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ORIGINAL RESEARCH ARTICLE

DEVELOPMENT AND PERFORMANCE EVALUATION OF AN OKRA SLICER

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ABSTRACT

The traditional method of slicing okra with kitchen knife is labourious, time-consuming and also prone to finger injury. Both traditional method and existing mechanized okra slicer result in damaged and unequal slices of okra which may hinder proper drying of the okra for preservation. An okra slicer was designed, constructed and evaluated. The main parts of the machine were cutting discs, guided removable tray, loading hopper, the transmission system and the supporting frame. In the evaluation of the machine with okra, the performance indices investigated were slicing efficiency, throughput capacity, mechanical damage index and slicing uniformity. The highest slicing efficiency and throughput capacity for okra were 99.88 % and 194.11 kg/h respectively. The least mechanical damage index value of 0.30 % was obtained at a cutting speed of 1200 rpm. The mean slicing uniformity was 93.87 %. The machine developed in this study was able to produce uniform slices of okra of about 3.4 mm thickness. Hence, Industrial production and shelf life of dried okra could be enhanced.

1.0 Introduction

Okra (*Abelmoschus esculentus L.*), also known as lady's fingers, is one of the most significant fruit vegetables grown throughout the tropics and warmer parts of the temperate climatic zone (Sankar et al., 2008). It is a tall (2 m) annual tropical herb cultivated for its edible green seed pod (Owolarafe et al., 2011). Okra could be available fresh all year-round in the southern part of Nigeria and from May to October in many other areas. Okra has both domestic and industrial applications. The leave buds and flowers are edible. The pods, when cut, exude a mucilaginous juice that is used to thicken stews (gumbo), and have a flavour somewhat like a cross between asparagus and eggplant (Ehler, 2010). Okra is a rich source of many nutrients, including fibre, vitamin B6, vitamin C and folic acid. It has many medicinal applications such as stability of blood sugar, binding excess cholesterol, replenishing sodium in the body and as anti-oxidants among others (Adeboye and Oputa, 1996). When fresh Okra fruits are harvested, the average moisture content is 11.42 % (wet basis) (Owolarafe and Shotonde, 2004). Okra is utilized in both fresh and dried forms for soups/stew making and the seed can be used to fortify non-protein foods. Also, Okra in powdered form has the properties of an emulsifier and can be useful in making emulsified prepared food (Douglas, 1982).

In West Africa, production of okra as fruit vegetable is estimated at 500,000 to 600,000 tonnes per year (Burkil, 1997). Okra farmers and marketers experience a lot of annual post-harvest losses caused by poor handling, inadequate storage facilities because of the high perishability nature of fresh okra fruits. The traditional method of preservation in Nigeria is to process the pods into a crispy dry product (Òrúnlá). This involves slicing the fresh fruit with a sharp knife, sun-drying and storage in sacks till when needed for cooking and marketing. The traditional method of slicing okra is quite labourious, time consuming, results in drudgery and also prone to hazard of finger injury (Aji et al., 2018). In the same vein, the existing motorized okra slicer employ the method of gravity in loading the okra to the slicing unit which result in damage, escape of okra and non-uniform slices of okra (Owolarafe et al., 2012). Although, this machine had a slicing efficiency of 85.7 % at a speed of 400 rpm, the conveyance of okra was by gravity which allowed the presentation of the okra to be longitudinal, lateral or in any other position to the slicing unit of the machine. In addition, the machine damaged some okra fruits by cutting them longitudinally as shown in Figure 1 (Owolarafe et al., 2012). The presentation of the Okra to the slicing unit determines the quantity and type of sliced material to be obtained. Therefore, it is imperative to have a machine that will slice the okra in an acceptable manner with a slicing capacity that is commensurate to the scale of production of the Okra fruits required with minimal mechanical damage. Hence, the objective of this work was to design and construct a slicing machine for Okra that feeds the fruit laterally to the slicing unit. This would enhance high production of Okra with minimal damage at uniform slices for preservation and storage.

Figure 1. Sliced Okra fruits from existing motorized okra slicer
Source: Owolarafe et al. (2012)

2 Materials and Method

2.1 Design Considerations

Some of the factors that were considered in the design of the machine included material availability, capacity of the slicer, lateral presentation of okra for slicing, shear force required to cut okra, moisture content of freshly harvested okra fruits, physical properties of okra and slicing uniformity. Experiments were carried out to determine some physical properties like length and diameter of okra fruits which were required for the design of an okra slicer. The ila-iroko variety of okra fruits was used in this study (Owolarafe et al., 2012). The average length and diameter obtained for okra fruit were 56.40 mm and 26.20 mm respectively. The average moisture content was 13 % (wet basis).

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2.2 Rotational force required to slice Okra

The required rotational force, F_c, to drive the shaft carrying the cutting discs was given by (Hall et al., 1983):

$$F_c = \frac{MD}{2}\left(\frac{2\pi N}{60}\right)^2 \quad (1)$$

where: M = mass of the cutting disc (kg), D = Diameter of the cutting disc (m) and N = speed of the shaft (rpm). Choosing M = 1.335 kg, D = 0.115 m (gauge 14 stainless steel) and N = 400 rpm (Owolarafe et al., 2012), the calculated value of rotational force was 134.69 N. This calculated value is greater than the shear force of 68 N required to cut okra (Daniela et al., 2012). Therefore, the force of the cutting disc was adequate to slice the okra.

2.3 Power required by the cutting discs

According to (Hall et al., 1983), the torsional moment, Mt available on cutting disc is given by:

$$M_t = F_c\frac{D}{2} \quad (2)$$

Where all the symbols are as earlier defined. Having Fc = 134.69 N, D = 0.115 m, the computed value of torsional moment was 7.74 Nm. Therefore, the power required to turn the shaft (P_D) was given by (Hall et al., 1983):

$$P_D = \frac{2\pi N M_t}{60} \quad (3)$$

where: N = 400 rpm (Owolarafe et al., 2012) and Mt = 7.74 Nm (as earlier calculated), the computed value of PD was 324.21 W

2.4 Design of the Cutting Disc Shaft

The shaft of the cutting discs was exposed to bending moment and torsional stresses. From the bending moments calculation, the maximum bending moment Mb obtained was 0.492 Nm.

According to (Hall et al., 1983), the required shaft diameter could be obtained from the equation

$$d^3 = \frac{16}{\pi_{S_s}}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \quad (4)$$

where: M_b = maximum bending moment (Nm), M_t = torsional moment (Nm), S_s = permissible shear stress (MPa), K_b = combined shock and fatigue factor applied to bending moment, K_t = combined shock and fatigue factor applied to torsional moment and d = required shaft diameter (m). For a rotating shaft with gradually applied load, the bending fatigue factor, K_b = 1.5 and the torsional fatique factor, $K_t = 1$, permissible shear stress, S_s = 95 MPa (Hall et al., 1983). Having M_b = 0.49 Nm, M_t = 7.74 Nm, K_b = 1.5, K_t = 1 and S_s = 95 MPa, the calculated value of diameter of the shaft was 7.47 mm.

2.5 Description of the Machine

The isometric projection, orthographic projection and pictorial view of the constructed motorized okra slicer are shown in Figures 2, 3 and 4 respectively. It comprises of a set of cutting discs which shear and cut the okra fruits that are brought in contact with them into slices. The other components of the machine are loading hopper, guided removable tray and transmission system.

2.5.1 Loading Hopper:

This is hopper in which the okra fruits are poured and allowed to fall by gravity on the guided removable tray. The okra fruits are further adjusted by hand to ensure that they are all lying laterally in the guides of the tray and all the guides are filled up. The loaded tray is later moved to the slicing section of the machine.

2.5.2 Guided Removable Tray:

This is where the okra fruits are placed horizontally during slicing operation. The tray was demarcated into rows to hold the okra fruits such that okra fruits were conveyed laterally to the cutting discs so as to ensure uniform slices.

2.5.3 Cutting Discs:

There were eight sharp plain-edged cutting discs of 115 mm diameter each. They were equally spaced at 3.5 mm interval along their shaft and each disc was 2 mm thick (gauge 14 stainless steel) so as to achieve okra slices of 3.4 mm thickness. They performed the actual slicing operation when rotated by an electric motor.

2.5.4 Transmission system:

This comprised of 2 hp electric motor, a speed reduction gear of ratio 1:3 and chain-sprocket and belt drives. This system was designed to move the tray of okra fruit through the cutting discs.

2.6 Operation of the Okra Slicer

The okra fruits are fed into the hopper. The okra fruits fall by gravity on the guided removable tray which is placed under it. The okra fruits are manually adjusted on the tray to ensure that they are positioned laterally with respect to the orientation of the slicing discs in order to enhance proper slicing. After the guided removable tray has been loaded and the okra fruits properly positioned, it is manually removed and placed on the carriage. The transmission system could move forward and backward in order to present itself for the placement and removal of the loaded guided removable tray within the cycle of operation of the machine. A loaded guided removable tray is placed on the carriage for conveyance to the cutting discs. When the machine is put on, the cutting discs start to rotate according the set speed and the guided removable tray moves the loaded tray through the cutting discs for the okra fruits to be sliced. After the okra fruits have been sliced, the tray is removed. The transmission system is actuated to move backward in order to enable another loaded guided removable tray to be placed on the carriage for conveyance to the cutting discs. The machine works on shearing and cutting principle and its operation is in batches.

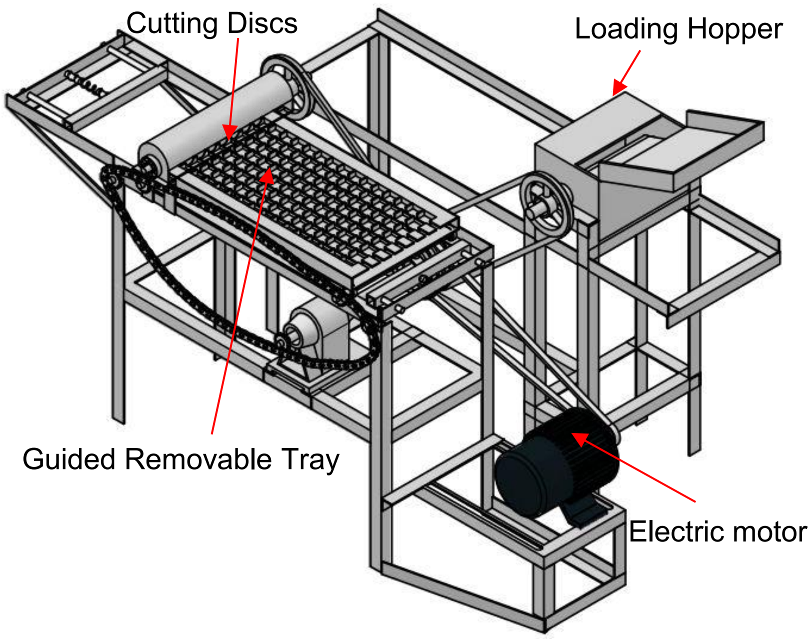

Figure 2. Isometric Projection of the Okra Slicer

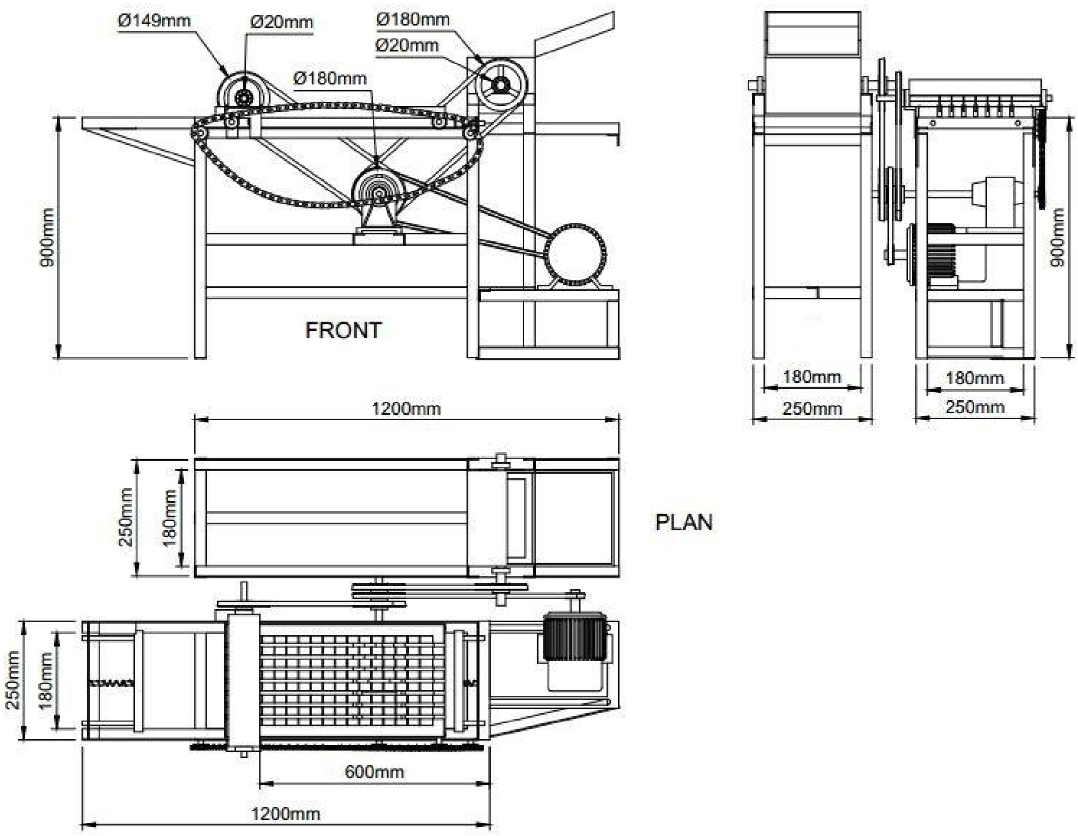

Figure 3. Orthographic Projection of the Okra Slicer

Figure 4. Pictorial View of the Constructed Okra Slicer

2.7 Performance Evaluation

The designed and fabricated okra slicing machine was tested to evaluate its performance on the basis of slicing efficiency, throughput capacity, mechanical damage and slicing uniformity. The machine was tested at cutting disc speeds of 300 rpm, 400 rpm, 500 rpm, 600 rpm, 700 rpm, 800 rpm, 900 rpm, 1000 rpm, 1100 rpm and 1200 rpm. The choice of this wide range of speed was due to the fact that a sharp cutting disc that is rotating at high speed is bound to make clean cut of the okra fruit. Moreover, Owolarafe et al. (2012) asserted that the okra slicer developed in their research had improved performance at a speed of 400 rpm. The okra at moisture content of 13 % (wb) used for the test were bought from Ipata market, Kwara state, Nigeria. For each treatment, a sample of okra was arranged on the guided tray and placed on the carriage of the machine. The movement of the tray was timed in order to determine the slicing time using stopwatch. The output materials obtained from the machine was collected and separated into two groups, that is, undamaged sliced material and damaged sliced material. The mass of each category was measured by using CL Series (Model 201) digital electronic balance. Each treatment was replicated six times.

Slicing efficiency

The slicing efficiency of the machine was obtained by using equation (5) which was used by Agbetoye and Balogun (2009).

$$S_E = \left(\frac{W_S - W_D}{W_S}\right) 100\% \tag{5}$$

where: S_E = Slicing efficiency (%), W_S = Weight of all slices of okra fruits (kg) and W_D = Weight of damaged slices of okra fruits (kg).

Throughput capacity

The throughput capacity equation utilized by Agbetoye and Balogun (2009) was employed to determine the throughput capacity of the machine.

$$T_C = \frac{W_S}{T} \qquad (6)$$

where: T_C = Throughput capacity (kg/h), W_S = Weight of all slices of okra (kg) and
T= Time of slicing operation (h)

Mechanical damage index

The mechanical damage Index of the machine was calculated by using the equation (7) as employed by Agbetoye and Balogun (2009)

$$M_D = \frac{W_D}{W_S} \times 100 \qquad (7)$$

where: M_D = Mechanical damage Index (%), W_S = Weight of all slices of okra (kg) and
W_D = Weight of damaged slices of okra (kg)

Slicing uniformity

For slicing uniformity determination, twenty five slices of undamaged sliced okra were randomly selected and each slice thickness was determined by Vernier caliper. Equation (8) was used by Fayose (2007) to calculate the slicing uniformity

$$Q = 100 \times \left(1 - \frac{\sigma}{\bar{x}}\right) \qquad (8)$$

where: Q = Slicing uniformity (%), σ = Standard deviation of measured slice thickness (mm) and $\bar{x}$ = Mean of the measured slice thickness (mm).

However, the standard deviation was calculated by using the equation (9) given by Freund and Wilson (2003):

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x - x_1)^2}{n - 1}} \qquad (9)$$

where: x = measured slice thickness (mm), x_1 = designed slice thickness (mm), n = number of slice pieces taken and i = serial number of slice pieces (1, 2, 3,..., n).

3 Results and Discussion

3.1 Effect of cutting disc on the Slicing efficiency of the machine

The effect of cutting disc speed on the slicing efficiency of the okra slicer is shown in Figure 5. The slicing efficiency value of 99.88 % was highest at a cutting disc speed of 1200 rpm. The least value obtained was 92.23 %. The high values of slicing efficiency could be as result of the principle of operation of the machine. Generally, the slicing efficiency increased with increase in cutting disc speed. This may be as a result of soft texture of the okra fruit. This observation agrees with the reports of Agbetoye and Balogun (2009) and Owolarafe et al. (2012).

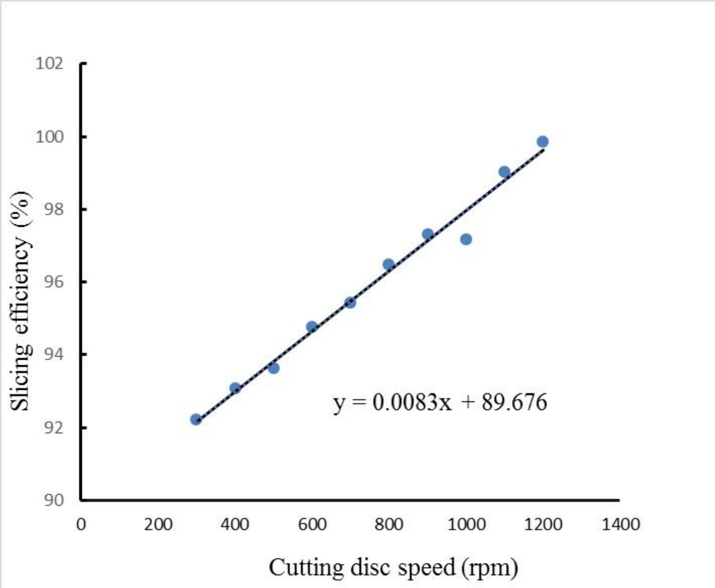

Figure 5. Effect of cutting disc speed on Slicing efficiency of the Okra slicer

3.2 Effect of cutting disc speed on Throughput capacity of the machine

The effect of cutting disc speed on the throughput capacity for okra slicer is as shown in Figure 6. The highest value of throughput capacity was obtained as 194.11 kg/h at a cutting disc speed of 1200 rpm. The lowest value observed was 82.33 kg/h. The throughput capacity increased with increase in cutting disc speed. This may be as a result of texture and fibre content of okra variety (ila-iroko) used in this study. Also, the cutting disc was able to cut faster at higher speed. Similar trend was reported by Agbetoye and Balogun (2009) and Owolarafe et al. (2012) for the effect of speed on throughput capacity of a multi-crop slicing machine and okra slicer respectively.

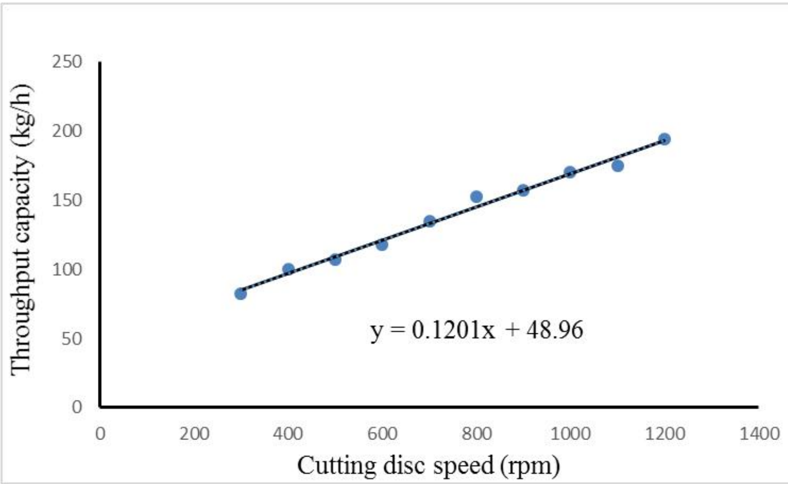

Figure 6. Effect of cutting disc speed on Throughput capacity of the Okra slicer

3.3 Effect of cutting disc speed on Mechanical damage index of the machine

The effect of cutting disc speed on the mechanical damage index is shown in Figure 7. The mechanical damage index value decreased from 16.05 % at 300 rpm to 0.30 % at 1200 rpm. This may be due to the fact that the machine was able to make neater cut on the okra at high speed. Also, the trend observed may be due to the okra variety (ila-iroko) used in this study. This trend agrees with that reported by Ogbobe et al., (2007), Agbetoye and Balogun (2009) and Owolarafe et al. (2012).

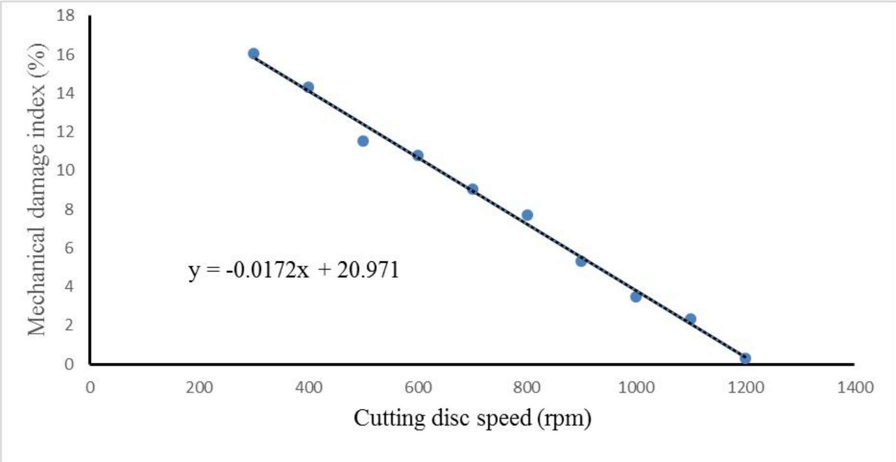

Figure 7. Effect of cutting disc speed on Mechanical damage index of the Okra slicer

3.4 Slicing uniformity

The mean thickness for okra was found to be 3.4 mm and standard deviation of 0.18. The average slicing uniformity for okra was also found to be 93.87 %. The value of slicing uniformity obtained is greater than those that were achieved by Owolarafe et al. (2012) and Ogbobe et al. (2007). This could be due to the fact that the mode of operation of the machine in this study allows for better slicing of the okra fruits. Once the cutting discs are sharp, there is no escape for the fruits and they would be neatly cut. Figure 8 depicts the sliced okra fruits products from the machine developed in this study.

In comparison, the machine reported in this paper was able to achieve a slicing efficiency of 99.88 % whereas the machine reported by Ogbobe et al., (2007), and Owolarafe et al. (2012) had slicing efficiency in the range of 85 to 86.7 % respectively. Likewise, the two earlier machines had throughput capacity ranging from 21 to 42.8 kg/h while the machine reported here had a throughput capacity of 194.11 kg/h. It should be noted that by the design of the guided removable tray, the throughput capacity of the machine could be increased by increasing the length of the tray.

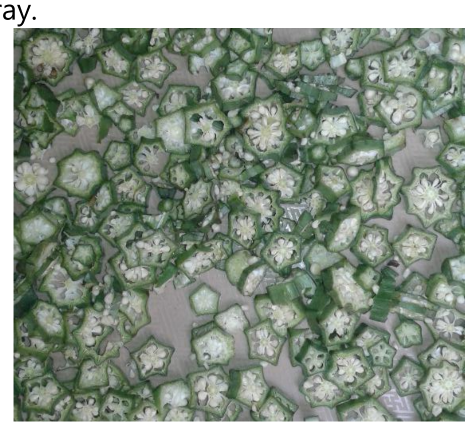

Figure 8. Sliced Okra fruits from the Okra Slicer

4 Conclusions

An okra slicing machine was developed and tested. Based on the results of the performance evaluation, the machine produced uniform slices with average thickness of 3.4 mm and standard deviation of 0.18. The highest slicing efficiency and throughput capacity for okra were 99.88 %, 194.11 kg/h respectively. The average slicing uniformity was 93.87 %. For okra, the least mechanical damage index of 0.30 % was obtained at a cutting speed of 1200 rpm. This machine could further enhance the scale of production and quality of dried okra.

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