Design and development of technology for walnut cracking

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Abstract The aim of the present study was to design, develop and evaluate hand operated and power driven crackers for walnuts. Kaghazi (thin shelled) and medium shelled walnuts after subjecting to pre-optimized soaking conditions were cracked by developed crackers. Different parameters were evaluated to check the performance of the power operated cracker and hand operated cracker in comparison to manual cracking. 100% shelling coefficient and cracking coefficient value of 1 were recorded in manual and hand operated cracking methods in both Kaghazi and medium shelled walnuts. The coefficient of wholeness was recorded highest in hand operated cracking method in both Kaghazi and medium shelled walnuts. The throughput capacity and effective throughput capacity was highest and labour requirement was least in power operated walnut cracking method followed by manual cracking and hand operated cracking methods in both Kaghazi and medium shelled walnuts. In both Kaghazi and medium shelled walnuts, the butter ball + kernel halve recovery and cracking efficiency was recorded maximum in hand operated cracking method. The economic analysis reveals that both hand operated and power operated crackers can be useful for small to medium scale walnut growers and processing industries.

Keywords Walnut cracker · Cracking efficiency · Kernel halves · Butterballs · Throughput capacity · Shelling coefficient

Introduction

Persian walnut (*Juglans regia* L.) is an edible tree nut classified under Juglandaceae family. It is recognized as an important temperate nut crop, grown widely in USA, Asia and Europe (Akça and Polat 2007). China is the leading walnut producing country in the world and India ranks seventh in the world walnut production (USDA 2017). Jammu and Kashmir (J&K) is one of the major walnut producing state of India. Agricultural and Processed Food Products Export Development Authority (APEDA) has identified the J&K state as major walnut export zone in India. During the year 2016–2017, the annual production of walnuts in J&K was estimated to be 266,280 metric tons from an area of 89,339 ha (Malik et al. 2018). Walnuts are mostly exported from J&K in kernel form and its trade occupies an important place in rural economy of the state.

Walnuts are traded both in inshelled and shelled (as kernel) form. However, the market value of kernels is about 4–5 times higher than the inshelled walnuts. Walnut kernels are rich in quality proteins, omega-6, omega-3 fatty acids, minerals and vitamins. After harvesting of walnuts, the shell is cracked in order to obtain the kernel. Organoleptic quality and halved kernel percentage are vital indices which govern the consumer acceptability of kernels. Presently, in J&K, walnuts after soaking for about 12–20 h are cracked manually by semi-skilled laborer's using wooden pestle or stones and then the kernels are separated from shell by hands, which is a very tedious, labor intensive, time consuming and irrational practice.

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Moreover, the impact force used in such manual practice is not uniform which leads to kernel damage. Walnut kernels obtained by such cracking practice have less market value due to low butter ball + halve recovery.

Many researchers have previously developed walnut crackers. However, the perusal of literature shows that the whole kernel recovery is less than 75% in all these crackers (Ghafari et al. 2011; Bernik et al. 2009).

Walnut growers and processors in Jammu and Kashmir still rely on conventional methods of walnut cracking which leads to kernel breakage. Therefore, there was an immense need to develop more efficient means of walnut cracking through mechanization so as to boost the export potential of walnuts in the state. Keeping in view, the aforementioned facts the present study on development of power and hand operated crackers was undertaken with an aim to increase butter ball + kernel halve recovery and to reduce boredom, drudgery and other constraints attributed with existing practice of walnut cracking.

Materials and methods

Power operated and hand operated walnut crackers were designed and developed by Srinagar Centre of All India Coordinated Research Project on Post-Harvest Engineering and Technology, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, India during the year 2015–2016.

Design and development of power operated walnut cracker

The material of construction for fabricating different parts of power operated walnut cracker were selected on the basis of availability, strength, cost and ease of maintenance and construction. The different schematic views of power operated walnut cracker are given in Fig. 1 and material of construction and brief specifications of the machine are given in Tables S1. The brief details of the different components of power operated walnut cracker are described below:

Frame

In order to protect the internal components of the machine, prevent shocks and transverse vibrations caused by rotating components and to give the structural rigidity to the machine, a frame made of galvanized iron was constructed.

Hopper

A rectangular shaped hopper with edges narrowing down along the axis was constructed at the top of the casing for

feeding. Through one end of the hopper, the graded walnuts are fed into the machine while the other end moves the walnuts towards the rotating shaft.

Rotating shaft

For efficient cracking of walnuts, a shaft driven by means of belt and pulley mechanism at a speed of about 140.62 rpm was constructed.

Motor

In order to provide the driving force to the machine, a 1 HP 3 phase AC motor with a rotational speed of 900 rpm was installed to the machine.

$$P(\text{Power}) = 1 \text{ HP} = \frac{1 \times 746}{1000} = 0.746 \text{ KW} \quad (1)$$

The net torque (T) in the motor was calculated as

$$T = \frac{9550 \times P}{N} \quad (2)$$

where N = rpm of the motor = 900

$$T = \frac{9550 \times 0.746}{900}$$

$$T = 7.915 \text{ Nm}$$

Belt and pulley system

Belt and pulley system was used for the purpose of transmitting power from one component of the machine to another. The two pulleys were used in machine (1) small pulley/driver pulley and (2) big pulley/driven pulley. The driver pulley transmits its power to the driven pulley which gets transmitted to the grooved shaft via a belt.

Diameter of driver pulley (D_1) = 0.0635 m

Diameter of driven pulley (D_2) = 0.4064 m

$$\frac{N_1}{N_2} = \frac{D_1}{D_2} \quad (3)$$

Where, N_1 = rpm of driver pulley = 900

N_2 = rpm of driven pulley

$$N_2 = \frac{N_1}{\frac{D_2}{D_1}}$$

$$N_2 = \frac{900}{6.4}$$

$$N_2 = 140.625 \text{ rpm}$$

Fig. 1 Schematic views of power operated walnut cracker. **a** Side view of power operated walnut cracker, **b** front view of power walnut cracker and **c** top view of power walnut cracker

Safe stress in belt (σ_{safe})

$$\sigma_{\text{safe}} = \frac{T_{\text{max}}}{B \times T} \quad (4)$$

where T_{max} = Maximum stress (in tight side of Belt) B = width of Belt = 1.5 cm = 15 mm T = Thickness of Belt = 1.1 cm = 11 mm

Belt has two tensions, one on the tight side (T_1) and another on lag side (T_2).

$$\text{Belt Speed}(V) = \frac{\pi D_1 N_1}{60} \text{ for driver pulley} \quad (5)$$

$$V = \frac{\pi \times 0.0635 \times 900}{60}$$

$$V = 2.99 \text{ m/sec.}$$

Reduction gear power was calculated by assuming the mechanical efficiency of the system as 80%

$P = 80\%$ of motor power

$$P = 0.80 \times 0.746 \quad (6)$$

$$P = 0.596 \text{ KW}$$

For calculation of tensions in the Belt (open belt system)

$$\begin{aligned}
 P &= (T_1 - T_2) \times V \\
 T_1 - T_2 &= P/V \\
 T_1 - T_2 &= \frac{0.596 \times 1000}{2.99} \\
 T_1 - T_2 &= 199.33 \text{ N}
 \end{aligned} \quad (7)$$

Since, V-Belt has been used in the system, thus T_1 was calculated as:

$$2.3 \log(T_1/T_2) = \mu \times \theta \quad (8)$$

where θ = Angle of contact between belt and pulley

μ = Coefficient of friction ($\mu = 0.3$)

Here θ is slightly less than 180° , it was therefore, calculated as:

$$\theta = 180 - 2\alpha \quad (9)$$

α = angle subtended by contact surface at the center of pulley

$$\alpha = D_2 - D_1/y \quad (10)$$

y = Distance between two pulleys = 0.508 m

Therefore, $\alpha = \frac{0.4064 - 0.0635}{0.508} = 0.675$ radian = 38.67°

$$\theta = 180 - 2 \times 38.67$$

$$\theta = 102.66^\circ$$

$$\theta = 102.66^\circ \times \pi/180$$

$$\theta = 1.79 \text{ radian}$$

Using the values in Eq. (8)

$$\log(T_1/T_2) = 0.3 \times 1.79/2.3$$

$$\log(T_1/T_2) = 0.233 (\text{antilog of } 0.233 = 1.7100)$$

$$T_1/T_2 = 1.7100$$

Therefore, $T_1 = 480.06$ N and $T_2 = 280.74$ N

$$T_{\max} = T_1 + T_2 = 480.06 + 280.74 = 760.8 \text{ N} \quad (11)$$

$$\text{Now } \sigma_{\text{safe}} = \frac{760.8}{15 \times 11}$$

$$\sigma_{\text{safe}} = 4.610 \text{ N/mm}^2 \text{ or } 4.61 \text{ MPa which is in safe range.}$$

Design and development of hand operated walnut cracker

A user-friendly low weight (170 g) hand operated walnut cracker was designed and developed. The overall dimensions of developed hand operated walnut cracker are 160 mm $\times$ 85 mm. Casted aluminum alloy was used for constructing the main frame (V-design clamp-piler) of hand operated walnut cracker owing to its strength, rigidity and vibration absorption characteristics. The clamp, handle, hinge pin and spring are necessary components of the hand operated cracker. Clamp is for holding the walnuts,

handle for pressing and hinge pin made out of cast iron gives strength and better shock resistance to cracker, while as excess force due to pressing of handle gets absorbed by the spring. Springsteel wire which provides higher corrosion resistance, ductility, strength and hardness was selected for making tension spring. The different schematic views of hand operated walnut cracker are given in Fig. 2.

Working operation

Power operated walnut cracker

As the graded walnuts are fed to the hopper, they move towards the space between the serrated rotating shaft and stationary grooved plate where the cracking takes place. The distance between the rotating shaft and stationary plate was made adjustable in the range of 15 mm to 45 mm depending upon the walnut size. The walnuts are cracked by shearing action of the shaft against the fixed grooved plate. The cracked walnuts get discharged through outlet chute.

Hand operated walnut cracker

In hand operated walnut cracker, the walnuts are placed inside the clamp (Fig. 2). The pressing of handle provides the necessary force for cracking of walnuts. The excessive force absorbed by the spring helps in reducing the kernel damage during walnut cracking.

Performance evaluation of developed walnut crackers

Performance of both power operated and hand operated walnut crackers was tested for two commercial walnut types of Jammu and Kashmir i.e., Kaghazi (thin shelled) and medium shelled. Both the walnut types were harvested at green, stick-tight stage from seedling tress grown in Srinagar district of Jammu and Kashmir, India. The harvested green walnuts were sprayed with 0.3% ethephon and after 4 days of spraying, the walnuts were dehulled using the dehuller developed previously, in a research project (Syed et al. 2016). Since kernels were to be extracted from whole walnuts, so no bleaching and washing was done prior to drying. The dehulled walnuts were, therefore, directly subjected to drying in solar tunnel drier at temperature of 35–45 $^\circ\text{C}$ and relative humidity of 75–80% till moisture content of $10 \pm 2\%$ was attained. 100 kg each of kaghazi and medium shelled walnuts dried in this fashion were cracked by means of power operated cracker, hand operated cracker and by traditional method of cracking using wooden pestle, after subjecting to soaking conditions, previously, optimized in the project (Annual report, AICRP

Fig. 2 Schematic views of hand operated walnut cracker. **a** Sectional front view of hand operated walnut cracker, **b** Sectional side view of hand operated walnut cracker and **c** top sectional view of hand operated walnut cracker

on PHET 2017). In each method of cracking, below mentioned parameters were studied:

$$(a) \quad \text{Shelling Co-efficient (\%age)} = \frac{M_{c_w}}{M_{t_w}} \times 100 \quad (12)$$

where M_{c_w} = mass of cracked walnuts, M_{t_w} = total mass of walnuts before cracking

$$(b) \quad \text{Coefficient of cracking} = 1 - \frac{M_{u_w}}{M_{t_w}} \quad (13)$$

where M_{u_w} = mass of uncracked walnuts after cracking

$$(c) \quad \text{Coefficient of wholeness of kernels} = 1 - \frac{M_{b_w}}{M_{t_w}} \quad (14)$$

where M_{b_w} = mass of broken kernels after cracking (includes big broken, small broken and fines)

$$(d) \quad \text{Throughput capacity (kg/hr)} = \frac{\text{Total weight of walnuts subjected to cracking (kg)}}{\text{Operating time (h)}} \quad (15)$$

$$(e) \quad \text{Effective Throughput capacity (kg/hr)} = \frac{\text{Actual weight of cracked walnuts (kg)}}{\text{Effective Operating time (h)}} \quad (16)$$

$$(f) \quad \text{Butter balls + halves (\%age)} = \frac{\text{Number of butter balls} + \text{Number of halves}/2}{\text{Number of soaked walnuts subjected to cracking}} \times 100 \quad (17)$$

$$(g) \quad \text{Big broken kernel (\%age)} = \frac{\text{Weight of broken kernel } \geq \frac{1}{4\text{th}} \text{ of butter ball size}}{\text{weight of kernels (butter balls + halves + brokens (large + small) + fines)}} \times 100 \quad (18)$$

(h)

$$\text{Small broken kernel (\%age)} = \frac{\text{Weight of small broken kernels } (\frac{1}{4\text{th}} \text{ to } \frac{1}{8\text{th}} \text{ of butter ball size})}{\text{Weight of kernels (butter balls + halves + brokens (large + small) + fines)}} \times 100 \quad (19)$$

(i)

$$\text{Fines (\%age)} = \frac{\text{Weight of fines } (< \frac{1}{8\text{th}} \text{ of actual butter ball size})}{\text{Weight of kernels (butter balls + halves + brokens (large + small) + fines)}} \times 100 \quad (20)$$

(j)

$$\text{Uncracked walnut (\%age)} = \frac{\text{Weight of uncracked walnuts}}{\text{Total weight of walnuts subjected to craking}} \times 100 \quad (21)$$

(k)

$$\text{Labor requirement (man-hours/quintal)} = \frac{1}{\text{Throughput capacity } \left(\frac{\text{kg}}{\text{h}}\right)} \times 100 \quad (22)$$

(l)

$$\text{Cracking efficiency} = 1 - \frac{M_{tw}}{M_{tw}} \left(1 - \frac{M_{bw}}{M_{tw}}\right) \times 100 \quad (23)$$

where M_{bw} includes Big brokens, small brokens and fines.

$$\text{Pay-back period} = \frac{IC \times H}{TB \times H} \quad (26)$$

where

IC = Initial cost (Rs.), TB = Total benefit (Rs.),
H = working hours

Economic analysis of power operated and hand operated walnut crackers

Inorder to determine the techno-economic feasibility of developed crackers, benefit–cost–ratio (BC ratio), break even point (BEP) and pay back period were determined as:

(a) Benefit cost ratio

$$= \frac{\text{Total benefit (Rs)}}{\text{Cost of Cracking } \left(\frac{\text{Rs}}{\text{kg}}\right) \times \text{Cracking capacity } \left(\frac{\text{kg}}{\text{h}}\right)} \quad (24)$$

(b) Break-Even point (BEP)

$$= \frac{\text{Total fixed cost } \left(\frac{\text{Rs}}{\text{h}}\right)}{\frac{\text{Cracking fee } \left(\frac{\text{Rs}}{\text{kg}}\right) - \text{Total variable cost } \left(\frac{\text{Rs}}{\text{h}}\right)}{\text{Working hours } \left(\frac{\text{h}}{\text{year}}\right) \times \text{cracking capacity } \left(\frac{\text{kg}}{\text{h}}\right)}} \quad (25)$$

(c)

Statistical analysis

Each measurement was replicated five times and data obtained was analyzed using SPSS Software (SPSS PASW 18.0) and means were separated using Duncan multiple test ($p \leq .05$).

Results and discussions

Performance evaluation of developed crackers

Kaghazi(thin shelled) and medium shelled walnuts after subjecting to optimized soaking conditions (Annual report, AICRP on PHET, 2017) were cracked by power operated cracker, hand operated cracker and traditional method of cracking using wooden pestle. Comparative evaluation of developed crackers and existing cracking method for cracking Kaghazi, and medium shelled walnuts is depicted in Tables 1 and 2, respectively.

Shelling coefficient and coefficient of cracking are important machine parameters and were determined to

Table 1 Comparative evaluation of manual and mechanical walnut cracking for Kaghazi (thin shelled) walnuts

Parameter	Shelling coefficient (%)	Coefficient of cracking	Coefficient of wholeness	Throughput capacity	Effective throughput capacity	Butter balls + kernel halves (%)	Big broken kernels (%)	Small broken kernels (%)	Fine (%)	Un-cracked walnut kernels (%)	Cracking efficiency (%)	Labour requirement man-hour required/ quintal
Manual cracking (T ₁)	100 ^a	1 ^a	0.80 ^c	3.42 ^b (kg/hr/person)	3.42 ^b (kg/hr/person)	54.34 ^c	36.23 ^a	7.25 ^b	2.17 ^c	0* (0.5) ^b	80.62 ^b	29.24 ^b
Hand operated cracker (T ₂)	100 ^a	1 ^a	0.96 ^a	1.61 ^c (kg/hr/person)	1.61 ^c (kg/hr/person)	90.34 ^a	2.41 ^c	4.48 ^c	2.75 ^b	0* (0.5) ^b	95.8 ^a	62.11 ^a
Power operated cracker (T ₃)	96.37 ^b	0.96 ^b	0.84 ^b	15.46 ^a (kg/hr)	14.90 ^a (kg/hr)	55.86 ^b	19.53 ^b	10.15 ^a	14.45 ^a	4.91 (2.21) ^a	79.8 ^c	6.46 ^c
C.D at 5%	1.985	0.212	0.024	1.123	1.332	0.956	2.61	1.60	0.21	0.051	0.313	2.352
SED	0.99	0.106	0.012	0.561	0.666	0.478	1.305	0.80	0.105	0.025	0.156	1.176

*Indicates transformed values

Values in the same column with different letters are significantly different ($p < 0.05$)**Table 2** Comparative evaluation of manual and mechanical walnut cracking for medium shelled walnuts

Parameter	Shelling coefficient (%)	Coefficient of cracking	Coefficient of wholeness	Throughput capacity	Effective throughput capacity	Butter balls + kernel halves (%)	Big broken kernels (%)	Small broken kernels (%)	Fines (%)	Un-cracked walnut (%)	Cracking efficiency (%)	Labour requirement man-hour required/ quintal
Manual cracking (T ₁)	100 ^a	1 ^a	0.72 ^c	3.21 ^b (kg/hr/person)	3.21 ^b (kg/hr/person)	35.10 ^c	39.52 ^a	22.02 ^b	1.06 ^c	0* (0.5) ^b	72.43 ^b	31.15 ^b
Hand operated cracker (T ₂)	100 ^a	1 ^a	0.94 ^a	1.29 ^c (kg/hr/person)	1.29 ^c (kg/hr/person)	84.19 ^a	0.8 ^c	10.22 ^c	4.81 ^b	0* (0.5) ^b	93.91 ^a	77.51 ^a
Power operated cracker (T ₃)	95 ^b	0.95 ^b	0.77 ^b	14.07 ^a (kg/hr)	13.38 ^a (kg/hr)	35.81 ^b	41.60 ^b	20.65 ^a	2.63 ^a	3.63 (2.21) ^a	78.08 ^c	7.10 ^c
C.D at 5%	2.154	0.34	0.08	1.381	1.553	0.313	1.10	1.55	0.98	0.062	1.515	3.356
SED	1.077	0.17	0.04	0.690	0.776	0.156	0.55	0.775	0.49	0.031	0.757	1.678

*Indicates transformed values

Values in the same column with different letters are significantly different ($p < 0.05$)

generate a basic idea about mass of walnuts cracked and left out uncracked walnuts during cracking operation. Shelling coefficient and coefficient of cracking of power operated walnut cracker was significantly different than hand operated cracker and manual method of cracking in case of both Kaghazi as well as medium shelled walnuts whereas both shelling coefficients and coefficients of cracking of hand operated cracker and manual method of cracking were statistically at par in Kaghazi as well as in medium shelled walnuts (Tables 1, 2). Shelling coefficient value of 100 and coefficient of cracking (1) were recorded in manual method of cracking as well as in hand operated cracking method for both the walnut types which indicates 100 percent cracking in both the cracking methods. At the same time, higher shelling coefficients of 95% and 96.37% and cracking coefficients of 0.95 and 0.96 were recorded for power operated walnut cracker in case of medium shelled and Kaghazi walnuts, respectively (Tables 1, 2). A lower shelling coefficient of 73.3% has been reported by Singh (2003) for water chestnut decorticator.

Coefficient of wholeness of kernels was calculated to determine the mass of whole walnut kernels obtained in relation to total mass of walnuts subjected to cracking. Significant difference in wholeness coefficient was observed for all the three methods of cracking in case of both kaghazi and medium shelled walnuts (Tables 1, 2). The coefficient of wholeness for power operated cracker, hand operated cracker and manual cracking was recorded to be 0.84, 0.96 and 0.80 (Table 1) respectively in case of Kaghazi walnuts whereas, in case of medium shelled walnuts, the wholeness coefficients were recorded as 0.77, 0.94 and 0.72 for power operated cracker, hand operated cracker and manual cracking method respectively (Table 2). Highest coefficient of wholeness in both the walnut types was observed for hand operated walnut cracker (Tables 1, 2) followed by power operated cracker which indicates less kernel breakage during such methods of cracking. Thus, both the developed crackers enhanced the whole kernel recovery compared to existing manual method of cracking. Lower wholeness coefficient of 0.66 has been reported by Ghafari et al. (2011) for their developed walnut cracking machine.

Throughput capacity indicates the quantity of walnuts subjected to cracking per unit time, irrespective of whether all the walnuts have been cracked or not, whereas effective throughput capacity indicates the quantity of walnuts actually cracked per unit time. Both the parameters are important and have significance in performance evaluation of the machines. Throughput capacity and effective throughput capacity of power operated cracker, hand operated cracker and manual cracking method were significantly different than each other in Kaghazi as well as in medium shelled walnuts. The throughput capacity of power

operated cracker, hand operated cracker and manual cracking method were recorded as 15.46 kg/hr, 1.61 kg/hr/person and 3.42 kg/hr/person in case of Kaghazi walnuts (Table 1) and 14.07 kg/hr, 1.29 kg/hr/person and 3.21 kg/hr/person in case of medium shelled walnuts (Table 2), respectively. Both throughput capacity and effective throughput capacity were found similar in case of hand operated cracker and manual cracking method in Kaghazi as well as in medium shelled walnuts, whereas, effective throughput capacity of power operated cracker was recorded as 14.90 kg/hr (Table 1) in case of Kaghazi walnuts and 13.38 kg/hr (Table 2) in case of medium shelled walnuts. Data depicted in Tables 1 and 2 indicate that both capacity as well as effective throughput capacity were higher in case of Kaghazi walnuts than in medium shelled walnuts in all the three cracking methods. Due to less shell thickness, force requirement for cracking Kaghazi walnuts is less than the medium shelled walnuts which could be the reason behind higher throughput capacity and effective throughput of cracking in case of Kaghazi walnuts. Ghafari et al. (2011) reported higher throughput capacity of 25.2 kg/hr for power operated walnut cracking machine. Similar throughput capacity results have been reported by Ojolo et al. (2010) for cashew nut shelling machine. Azam and Judge (2004) reported much lesser throughput capacity of 0.875 kg/hr/person for manual shelling of nuts.

In walnut cracking, the kernel halve recovery is always desirable, even butterball, which is actually un-separated whole kernel, is separated into halves for marketing. The halved kernels are sold at premium prices in the market. It is therefore obvious that walnut industries want highest percentage of cracked walnuts to come out as halves. Butter ball (BB) + halve recovery was significantly different for all the three methods of walnut cracking in both Kaghazi and in medium shelled walnuts. The highest BB + halve recovery percentages of 90.34 (Table 1) and 84.19% (Table 2) were recorded in case of hand operated cracker for Kaghazi and medium shelled walnuts respectively. Comparable but statistically different BB + halve recovery percentages of 55.86% and 54.34% (Table 1) and 35.81% and 35.10% (Table 2) were recorded for power operated walnut cracker and manual method of walnut cracking in Kaghazi and medium shelled walnuts, respectively. In order to achieve the goal of maximum butter balls + kernel halve recovery, hand operated cracker was found most promising followed by power operated cracker which is also evident by high wholeness coefficient obtained for hand operated and power operated crackers in comparison to existing manual method of cracking. The least butter balls + halve recovery was recorded in case of existing manual cracking method due to excess kernel breakage resulting from non-uniform force applied in such method of cracking. The spring in between the handle of

hand operated cracker absorbs the excessive force, which prevents the kernel breakage during cracking. Therefore, there is possibility that hand operated cracker may prove to be a good option for small scale walnut processing industries due to maximum butter balls + kernel halve recovery and low throughput capacity. While as power operated cracker may be used in future by large scale walnut industries due to high throughput capacity. Overall butter balls + kernel halve recovery was maximum in case of Kaghazi walnuts followed by medium shelled walnuts in all the three methods of cracking. During soaking of walnuts prior to cracking, both shell and packing tissue of Kaghazi walnuts become soft easily due to less shell thickness, which could be the reason for maximum recovery of butter balls + kernel halves in Kaghazi walnuts than in medium shelled walnuts. Irrespective of walnut type, the results of BB + kernel halve recovery were found very well in correlation with the results of coefficient of wholeness in all the three methods of cracking. Results in close resemblance with our findings have been reported by Ogunsina et al. (2014) and Okoko et al. (2017) for cashew and palm kernel nut shelling, respectively.

The results of big broken kernel percentage, small broken kernel percentage and fine percentage obtained in Kaghazi and medium shelled walnuts during different cracking methods are presented in Tables 1 and 2, respectively. Significant difference in big broken kernel percentage, small broken kernel percentage and fine percentage was observed for all the three cracking methods in both the walnut types. In case of Kaghazi walnuts, the highest big broken kernel percentage was recorded in manual cracking (36.23%) followed by power operated cracking method (19.53%) and hand operated cracking method (2.41%), whereas small broken kernel percentage was highest when cracking was done by power operated cracker (10.15%), followed by manual cracking (7.25%) and hand operated cracking method (4.48%) (Table 1). In case of medium shelled walnuts, the highest big broken kernel percentage was recorded when cracking was done by power operated cracker (41.6%), followed by manual cracking (39.52%) and hand operated cracking method (0.8%), whereas highest small broken kernel percentage was recorded in manual cracking (22.02%), followed by power operated cracking method (20.65%) and hand operated cracking method (10.22%) (Table 2). From the results, it can be deduced that in both types of walnuts, lowest broken kernel percentages (both big broken and small broken) were obtained when cracking was done by hand operated cracker which validate its high coefficient of wholeness and BB + halve recovery than other two methods of cracking. Higher broken kernel percentages than what has been recorded in the present study has been

reported by Ghafari et al. (2011) in walnut cracking and Olalusi and Bolaji (2011) in Bush mango nut sheller.

Regarding fine percentage, in case of Kaghazi walnuts, highest fine percentage (14.45%) was observed when cracking was done by power operated cracker, followed by hand operated cracker (2.75%) and manual cracking (2.17%), whereas fine percentage in case of medium shelled walnuts was recorded highest in hand operated cracking method (4.81%), followed by power operated cracking method (2.63%) and manual cracking (1.06%). Overall Kaghazi walnuts are thin shelled and brittle in contrast to medium shelled walnuts, so are prone to more kernel damage.

Irrespective of walnut types, no walnut was left uncracked during manual cracking and hand operated cracking methods, which is evident by 100% shelling coefficient of such methods. However, when walnut cracking was done by power operated cracker, the uncracked walnut percentage was recorded as 4.91% (Table 1) in case of Kaghazi walnuts and 3.63% in case of medium shelled walnuts (Table 2). Ojolo et al. (2015) and Oyebanji et al. (2012) reported higher percentage of uncracked nuts for variable size nut cracker and palm nut cracker machines respectively. Higher unbroken walnut percentage than the present study was reported by Ghafari et al. (2011) in mechanical walnut cracking.

Cracking efficiency indicates mass of cracked nuts to the total mass of walnuts fed for cracking. In both Kaghazi and medium shelled walnuts, cracking efficiency was significantly different in all the three methods of cracking (Tables 1, 2). In case of Kaghazi walnuts, highest cracking efficiency of 95.8% was recorded for hand operated cracker, followed by manual cracking (80.62%) and power operated cracker (79.8%) (Table 1). However, in case of medium shelled walnuts, highest cracking efficiency of 93.91% was obtained for hand operated cracker followed by power operated cracker (78.08%) and manual cracking (72.43%) (Table 2). Tables 1 and 2 also reveal that cracking efficiency was higher in kaghazi walnuts than medium shelled walnuts for all the three cracking methods. Due to more shell thickness, force required for cracking medium shelled walnuts is more than the Kaghazi (thin shelled) walnuts, which was the possible reason for higher cracking efficiency of power operated walnut cracker for medium shelled walnuts than manual cracking. The same justification holds for higher cracking efficiencies of all the cracking methods for Kaghazi walnuts than medium shelled walnuts. Almost similar cracking efficiency results have been reported by Ojolo et al. (2010) and Ajewole (2014) for cashew nut shelling machine and palm kernel nut cracking machine respectively. However, a lower cracking efficiency than the present study has been

reported in case of almond kernel extraction machine by Marey et al. (2017).

Labor requirement in terms of man-hour needed for cracking one quintal of walnuts was calculated from effective throughput capacity. There was a significant difference in labour requirement in all the three methods of cracking, for both Kaghazi and medium shelled walnuts. For Kaghazi as well as medium shelled walnuts, the highest labour requirement was recorded in hand operated cracking method, followed by manual cracking. The least labour requirement was observed when cracking was done by power operated cracker in both walnut types. High throughput capacity corresponds to low labour requirement. Therefore, due to low throughput capacity, the labour involvement for cracking medium shelled walnuts was higher than Kaghazi walnuts in each of the cracking method.

Economic analysis of the developed crackers

The analysis of various economic parameters i.e., cost of cracking, benefit–cost–ratio, break-even point and pay-back period revealed that all the economic parameters can be optimally achieved if developed crackers are adopted for walnut cracking.

Benefit cost (B/C) ratio is an economic analysis parameter used to compare the benefit and cost of the machine in order to make a decision regarding its adoption. A B/C ratio greater than 1 implies that an investment in a particular machine is theoretically beneficial. B/C ratio of 1.12 was obtained for power operated cracker and 1.79 for hand operated cracker which indicates that developed crackers are highly beneficial and economical.

Break even point (BEP), a point of zero economic profit quantifies the level of production at which total revenue generated equals the total costs. Once the production exceeds the breakeven point, the use of particular machine can generate gross profit or net gain. Breakeven point was estimated to be 8601 kgs for power operated cracker and 9.6 kgs for hand operated cracker. Based on BEP, the inference drawn was that for commercial purposes, the small-scale walnut processing units can successfully use hand operated cracker, and small to medium scale walnut processing units can use power operated walnut cracker for cracking of walnuts.

In order to estimate the time required to recover the incurred investment in a particular machine, payback period was determined. Less pay back periods of 645.16 h (3.10 months) and 5.54 h recorded for power operated cracker and hand operated crackers, respectively, indicate that developed crackers can be used successfully for commercial purposes.

Hence, it was concluded from economic analysis that both hand operated and power operated crackers are economically viable and suitable for small and medium scale walnut processing industries.

Conclusion

A hand operated walnut cracker and a power driven walnut cracker was designed and developed with an aim to overcome the constraints associated with the existing manual cracking of walnuts, and to increase the kernel halve recovery. The crackers were tested for Kaghazi (thin shelled) and medium shelled walnuts. The effective throughput capacity was recorded highest and labour requirement as least when walnuts were cracked by power operated cracker in both the walnut types. However, in both the walnut types, highest cracking efficiency and Butter balls + halve recovery were recorded when walnuts were cracked by hand operated cracker. Overall, the economic analysis and performance evaluation results revealed that both the developed crackers are highly beneficial and economical. Hand operated cracker can be useful to small scale walnut processing industries, whereas power operated walnut cracker can be useful for small scale to medium scale walnut processing industries.

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