Evaluation of a portable watermelon juice extracting machine

Adekanye T. A.*, O. J. Adelakun

(*Department of Agricultural and Biosystems Engineering, Landmark University, P.M.B. 1001, Omu - Aran, Kwara State, Nigeria*)

Abstract: A small-scale machine for extracting watermelon juice was developed with locally available materials and evaluated to determine its best extracting operating factors. The machine slices a whole watermelon and extracts its juice. This machine operates on the principle of compressive and shearing force which exerts through an auger. Component parts includes feeding hopper, conveyor shaft, auger conveyor housed in a cylindrical chamber, juice sieve, juice collector, seed and pulp outlet, gear and main frame. It was powered by a 1 hp electric motor, coupled to a gear reduction speed to operate at 46.67 rpm. In operation, watermelon fruits introduced via the hopper were squeezed and transferred to the auger conveyor. The auger presses and squeezes the watermelon fruit to extract the juice. The juice extracted is filtered through the juice sieve into juice collector while the seeds and pulp are discharged through another outlet. Performance evaluation was carried out using different sizes of watermelon fruit (2.3 kg, 2.6 kg, 2.8 kg, 3.1 kg and 3.3 kg) to determine juice yield, extraction efficiency and extraction loss. Results revealed maximum juice yield of 86%, extraction efficiency of 92.6% and extraction loss of 18% respectively. The machine has a capacity of 49.04 kg hr^{-1}. The portable watermelon juice extracting machine is simple to operate and maintain, therefore it is recommended for small scale farmers and local fruit juice processors.

Keywords: watermelon, juice, extraction, small scale, evaluation

Citation: Adekanye, T. A., and O. J. Adelakun. 2017. Evaluation of a portable watermelon juice extracting machine. Agricultural Engineering International: CIGR Journal, 19(4): 219–223.

1 Introduction

Watermelon (*Citrullus lanatus*) belongs to the family Cucurbitaceae (Schippers, 2000). It is grown in over 96 countries worldwide (Produce, 2008). China is the world leading producer of watermelon, with 70.3% of the total production in 2015. Other leading countries are Turkey, Iran, Brazil, USA and Egypt (FAOSTAT, 2016). Its center of origin has been traced to both the Kalahari and Sahara deserts in Africa (Jarret et. al., 1996) and these areas have been regarded as points of diversification to other parts of the world (Schippers, 2000). The crop has a wide circulation as a garden crop, while as a commercial vegetable production, its cultivation is restricted to the savanna regions of Nigeria (Huh et al., 2008). Watermelon seeds are high in proteins and fats, also can find applications as a protein source in various food formulations and preparation (El-Adway and Taha, 2011; Adekanye, 2014). Presently, the largest production of the crop in Nigeria still comes from the northern parts (Ajewole, 2015). Watermelon is highly relished as a fresh fruit in Nigeria because of its thirst-quenching attribute in addition to many other identified nutritional values and advantages. Therefore, the consumption of the commodity in the recent times has witnessed remarkable increase as it cuts across all socio-economic classes.

Manual methods are mostly employed in the extraction of watermelon juice. This involves macerating fruit with hand or peeling, slicing, blending and pressing the fruit. This method consumes energy and time, and the yield is always low and unhygienic. Now there is a general awareness in Nigeria and other developing countries that the rapid development of agriculture depends to a large extent on the successful introduction of modern and small scale agricultural machinery to a large extent (Timothy and Olaoye, 2013). Therefore, there is the need to develop a small mechanical device for small scale watermelon juice extraction. There is an urgent need to design and fabricate a machine that will extract

Received date: 2016-11-07 **Accepted date:** 2016-12-18
* **Corresponding author: Adekanye T. A.**, Email: adekanye.timothy@yahoo.com

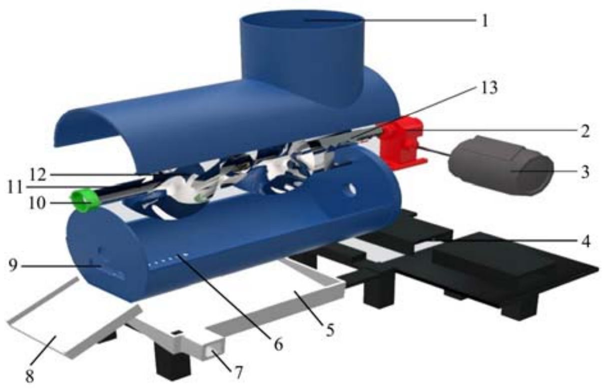
watermelon juice so as to make it readily available and enhance economic returns to watermelon farmers.

The main objective of this project was to design and construct a watermelon juice extracting machine and evaluate its performance. Development of watermelon juice extractor will contribute immensely towards providing on-farm processing of watermelon by small scale farmers in such a way that harvested watermelon can be processed directly to extract the juice in less possible time. This study will contribute greatly to the existing knowledge on watermelon juice production with a view of improving its production and reduce seed damage and also serve as a baseline for further research work.

2 Materials and methods

2.1 Description of watermelon juice extracting machine

As shown in Figure 1, the watermelon juice extracting machine consists of the following major component parts: hopper, extraction chamber, juice outlet, seed and pulp outlet, frame, and 1.5 hp electric motor (prime mover). The extraction chamber consists of a uniform diameter stainless steel conveyor shaft that carries the blade that do the cutting through the rotation of the shaft by transmission of power from the electric motor. It has a length of approximately 598 mm and hinged at both ends by bearings. The screw conveyor is a decreasing-pitch type of screw blade arrangement and it enhances the juice extraction. In operation, the screw conveyor presses the watermelon fruits against the abrasive drum surface in such a way that the watermelon is crushed. The extraction is actually achieved by the action of the screw conveyor in pressing the macerated watermelon against the abrasive internal surface of the perforated cylindrical drum along the line of travel. The juice extracted is drained through the juice channel into the juice outlet from where it is collected while the seeds and pulp are collected at the other outlet. Materials used for fabrication of this extractor are locally available at affordable costs.



1. Hopper 2. Gear system 3. Electric motor 4. Frame/stands 5. Collector 6. Sieve 7. Juice collector 8. Waste collector 9. Waste exit 10. Bearing 11. Shaft 12. Conveyor 13. Blade

Figure 1 Exploded view of watermelon juice extractor

2.2 Design of machine components

2.2.1 Design considerations

Factors considered in the design of juice extracting machine were strength of machine components, cost of construction, simplicity of materials of construction, ease of operation, maintenance, easy inspection, serviceability, maintenance of the machine and energy requirement.

2.3 Design analysis

2.3.1 Design of screw shaft

The juice extracting machine works on the principle of compression and shear. Selection of materials and sizes of machine components were based on stress – strain analysis. Diameter and thickness of the conveyor housing was designed using Equations (1) and (2) used by Aviara et al., (2013):

$$D = \sqrt{\frac{4Q}{\pi V}} \tag{1}$$

$$T = \frac{PD}{2\delta t} \times c \tag{2}$$

where, D = internal diameter of the conveyor housing (mm); Q = mass flow rate (g min^{-1}); V = linear velocity (mm min^{-1}); c = material constant; P = internal pressure (Pa); δt = stress (Pa); T = thickness of the conveyor housing (mm); π = constant = 3.14.

The shaft diameter of the extracting machine was determined using Equation (3) used by Khurmi and Gupta (2008).

$$d^3 = \left[\frac{16}{\pi} S_s\right] \times [(K_b M_b)^2 + (K_t M_t)^2]^{1/2} \tag{3}$$

where, d = diameter of the shaft, m; S_s = axial stress, N m^{-2}; K_b = combined shock and fatigue factor applied to bending moment; M_b = bending moment, N m; K_t = combined shock and fatigue factor applied to torsional moment; M_t = torsional moment, N m; S_b = bending stress, N m^{-2}, and π = constant = 3.14.

2.3.2 Design of screw conveyor

The screw pitch was designed using Equation (4);

$$P_s = \frac{4VDL}{\frac{\pi}{4}(D^2 - d^2)N} \quad (4)$$

where, Ps = screw pitch, mm; V = inlet velocity of material, m s^{-1}; D = outside diameter of screw, mm; d = inside diameter screw, mm; L = length of the screw shaft, mm; N = speed of shaft, rev min^{-1}; π = constant = 3.14.

2.3.3 Design of power required

Power required to drive the juice extractor was determined by using Equation (5);

$$P = Tw \text{ (kW)} \quad (5)$$

where, P = Power required, kW; T = torque, N-mm, and w = angular velocity of rotation, rad s^{-1}. A single phase electric motor of 1.5 hp was selected to drive this machine.

2.3.4 Design of hopper

The hopper of the machine was designed by using Equation (6);

$$A=2\pi r[r+h] \quad (6)$$

where, A = Area of cylinder (m^2); h = height (m); r = radius (m); π = constant = 3.14. Given that height and radius were 135 mm and 99 mm respectively, hence, A = 0.146 m^2.

2.3.5 Machine operation

This machine was designed on the principle of compression and squeezing (Figure 2). The first step is to wash the watermelon fruit before loading it into the hopper. The shaft powered by the gear train rotates anti-clock wise and the slicing blade will slice the watermelon and transfer it to the conveyor. The screw conveyor presses the watermelon fruits against the internal surface to extract the juice. Juice extracted is drained through juice outlet while seed pulp^{-1} is collected through the other outlet. The machine is powered by a 1.5 hp single phase electric motor and its production cost is ₦57, 360 (about USD 151). Materials used in construction were locally sourced.

Figure 2 Watermelon juice extracting machine

2.3.6 Performance evaluations

Watermelon fruits were obtained from the Omu Aran market. The fruits were washed, weighed and prepared ready for juice extraction experiment. The machine was set into operation and known weights of the fruits were fed into the machine through the hopper. In the extraction unit, the slicing blade cut the whole watermelon; the conveyor conveyed the fruit, pressed and squeezed it against the perforated cylinder chamber in order to extract the juice. The juice extracted was drained through the stainless screen into the base collector, discharged through the juice channel and weighed while the residual wastes were collected and weighed separately. From the values obtained, juice yield, extraction efficiency, extraction loss and extraction capacity were calculated using Equations (7) to (10) used by Aviara et al. (2013) and Olaniyan and Obafemi (2014):

$$\text{Juice yield,} \quad J_y = \frac{W_{JE}}{W_{JE} + W_{RW}} \times 100 \quad (7)$$

$$\text{Extraction efficiency,} \quad E_e = \frac{W_{JE}}{XW_{FS}} \times 100 \quad (8)$$

$$\text{Extraction loss,} \quad E_l = \frac{W_{FS-[W_{JE}+W_{RW}\}}}{W_{FS}} \quad (9)$$

$$\text{Extraction capacity,} = \frac{W_{JE}}{time} \text{ (kg hr}^{-1}\text{)} \quad (10)$$

where, Jy = juice yield (kg); W_{JE} = weight of juice extracted (kg); W_{RW} = weight of residual waste (kg); W_{FS} = weight of feed sample (kg).

3 Results and discussion

The fabricated watermelon juice extracting machine was evaluated at the processing laboratory of Agricultural and Biosystems Engineering Department, Landmark University, Omu Aran, Kwara State, Nigeria. Tables 1 and 2 present results obtained from the measurement of some physical and mechanical properties of watermelon (Standard Deviation (SD) in Parenthesis) while performance evaluation results for five replications are presented in Table 3 and Table 4. Results of evaluation revealed that maximum juice yield was 86%, extraction efficiency, extraction loss and capacity were 92.6%, 18% and 54 kg hr^{-1}, respectively. while 75%, 81.2%, 6% and 44.8 kg hr^{-1} were the lowest values obtained for juice yield, extraction efficiency, extraction loss and capacity. The lowest and highest extraction efficiency obtained comparing with results which were obtained by Ishiwu and Oluka (2004), Oyeleke and Olaniyan (2008), Olaniyan and Obafemi (2014).

Table 1 and Table 2 established the power required and minimum extraction force. To extract juice from watermelon fruit using a mechanical device, the applied force must exceed the maximum crushing strength of the fruit.

Table 1 Some physical properties of watermelon fruit

Property	Whole Fruit
Longitudinal diameter, mm	197.92 (1.32)
Lateral diameter, mm	202.94 (10.13)
Density, kg m^{-3}	945.47 (2255.14)

Table 2 Some mechanical properties of whole watermelon fruits (SD in parenthesis)

Property	Whole fruit
Maximum breaking force, kN	0.84 (0.34)
Maximum deformation at failure, kN	0.84 (0.46)
Bio yield point, kN	0.32 (0.47)
Crushing strength, kN m^{-2}	0.56 (0.42)
Stiffness modulus, kN m^{-1}	0.01 (0.005)
Modulus of resilience, J	7.16 (7.39)
Modulus of toughness, J	16.09 (12.86)

Table 3 Experimental results for five replications

Mass of watermelon, kg	Mass of extracted juice W_{JE}, kg	Time taken, hr	Juice yield, %	Mass of residual waste W_{RW}, kg	Extraction efficiency, %	Extraction loss, %	Extraction capacity, kg hr^{-1}
2.3	1.62	2.00	86	0.27	81.21	18	54
2.6	1.80	2.27	82	0.39	82.82	16	46.25
2.8	2.05	2.43	84	0.39	85.41	13	53.75
3.1	2.24	2.70	76	0.65	92.13	7	44.80
3.3	2.33	2.87	75	0.77	92.62	6	46.4

Table 4 Evaluation of watermelon juice extractor (*n*=5)

Parameters	Mean	SD
Mass of watermelon loaded, kg	2.82	0.40
Mass of juice extracted, kg	2.04	0.29
Time taken to extract juice, min	2.45	0.344
Juice extraction capacity, kg hr^{-1}	49.04	4.46
Juice extraction efficiency, %	87.80	4.60

4 Conclusions

A small-scale machine for extracting watermelon juice from watermelon fruit was designed, fabricated and tested. The extracting machine was portable enough for local production, operation, repair and maintenance while all the materials of the construction were sourced locally and at affordable costs. It was designed to extract juice based on the principle of compression and shear due to the action of conveyor belt and screw conveyor. The extractor is a portable device designed for small scale farmers and families use. The machine has maximum juice yield, extraction efficiency and extraction loss of 86%, 96.2% and 18% respectively, and production cost of 57, 360 (about USD 151). This machine will be an advantage for small scale watermelon farmers and can be improved in large scale applications.

References

Adekanye, T. A. 2014. Evaluation of some engineering properties of watermelon seed relevant to the design of processing equipment. *Advances in Agriculture, Sciences and Engineering Research*, 4(7): 1677–1686.

Ajewole, O. C. 2015. Income and factor analysis of watermelon production in Ekiti State, Nigeria. *Journal of Economics and Sustainable Development*, 6(2): 67–73.

Aviara, N. A., A. A. Lawa, D. S. Nyam, and J. Bamisaye. 2013. Development and performance evaluation of a multi-fruit juice extractor. *Global Journal of Engineering, Design and Technology*, 2(2): 16–21.

EL-Adaway, T. A., and K. M. Taha. 2011. Characteristics and composition of different seed oil and flours. *Food Chemistry*, 74(1): 47–54.

FAOSTAT. 2016. Agricultural Production Primary Crops. Available at://www.fao.org. Accessed 8 February, 2016.

Huh, Y. C., I. Solmaz, N. Sari, and M. Pitrat. 2008. Morphotogical characterization of Korean and Turkish watermelon germplasm. In *Proc. 9th EU CARPIA Meeting on Genetics and Breeding of cucurbitaceae*, eds. M. Pitrat, 327–333.

Avignon, France, 21-24 May.

Ishiwu, C. N., and S. I. Oluka. 2004. Development and performance evaluation of a juice extractor. In *Proc. 5th International conf. and 26th Annual General Meeting of the Nigerian Institution of Agricultural Engineers*, 391–395. Address: 23 February, 2016.

Jarret, B., R. Bill, W. Tom, and A. Garry. 1996. Cucurbits Germplasm Report. Watermelon National Germplasm System. Agricultural Service, U.S.D.A.

Khurmi, R. S., and J. K. Gupta. 2008. Theory of machines. 14th eds. New Delhi, India: S. Chand and Company Ltd.

Olaniyan, A. M., and I. O. Obafemi. 2014. Design, development and test of a small-scale mango juice extractor. *Journal of Agricultural Science and Technology B*, 4(1B): 1–7.

Oyeleke, F. I., and A. M. Olaniyan. 2008. Extraction of juice from some tropical fruits using a small scale multi-fruit juice extractor. In *8th African Crop Science Conf.*, 1803–1808. Ei-Minia, Egypt: 27-31 October 2007.

Produce, P. 2008. Baby Seedless Watermelon. Seedless Watermelon. Available at: //www.producepete.com/ index.html. Accessed 12 June 2016.

Schippers, R. R. 2000. *African Indigenous Vegetable: An Overview of the Cultivated Species*. Chatham, UK: Natural Resources Institute/ACP-EU Technical Center for Agricultural and Rural Cooperation.

Timothy, A. A., and J. O. Olaoye. 2013. Performance evaluation of motorized and treadle cowpea threshers. *CIGR Journal*, 15(4): 300–306.