Design, development and evaluation of walnut cracking machine

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Abstract: The traditional method of cracking walnut using hammer or stone is laborious, time consuming, and cumbersome with huge wastage. A prototype of walnut cracking machine was developed and evaluated under three different levels of shell moisture content (db) (25%-30%,15%-20% and 8%-12%) and three different levels of roller speeds (25, 43 and 69 rpm) of the cracking unit. The machine consists of motor, frame, hopper, conveying tray, cracking unit, conveying chute and collecting bin. The main working principle of cracking unit is based on the compression of the walnut between two rollers rotating in opposite direction. The rupture force was minimum (90.16 N) along Z-axis (suture line) at 8%-12% (d.b) shell moisture content and maximum (200.90 N) along X-axis and at shell moisture content of 25%-30% (d.b). The effective throughput capacity significantly increased with rotational speed of the rollers. The cracking efficiency was found highest (82.1%) at 43 rpm and 15%-20% shell moisture content, while it was lowest (70.9%) at 63 rpm and 8%-12% (d.b) shell moisture content. The kernel damage increased linearly with the rotational speed of roller and found highest (21.8%) at 69 rpm and 8%-12% (d.b) shell moisture content, while it was lowest (11.7%) at 25 rpm and 15%-20% (d.b) shell moisture content. At standardized speed of operation (43 rpm) and shell moisture content (15%-20%), the throughput capacity of the machine was recorded as 56.1 kg h^{-1} with cracking efficiency of 82.1% and kernel damage of 13.8%. While throughput capacity observed with traditional method was 2.5 kg h^{-1} with cracking efficiency of 85.9%, and kernel damage of 8%-9%. About 437 man h t^{-1} labour requirements could be saved with the use of developed machine over traditional method of walnut cracking. So, the walnut cracking machine is very useful and innovative for marginal and small farmers of the regions.

Keywords: Walnut cracker, kernel damage, shell moisture, throughput capacity, cracking efficiency, rupture force

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1 Introduction

Walnut (*Juglans regia* L.) is one of the most important temperate nut grown all over the world. India is ranked seventh in the world with annual production of 229000 MT during 2015-16 (Anon., 2017). The country has exported 2,191.19 MT of Walnuts to the world for worth of Rs. 55.27 crores during the year 2016-17 (Anon., 2017). About 89.7% of total walnut production in India is from Jammu and Kashmir State alone; having an area of 88,900 hectares with an annual production of 213860 MT (Anon., 2017). The most important post-harvest operation in walnut is separation of kernel from the shell. This process is still carried out manually in India particularly in Jammu and Kashmir, which results in increased cost and

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processing time for kernel extraction. The market value of the walnut is determined on the basis of its quality i.e. colour, quality of shell and kernel which is considerably influenced by harvest and post-harvest practices adopted. The price of kernels is determined on the basis of whole kernels/broken kernel. Manual walnut cracking requires a lot of skill and patience for safe recovery of nuts from the shell which is too slow and risky. The average capacity of walnut cracking manually has been reported as 14-18 kg/day, depending upon the efficiency and the skill of the worker (Khan et al., 2009).

Broken kernel fetches lower prices than whole ones. Since the walnut cracking is the most critical operation for getting high quality kernels, so efficient methods and devices used to crack walnut shell are urgent to be designed and developed based on the physical characteristics and mechanical properties of walnut. Physic-mechanical properties of the agricultural products is of fundamental importance for the proper storage and for design, manufacturing and operating different equipments used in post harvest operations (Correa et al., 2007; Guzel et al., 1999). In recent years, physic-mechanical properties have been studied for various nut crops such as hazelnuts (Aydin, 2002; Guner, 2003), areca nut kernel (Kaleemmullah and Gunasekar, 2002), almond nut kernel (Aydin, 2003), shea nut (Olaniyan and Oje, 2002) and walnut (Ghafari et al., 2011).

Xavier (1992) reported that size, shape, shell thickness and texture were the most important parameters affecting the kernel extraction quality in macadamia nuts. Ghafari et al. (2011) designed and constructed a prototype of walnut cracking machine based on principle of attrition using crushing force from a cylinder and helix. The capacity of the machine was reported as 25.2 kg h^{-1} with 66.66% of whole kernels. Although, some walnut cracking machine have been developed in Iran and China, however, the intact kernel recovery was only 20 percent (Borghei et al., 2000) and they have not been able to replace the conventional methods. But in India, cracking walnut manually using hammer is still prevalent even at walnut processing industries.

Keeping these factors in view, the present study was undertaken to examine physical and mechanical properties of Kashmir walnut and development of walnut cracking machine.

2 Material and methods

2.1 Design considerations

Keeping in view the functional requirements and design considerations of prototype, a conceptual design of machine was prepared using AUTOCAD software-2016 (Fig. 1). During the development of walnut cracker, a number of points such as high cracking capacity, minimal kernel damage, low cost of construction, timeliness of operation, labor requirement, simplicity in design, availability of locally available materials, choice of materials and overall weight were considered.

2.2 Physico mechanical characteristics

The shape of Kashmiri walnut was found to be spherical with three major perpendicular dimensions, Length (L), width (W) and thickness (T). Three categories of walnut (Soft, medium and hard shelled walnut) was taken for the study. The categorization of walnut was done based on kernel-shell ratio. The randomly selected sample of walnut from each categories was broken one by one, using a hammer, and divided into the kernel and shell components. The shells and kernels were weighed to determine the kernel -shell ratio. The kernel-shell ratio was 60:40, 50:50 and 40:60 in case of soft shelled, medium shelled and hard shelled walnut, respectively. The physical dimensions were determined randomly measuring the length, width and thickness of each category using MITUTOYO digimatic calipers to an accuracy of 0.01 mm. To obtain the unit mass, each nut was weighed with an electronic balance (Make: Mettler Toledo, capacity: 1520 g, accuracy of 0.01 g). From the average axial dimensions, the geometric mean diameter (D_g) was calculated using Equation 1 (Mohsenin, 1986; Joshi et al., 2002):

$$Dg = \sqrt[3]{LWT} \qquad (1)$$

Where: Dg is the Geometric diametr (mm), L is the Length is the dimensions along the longest axis (mm),W is the Width is the dimension along the longest axis perpendicular to L (mm), T is the Thickness dimension along the longest axis perpendicular to both L and W (mm).

The spherecity (ϕ) was calculated using Equation 2 (Mohsenin, 1986):

$$\phi = \frac{Dg}{L} \times 100 \qquad (2)$$

The volume of un-shelled walnut was determined by using toluene displacement method. A sample of individual walnut was immersed in container filled with toluene provided with tap at top. The displaced toluene comes out through the tap which was collected in cylindrical breaker of 50ml. The same procedure was repeated for 3 times and their mean value was determined. The angle of repose was determined using a specially constructed topless and bottomless hopper made, with a removable front panel (Olaoye, 2000). The hopper was filled with walnuts placed on the box, the front panel was quickly removed allowing the walnuts to slide down and assume natural slope. This value used in the design of agricultural machine hopper and other conveying equipment. The angle of repose was calculated from the measurements of the height (*h*) of the free surface of the walnuts and the length (*l*) of the heap formed outside the box using Equation 3 (Bamgboye and Adejumo, 2009):

$$\theta = \tan^{-1}\left(\frac{h}{l}\right) \qquad (3)$$

Where: θ is the Angle of repose (degrees), h is the height of the free surface of the walnuts (cm), *l* is the length of the heap formed outside the box (cm).

Mechanical properties of walnut were expressed in terms of rupture force required for breaking of walnut shell. A mechanical set up was developed in the engineering workshop for measurement of rupture force (force required for cracking walnut). This device has three main components which are a fixed base plate and a moving parallel plate, a driving unit, and the data acquisition system composed of a spring balance of accuracy 0.1 g. The base plate was attached with head stock of lathe machine while moving parallel plate was connected with tool carriage of lathe. The walnut was placed on the base plate and pressed by the moving parallel plate until the shell ruptured. The rupture force along x- axis, y-axis and z-axis were measured for different categories of walnut. Three replicates were made for each test. The mechanical behavior of walnut was expressed in terms of rupture force. The X-axis is the longitudinal axis through the hilum (length position), the Y-axis (width position) and the Z-axis is in the plane containing the suture line (Braga et al., 1999).

2.3 Description of machine parts

The developed prototype consists of a frame, hopper fitted with flow rate control device, a cracking unit, conveying tray, collecting bin and power system. The prototype operates on the principle of compression of the walnut between two rollers rotating in opposite direction. The clearance between the two rollers rotating in opposite direction accommodates the raw materials and by the compressive forces, the walnut shell is broken. The clearance surface is adjusted according to the size of the walnuts to be broken. The brief specifications of the developed machine are given in Table 1.

2.3.1 Frame

The frame consisted of four 900 mm long vertical mild steel angle iron bars 40×40×5 mm to support the weight of the various system of the prototype and provide strength to avoid the toppling or excessive vibration of the prototype. The four vertical angle iron bars of length 970 mm were supported by the eight horizontal angle iron bars; two of which are welded at bottom and six at top. The shape of the frame is rectangular having the overall dimension 971 mm × 720 mm × 530 mm.

2.3.2 Hopper

The hopper, which is trapezoidal shaped, is mounted on the stand and held in place by a hopper support frame. It is connected to the cracking unit by the nut feed flow channel inclined from the hopper base to the top of the cracking unit at the nut's angle of repose. The hopper of length 325mm, top width 310mm, bottom width 150 mm and height 300mm was fabricated for holding the walnuts during the operation of the machine. The volume of hopper was $0.021m^3$ having capacity to hold 7 kg of walnut. The hopper was constructed from 16 gauge mild steel sheet considering easy availability and low cost. A nut flow rate control device is fitted between the hopper and the cracking unit to regulate the feed rate.

2.3.3 Cracking unit

The cracking unit is the most important component of the machine which is based on the principle of application of compressive force. It consists of two plastic rollers which are grooved along circumference. The size of the groove was taken as 25.4 mm along the peripheral length of the roller that whole walnut can accommodate in the groove. The clearance between the rollers is adjustable in order to accommodate nuts of varying sizes. Both the cracking rollers run at different speed and n opposite direction for effective cracking. The rollers having 150 mm diameter and 300 mm length and are supported on the two cylindrical shafts that provide rotation to the rollers. The shafts are supported by ball bearings at both ends. Each shaft consists of a pulley at one side for power transmission.

2.3.4 Power system

The power for the machine was obtained from 0.75 kW single phase, 1400 rpm AC electric motor. The power from the motor to the main cracking unit is transmitted through belt and pulley drive and speed reduction gear drive. The transmission system was designed in order to obtain appropriate rpm of rollers. A 55 mm diameter pulley is fixed on the motor and was connected to the pulley of diameter 125 mm, on the main shaft through v-belt. Two worm gears are fixed on the main shaft having diametrical pitch corresponding to the receptivity spur gears. These worm gears are meshed with two spur gears having 20 teeth each. The two shafts of spur gears have two pulleys, one each attached to them. The two pulleys have same rpm as spur gears and are having diameter 75 mm and 103 mm. The pulley having diameter of 75 mm is connected to another pulley of sane diameter which is in turn mounted on the shaft of rollers. The pulley having diameter 103mm is connected through belt of size 49A to the pulley having diameter 65mm which is also mounted on the shaft of another roller. The size of the pulley is kept different in order to achieve different rpm of the rollers which helps in producing of shearing force on the feed.

2.3.5 Conveying tray

The conveying system is attached to the hopper. Its purpose is to convey unshelled walnut from the hopper to the cracking unit. The quantity of walnut entering into the cracking unit per unit time can be regulated and varying feed rates achieved. The conveying tray consists of corrugated sheet having six corrugations in order to convey the walnut directly to the grooves of rollers of cracking unit. The tray is made up of 16 gauge sheet. The size (L × B × H) of conveying unit was 225 mm × 330 mm × 57.5 mm.

2.3.6 Conveying chute

It is designed to collect the cracked walnut from the cracking unit. The conveying chute is made up of 16 gauge MS sheet with size (L × B × H) as 590 mm × 440 mm × 98.5 mm. An inclination of 24^o with horizontal has been provided in order to facilitate the discharge of cracked walnuts.

2.3.7 Collecting bin

A collecting bin of rectangular shape with size of 465 mm × 240 mm × 75 mm.is made from mild sheet of 14 gauge. The purpose of collecting bin is the collect the final product. After fabrication of each component the machine was assembled.

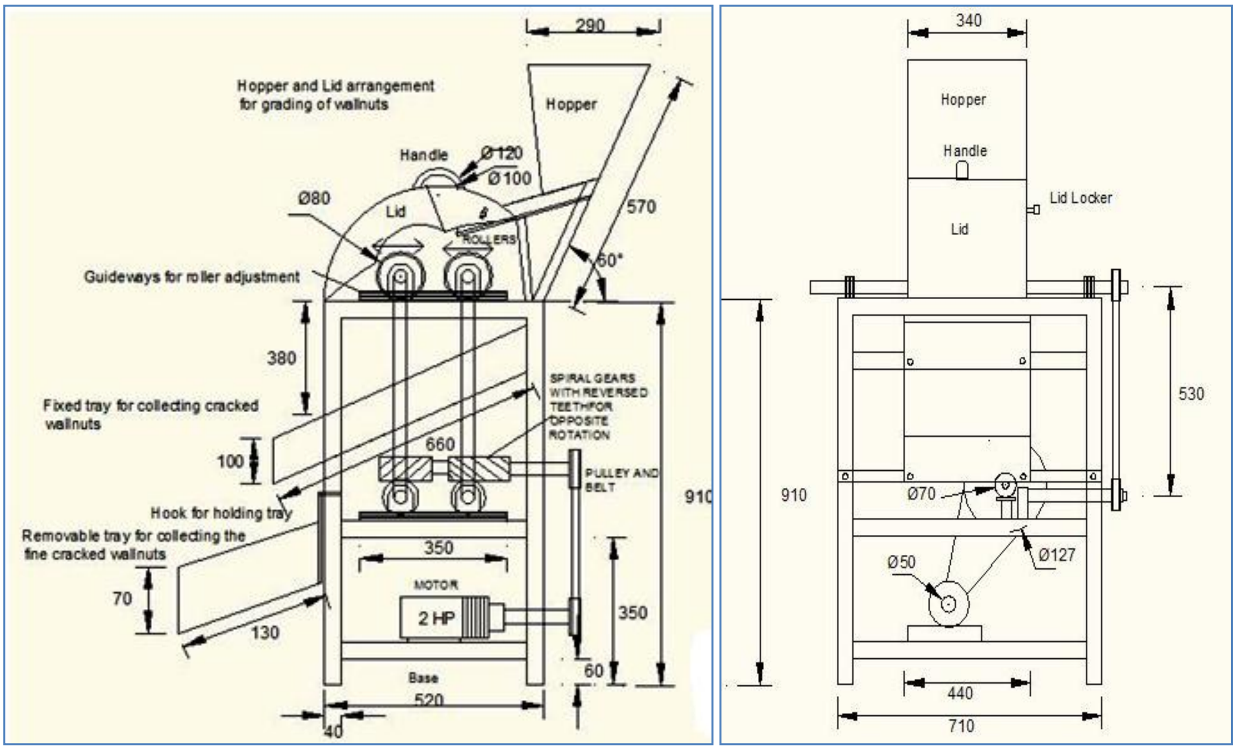

Figure 1 Schematic of a complete assembly of the walnut cracker

Note: All dimensions in mm, if otherwise specified.

Table 1 Specifications of walnut cracker

S. No.	Parameters	Specification
	Overall dimensions (L × B × H), mm	970 × 60 × 530
	Power source	0.75 kW single phase electric motor Rated rpm: 1400
	Frame (L × B × H), mm	971 × 720 × 530, rectangular shape
	Hopper (mm)	Trapezoidal shape, 324 × (309, 145) × 300
	Conveying tray (L × B × H), mm	225 × 330 × 57.5
	Cracking unit	2 plastic rollers, groove size 24.5mm, Size of roller (dia × length): 150 × 300
	Conveying chute, (L × B ×H), mm	590 × 440 × 98.5
	Collecting bin (L × B × H), mm	465 × 240 × 75
	Total weight of machine	117 kg
	Discharge unit	Collecting tray type
	Drive mechanism	Belt, pulley and gear drive

2.4 Evaluation of cracker

The machine was evaluated (Figure 2) for three levels of shell moisture content (8%-12%, 15%-20% and 25%-30% on dry basis) and three levels of speed of cracking unit (25, 43, 69 rpm). The de-hulled walnut of three categories i.e. soft shelled, medium shelled and hard shelled walnut that are cultivated in the Srinagar of India were used for evaluation. The performance was evaluated in terms of throughput capacity, cracking efficiency and percentage of kernel damage using Equations 4 and 5.

$$\text{Throughput capacity} = \frac{\text{total mass of walnut sample before cracking (kg)}}{\text{Time used in cracking (h)}} \tag{4}$$

$$\text{Cracking efficiency} = \frac{\text{Mass of cracked walnut + weight of shell} - \text{weight of damaged walnut}}{\text{mass of walnut sample fed to machine}} \tag{5}$$

2.5 Data Analysis

The randomised complete block design (two factorials) was followed in the study. The experimental data was analyzed statistically using

'Opstat-1998' software. While standardization, goal for independent parameters was to keep them in range while among responses, the goal for throughput capacity and cracking efficiency was to maximize them and for kernel damage was to minimize. The standardized data (at 15%-20% shell moisture content and 43 rpm roller speed) of developed machine was computed and compared with traditional method of walnut cracking (beating with hammer/stone).

Figure 2 Evaluation of developed walnut cracker

3 Results and discussion

3.1 Physical properties

Physical characteristics of walnut for three categories (soft shelled, medium shelled and hard shelled) of walnuts are reported in Table 2. The mean of length, width and thickness for different categories were 37.3, 28.7 and 33.3 mm, respectively. Sphericity coefficient for soft shelled, medium shelled and hard shelled walnut were 0.850, 0.845 and 0.857, respectively. The geometric mean diameter of different categories of walnut was observed as 32.95 mm. The mean angle of repose was measured as 52.66°. All the physical properties were lowest in medium shelled walnuts which were due to genetic characters.

3.2 Shell Rupture Force

The rupture force required to break walnut shell was dependent on the shell moisture content and orientation of axis for compression. Shell rupture force significantly increased as moisture content increased for compression along all axes of orientation (Table 3). The lower rupture forces at lesser moisture contents might have resulted from the fact that the nut tended to be soft at low moisture content (Figure 3). Statistical analysis showed a significant difference between the forces along the X, Y, and Z-axis. In terms of rupture force required to rupture shell, the walnut shell have a higher strength when compressed along the X-axis (length position). Compression of walnut at the suture line (Z-axis) presented the least resistance to shell rupture. Previous works have shown that rupture force decreased with increase in moisture content in case of hazelnut and cashew nut (Braga et al., 1999; Guner et al., 1999; Gezer et al., 2002 and Aydin, 2002). The highest mean rupture force (155.82 N) was recorded when the load was applied in the X-axis (length position) while lowest rupture force (138.18 N) was observed along the Z-axis. Sharifian and Derafshi (2008) also reported similar results. Dursun (1997) found minimum walnut rupture force in suture line (z-axis) but the maximum walnut rupture force occurred along width position.

3.3 Effect of roller speed and moisture content on machine performance

3.3.1 Throughput Capacity

The throughput capacity of the cracker was greatly affected by the speed of the roller and moisture content of the walnut shell. The throughput capacity significantly increased with rotational speed of the rollers (Table 4). The mean throughput capacity was found highest (58.3 kg h^{-1}) at 69 rpm and 15%-20% shell moisture content. The lowest throughput capacity (52.2 kg h^{-1}) was found at 25 rpm and 25%-30% shell moisture content. The maximum throughput capacity was found at 15%-20% shell moisture content irrespective of speed of rotation, while the lowest throughput capacity was recorded at 25%-30% shell moisture content. Statistically, there was significant difference between shell moisture content, speed of rotation and the throughput capacity at 5% level of significance. The higher the throughput capacity, the higher the kernel damage.

Table 2 Physical properties of different categories of walnut

Parameters	Category of walnut			Mean
	Soft shelled	Medium shelled	Hard shelled	
Size (L ×W×T) (mm)	37.2 ×28.6×33.1	35.8 ×27.3×31.5	39.1×30.4×35.3	37.3 ×28.7×33.3
Volume (cm^3)	14.6	13.8	15.1	14.5
Mass (g)	12.1	11.7	13.2	12.3
Geometric mean diameter (mm)	32.77	31.34	34.74	32.95
Sphericity	0.850	0.845	0.857	0.850
Angle of repose (degree)	48	53	58	52.66

Table 3 Effect of shell moisture content and orientation of axis on rupture force

Shell moisture content (A)	Rupture force (N)		
	Orientation of axis (B)		
	X-axis	Y-axis	Z-axis
Soft shelled walnut			
25%-30%	173.46	149.94	140.14
15%-20%	128.38	140.14	119.56
8%-12%	111.72	102.9	90.16
Average	137.2	130.34	116.62
C.D ($p \geq 0.05$)	Factor A=11.093	Factor B= 11.093	Factor (A ×B)=NS
Medium shelled walnut			
25%-30%	177.38	168.56	159.74
15%-20%	168.56	159.74	148.96
8%-12%	118.58	129.36	106.82
Average	154.84	151.9	138.18
C.D ($p \geq 0.05$)	Factor A=10.221	Factor B= 10.221	Factor (A ×B)=NS
Hard shelled walnut			
25%-30%	200.9	191.1	180.32
15%-20%	177.38	159.74	168.56
8%-12%	148.96	138.18	131.32
Average	175.42	162.68	159.74
C.D ($p \geq 0.05$)	Factor A=10.642	Factor B=10.642	Factor (A ×B)=NS
Mean Rupture force (N)	155.82	147.98	138.18

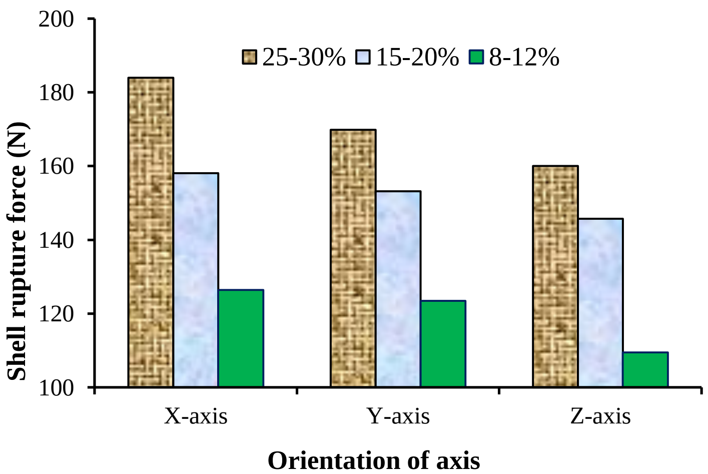

Figure 3 Effect of orientation of axis and shell moisture content on rupture force

Table 4 Effect of shell moisture content and rotational speed of roller on throughput capacity

Shell moisture content (A)	Throughput capacity (kg/h)		
	Speed of operation (B)		
	25 rpm	43 rpm	pm
Soft shelled walnut			
25%-30%	52.4	55.8	56.3
15%-20%	53.5	56.2	58.3
8%-12%	54.2	57.1	57.9
Average	53.3	56.3	57.5
C.D ($p \geq 0.05$)	Factor A=1.021	Factor B=1.021	Factor (A × B)=NS
Medium shelled walnut			
25%-30%	52.2	55.3	56.8
15%-20%	54.8	56.1	58.1
8%-12%	53.7	55.9	57.5
Average	53.5	55.7	57.4
C.D ($p \geq 0.05$)	Factor A=1.040	Factor B=1.040	Factor (A × B)=NS
Hard shelled walnut			
25%-30%	52.8	55.3	56.2
15%-20%	53.8	57.6	58.8
8%-12%	54.7	56.4	57.6
Average	53.7	56.4	57.5
C.D ($p \geq 0.05$)	Factor A=1.116	Factor B=1.116	Factor (A × B)=NS

3.3.2 Cracking efficiency

It can be seen that there is a dependence on the shell moisture content and speed of the roller (Figure 4). The cracking efficiency was found highest (82.1%) at 43 rpm and 15%-20% shell moisture content, while it was lowest (70.9%) at 63 rpm and 8%-12% shell moisture content. At lower speed, walnut passed through groove of roller without breaking and also needed long time. While at higher rotational speed, the percentage of damaged walnuts kernel and un-cracked walnut were higher and because of sudden stress on walnut, kernels were crushed and broke. With the increased shell moisture content of walnut, amount of un-broken kernel decreased, but amount of uncracked walnut increased. Because of that medium shell moisture content (15%-20%) facilitated better kernel recovery and walnut from its suture line was broken.

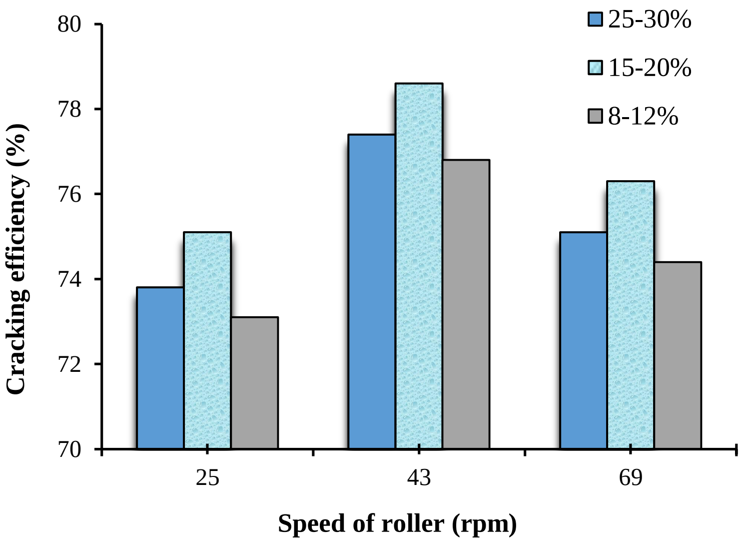

Figure 4 Effect of shell moisture content and speed of roller on cracking efficiency

3.3.3 Kernel damage

The kernel damage increased linearly with the speed of roller. The kernel damage was found highest (21.8%) at 69 rpm and 8%-12% shell moisture content, while it was lowest (11.7%) at 25 rpm and 15%-20% shell moisture content (Figure 5). Increasing speed of the cracking roller results in an increase in kernel damage. Higher the speed, the higher the kernel breakage ratio due to increase in impact velocity which also increases the impact energy. The breakage of kernel is a result of absorption of excess energy generated by the system. The breakage of kernel was lowest at medium moisture contents (15-20%). For the optimum performance of the cracker, the efficiency should be the function of cracking speed and shell moisture content.

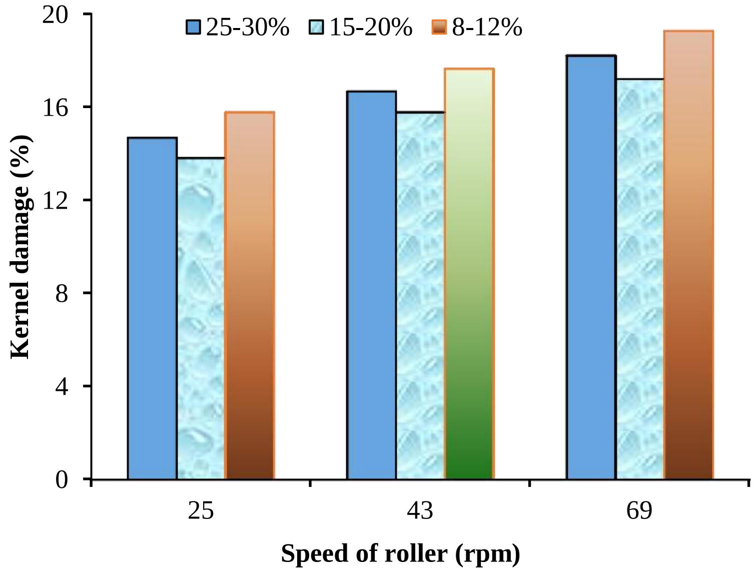

Figure 5 Effect of shell moisture content and speed of roller on kernel damage

3.4 Standardization of shell moisture content and speed of operation

The shell moisture content and speed of operation were standardized keeping in view of higher cracking efficiency, low kernel damage and higher throughput capacity. The cracking efficiency was highest at 43 rpm and 15%-20% shell moisture content while the throughput capacity was highest at 69 rpm and 15%-20% shell moisture content. The kernel damage was lowest at lower speed (25 rpm) and 15%-20% shell moisture content. Hence, taking into consideration, the maximum cracking efficiency, minimal kernel damage and higher throughput capacity, the speed of operation was recommended as 43 rpm and the shell moisture content as 15%-20% as standardized operating parameters for the efficient operation of developed walnut cracker. The standardized data (at 15-20% shell moisture content and 43 rpm roller speed) of developed machine was computed and compared with traditional method of walnut cracking (Table 5).

Table 5 Comparison between the mechanical and manual (conventional) walnut cracking

Parameters	Developed walnut cracker	Manual cracking
Throughput capacity(kg h^{-1})	56.1	2.5
Cracking efficiency (%)	82.1	85.9
Percentage of kernel damage (%)	13.8	8-9
Labour requirement(man-h/t)	17.8	454.5

4 Conclusions

A walnut cracking machine with overall weight of 117 kg was developed and evaluated with different levels of shell moisture content and roller speed. The shell moisture content and roller speed had significant effect on throughput capacity, cracking efficiency and kernel damage. With increasing roller speed, the throughput capacity of the machine increased but kernel damage also increased. Similarly with increasing shell moisture content, both cracking efficiency and throughput capacity decreased. At standardized shell moisture content of 15%-20% and roller speed of 43 rpm, the throughput capacity of the developed walnut cracking machine was 56.1 kg h^{-1} with cracking efficiency of 82.1% and kernel damage of 13.8%. The labour requirement for cracking of walnut with the developed machine was 17.8 man h t^{-1} as compared to 454.5 man h t^{-1} with traditional method of walnut cracking. The cost of the machine was worked out to be Rs. 15000. By use of this machine, the farmers will be relieved with arduous job of walnut cracking.

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