Design of a blackberry (*Syzygium cumini*) pulp extractor

Md Rashidur Rahman[1], Subroto Pandit[1], Md Arman Ali[1], Md. Sazzat Hossain Sarker[2], Maruf Ahmed[1*]

(1. Department of Food Processing and Preservation, Hajee Mohammad Danesh Science and Technology University, Dinajpur, 5200, Bangladesh;
2. Department of Food Engineering and Technology, Hajee Mohammad Danesh Science and Technology University, Dinajpur, 5200, Bangladesh)

Abstract: A medium-sized blackberry pulp extractor was designed and built so that blackberry juice could be made quickly, hygienically, and commercially. The machine was designed based on the principle of compression and shear due to the action of screen cylinder and wing shaft as well as evaluated various performance indicators such as throughput of the pulp extractor, juice yield, extraction efficiency, and extraction loss. It consists of a strong frame, hopper, screen cylinder, wing shaft, prime mover, and power transmission devices with the main shaft. The data obtained from the design analysis of the components were used in the sizing, fabrication, and assembling of the machine. The throughput of the pulp extractor, pulp yield, extraction efficiency, and extraction loss were 39.58 $\pm$ 0.29 kg h^{-1}, 77.49% $\pm$ 1.18%, 96.72% $\pm$ 1.06% and 6.38% $\pm$ 0.5% respectively. Therefore, the invented blackberry pulp extractor would be recommended for commercial blackberry fruit juice producers.

Keywords: blackberry fruits, pulp extractor, pulp yield, extraction efficiency, extraction loss

Citation: Rahman, M. R., S. Pandit, M. A. Ali, M. S. H. Sarker, and M. Ahmed. 2022. Design of a blackberry (*Syzygium cumini*) pulp extractor. Agricultural Engineering International: CIGR Journal, 24(4): 174-182.

1 Introduction

Blackberry fruit or Black palm (*Syzygium cumini*) is native to Bangladesh, India, Pakistan, Afghanistan, Myanmar, and Pacific Asia, including Indonesia (Qamar et al., 2022) and available throughout Indian plains. It is highly rich in vitamins, minerals, and various bioactive compounds that contribute to reducing blood sugar levels (Raza et al., 2017), suppressing the growth and invasive potential of cancer cells (Li et al., 2021; Kausar et al., 2012), and has beneficial pharmacological properties for human skin, hair, and oral care because of the presence of phytoconstituents (Parate et al., 2019). Blackberry fruits are rapidly spoiled after harvest due to their highly perishable nature (Martínez-Camacho, et al., 2022; Shahnawaz et al., 2009). A surplus of blackberry fruits in the market during the peak harvest season results in lower prices and distressed sales. The health benefits of Jamun are well known, but the short shelf life of the fruit makes it hard to keep a steady

Received date: 2022-01-02 **Accepted date:** 2022-06-20
***Corresponding author: Maruf Ahmed,** Professor, Department of Food Processing and Preservation Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, Bangladesh. Phone: +88-01750777899. Email: maruf@hstu.ac.bd.

supply all year (Nayak et al., 2020).

Blackberry fruit is eaten freshly or with plain or black salt, sprinkled over it. Traditional methods, for instance, macerating fruit with hand or peeling, slicing, blending, and pressing the fruit are still applied to make blackberry juice (Sarkar et al., 2015), squashes, jam, and jellies (Dagadkhair et al., 2017). These methods are time consuming, unhygienic, and noncommercial. The traditional method of blackberry extraction cannot be employed for small to medium scale production to fulfill the commercial need. Pulp extraction is a process of separating pulp and seed from the fruit. It takes place by the process of crushing, squeezing, and pressing of whole fruit in order to obtain the pulp and reduce the size of the fruit to liquid and pulp. Usually, the good quality extractor is efficient to remove pulp as much as possible from the fruit without breaking the seed. Therefore, to meet this demand, there is a need to develop a medium to large size mechanical device that is capable of extracting pulp from blackberry. There is no extractor available for the extraction of blackberry pulp or juice. Several combined fruit juice extractors have been designed, likes a juice vending machine (Rooshan et al., 2021), a multi-fruit juice extractor, a centrifugal beach juicer machine (Nnamdi et al., 2020), and so on. These machines have limitations in extracting pulp properly because of the fragileness of blackberry seed. Thus, a huge amount of fruits are lost. Therefore, to reduce these losses, the purpose of this study was to design and build a small-scale commercial blackberry pulp extractor as well as to analyze several performance indicators for industrial use.

2 Material and methods

2.1 Materials

The study was conducted in Food Processing and Preservation Laboratory, Hajee Mohammad Danesh Science and Technology University, Dinajpur (25°41′52.8″N, 88°39′18″E) from February 2019 to July 2020. Fresh, ripened, and whole blackberry fruits were collected from the domestic market of Dinajpur, Bangladesh (25°40'26.9"N, 88°39'7.6"E). The fruits were cleaned using water manually.

2.2 Design methodology

2.2.1 Design consideration

Engineering properties such as production rate, size, shape, and crushing strength of the Blackberry fruit were considered in the design and development of the extractor. High pulp yield, high extraction efficiency, low extraction loss, and high quality of juice were considered the crucial parameter for designing of blackberry pulp extractor. Hopper, screw conveyor, extraction chamber, and juice outlet were made using 304 Austenitic stainless steel to avoid contamination, Extraction chamber was designed to accommodate the required quantity of fruit and screw conveyor was designed on the basis to get maximum conveyance, abrasion, and maceration of the fruit. In addition, the design of the whole machine availability of machine parts, quality and cost of construction materials, the strength of the main frame, and minimum driven power was taken into consideration. The machine was designed in SOLIDWORKS 2016 software.

2.2.2 Approach of design of the pulp extractor

The machine consists of a strong frame, hopper, screen cylinder, screw conveyer, screw shaft, prime mover, and power transmission devices with the main shaft.

2.2.3 Main frame

The unit was mounted on a frame made of mild steel angle iron skeleton. Two factors considered in selecting the material required for the frame are weight and strength. However, the size was customized to make the frame attractive.

2.2.4 Design of screw conveyor

A screw conveyor is designed to move fruits from the inlet to the outlet of the screen cylinder. Its shaft consists of a screw shaft/wing shaft, screen cylinder, and hopper.

2.2.4.1 Screw shaft

The shaft with wings forces the fruits forward and keeps contact with the screen cylinder (Figure 1).

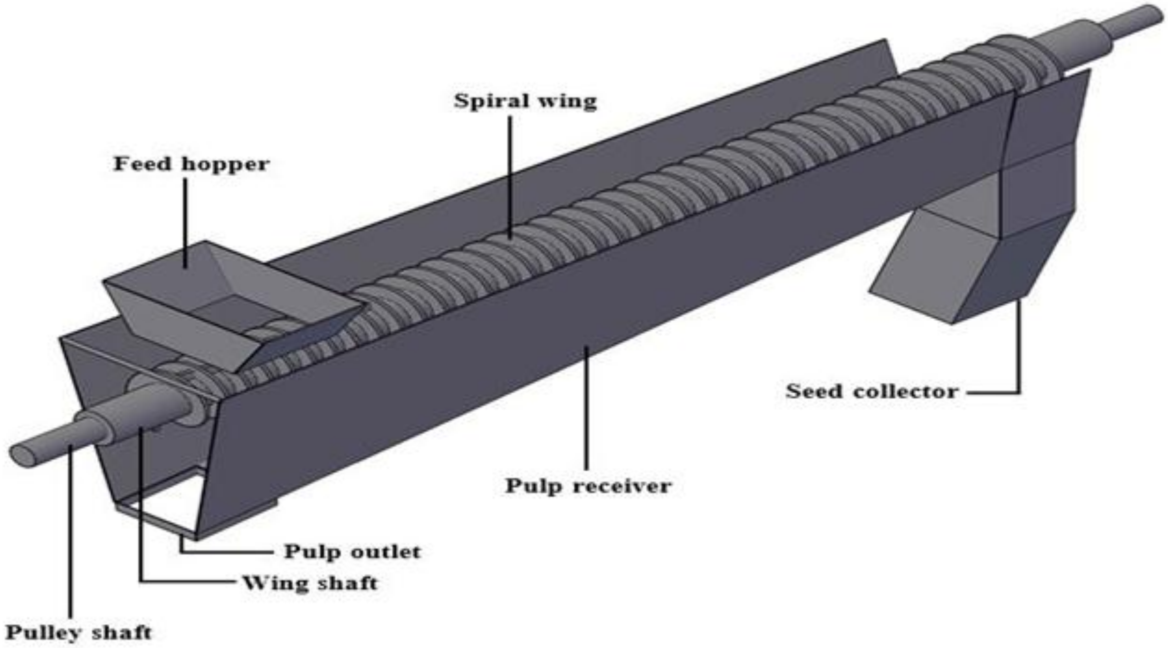


Figure 1 3D view of the blackberry pulp extractor

The diameter of the shaft was determined by applying the equation suggested by Khurmi and Gupta (2008) as:

$$d_s^3 = \frac{16}{\pi S_s}[(K_b M_b)^2 + (K_t M_t)^2]^{\frac{1}{2}} \quad (1)$$

where, d_s is the diameter of the screw shaft (mm); S_s is maximum shear stress, 74 MPa; K_b is combined shock and fatigue factor for bending, 1.5; K_t is combined shock and fatigue factor for torsion, 1; M_b is bending moment of the shaft, 56.83 N m; and M_t is torsional moment of the shaft, 9.44 N m.

2.2.4.2 Screen cylinder

It is the part where the extraction of pulp takes place. A thin-walled screen cylinder is subjected to internal pressure for the puling effect as shown in Figure 2.

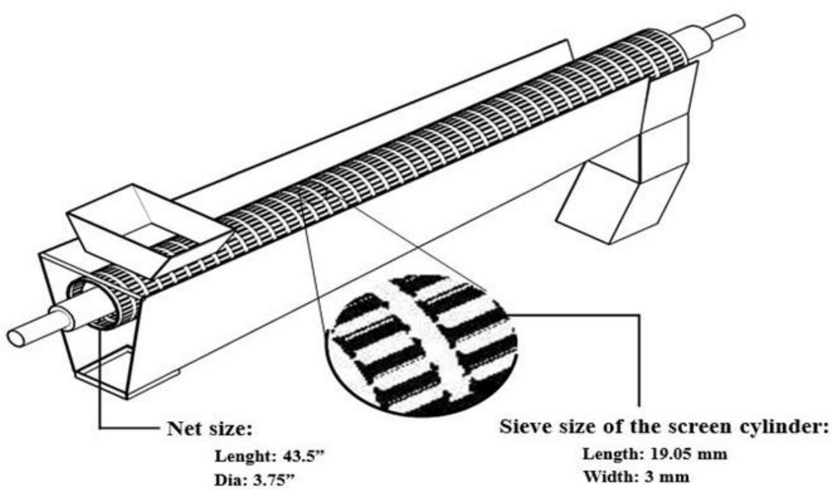


Figure 2 Blackberry pulp extraction with screen cylinder

2.2.4.3 Screw pitch

The screw pitch was designed using the equation given by Gbabo et al. (2013):

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

where, P_s is the screw pitch (mm); V is the inlet velocity of raw material, 0.059 m s^{-1}; D is the outside diameter of screw, 0.1016 m; d is the inside diameter of screw, 0.0508 m as shown in Figure 3.

L is the length of the screw shaft, 2.299 m; and N is the shaft speed, 360 (min^{-1}).

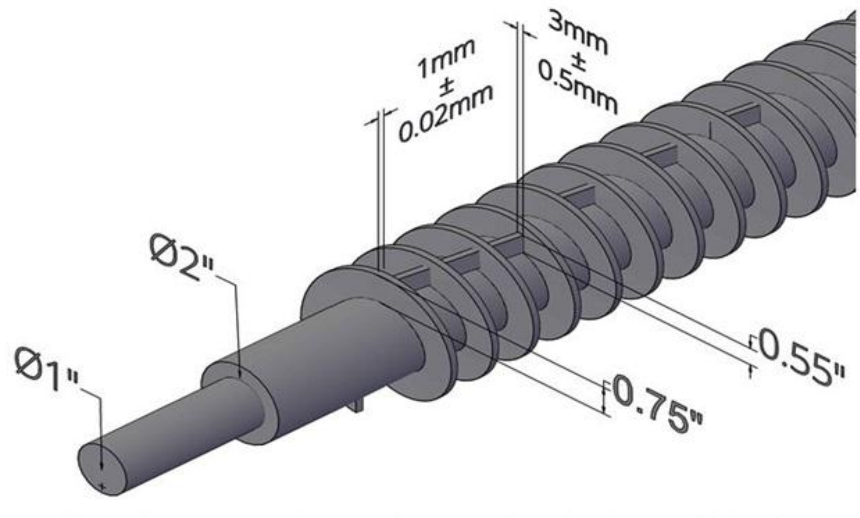


Figure 3 Close view of blackberry pulp extractor shaft and wing

2.2.4.4 Hopper

The feed hopper is designed to be fed in a vertical position and induct Blackberry fruits into the inner perforated stainless-steel cylinder. It has the shape like an inverted pyramid truncated at the top, with top and bottom having square form. The volume of the hopper was calculated as the volume of the trapezoidal prism (Aye and Ashwe, 2012) as follows:

$$V_{hopper} = \frac{l\times h\times(a+b)}{2} \quad (3)$$

where, V_{hopper} is the volume of the hopper (mm^3), h is the height of trapezoid, 127 mm; l is the length of trapezoid, 203 mm; b is the width of trapezoid, 127 mm; and a is the width of the rectangular bottom, 127 mm.

2.3 Calculation of power required for driving the screw shaft

The power required for driving the shaft was calculated using the equation applying Obajemihi and Olaniyan (2013):

$$P_r = \frac{(D^2-d^2)\times\rho\times g\times N\times P_a\times F\times L}{8000} \quad (4)$$

where, P_r is the power required to drive the machine; ρ is the density of blackberry pulp, 1062 kg m^{-3}; g is the acceleration due to gravity, 9.81 m s^{-2}; F is the material factor, 3; L is the length of the screw shaft, 2.299 m; P_a is the average screw pitch, 0.0254 m; D is the outside diameter of screw, 0.1016 m; d is the inside diameter of screw, 0.0508 m; and N is the shaft speed, 360.

2.4 Capacity of pulp extractor/ Machine throughput

The throughput capacity of pulp extractor was calculated using the equation given by Hmar et al. (2017):

$$C_s = \frac{f}{T} \quad (5)$$

where, C_s is the machine throughput, kg h^{-1}; f is the amount of pulp fed inside the hopper (kg); and T is the Pulp extraction time (hour).

3 Performance analysis of blackberry bulb extractor

3.1 Determination of bulb yield

Pulp yield was determined using the approach of Kasozi and Kasisira (2005) as follows:

$$J_{y,\%} = \frac{100 \times W_{JE}}{W_{JE} + W_{RW}} \quad (6)$$

where, W_{JE} is the mass of pulp extracted (g); and W_{RW} is the mass of residual waste (g).

3.2 Determination of extraction efficiency

Extraction efficiency was calculated using the equation prescribed by Hmar et al. (2017):

$$E_{f,\%} = \frac{W_{JE} \times 100}{X} \quad (7)$$

where, W_{JE} is the mass of pulp extracted (g); and X is the actual mass of pulp contained (g).

3.3 Estimation of extraction loss

Extraction loss was to estimate by the following equation described by Aye and Ashwe (2012):

$$E_{l,\%} = \frac{100 \times \left(W_{FS} - (W_{JE} + W_{RW})\right)}{W_{FS}} \quad (8)$$

where, W_{JE} is the mass of pulp extracted (g); W_{FS} is the mass of fed sample (g); and W_{RW} is the mass of residual waste (g).

3.4 Cost estimation of the pulp extractor

Toal expanses of the fabrication was estimated by the procedure described by Aviara el al. (2008). These comprise the cost of components brought, cost of materials and parts fabricated and cost of machining and non-machining jobs.

Operating cost was calculated with slight modification of the equation below described by Brennan (2020).

$$OC = \sum UC + \sum LC + \sum EC$$

where, OC is operating cost per hour, UC is utility cost per hour, LC is labour cost per hour, EC is the extra cost per hour including overhead and maintenance cost.

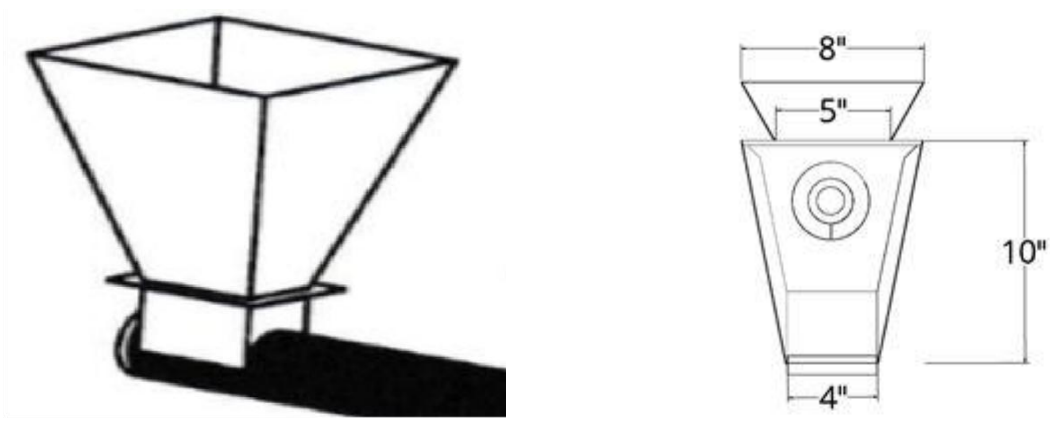
4 Result and discussion

4.1 Description of blackberry pulp extractor

The major components of the machine were feed hopper, extraction chamber, screw conveyor, pulp outlet, seed outlet, frame, and electric motor.

4.1.1 Feed hopper

The feed hopper, stayed on top of the pulp extraction chamber, was trapezoidal in shape and inclined at 30° with horizontal line that enabled mass flow of feed into the extraction chamber to be achieved. The hopper had rectangular upper (width 203 mm × length 127 mm) and base (width 127 mm × length 127 mm) and 127 mm height. It was made of stainless-steel sheet of 1 mm thickness as shown in Figure 4.



(a) Perspective view (b) Side skeleton view

Figure 4 Feed hopper

4.1.2 Extraction chamber

The extraction chamber was attached directly to the lower part of the hopper. Through this extraction chamber ran a shaft of 50.8 mm diameter, rolled round with a screw (spiral blade), and 6 pieces of stainless-steel bar were placed with the shaft at a 45° angle to the screw. The height and thickness of the screw were 25 mm and 1 mm respectively. The stainless-steel bar was 5 mm thick, 17 mm height and 152 mm long. 25.04 mm minimum screw pitch diameter was selected for the shaft.

It was determined that, for less than 25 mm shaft diameter caused broken the blackberry seed and more than 25 mm reduced extraction rates. Therefore, a 25 mm screw pitch was installed in the machine to get the desired efficiency. The minimum shaft diameter was found 18.07 mm from the Equation 1. In this study, a 50.8 mm diameter shaft was used to provide extra rubbing area which enhanced pulp extraction efficiency and reduce losses.

The screw conveyor and perforated cylinder provided the shear and compressive forces which were used to crush the fruit and separate pulp and seed. At the outside of the extraction chamber, was a perforated screen made of stainless steel. It permitted the pulp extracted from the fruit and flows down into the pulp receiver through the pulp outlet.

This shaft and screw assembly known as the wing shaft, received power from an electric motor via a reduction pulley and ran in a journal bearing. Stainless steel made screw conveyor was used to compact and crush fruit against a static perforated cylinder. The seed discharge outlet was located at the end of the extraction chamber.

4.1.3 Pulp receiver

It was the rectangular shape pulp extraction unit and starting point was width 228.6 mm × height 254 mm and gradually decreased to width 101 mm × 101 mm height at end point. The length of the conveyor housing was 1016 mm (Figure 5).

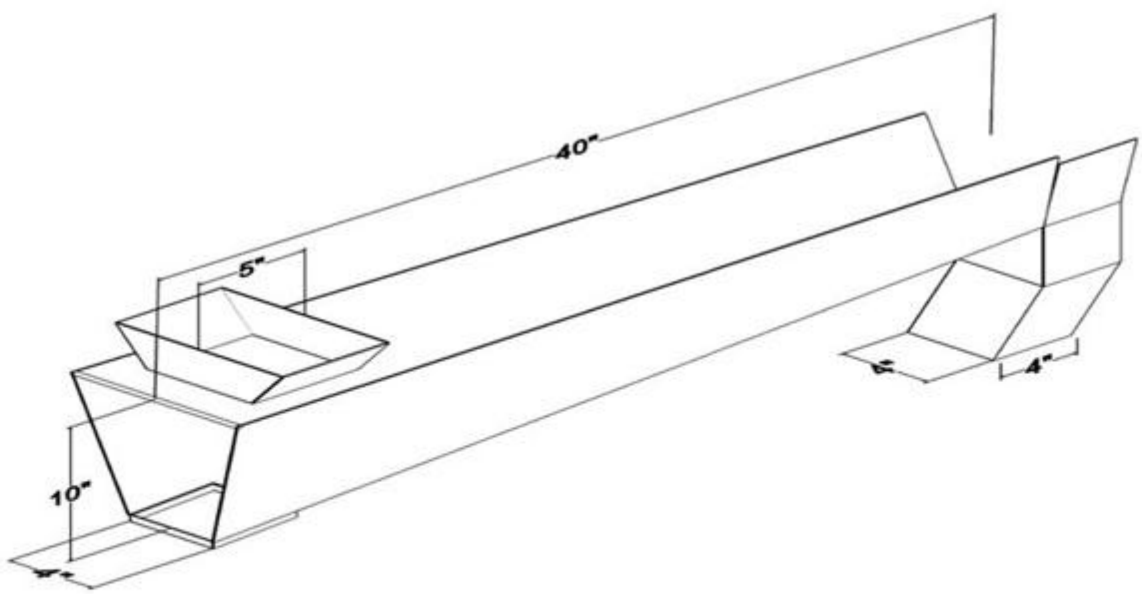


Figure 5 Skeleton view of collector and hopper of blackberry pulp extractor

It permitted the pulp extracted from the fruit flow through the pulp outlet while seeds expelled through a separate outlet.

4.1.4 Power unit

It was seen from the Equation 4 that a minimum 0.477 kW motor need to get the best performance. The power unit consisted of a 0.75 kW electric motor having a 1428 rpm capacity, which powered the machine via a belt and pulleys arrangement. The motor was placed in the base attached with the frame. The screw conveyor shaft was powered by a pulley of 228.6 mm diameter which was mounted and driven by a belt that received power from a 50.8 mm diameter pulley mounted on the motor shaft. A 3D view of the full machine is mentioned in Figure 6.

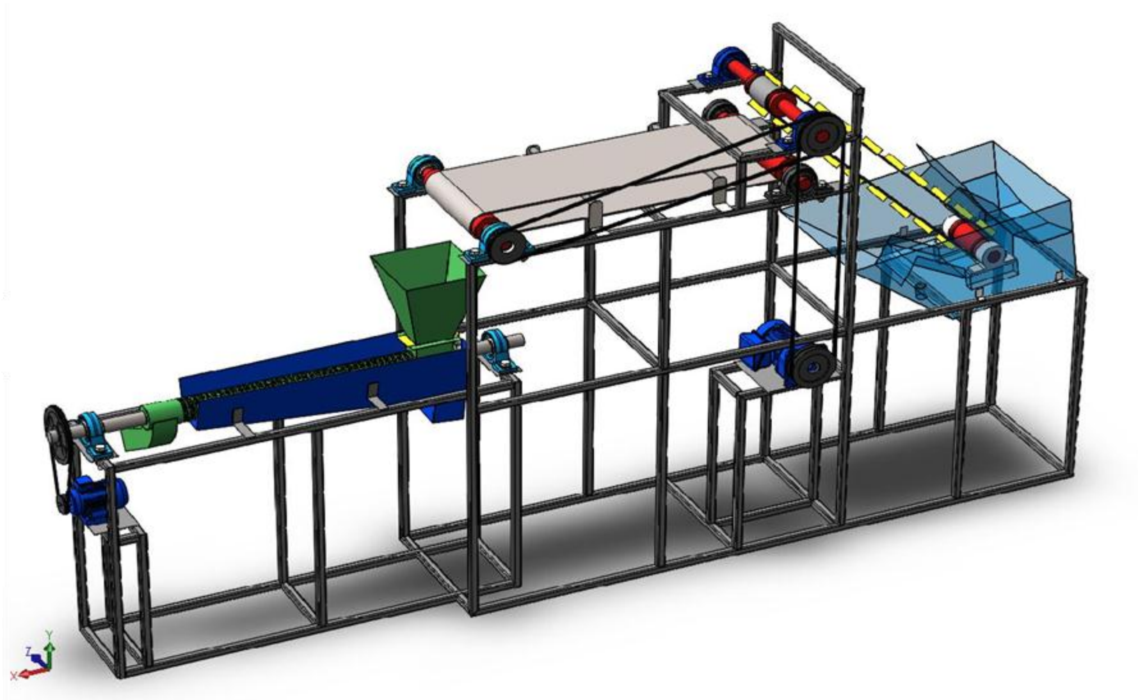


Figure 6 3D view of blackberry pulp extractor

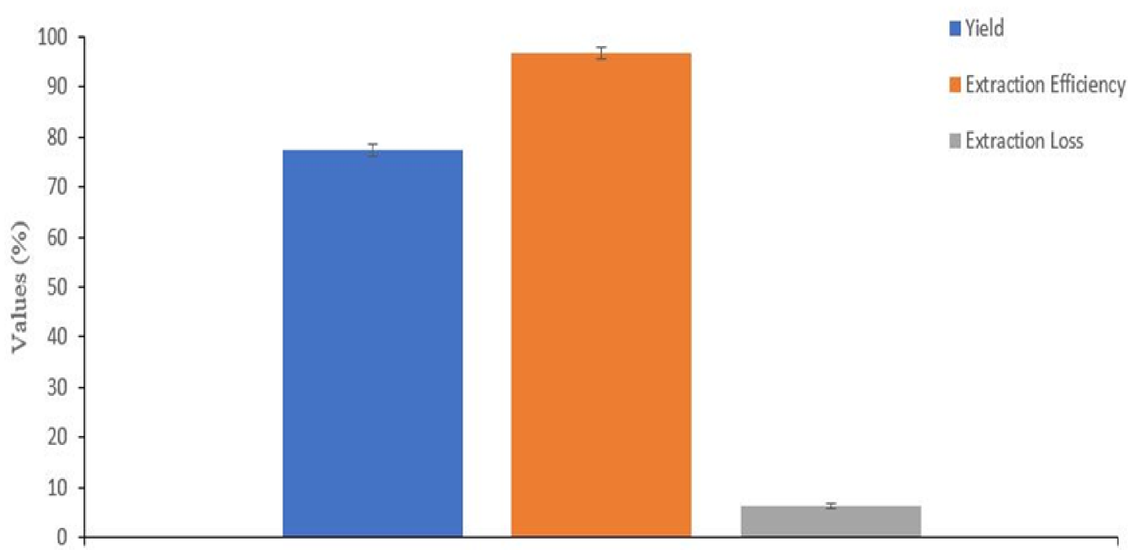


Figure 7 Performance index parameter of blackberry pulp extractor

4.2 Performance analysis of blackberry pulp extractor

The throughput of the pulp extractor was 39.58 ± 0.29 kg h^{-1}. Pulp yield, extraction efficiency, and extraction loss were 77.49% ± 1.18%, 96.72% ± 1.06%, and 6.38% ± 0.50% respectively (Figure 7).

These values were almost similar to Aviara et al. (2008) who found 77.03% -79.53% juice yield, 94.23% -96.60% extraction efficiency and 2.10% -2.90% extraction loss for pineapple, orange and watermelon, respectively. Obajemihi and Olaniyan (2013) also found 34.56% juice yield, 55.14% extraction efficiency and 10.15% extraction loss for mango fruit. The results of the tests showed that the machine performed satisfactorily compering with other fruit juice extractors.

4.4 Specification and summary of cost estimation of the pulp extractor

A total $ 175.67 was expended for the cost of producing and specification of the extractor which is presented in Table 1.

Table 1 Specification and summary of cost estimation of various components of the pulp extractor

Item No.	Name of components	Materials	Specifications	Cost (US$)
1.	Main frame	Mild steel	90 degree 3 mm thick, 38.1 mm Angled M/S iron bar	15
2.	Hopper	Stainless steel	125 mm height, 1 mm thickness, 3125 cm^3	4
3.	Screen cylinder(Net)	Stainless steel	1104.9 mm (43.5-inch) length, 101.6 mm (4-inch) diameter, and 19.05 mm, 3 mm length and width respectively of hole.	7
4.	Screw shaft	Stainless steel	95.25 mm (3.75 inch) diameter	27
5.	Pulp receiver and Outlet	Stainless steel	1016 mm (40-inch) length of receiver and 127 mm (5-inch) length and 127 mm (5-inch) width of outlet	5
6.	Motor		1 hp, 14435 rpm, 415 V, 3 Phase, 50 Hz	65
7.	Bearing	Stainless steel	SS Ball bearing	5.67
8.	Fabrication Charge			47
	Total Cost in U.S. dollar			175.67

Operating cost of the extractor was determined 0.90 $ h^{-1}.

5 Conclusion

A mechanical blackberry pulp extractor was designed, fabricated and tested. The extractor was designed to extract pulp based on the principle of compression and shear due to the action of covering net and screw conveyor. Food grade stainless steel was used in extraction chamber to maintain food quality. Other materials were Bengaly available for fabrication to ensure that the machine was produced at a relatively cheap price. The proposed pulp extractor was found to be functioning quite well for extracting of blackberry pulp. The overall performance of the extractor was satisfactory. The machine is cheap to fabricate, durable, and the cost of operation is low. The machine is recommended for use in blackberry juice production at the industry level.

Acknowledgements

The Authors are very much grateful University Grant Commission (UGC) through the Institute of Research and Training (*IRT*), Hajee Mohammad Danesh Science and Technology University (grant no. 03, Year 2020-2021), and Onnesha ChanaChur, Dinajpur, Bangladesh for financial support to conduct this research. The author would also like to express gratitude to the Bangladesh Bureau of Educational Information and Statistics (BANBEIS), Project no. LS 2018762 (2018-2021), Ministry of Education, Government of the People's Republic of Bangladesh, for providing partial financial support for this project.

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