
<td>8.63</td>
</tr>
</tbody>
</table>

#### B. Performance of manual slicing

Table 2: Manual Ginger Slicing Performances

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Average Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily production (kg)</td>
<td>720</td>
</tr>
<tr>
<td>Slicing capacity (kg/h/labor)</td>
<td>10.28</td>
</tr>
<tr>
<td>Slicing efficiency (%)</td>
<td>&gt;98</td>
</tr>
<tr>
<td>Mean thickness of slicers (mm)</td>
<td>8.71 ± 1.07</td>
</tr>
</tbody>
</table>

Altogether thirteen female labors involved in the slicing of ginger with working hours of 8 hours per day (including the one hour lunch break). For the slicing of peeled ginger kitchen knives are used. The existing performance of the manual slicing are given in Table 2. The ergonomic designs of kitchen knives are at very poor conditions and there were many hazardous incidences due to the unsafety and the mishandling. During the peak period of production, labors are plastered their fingers by using surgical plasters to avoid the cuts and bruises from the tools.

#### C. Performance evaluation of the machine

The machine was tested at two different rpm and compared the performance at each speed. The driver motor was run at a speed of 400 rpm and the shaft was coupled with a 110 mm pulley. Then a 90mm pulley was selected from the step pulley and the speed of the rotary disc was calculated as 480 rpm for the second trial. Table 3 shows the performances at two rotational speeds, with three replicates.

1) Slicing efficiency

The results shows that the average slicing efficiency is higher in the low rotational speed (400 rpm) compared to higher speed. This parameter is the most important one among the other three evaluated parameters because it directly connected with the quality of the final product. While the ginger is been sliced, some pats get damaged due to the impact forces of the rotary slicing disc and those broken pieces also been collected at the collection area of the machine. At higher speeds, the generated impact forces are higher and that may be the reason for reducing slicing efficiency at the 480 rpm trial. Proper sharpness of the slicing blade and the smooth movement of the conveyor belt may further increase the slicing efficiency of the machine.

2) Material loss

The material loss is mainly occur due to the scraping of the rhizomes while slicing happens and the scraped ginger particles were collected at the inner side of the safety guard of the rotary disc. This loss can be further minimized by using a smooth surface for the rotary disc. The results at the evaluation shows, there is a reduction of the material loss percentage at lower speeds due to the lesser impact forces.

3) Machine capacity

The capacity of the machine is higher in the higher speed. 81.05 kg/h at 480 rpm is more than 7 times higher compared with the labor capacity where 10.28 kg/h/labor. Mean thickness of the slices is more acceptable with required thickness 10 mm at 400 rpm.

### CONCLUSION

The ginger slicing mechanism for achieving uniform slices of ginger was successful. The obtained values shows that the overall efficiency of the machine was higher while the machine is operating at a lower speed. The average machine capacity was 7 times higher compared to the labor capacity of 10.28 kg/h with a higher uniformity on slicer thickness.

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### References


