Modification and performance evaluation of a dual-function okra processing device

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Abstract: The performance evaluation of a dual-function device for slicing and drying Okra developed at the Federal College of Agriculture, Ishiagu Nigeria was carried out and reported. The device was designed to slice and dry okra in one single-sequence operation. To evaluate the device, some physical characteristics including the axial length, mean equivalent diameters and sphericity of okra samples were measured to determine slicing blade characteristics and other machine considerations. The results showed that the mean axial length, equivalent diameters and sphericity determined for each okra sample categorized as big (A), medium (B) and small (C) are; axial length: 74.62, 59.7 and 44.03mm, equivalent diameters: 24.54mm, 19.20mm and 15.79mm, sphericity: 0.56, 0.55, 0.62 respectively. Evaluating the performance of the device, the overall slicing efficiency is 95.29%, with a maximum efficiency of 97.50% recorded while slicing small size okra. The overall machine capacity is 12.59 kg h-1 while the average chip length, width and thickness are 19.56mm, 7.52mm and 3.39mm, respectively while the drying efficiency of 87.68% was obtained within the drying chamber. The results showed significant improvement in modified machine performance over the existing machine in terms of slicing efficiency and output capacity.

Keywords: Okra, slicing, drying, efficiency, sphericity, device

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1 Introduction

Okra is a dicotyledonous horticultural plant grown throughout the tropics and warm temperate regions for its fruit suitable for human consumption and a high source of energy (4550 kcal kg-1) (Sengkhamparn et al., 2009; Owolarafe et al., 2011; Ngbede et al., 2014). Because of the high perishability of fresh okra and relatively poor storage, handling after harvest, it's processing and preservation has become imperative. Okra is a major component of today's meal and with its high market demand, its processing is profitable and can serve as source of revenue for households. However, insufficient buyers of freshly harvested fruits, lack of storage and processing facilities constraints could be alleviated by providing efficient machines to process fresh fruits produced into more durable finished products. Among several technological processes employed in processing and preservation of fresh (Okra), slicing and drying are most critical. Slicing is a form of size reduction by mechanical means without change in material chemical properties, uniformity in size and shape of individual units of the end product (Leo and Balogun, 2009; Kamaldeen et al., 2016) while drying is the reduction of product moisture content to a final value at which the material can be stored. These processes can be achieved

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traditionally and mechanically.

Traditionally, Okra are sliced with kitchen knife; a considerably slow and tedious process, after which it will be spread in flat basket or tray pan exposed to sunlight on roof top of low buildings and open spaces. This practice is found to be dangerous as well as time consuming with low output. A new approach is required. The manual method of slicing is affected the farmer's productivity (output) and time loss, danger of knife cut, and possibility of product contamination etc. A manually operated device developed by Owolarafe et al. (2007) adopted as a unit of an integrated system for Okra processing by rural women in South-Western Nigeria because it reduced the drudgery associated with manual slicing appreciably.

Olajide et al. (1997) evaluated an Okra slicer and found that there was higher loss in the traditional method of slicing than in the mechanical slicer. He reported a 65% slicing efficiency and 312 kg hr-1 capacity. Ogbobe et al. (2007) designed a motorized Okra slicer with 42.8 kg hr-1 capacity and 95% efficiency when compared with hand slicing and manually operated machine methods. It produced slices of uniform thickness with deviation and variance of 0.13 and 0.14, respectively. Kamaldeen and Awagu (2013) designed a manual tomato slicing machine to cut tomatoes at 2cm thickness. The capacity of the machine was 540.09 g min-1 and its slicing efficiency was rated 70%.

Various drying methods had been employed in drying different agricultural products with varying advantages and limitations. Many of such systems utilized both direct and indirect solar radiation (Rossello et al., 1990): Direct solar drying of whole pods or sliced pieces using a kitchen knife at near-regular sizes is done by spreading out on trays exposed to sun radiation. This method predisposes the product to losses both in quantity and quality because of the dependence on direct solar drying and exposure of the vegetable to disease infestation and contamination. Indirect solar drying utilizes heat from the sun to heat a collector surface to either heat air or in direct contact application on the product. Choosing the right drying system for fruits and vegetables is thus important for more uniform, hygienic and attractively coloured dried product with promising results in postharvest losses prevention and prolonged shelf lives.

Traditionally, drying of Okra can be achieved by combined effect of drying time and slice thickness on the solar drying. A study by Adom et al. (1997) concluded that solar drying was an effective method for producing dried Okra at shorter drying periods compared with the traditional open-air sun drying method. From this study, it was observed that the thicker the slice, the more the drying time required and the organoleptic evaluation of dried products showed that the drying limit of Okra could be determined when the Okra pods became brittle on slight pressure application.

Several devices in Okra processing had equally been developed for unit operations. However, considerations have also been given to integrated system approach in combines process operations such as slicing and drying. Such efforts had yielded the experimental machine used for this research work. Preliminary evaluation of this device indicated a slicing efficiency of 89.41% while the machine capacity was 20.15 kg hr-1. The average slice thickness of samples obtained is 8.6 mm. The drying chamber at no-load condition reached a temperature of about 50C and due to convective heat transfer, it takes approximately 4.5 minutes for the compartment above the tray to experience temperature increase. Efficient performance of engineering machinery is the hallmark of engineering profession and an integral part of research innovations in technological development, hence this performance can be improved on which is a major objective of this research.

2 Materials and method

2.1 Material selection

Two major materials of consideration are: the crop material consideration and the materials for machine construction based on material properties, availability, physical, mechanical and economic considerations.

Crop material considerations: Freshly harvested Okra fruits were sourced from local markets around the institution; dark green coloured fruits were selected for the study (Figure 1). The average dimensions (length and mean diameter) of the fruits were taken. Due to the variations in okra physical characteristics from specie to specie, which affects machine performances, the selected sample specie (Abelmoscus esculentus L) were sorted for rejects and particulate materials. The sample fruits categories were thoroughly washed and sliced using the developed machine.

Figure 1 Fresh Okra fruit samples (Abelmoscus esculentus L.)

Machine considerations: The experimental device is a dual-process okra slicing and drying device developed at the Department of Agricultural and Bio-Environmental Engineering Technology, Federal College of Agriculture, Ishiagu. The machine shown in Figure 2 (existing and modified)) is a dual function assembly comprising two compartments, the slicing and drying units; each performing different functions of slicing and drying, respectively. Each component is described as below.

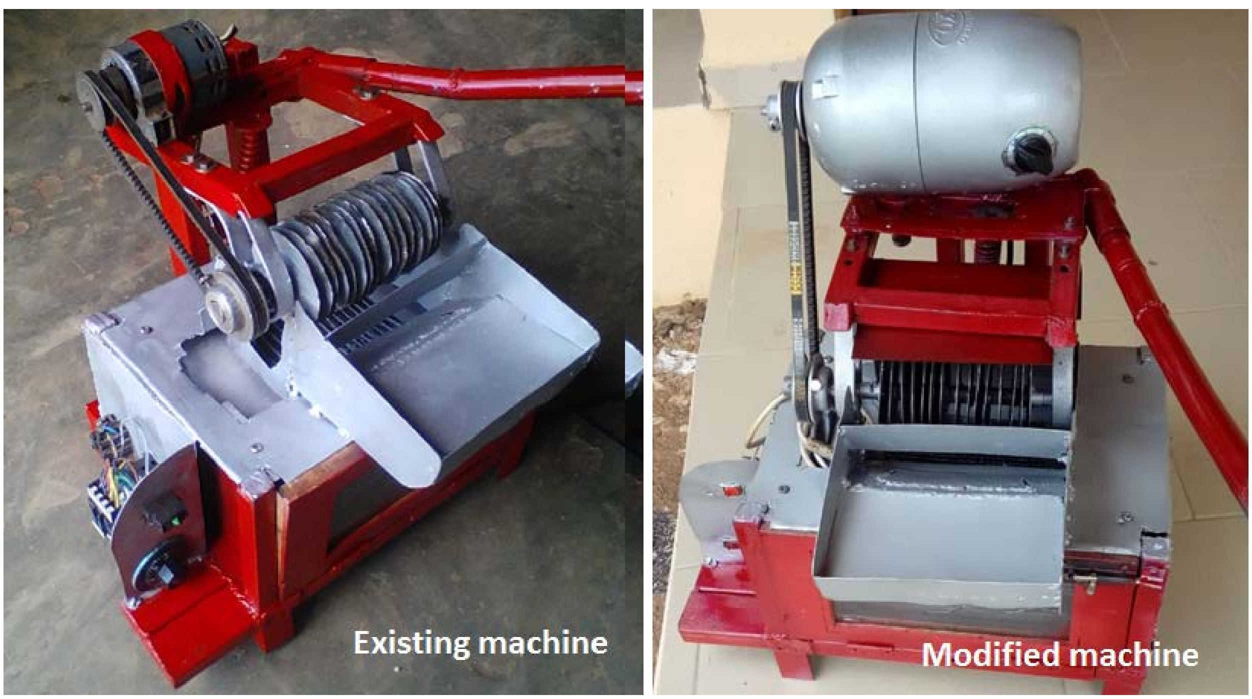

Figure 2 The existing experimental machine before and after modification

a. Slicing unit: The slicing unit comprises the hopper, the slicing unit, a G-frame and an ac/dc electric motor. The hopper constructed of a 2 mm galvanized steel sheet is a rectangular shaped platform opening into the slicing chamber. Okra is fed at controlled feed rate into the slicing chamber where a set of rotary disc blades slices through the Okra. The angle of repose of Okra plays a significant role in ensuring a self-feed arrangement. The slicing unit comprises the cutter assembly which is a set of 15-piece galvanized discs 80mm diameter cutting disc, arranged in gang on a shaft simply supported on two pressure lubricated bearings. The disc while in operation shears the non-fibrous Okra pods into slices. The sliced Okra passes through the slots into the drying grills below. The operational lever is a 500mm long mild steel pipe attached to the carriage to provide leverage for slicing assembly during loading and unloading operations. An ac/dc induction coil driven by a belt and pulley drives the slicing assembly mounted on two pressure lubricated ball bearings.

b. The drying unit: The drying unit comprises a drying and heating chambers and electrical control units. The drying chamber consists of a heating element, a contactor, a regulator, thermostat sensor and temperature control and the drying chamber (a drying grill, wood insulated housing) and an outer wall with heat reflective galvanized mild steel. The heating element converts electricity into heat through the process of joule heating to remove moisture for the Okra at a controlled rate. The drying tray is a grill which offers a more rapid moisture removal from the sliced product. The electrical control unit consists of a heat regulator, thermostat and thermocouple sensor WHILE The regulator controls the temperature of the dryer at desired set point. The thermostat regulates the quantity of heat flow into the drying chamber by controlling the switching on and off of the heating element as needed to maintain the correct temperature. Thermostats can be constructed in many ways and may use a variety of sensors to measure the temperature. The output of the sensor then controls the heating or cooling of the element. The type of thermostat used in this design is an electronic thermostat.

2.2 Methodology

(1) Determination of physical characteristics of okra samples: The weight, mean axial length, diameter, density, volume, sphericity and roundness of the fruits were measured using a venier caliper for each sample and the approximate values calculated using the following procedures and equations.

a. Determination of crop sample weights: The samples were graded into three size categories of small size fruits (sample A), medium size fruits (sample B) and big size fruits (sample C) (Figure 1). Each category was weighed using a precision electronic weighing scale (SF-400, capacity 5000g x 1g), and the number of fruits noted.

b. Mean axial length of okra: The mean axial length, butt diameter (a), intermediate (b) and apical (c) diameters, weight of 20 randomly selected fruits from each sample categories were measured and the mean of three sample replicate readings were taken for each sample and recoded.

c. Okra mean diameter: The okra mean diameters were determined by measuring the dimension of the principal axis; butt (major), intermediate and minor (apical) diameters of randomly selected fruits samples using venire calliper. The major, minor and intermediate axes for okra are shown in Figure 3.

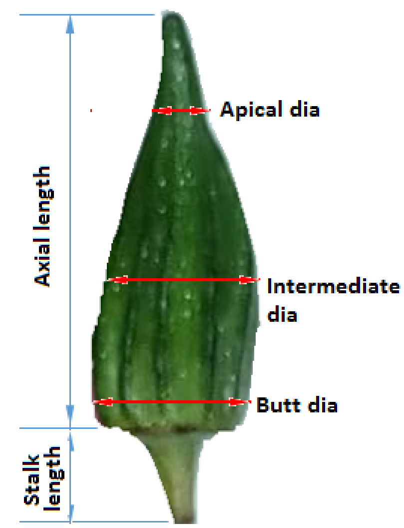

Figure 3 The measured dimensions of okra fruits

The mean diameter dp in mm was calculated using the following expression (Mohsenin, 1986; Bello and Odey, 2011):

$$d_p = \frac{a+b+c}{3} \tag{1}$$

Where

a= Butt (major) diameter of okra

b= Minor (apical) diameter of okra

c= Intermediate diameter of okra

d. Sphericity of okra fruit: Sphericity (ϕ) is defined as the ratio of the surface area of the sphere having the same volume as that of the fruit to the surface area of the fruit, determined through equation (Mohsenin, 1986; Dursun and Dursun, 2005; Bello et al., 2018):

$$Sphericity(\phi) = \frac{[abc]^{\frac{1}{3}}}{a} \quad (2)$$

e. Volume of okra fruit: Fruit volume (V) was calculated using the equation given by Al-Mahasneh and Rababah (2007), Bello et al. (2018):

$$V = \frac{\pi b^2 a^2}{6(2a-b)} \quad (3)$$

(2) Device modification factor: The following considerations were used as basis for the modifications.

a. Power supply: The machine was evaluated to determine if the power available is adequate to sufficiently power the machine.

b. Effectiveness of cutting mechanism: The machine capacity to slice fed okra. The machine was also observed to determine the efficiency.

c. Performance of drying mechanism: The drying unit was also investigated to determine power supply and scheduling between the cutting unit and the drying unit.

d. Other considerations: Other considerations include safety of operation, maintainability, user friendliness and ease of operation.

2.3 Machine performance indicator

Testing is a vital step in machine process development. The following indicators were used to measure the performance of the machine.

a. Slicing efficiency: Slicing efficiency is expressed as the effectiveness of machine slicing a unit feed of Okra compared to known machine performance. The slicing efficiency is given by the following expression (Balasubramaniam et al., 1993):

$$\alpha = \frac{Number\ (mass)\ of\ okra\ effectively\ sliced}{Total\ number\ (mass)\ of\ okra\ fed} \times 100\% \quad (4)$$

Also,

$$\alpha = \frac{N_T - N_D}{N_T} \times 100\% \quad (5)$$

Where: α = slicing efficiency (%), NT = Total number of okra fed into machine, ND = Number of total Okra sliced

b. Machine capacity: Actual capacity/throughput of the machine was also determined by feeding Okra into the machine and finally weighing all the slices irrespective of damage. Machine capacity expressed as the quantity of Okra sliced per unit time of measurement:

$$Machine\ capacity = \frac{Total\ weight\ of\ pkra\ sliced}{Time\ taken} \left(\frac{kg}{hr}\right) \quad (6)$$

c. Slice thickness: Three randomly drawn samples of each category, containing 30 slices were used for determination of slice thickness, uniformity and shape. Slice thickness was determined at four points around the periphery of the slice using micrometer screw gauge.

d. Dryer performance evaluation: The dryer was evaluated at both no-load and loading conditions. In the no-load test condition, the thermostat of the dryer was set at temperatures of 50 and 70ºC and the temperature monitored over time at the two trays levels (upper and lower) in the dryer. 50 g of the samples was dried in the chamber until a constant weight was obtained. The effect of temperature, slice thickness and tray position was then observed.

e. Product evaluation: After machine test, the product samples were sorted into three categories: whole sliced, chopped slice and unsliced. The mean sample of each product sizes were determined.

3 Results and discussions

Geometric properties

The diameters and axial lengths of randomly sampled 20 Okra fruits picked from the three categories (A, B, and C) were measured with a mean average butt diameter of 28.10, 22.65, 19.23 mm for A, B and C, respectively; intermediate diameters of 32.81, 26.45, 21.48 mm for A, B and C, respectively, and apical diameters of 13.14, 8.95, 7.16 mm for A, B and C, respectively. The mean axial lengths of 74.62, 59.7 and 44.03 mm were also determined for A, B and C, respectively. From these results, it is evident that the okra specie has a larger diameter at the intermediate section than the butt and the apex. The geometric mean characteristics of okra were determined and presented in Table 1 with mean equivalent diameters for sample categories A, B, and C equals; 24.54, 19.20 and 15.79 mm, respectively. The measured sphericity for each sample are 0.56, 0.55 and 0.62 respectively with an average sample sphericity of 0.58. This is an indication that all the samples have an oval shape with the fruits at rest along the longitudinal axis. By implication, the okra will approach the blades in longitudinal axis, hence increasing the tendency of uniform slice.

Table 1 Geometric mean characteristics of all sampled Okra

Okra sample	Mean axial length			Equivalent diameter			Sphericity		
	A	B	C	A	B	C	A	B	C
	81.10	68.20	46.30	25.22	20.25	14.99	0.50	0.50	0.60
	76.20	63.30	42.30	25.53	21.75	17.01	0.60	0.60	0.60
	71.30	56.20	42.10	24.98	16.88	15.56	0.60	0.50	0.60
	90.10	58.20	50.20	24.01	20.31	17.29	0.50	0.60	0.60
	64.30	67.20	52.30	24.13	19.91	16.65	0.60	0.50	0.60
	74.20	49.10	47.20	22.53	16.43	15.72	0.50	0.60	0.60
	73.30	64.20	44.30	24.98	20.43	14.71	0.60	0.50	0.60
	65.20	58.20	45.20	26.33	17.60	17.00	0.60	0.50	0.60
	77.20	56.20	35.20	24.11	19.06	14.70	0.50	0.60	0.70
	73.30	56.20	35.20	23.62	19.38	14.29	0.60	0.60	0.70
Mean	74.62	59.70	44.03	24.54	19.20	15.79	0.56	0.55	0.62

Modifications made on device: The modifications made on the machine were tabulated in Table 2.

Table 2 Modifications on the experimental machine

Units	Observations	Modifications
Slicing chamber	Okra freely jump out of the chamber unsliced High risk if injury from exposed blades while in operation	A stopper plate introduced above the chamber which stretched above the blades.
Electric motor	Existing motor could not power the machine under load	A higher capacity induction coil was used to replace the initial one
Carriage	The carriage base could not support the electric motor	The carriage was modified to carry the electric motor
Control system	The carriage base could not support the electric motor	Bye-pass circuit introduced The contactor changed

4.1 Machine performance evaluation

Slicing unit performance tests: The machine performance evaluation on the basis of the slicing efficiency and the output capacity after modification indicates improved power development with the coil was able to effectively power the slicing assembly under load.

The product samples obtained from the slicing operation were sorted and categorized into three: well-sliced, unsliced and chopped as shown in Figure 4. Figure 5 shows different products obtained from the products ranging from chopped, sliced, chipped and unsliced samples.

Figure 4 Products obtained from each sample categories

Figure 5 Randomly sorted chips from product samples

Ten pieces of sliced, chopped and unsliced okra were randomly but carefully sorted from the chipped samples in each of the three categories and the length and width of each chip/sliced samples measured and the slicing efficiency calculated on the basis of chip slices (Table 3).

Table 3 Mean sizes of sliced, chopped and unsliced okra

Chip Replicates	Chopped sample		Well-sliced sample			Unsliced sample	
	Length	Width	Length	Width	Thickness	Length	Width
1	31.10	8.20	18.10	7.10	3.12	38.10	9.10
2	21.10	10.10	27.20	6.10	2.74	33.10	11.10
3	18.20	10.10	27.10	8.10	4.21	42.10	17.10
4	31.10	11.10	17.20	8.10	2.78	35.10	13.10
5	35.10	9.20	17.10	8.10	3.52	40.20	16.10
6	26.10	9.10	15.20	8.10	4.36	36.10	19.10
7	29.20	11.10	24.20	8.20	3.44	52.20	12.10
8	29.20	14.10	15.20	7.20	2.87	50.20	22.20
9	23.20	9.10	16.20	6.10	3.65	35.10	10.10
10	22.10	8.10	18.10	8.10	3.23	56.20	7.20
Mean	26.64	10.02	19.56	7.52	3.39	41.84	13.72

The chopped slices are unevenly sliced and have greater number of shredded pieces, while the well-sliced samples have relative uniformity in width and thickness. More of the unsliced samples are found among the small size categories. The chopped sizes have wide variation in lengths (31.10-22.10) mm with an average of 26.64mm, the width range is (8.10-11.10) mm with an average of 10.02 mm, while the well-sliced sample has an average thickness of 3.39 mm.

Slicing efficiency: The effectiveness of the slicing unit is presented in Table 4. The overall slicing efficiency of the slicing is 90.76%.

Table 4 Slicing efficiency of modified machine

Trials	Total pods fed	No. well sliced	Number unsliced	Efficiency (%)
1	55	51	4	85.46
2	77	74	3	92.21
3	80	78	2	95.00
4	40	38	2	90.00
5	90	86	4	91.11
Total	342	327	15	90.76

Machine capacity: The through-put (capacity) of the machine was obtained as a ratio of the weight of Okra pods sliced to the time it takes to slice the pods completely. Table 5 shows a mean capacity is 12.40 kg hr-1. There are no significant differences between the output capacity of the existing (11.97 kg h-1) and modified machine.

Table 5 Slicing unit machine capacity

No of trials	Weight of pods fed (kg)	Time taken (min)	Machine capacity (kg hr^{-1})
1	0.48	2.00	14.55
2	0.67	3.00	13.40
3	0.77	4.00	11.00
4	0.96	5.40	10.67
5	1.15	5.60	12.37
Total	**4.03**	**3.80**	**12.59**

Slice thickness: The uniformity of slice thickness is examined by randomly examining sample slices (Figure 6) from the cut bulk. There are notable variations in thickness of the slices with average slice samples of 8.6mm.

Figure 6 The sliced okra chips

Dryer performance tests: The energized drying chamber receives sliced okra directly from the slicing chamber while drying commenced at a regulated temperature of 80°C for about 30 minutes. The thermal environment of the drying chamber is effectively regulated by the thermostat and sensor. The chamber can be operated at a stable drying temperature using these features.

Product quality and acceptability: The chopped samples are exceptionally preferred for direct soup making while the unsliced samples are either dried directly for storage or returned to the machine for re-slicing. The well-sliced are more valuable and marketable when-dried for preservation. Figure 7 shows the sliced and dried samples in two batch operations. The colour changes from light green to light-golden brown after the drying process. Dried products from the drying chamber has golden brownish colouration, which is generally an acceptable quality of dried okra.

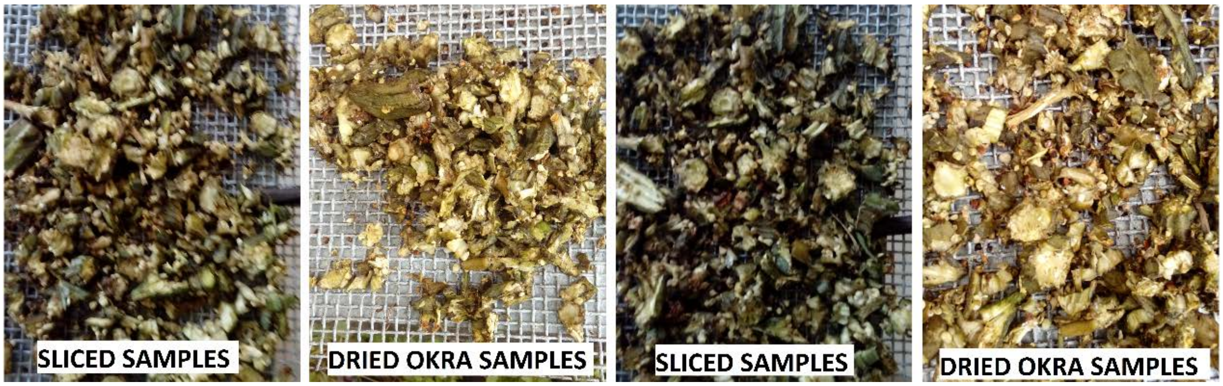

Figure 7 Sample okra dried in the modified experimental machine

Comparison between existing and modified machine: Comparative analysis of the existing and the modified machines. Table 6 below compares the performances of the modified machine with the existing machine.

Table 6 Comparison between existing and modified machine

Parameter measured	Existing machine	Modified machine
Slicing efficiency		90.76%.
Size of slice: width and thickness	10.42 and 6.02mm	7.52and 3.39mm
Slice uniformity	Non-uniform	Uniform
Mean capacity	12.40 kg hr^{-1}	11.97 kg h^{-1}
Drying efficiency	68.53%.	87.68%.
Drying time kg^{-1}	~4.50 min	~1.06 min

4 Conclusions

The existing okra slicing and drying device has been successfully modified and its performance is evaluated. The modified device is suitable for slicing and drying fresh okra for household cooking for storage. Some engineering properties of fresh Okra were also studied. The mean equivalent diameters for each sample category A, B and C are 24.54, 19.20 and 15.79 mm, respectively. The maximum slicing efficiency of the modified device is 95.00% with an overall efficiency of 90.76%, the overall machine capacity is 12.59 kg hr-1 while the average chip length, width and thickness are 19.56mm, 7.52mm and 3.39mm respectively. The drying efficiency of the device is 87.68% at a drying temperature of 80°C and 30-minute duration. There is a significant improvement in the slicing and drying efficiencies, size of slice, uniformity, capacity of the modified machine compared to the existing machine.

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