Pak. J. Agri. Sci., Vol. 57(1), 199-204;2020
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
DOI: 10.21162/PAKJAS/20.9129
http://www.pakjas.com.pk

DEVELOPMENT AND PERFORMANCE EVALUATION OF AN IMPROVED MECHANIZED FRUIT PULP EXTRACTING UNIT

Hasan Farid Khan[1,*] and Ahmad Shafi[1]

[1]Department of Mechanical Engineering, The University of Lahore, Lahore, Pakistan.
[*]Corresponding author's e-mail: hassan.farid@me.uol.edu.pk

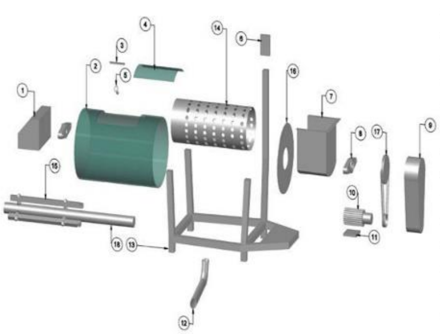
The purpose of the research work was designing and fabrication of a fruit pulp extracting unit for transformation of locally produced fruits into pulp in order to enhance profitability in orchard farming and to reduce the post-harvest losses in Pakistan. It was also required to be cheap and indigenously manufactured. The centrifugal and shearing force exerted through blades with incorporated teeth is the basic operational principle of the machine. It consists of a mild steel tapered frame, beater shaft with three blades having teeth, sieve mesh cylinder; pulp collection chamber, hopper, discharge channel. The machine is run by a set of pulleys and 1 HP A/C electric motor. Three mango varieties i.e. Sindhari, Chaunsa and Langra at two sieve mesh sizes 700 micron and 400 micron, two levels of clearance 35mm and 25 mm between sieve mesh cylinder and beater were selected and tested at 600 rpm. The machine was evaluated according to the methods set for standard evaluation. The time taken by unit for juice extraction, mass of extracted juice, mass of fruits and mass of residual wastes were noted and used to find the performance indicators considered. Sindhari variety was the highest juice yielder with juice yield (63.44%,), extraction efficiency (56.7%) and extraction loss (10.44%) at 700 micron sieve mesh size and 35 mm clearance between sieve and beater. Pulp extracting capacity of the unit is 25 kg of pulp per hour with an affordable cost of Rs.2, 25,000.
Keywords: Postharvest losses, mango shelf life, mango pulp extraction, beater shaft, sieve mesh cylinder, sieve mesh size, extraction efficiency.

INTRODUCTION

Pakistan had a total fruit production of about 6,567,286 tones in year 2016. Agriculture Department estimated that 30% of vegetables and fruits production in Pakistan is wasted due to lack of available facilities required for processing (Jamil *et al*., 2016). Processing of fruit is a viable and profitable business opportunity in Pakistan and has a lot of potential in it. Due to rich flavor, health value, aroma, minerals contents and nutrients, Pakistan mango has high demand in the international market and is the 5th largest fresh mango exporter. However, the fruit is a perishable commodity and have a poor shelf life. This leads to high loss to farmers, fruit merchants and processors. Therefore, it is needed to process the fruit to pulp form in order to easily store, preserve, package, transport and consume the product all the year round. In the same development, mango juice can be a valuable raw material in food and beverage industries which have a lot of potential for export of mango pulp. Juice extractors are designed in different types including continuous screw expellers (Ihekoronye and Ngoddy, 1985), taglith-type extractor, roller-press, plunger-type press, halving and burring machine, and rotary juice extractor (Hans and Joachin, 1986). Oyeleke and Olaniyan (2008) performed experiments in the laboratory on a small scale fruit juice extracting unit for different fruits to determine the juice yield of tangerine, water melon, pine apple and grapes. Aviara *et al.* (2013) designed, constructed and evaluated multi-fruit juice extractor using orange, pineapple, and melon. The machine operated on the principle of shear and compressive squeezing force. Olaniyan (2010) worked on designing and fabrication of a small scale motorized orange juice extractor. The main components of the extractor were hopper, worm shaft, sieve mesh, collector, main frame, waste outlet and pulleys. The worm shaft propels, crushes, and squeezes the fruit to extract juice from it. Chuba *et al.* (2019) developed a device to pulp bocaiuva. Immanvel *et al*. (2014) designed and fabricated a pomegranate pulp extractor with an efficiency of 75% extraction of fruit seed while focusing on the hygiene standards. Matthew *et al*. (2014) designed and developed small scale mango juice extractor using screw shaft as major juice extracting component. The unit has an average juice yield (34.56%), extraction efficiency (55.14%) and extraction loss (10.15%). Sonar *et al*. (2018) designed and fabricated brush type mango pulp extraction machine having brush linkage fitted on a shaft that rotates inside a fixed tube called the perforated sheet. Till date work has been done on fruit processing units having feed regulation screw (Matthew and Ibafemi, 2014) and brush type beaters having separate cutting mechanism (Sonarl *et al*., 2018). A highly effective beater-type continuous pulp extracting unit was developed which is easy to operate. Conventional designs of feed regulation screw and brush type beaters having separate cutting mechanism were replaced by innovative design of new rotary beater with built-in knives for cutting purpose thus reducing the size and weight of the machine as well as its fabrication and operational costs as shown in Figure 1. Pulp extraction capacity of the unit is 20-25 kg/h. The extractor is portable, easy to operate and maintain. All the materials used were locally and easily available. The machine is recommended for small scale mango pulp extraction requirement in the rural and urban communities and can be upgraded for industrial usage. The design of the machine was improved by replacing the screw conveyer with beaters having incorporated teethes. It has lowered the cost of fabrication and operating cost.

MATERIALS AND METHODS

The main frame was made of 40 mm x 40 mm MS angle iron and has a thickness of 2 mm. All major parts of the machine were welded and bolted on this main frame. The pulp extracting unit is inclined at an angle of 15° to give an easy forward movement to the fruits. Circular drum with hopper attached to it hosts the perforated drum and the beater shaft in it. Three stainless steel blades with incorporated teeth are attached to the main shaft at an angle of 120° to each other for crushing and beating purpose. The beater blades have the provision to adjust the clearance from 25 mm to 35 mm between sieve mesh stationery cylinder and beater blades. A set of two sieve mesh cylinders were fabricated with a sieve mesh size of 700 micron and 400 micron. The hopper acts as a feeding point which then passes the fruit to the beating chamber. It is trapezoidal in shape with inlet area of 215 mm x 230 mm, and outlet area of 200 mm x 160 mm with a height of 240 mm. . The pulleys and belts were used to transmit the rotary motion developed by the motor to the shaft. Motor is used as a power source to drive the extractor. It is mounted on the machine frame below the shaft pulley. Perforated drum was used as extraction chamber and strainer.



PARTS	DESCRIPTIONS
1	Discharge Channel
2	Drum
3	Drum Handle
4	Drum Cap
5	Drum Lock
6	Electronic Control Panel
7	Hopper
8	Universal Bearings
9	Cover
10	Motor
11	Motor Seat
12	Collector
13	Main Frame
14	Sieve Mesh
15	Blade
16	Disc
17	Belts
18	Shaft

Figure 1. Exploded views of fruit pulp extraction unit.

A thin-walled screen cylinder is subjected to internal pressure in pulping procedure. A reasonable clearance is provided in between the sieve mesh cylinder and the housing to prevent the stucking of the fruit material under pulping. At the lower end, pulp collector is present to collect the extracted pulp. Two universal bearings one at each end were fitted to support and align the shaft to absorb torque and make the operation almost frictionless. Discharge channel is used to pass the waste out of the extraction chamber and is made of stain less steel. Electronic control board was installed at an appropriate height to control the operation of the fruit pulp extraction unit. A time delay relay was fitted to the distribution panel to avoid electric hazards. An auxiliary 4 wheel spare frame was fabricated for manual transportation.

After searching for various fruit pulp extracting units in the scientific literature and specifically for mango pulp extracting units, it was established that a pulp extracting unit with beaters with built-in knives (Fig. 2 and 3) innovative mechanism was needed for mango pulp recovery.

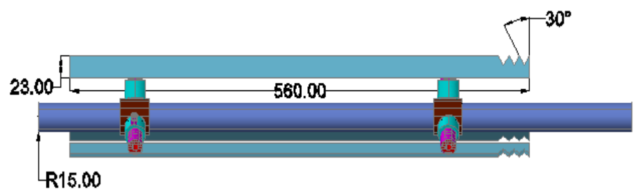


Figure 2. Front view of proposed design of rotary beater with knives (mm).

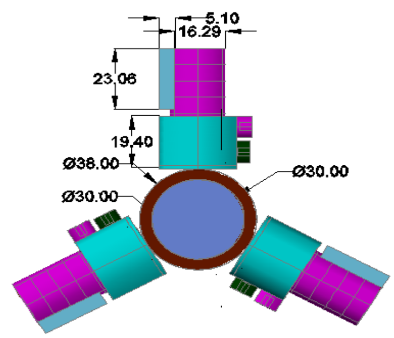


Figure 3. Side view of rotary beater with knives (mm).

***Main components of fruit pulp extracting unit*:** The unit consists of two major parts; extraction chamber and the structural frame. The extraction chamber is made of stainless steel and consists of a perforated inner cylinder 115 mm x 180 mm, beater shaft having three blades with incorporated teeth, non-perforated outer cylinder of length 120 mm and breadth 180 mm and discharge pipe. The structural frame 350 mm x 415 mm x 60 mm is made of mild steel of L-Section. Figure 1 shows the part list, Figure 4 shows the X-Ray view of the pulp extracting unit.

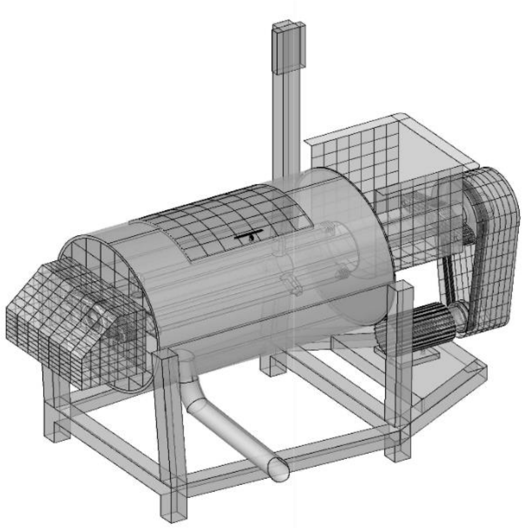


Figure 4. Isometric X-ray view of fruit extracting unit.

***Beater supporting shaft*:** Shaft is the main components to which blades are mounted. Diameter of the shaft (d) was calculated from formulas 1-4 (Khurmi and Gupta, 2005).

$T = (P\times60)/2\pi N$ (1)

As the shaft is only subjected to a twisting moment, torsion equation is used to find the diameter of the shaft

$T/J = \tau/r$ (2)

Where T = Twisting moment, J = Polar moment of inertia, τ = Torsional shear stress, r = Distance from neutral axis to the outer most fiber

= d / 2; where d is the diameter of the shaft.

$J= \pi/32\times d^4$ (3)

$T= \pi/16 \times\tau\times d^3$ (4)

From above, we determined the diameter of round solid shaft (d) which is 30 mm.

***Diameter of the pulleys*:** To evaluate the pulp extraction unit at the speed of 600 rpm, diameter of the set of pulleys was calculated by the formula 5 (Budynas and Nisbett, 2015).

N_1D_1/N_2D_2 (5)

where $N_{1=}$ motor speed (rpm), $N_{2=}$ speed of the shaft (rpm), D_1 = diameter of the shaft pulley (mm) and $D_{2=}$ diameter of the motor pulley(mm). For N_1 =1440 rpm, N_2 =600 rpm, sizes of pulleys are D_1 = 53 mm and D_2 = 127 mm

***Design capacity of the Fruit Pulp Processing Unit*:** Design capacity of the processing unit is calculated by subtracting the volume of shaft and connected beaters from the volume of the compression chamber using formulas 6 and 7 (Budynas and Nisbett, 2015).

Volume of the Sieve Mesh Cylinder

$V= \pi r^2h$ (6)

$V= 0.019m^3$ (A)

Volume of Shaft and Beaters

$= \pi r^2h + [3(L\times H\times W) + 6(\pi r^2h)]$ (7)

$= 3.14\times152\times630 + 3(25\times555\times4) +6(3.14\times8^2\times40)$

$V = 0.002158m^3$ (B)

So, the design capacity of the processing unit is A – B

$V= 0.016842m^3$

***Feeding hopper*:** The hopper design was based on the composite volume which is segmented into three rectangles and two triangular prisms. The volume of a rectangle and triangular prism is established in formulas 8 and 9 (Earl, 2015) as follows

Volume of a rectangle= lwh (8)

$= 215\times230\times240 = 0.036m^3$

Volume of triangular prism= $bhl/2$ (9)

$= 75\times240\times215/2 = 0.001m^3$

Therefore, the volume of the hopper is:

$V_h = 3(lwh) + 2(bhl/2)$

$= 0.0398\ m^3$

Where; l = length of the rectangle or triangular prism as it applies, b = base of the triangular prism, h= height of the rectangle or triangular prism as it applies, w = width of the rectangle.

Length of the transmission belts: Length of the open V- belts was calculated using equation 10 (Khurmi and Gupta, 2005).

$L= \pi (r_2 - r_1) + 2x + (r_2 - r_1)^2/x$ (10)

$= 3.14(74) + 559 + (127-53)^2 /559$

= 801 mm ~31.52 inches

= 37.80~ 38.0 inches (Applying tolerance factor 1.2)

A pair of A-37 V belts was selected after calculating the center to center distance of pulleys and diameter of the pulleys.

***Design of extraction chamber*:** During loading and extraction process, the internal cylinder would develop a stress which would cause efficient compression of juice. Maximum stress during compression is calculated by equation 11 (Earl, 2015).

$\acute{Y}= P_r /4t$ (11)

where Ý = the maximum shear stress the cylinder will be subjected before failure and has a value 81 MN/m^2 for a factor of safety 2. P =internal pressure of cylinder i.e. 35MN/m^2, r = internal radius of cylinder, 100mm, the thickness of outer cylinder, t is 2.5 mm.

***Torque developed in the rotating shaft of the pulp extracting unit*:** Torque developed in the rotating shaft of the pulp extracting unit was found by equation 12 (Khurmi and Gupta, 2005).

M = w/g, G= gravitational acceleration, M = mass of shaft and blades. Collective weight of these components is 7kg.

The weight of fruit processed is 5kg, total weight = 7kg + 5kg = 12kg, M = w/g = 12/9.81 = 1.22kg, $Fc = MW^2R$ (12)

$=1.22 \times (62.8)^2 \times 38mm =182.84$ N, so using T = fc x R, Torque is 6.94N/M

***Power required for extraction of juice*:** Power required for extraction of juice is determined by the equation 13 (Khurmi and Gupta, 2005)

P = T x W (13)

So, P = 435.832 watts or 0.44 KW so including margins .75 KW motor was used.

***Machine fabrication and assembly*:** After the design, the machine was fabricated and assembled according to designed specifications using workshop tools, machines and standard procedures. Table 1 given below show the materials used and their specifications of those materials.

Table 1. List of materials and their specifications.

Materials	Specifications
Stainless steel sheet	1 mm thickness
Stainless steel sheet	1 mm thickness
Stainless steel rod	ϕ 30 mm SAE 304
Stainless steel mesh hole size	1 mm thickness. 400 & 700 micron
Mild steel angle iron	40 mm × 40 mm ×2 mm
Universal bearing	ϕ 25 mm
Cast iron beater shaft pulley	ϕ 127 mm
Cast iron motor pulley	ϕ 53 mm
V- belt	A-37
Nuts and Bolts	M 10, M 13. M 19
Welding electrode	Guage 12 stainless steel
Cutting disc	ϕ 200 mm
Grinding disc	ϕ 200 mm

***Mode of machine operation*:** Motor was switched-on to enable the beater shaft rotate with the help of pulleys and belts. The hopper was fed uniformly with the mangoes. The knives cut the mango and beater beats the mango fruit against the perforated drum. Shaft with beaters is shown in Figure 5.

Figure 5. Beater shaft with incorporated teeth.

The shear and centrifugal forces of the beater extract the pulp from the mango leaving behind mango seed and skin which are expelled out of the machine through discharge channel. Pulp is collected at the bottom of the cylinder and is expelled out through collector attached at the base Pulp extraction unit took 7 minutes and 30 seconds to process 5 Kg of mango into pulp. The process of feeding of mangoes and pulp coming out of the pulp extracting unit is shown in Figure 6 and 7.

Figure 6. Feeding of mango in pulp extraction unit.

Figure 7. Extraction of mango pulp in process.

RESULTS AND DISCUSSION

The performance evaluation of the machine was carried out by introducing a measured mass of 5 Kg of each mango variety into the extraction chamber where the mangoes were crushed and compressed under the application of a compressive force thereby forcing the pulp out of the mangoes through stationary perforated sieve cylinder. For each variety, five replicates were used, and their average was analyzed for further calculations as shown in Table 2 and 3 Using equations 14-16 (Tressler and Joslyn, 1961) shows the formulas for the performance indices considered during the extraction process.

$$\text{Juice yield} = \frac{100\, W_{JE}}{W_{JE} + W_{RW}} \% \quad (14)$$

Extraction efficiency $= \frac{100W_{JE}}{XW_{FS}}\%$ (15)

Extraction loss $= \frac{100[W_{FS}-(W_{JE}+W_{RW})]}{W_{FS}}\%$ (16)

Extraction capacity = $\frac{\text{Weight of juice (g)}}{\text{Time Taken (min)}}$ (17)

Where, W_{JE} = weight of juice extracted from the fruit, kg, W_{RW} = weight of residual waste of the fruit, kg, W_{FS} = weight of feed sample, kg.

All the data was statistically analyzed at 5% level of confidence to determine the extent to which the type of variety, sieve mesh size and clearance between beater and perforated drum affected the performance indices with 5 replications which are shown in Table 2 and 3.

Table 2. Factors along with their levels description and symbols.

Factor	Levels / Description	Symbol
Variety	Sindhari	V1
	Chaunsa	V2
	Langra	V3
Sieve mesh hole size	0.40 mm	S1
	0.70mm	S2
Clearance between Sieve	25mm	C1
And Beater Drum	35mm	C2

Table 3. Juice yield, extraction efficiency & extraction loss with respect to variables.

Sr .	Combinations	Juice Yield (%)	Extraction Efficiency (%)	Extraction Loss (%)
1	V1S1C1	62.11	59.36	4.44
2	V1S1C2	53.90	45.78	15.08
3	V1S2C1	59.30	53.20	10.30
4	V1S2C2	63.30	56.70	10.44
5	V2S1C1	62.00	58.80	5.40
6	V2S1C2	57.60	45.10	16.40
7	V2S2C1	60.60	52.50	13.30
8	V2S2C2	62.10	55.90	10.00
9	V3S1C1	59.30	51.00	14.00
10	V3S1C2	43.40	38.28	11.80
11	V3S2C1	60.40	52.00	14.00
12	V3S2C2	51.30	43.76	14.76

Effect of varieties on juice yield: Sindhari variety is the maximum juice yielding variety (63.3%) because of thin seed and less fiber contents followed by Chaunsa variety (62.1%); however, Langra variety (60.4%) stands as the lowest juice yielder. Size of seed and fiber content present in any variety plays a vital role in juice yield.

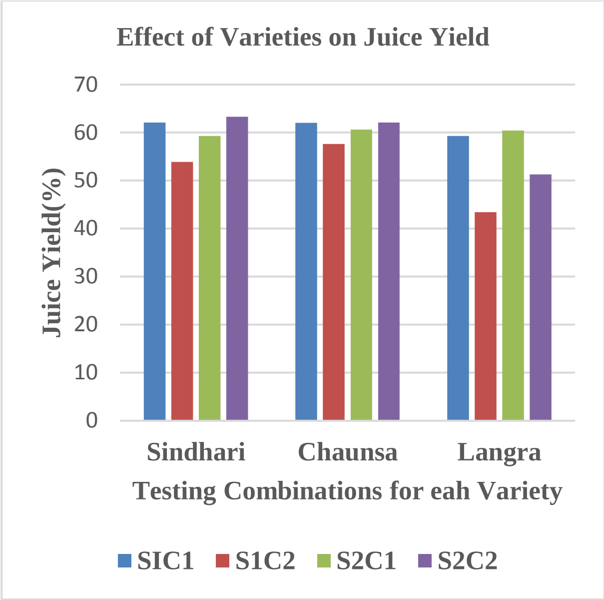


Figure 8. Effect of varieties on juice yield.

Effect of sieve mesh size on juice yield: Sieve mesh size of 700 micron is analyzed to give the maximum juice yield as compared to sieve mesh size of 400 micron.

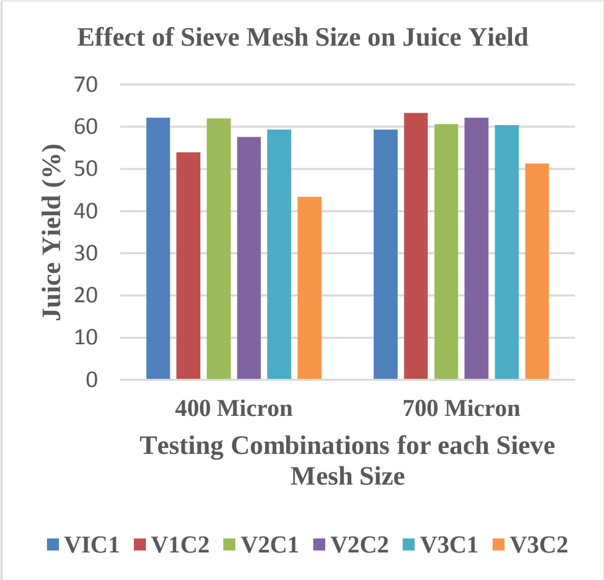


Figure 9. Effect of sieve mesh size on juice yield.

Effect of clearance between beater and sieve mesh cylinder on juice yield: Less clearance between beater and sieve mesh gave the good results on average as beater can beat the fruit in a comprehensive manner getting maximum pulp out of it.

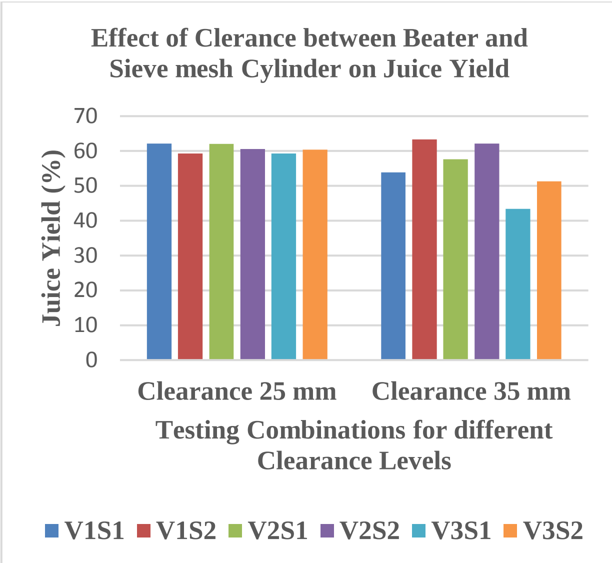


Figure 10. Effect of clearance between beater and sieve mesh cylinder on juice yield.

Conclusion: Keeping in view the current production status of fruits and their post-harvest losses at rural and urban level in Pakistan, a small scale pulp extracting unit was designed, fabricated and tested for its juice yield, extraction efficiency and extraction loss. The data calculated during testing procedure was analyzed at 5% confidence interval and followings results were concluded. Sindhari mango variety with thin seed size and less fiber content gives maximum juice yield. Large sieve mesh size i.e. 700 micron gives maximum juice yield allowing easy flow of pulp. Minimum permissible clearance between beater and sieve mesh cylinder i.e. 25 mm helped to get the maximum juice yield.

REFERENCES

Aviara, N.D.A., A.B.A. Lawal, D.S. Nyam and J. Bamisaye .2013. Development and performance evaluation of a multi-fruit juice extractor. G.J.E.D.T. 2:16-21.

Budynas, R.J and J.K. Nisbett. 2015. *Shigley's* Mechanical Engineering Design. McGraw-Hill Education. New York. USA; p.890.

Chuba1, C.A.M., R.E.P. Silva, A.C.D Santos and E.J.S. Argandoña. 2019. Development of a device to pulping fruits of Bocaiuva (*Acrocomia aculeate sp.*). JAS. 11:397-407.

Earl, L.W.2 015. Math Handbook of Formulas, Processes and Tricks. Earl Whitney, Reno NV; pp. 76-77.

Hans, J.B. and W. Joachin. 1986. Fruit Juice Processing. Institute of Fruit and Vegetable Technology, Technical University of Berlin, Germany; pp.212-213.

Ihekoronye, A.I. and P.O. Ngoddy. 1985. Integrated Food Science and Technology for the Tropics. Macmillan Education Ltd., London, UK; p.321.

Immanvel, A., M. Manikandan, I.M. Sadiq, R. Sridhar, K. Velmurugan. 2014. Design and fabrication of pomegranate aril (Pulp) extractor. International Conference on Engineering Technology and Science (ICETS'14) 3:1218-1221.

Jamil, A., H. Ullah and S. Amin. 2016. Fruit, vegetables and condiments statistics of Pakistan. Fruit Pulping & Grading Unit (Mango & Guava**),** SMEDA, Pakistan; pp.5-7.

Khurmi, R.S. and J.K Gupta. 2005. A Textbook of Machine Design**.** Eurasia Publishing House (Pvt) Ltd., New Delhi, India; pp.511-514.

Olaniyan, A.M. 2010. Development of a small scale orange juice extractor. J. Food Sci. Technol. 47:105-108.

Olaniyan, A.M. and O.I. Obajemihi. 2014. Design development and testing of a small scale mango Juice. JAST. 4:1-7.

Oyeleke, F.I. and A.M. Olaniyan. 2008. Extraction of juice from some tropical fruits using a smallscale multi- fruit juice extractor. Afr. Crop Sci. Proc. 8:1803-1808.

Sonar1, D.J., A.A. Chindhe, J.N. Phapale, S.B. Pansambal and B. Ajinath. 2018. Design and fabrication of mango pulp extraction machine. IJRASET. 6:849-852.

Tressler, D.K. and M.A. Joslyn. 1961. Fruit and vegetable juice processing technology. Westport, Conn., Avi. Pub. Co.; pp.143.

[Received 14 June 2019; Accepted 25 July- 2019; Published (online) 16 Nov 2019]