Design of rotary disc type garlic clove peeling machine

S. N. Singh[1*], S. K. Vekariya[1], P. S. Pandit[2], F.M. Sahu[2], R. G. Burbade[1]

(1. Department of Processing and Food Engineering, College of Agricultural Engineering ;
2. Center of Excellence on Post Harvest Technology, ACHF, Navsari Agricultural University, Navsari)

Abstract: Garlic peeling is a tedious, laborious and time consuming process and creates some health issues like irritation in fingers and nail breakings in the kitchen. Knowledge of engineering properties of garlic bulb and garlic clove is very important for development of machinery. Hence, study was conducted to determine engineering properties of garlic (GG-4) relevant to development of garlic peeler. Some engineering properties were measured for garlic bulb and garlic clove at 41.69% moisture content wet basis. On the basis of above problems and engineering properties of garlic the rotary disc type garlic clove peeling machine were designed and evaluated. The performance of the rotary disc type garlic peeler with the recommended specifications was evaluated. The peeling efficiency of rotary disc type garlic peeler was found 89.43%. The total cost of peeling machine was found to be $ 137.

Keywords: engineering properties, garlic peeler, peeling efficiency, design and develop, garlic clove, peeling time, peeling machine cost

Citation: Singh, S. N., S. K. Vekariya, P. S. Pandit, F.M. Sahu, and R. G. Burbade. 2022. Design of rotary disc type garlic clove peeling machine. Agricultural Engineering International:CIGR Journal, 24 (1):228-238.

1 Introduction

Garlic (*Allium Sativum* L.), belongs to the Liliaceae family, one of the important bulb crops grown and used as a spice or condiment throughout world. India is the second largest producer of garlic in the world with 2916.97 metric tonnes production from area 362.95 thousand hactare in the year 2020. The major garlic producing states in India are Rajasthan, Madhya Pradesh, Uttar Pradesh, Gujarat and Punjab followed (Horticultural Statistics at a Glance, 2018). The study revealed that the area and production of garlic is increasing in most of the states. The physical and mechanical properties such as size, friction angle, angle of repose, crushing strength and bulk density are important in the design of the handling system and grading (Chandrasekar and Viswanathan, 1999; Bahnasawy, 2007). Abd-Alla et al., (1995) reported that the shape index and coefficient of contact surface had a highly significant effect on the rupture force and broken percentage in milling process.

Garlic processing involves bulb breaking, peeling, dehydration, grinding and other unit operations. Garlic peeling is one of the most important and essential key unit operations prior to any subsequent processing activity. During garlic peeling, the thin membranous skin, inedible part is to be removed off from the segments. Traditional peeling methods, including hand peeling, flame peeling, oven peeling and chemical peeling (Dhananjay et al., 2015; Rajesh et al., 2018). A batch type abrasive mechanical peeler consisting of an upright cylinder, provided on the undulating movement. The inner and the upper surface of the disk are coated with abrasive carborundum (Cruess, 1958). Peeling efficiency

Received date: 2020-11-18 **Accepted date:** 2021-06-25

***Corresponding author:** **S. N. Singh,** M. Tech, Assistant Professor and Head, Department of Processing and Food Engineering, College of Agricultural Engineering and Technology, NAU, Dediapada-393 040, Gujarat, India. Email:snsingh@nau.in. Tel: 02649-235200, Fax: 02649-235200.

of low cost garlic clove peeler was 97%-98% (Mudgal and Chapawat 2008).

Very little work has been done on the garlic peeling and it is restricted to traditional peeling method only. Traditional peeling method, hand peeling, flame peeling, oven peeling, and chemical peeling are being used in processing industries, big restaurants, hotels and kitchens. These are laborious, time consuming, cost intensive and restrict speed of processing activity (Kaur et al., 2019). The manual method of garlic peeling involved higher labour cost, time consuming etc. It also creates some health issues like irritation in fingers, blisters in hands and nail breakings in the kitchen. To overcome these problems and cater the needs of garlic peeling in an easier manner, the rotary disc type garlic peeler was designed and evaluated.

2 Material and methods

2.1 Determination of various engineering properties of garlic bulb and garlic clove

The variety GG-4 which was developed by Junagadh Agricultural University was used for the experiment as this was identified as a suitable variety generally available in local market of Narmada District. The fresh, well matured and cured garlic bulbs were procured from the farm of CAET, NAU, Dediapada, Gujarat, India. The procured materials were packed in a bag and kept in storage until use. Engineering properties of garlic relevant to the development of garlic peeler were identified and determined. All the engineering properties were measured for garlic bulb and garlic clove at 41.69% moisture content wet basis.

2.1.1 Length, width and thickness of garlic bulb and clove

A random sample of 100 garlic bulbs and garlic cloves were selected and measured as specified by length, width and thickness at the three mutually perpendicular axes by vernier caliper to an accuracy of 0.01 mm (Haciseferogullari et al., 2005).

2.1.2 Geometric mean diameter and sphericity of garlic bulb and clove

The geometric mean diameter (D) of the garlic bulb and clove were calculated by using the following formula (Mohsenin, 1986; Bahnasawy, 2007).

$$D = (w \times l \times t)^{1/3} \quad (1)$$

Where,

D = Geometric mean diameter (mm)

w = Equatorial diameter or width (mm)

l = Polar diameter or length (mm)

t = Thickness (mm)

The sphericity of the garlic bulb and garlic clove was calculated using the following formulae (Mohsenin, 1986; Abalone et al., 2004).

$$S = \frac{(l \times w \times t)^{1/3}}{l} \quad (2)$$

Where,

S = Sphericity

2.1.3 Shape index

Shape index is used to evaluate the shape of the garlic bulbs and cloves. It was calculated according to the following Equation 3 (Abd-Alla, 1993):

$$Shape\ Index = w/\sqrt{l \times t} \quad (3)$$

2.1.4 Mass

A randomly sample of garlic bulb, garlic clove and 1000 clove mass was measure using an electronic balance having an accuracy of 0.001g. This parameter would govern the material handling capacity of the machine.

2.1.5 Volume of clove

Volume of intact agricultural product due to irregular shape is usually determined by volume displacement method using a general purpose reagent (toluene rectified) with the help of measuring cylinder and following equation is used for calculating the volume:

$$Volume = \frac{Weight\ of\ displaced\ tolune}{Density\ of\ tolune} \quad (4)$$

2.1.6 Bulk density

The bulk density of cloves was determined by using a wooden box with an inside dimension of 0.26 × 0.26 ×0.40 m and an electronic balance. This wooden box was fully filled with upper surface excess clove removed and weighed. The bulk density was calculated as follows:

$$\gamma = \frac{m}{v} \quad (5)$$

Where,

γ = the bulk density (kg m^{-3})

m = the mass of the cloves (kg)

v = the volume of wooden box (m^3)

2.1.7 Co-efficient of static friction

The coefficient of static friction of garlic bulb and cloves were determined by inclined plane method. The test surfaces used were mild steel and glass. The samples were placed on the test surface at the top edge. The inclined surface was tilted until the samples begin to move leaving an inclined surface. The angle of inclination with the horizontal was measured by a scale provided and taken as an angle of internal friction and tangent of the angle was taken as co-efficient of friction between surface and sample (Sahay and Singh, 1998).

$$\mu = \tan\theta \qquad (6)$$

Where,

μ = *Co-efficient of static friction,*

θ = *Angle of inclination of material surface, º*

2.1.8 Angle of repose

The angle of repose is the angle between the base and the slope of the cone formed on a free vertical fall of the granular material to a horizontal plane. The dynamic angle of repose of garlic cloves were measured by the 'emptying method'. A metal container having 125 mm diameter width and 200 mm height was used to determine the dynamic angle of repose of garlic cloves. A removable front panel with 200 mm height and 125 mm width was used to release the material sideways. The container was filled with the garlic sets leveled and then the front panel was quickly slide upwards allowing the garlic cloves to flow out. The angle of repose was calculated from the movement of the maximum depth of the free surface of the sample and the diameter of the container. The procedure was replicated five times with different samples and the mean was calculated (Mohsenin, 1986; Karababa, 2006; Manjunatha, 2008).

$$\theta = tan^{-1} \ \frac{2\mathrm{H}}{\mathrm{D}} \qquad (7)$$

Where,

θ = *Angle of repose (º)*

H = Height of the sample (cm)

D = Diameter of sample (cm)

2.1.9 Moisture content

Moisture content of the garlic cloves was determined by convection oven method. Three samples of 15 g each were weighed and placed in moisture boxes. The samples were heated (105 ± 0.5 °C) for 24 or 36 h to until constant weight. Mass was obtained, than the samples were taken out and cooled in desiccators and weighed in electronic balance. The percent moisture was determined by using following formula (AOAC, 2000):

$$\mathrm{M.C, \% \ (w.b.)} = \frac{Initial\ weight\ of\ sample - Final\ weight\ of\ sample}{Initial\ weight\ of\ sample} \times 100 \qquad (8)$$

2.1.10 Compressive force

The compressive force is relevant in studying energy requirement during bulb breaking, garlic peeling, garlic powder making, material resistance, mechanical damage etc. The compressive force of garlic was determined using a Texture Analyzer (Model TA. HDi).

2.1.11 Terminal velocity of clove

The terminal velocity is a useful parameter in designing blowers for aeration and separation of undesirable materials. The terminal velocity of garlic cloves was measured using an air column. For each test, a small sample was dropped into the air stream from the top of the air column, up which air was blown to suspend the material in the air stream. The air velocity near the location of the clove suspension was measured by a digital hot wire anemometer having a least count of 0.1 m s^{-1} (Zewdu and Solomon, 2007; Bakhtiari and Ahmad, 2015).

2.1.12 Husk to clove ratio

Husk to clove ratio is the ratio of the mass of husk to the mass of garlic clove.

$$husk\ to\ clove\ ratio = \frac{mass\ of\ husk}{mass\ of\ clove} \qquad (9)$$

2.1.13 Number of clove in one bulb

Numbers of garlic cloves in one garlic bulb were measured by physically breaking 10 garlic bulbs and count number of garlic clove in each bulb. The mean values of garlic cloves were calculated by a taking mean of 10 garlic bulbs clove.

2.1.14 Bulb to waste ratio

Bulb to waste ratio of garlic bulb was measured by using following formula.

$$Bulb\ to\ waste\ ratio = \frac{weight\ of\ garlic\ bulb}{weight\ of\ garlic\ bulb\ waste} \quad (10)$$

2.1.15 Clove to waste ratio

Clove to waste ratio was measured by using following formula

$$clove\ to\ waste\ ratio = \frac{weight\ of\ clove}{weight\ of\ waste} \quad (11)$$

2.2 Basic considerations in development and fabrication of the garlic peeler

The following points were kept in mind while developing and fabricating the garlic peeling machine (Manjunatha, 2007).

The machine must be simple and easy to fabricate.

The feeding is to be done manually.

The peeling unit should peel the clove efficiently with minimum damage.

The cleaning should manually.

There should be a provision for easy adjustments of disc speed.

Source of power would be electric motor.

Based on above considerations, the garlic peeler design was finalized which consists of the following units i.e feeding unit, peeling chamber and rotating disc, discharge, outlet of husk, blower, motor, speed controller and main frame.

2.3 Design and development of rotary disc type garlic clove peeling machine components

Rotary disc type garlic clove peeler shows the basic components of the developed machine and works on the principle of the surface shearing. The disc coated with high quality rubber rotates against fixed cylinder as result of which the garlic get peels off due to shearing and frictional action. The objective of this study was to obtain developmental values of different components of the peeler to obtain maximum peeling efficiency, minimum material damage and energy consumption. Therefore, an experimental peeler was fabricated with provision to change speed of the rotary disc by speed regulator (Figure 1).

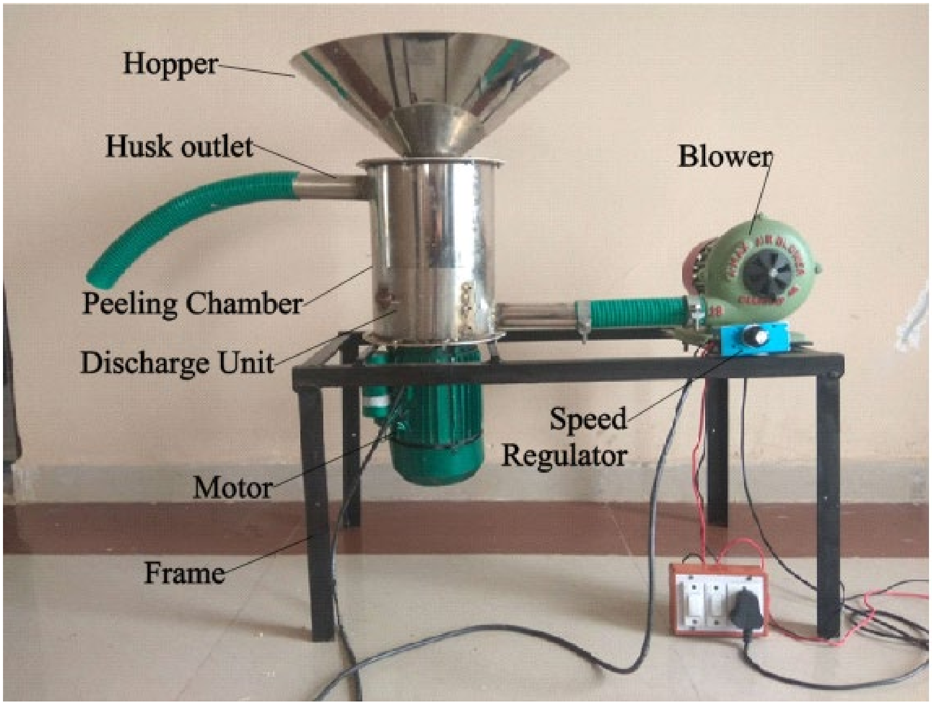

Figure 1 Rotary disc type garlic peeling machine

2.3.1 Feed hopper

The feed hoper is required to feed the garlic into the peeling unit. The feed hopper with frustum cone type was considered suitable for feeding due to its simplicity and ease of fabrication. The angle of repose and bulk density was a guiding factor for developing the hopper. The feed hopper was made from 2 mm stainless steel sheet (S.S. sheet) and it was mounted on the cylindrical peeling chamber unit to feed garlic into peeling unit in order to have advantage of gravity force for free flow of the material from the hopper to the peeling unit. Following expression was used for determining volume or holding capacity of hopper (Mohsenin, 1970; Sitkei, 1976; Singh and Goswami, 1996) (Figure 2 and 3).

$$V = \frac{M}{\rho} \quad (12)$$

Where,

V = volume or holding capacity of the feed hopper (m³)

M = mass of garlic fed into the feed hopper during each filling (kg)

ρ = bulk density of the garlic (kg m^{-3})

2.3.1.1 Design calculation of hopper

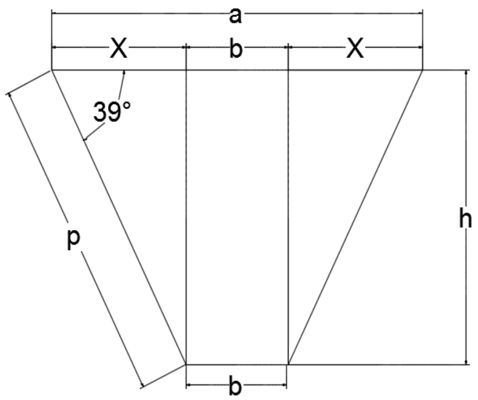

Figure 2 Hopper

The shape of the hopper is in shape of frustum cone. Therefore, the frustum cone formulas for calculating dimensions of hopper were used (Figure 2).

Let,

a = top base diameter of frustum cone, cm

b = bottom base diameter of frustum cone, cm

h = height of the frustum cone, cm

ø = angle of repose of garlic = 39° (Taken from Table 3)

R = radius of the upper base frustum cone = $\frac{a}{2}$ cm

r = radius of the lower base frustum cone = $\frac{b}{2}$ cm

From the above figures we get,

$$tan\,39 = \frac{h}{x} \quad (13)$$

$$x = \frac{h}{\tan 39} \qquad x = 0.81h \quad (14)$$

Using mathematical equation for calculating the volume of truncated cone is,

$$V = \frac{\pi}{3}[R^2 + r^2 + (R \times r)]h \quad (15)$$

Where,

R = radius of the upper base frustum cone

r = radius of the lower base frustum cone

V = volume of the frustum cone

h = height of the frustum cone

Assuming radius of the lower base frustum cone

$$r = 3.5\ cm \quad (16)$$

From above figure

$$R = x + 3.5 \quad (17)$$

Putting the values of x from Equation (14).

$$R = 0.81h + 3.5 \quad (18)$$

Using Equation 12.

$$V = \frac{M}{\rho} \quad (19)$$

Where,

V = volume or holding capacity of the feed hopper, m ³

M = mass of garlic fed into the feed hopper during each filling, kg

ρ = bulk density of the garlic, kg m^{-3}

From the experiment we get,

Bulk density of the garlic (ρ) = 432 kg m^{-3}

Assuming the capacity of hopper is 2 kg.

Therefore mass of garlic, M = 2 kg

$$V = \frac{2}{432} \quad (20)$$

V = 4.6×10^{-3} m^3

V = 4600 cm^3

Assuming 5% free spaces in the hopper then,

Total volume V = 4600 + 230 cm^3

V= 4830 cm^3

Putting the whole values in Equation 15,

$$4830 = \frac{3.14}{3}[(0.81h + 3.5)^2 + 3.5^2 + ((0.81h + 3.5) \times 3.5)]h \quad (21)$$

$$4612.3 = (0.656h^2 + 5.67h + 12.25 + 12.25 + (0.81h + 3.5) \times 3.5)h$$

$$4612.3 = (0.656h^2 + 5.67h + 24.5 + (2.835h + 12.25))h$$

$$4612.3 = ([0.656h^2 + 5.67h + 24.5] + (2.835h + 12.25))h$$

$$4612.3 = (0.656h^2 + 8.505h + 36.75)h$$

$$(0.656h^2 + 8.505h + 36.75)h - 4612.3 = 0$$

$$0.656h^3 + 8.505h^2 + 36.75h - 4612.3 = 0 \quad (22)$$

Equation 22 is the cubic equation of $ax^3 + bx^2 + cx + d = 0$

then,

a= 0.656 b= 8.505 c= 36.75 d= -4612.3

Solutions of the cubic equation $0.656h^3 + 8.505h^2 + 36.75h - 4612.3 = 0$ are h_1= 14.91 cm

h_2= -13.93 + i.16.65 cm, h_3= -13.93 - i.16.65 cm

Where, h_2 and h_3 are complex numbers so, taking $h = h_1$ = 14.91 cm.

Now, finding the value of x in Equation 14.

$x = 0.81h$, $x = 0.81 \times 14.91$, $x = 12.07\ cm$

As per value of x and value of h finding the incline height of cone

Here is the formula of defining inclined height as follows:

$$p^2 = x^2 + h^2$$

$$p = \sqrt{x^2 + h^2}$$

$$p^2 = \sqrt{12.07^2 + 14.91^2}$$

$$p^2 = \sqrt{145.68 + 222.31}$$

$$p^2 = \sqrt{367.99}$$

$$p = 17.18\ cm$$

Now finding the value of R as follows:

Putting the value of h in Equation 18.

R = 0.81h + 3.5

R = (0.81 × 14.91) + 3.5

R = 15.57 cm = 155.7 mm

r = 3.5 cm = 35 mm

Therefore, the dimensions of the hopper are:

Top base diameter of hopper (a) = 2R = 2 × 15.57 = 31.14 cm = 311.4 mm

Bottom base diameter of hopper (b) = 2r = 2 × 3.5 = 7 cm = 70 mm

Inclined length of hopper (p) = 17.18 cm = 171.8 mm

Height of the hopper (h) = 14.91 cm = 149 mm

Figure 3 Feed hopper

2.3.2 Peeling chamber and disc

Peeling chamber with rubber coated were required to peel the garlic. It was developed to peel the garlic with minimum damage to the clove and with maximum peeling efficiency. This unit mainly comprises of a cylinder inner side coated with food grade rubber. The hollow cylinder used for peeling was made up of 2 mm thickness stainless steel with height of 250 mm. (Figure 4).

Figure 4 Peeling chamber

2.3.2.1 Design of cylindrical peeling chamber:

Bulk density of garlic = 432 kg m^{-3}

The capacity of hopper = 2 kg,

Therefore, the capacity of peeling chamber = 1.5 times of capacity of hopper

= 3 kg

Volume of the peeling chamber (V) = $\frac{3}{432}$

= 6.9 × 10^{-3} m^3

= 6900 cm^3

Here using mathematical hollow cylinder Equation (23).

$$V = \pi r'^2 H \quad (23)$$

Where,

V = Volume of peeling chamber

r' = Radius of the peeling chamber

H = Height of the peeling chamber

Assuming the height of the cylindrical peeling chamber (H) = 25 cm

Putting the values of V and h in Equation 23.

$6900 = 3.14 \times r'^2 \times 25 \quad r'^2 = \frac{6900}{3.14 \times 25}$

$r'^2 = 87.8$

r’ = 9.3 cm = 93 mm

Diameter of the peeling chamber (D) = 18.6 cm = 186 mm

Therefore, the dimensions of the peeling chamber are:

Diameter of peeling (D) = 2r’ = 2 × 9.3 cm = 18.6 cm = 186 mm

Height of peeling chamber (H) = 25 cm = 250 mm

2.3.2.2 Calculation of rotary disc diameter

The rotary disc was fitted in the peeling chamber. For free rotations of rotary disc in the chamber, 0.25 cm clearance between disc and inner wall of the peeling chamber was fixed. Therefore the diameter of rotary disc = 18.60 – 0.50 = 18.10 cm = 181 mm. The diameter of cylinder was 186 mm with one end open and one ends closed. The inner surface of the cylinder was coated with 3 mm thick high quality semi hard food grade white rubber. Rotating disc having 181 mm diameter with food grade white rubber coated. The disc made from stainless steel was peeled the garlic cloves. Cylinder was fixed with motor and disc was free to rotate inside a peeling chamber. Speed regulator to control the speed of the motor shaft and the disc was fixed on the shaft.

2.3.3 Discharge of peeled product

The cross sectional area of discharge unit of peeled products was 80 mm x 100 mm. The blower is connected to the discharge unit. When air comes from blower to the discharge unit, the husk content of garlic was removed through husk content outlet. After that the mixture of peeled garlic, unpeeled garlic and damaged garlic were collected and separated manually from discharge unit. (Figure 4)

2.3.4 Motor

Induction motor of 0.746 kW capacity was used to rotate the rotary disc in peeling chamber. The rotary disc was attached with the shaft of motor. The speed of the motor was 2880 rpm.

2.3.5 Blower

The blower consists of three leaf impeller fixed to the central shaft. That rotates horizontally with the help of 0.186 kW electric motor, Blower was used to supply air for separation of peel from peeled garlic cloves. It rotates at the speed of 2800 rpm and volume of air supply can be adjusted with the help of impeller suction section provided at side of the blower.

2.3.6 Speed regulator

Speed regulator was used to regulate the speed of the motor.

2.3.7 Main frame

The main frame was required to support other parts of the garlic peeler. The main frame was fabricated from M.S. angle (25 × 25 × 3 mm) for supporting hopper, cylinder, blower and electric motor. The hopper, cylinder, blower and electric motor were assembled on main frame using nuts and bolts.

2.4 Overall dimensions of rotary disc type garlic clove peeling machine

On the basis of engineering properties of garlic bulb and clove, the rotary disc type garlic clove peeling machine were designed and developed. The overall dimensions of developed garlic clove peeling machine were presented in Table 1 and Figure 5.

Table 1 Overall dimensions of rotary disc type garlic clove peeling machine

Machine parts	Dimensions
Hopper (S.S Sheet)	
Top base diameter of hopper	311.4 mm
Bottom base diameter of hopper	70 mm
Inclined length of hopper	171.8 mm
Height of the hopper	149 mm
Peeling chamber (S.S Sheet)	
Diameter of peeling	186 mm
Height of peeling chamber	250 mm
Rotary disc (S.S Sheet)	
Diameter of rotary disc	181 mm
Discharge outlet (S.S Sheet)	
Height of discharge outlet	80 mm
Width of discharge outlet	100 mm

Discharge of husk (S.S Sheet)	
Diameter of discharge of husk	40 mm
Length of discharge of husk	100 mm
Main frame (M.S Sheet)	
Length of frame	650 mm
Width of frame	400 mm
Height of frame	350 mm
Motor	1 HP
Blower	0.25 HP

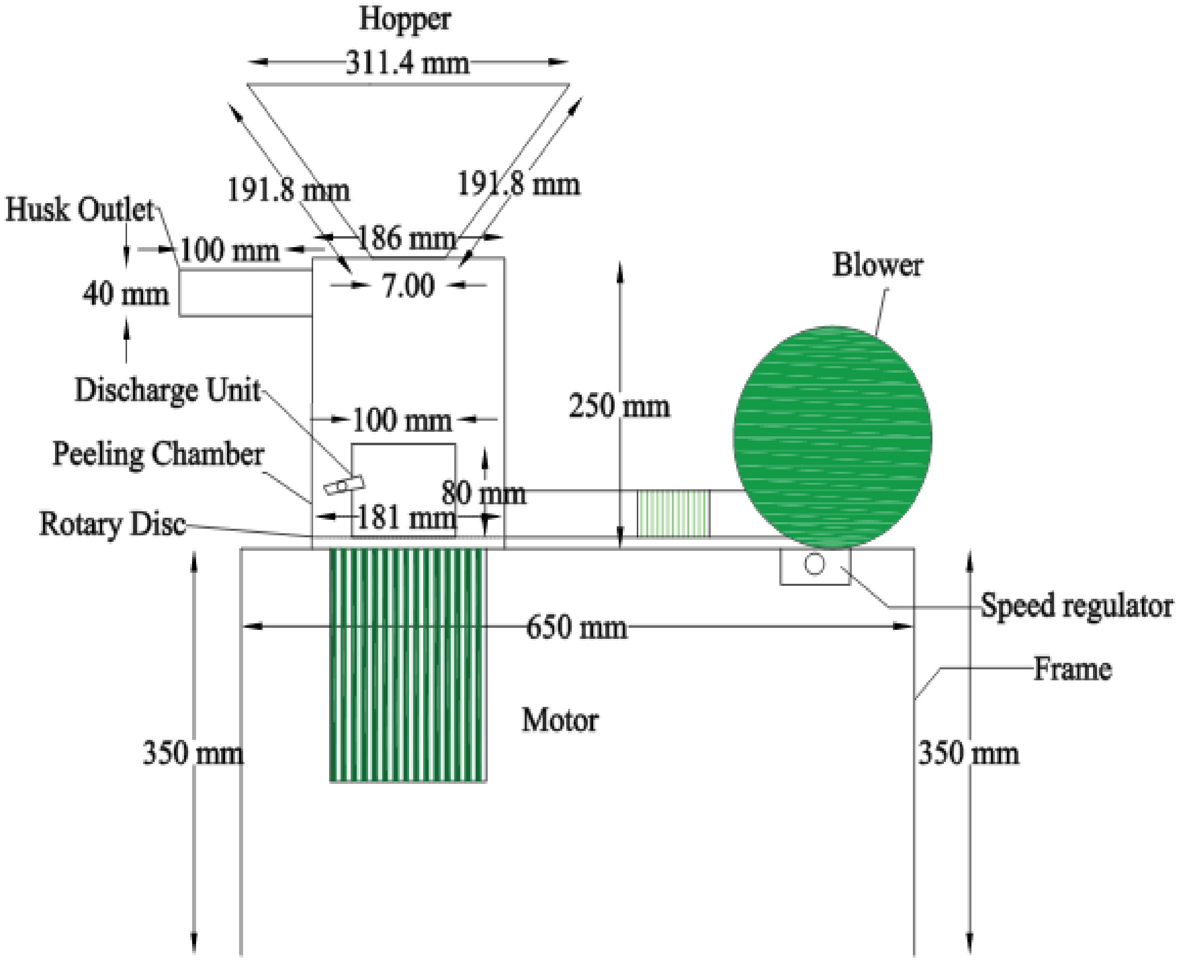

Figure 5 Rotary disc type garlic peeling machine

2.5 Peeling efficiency

The following formula was used to calculate the peeling efficiency as suggested by Sharma and Madhyan (1988)

$$E = \left(1 - \frac{M_u}{M_t}\right) \times \left(1 - \frac{M_d}{M_t}\right) \text{ x } 100 \quad (24)$$

Where,

E = Efficiency of peeling (%)

M_u = Mass of unpeeled garlic (g)

M_d = Mass of damaged garlic (g)

M_t = Mass of total garlic used for peeling (g)

3 Results and discussions

3.1 Engineering properties of garlic bulb

The engineering properties like: length, width, thickness, geometric mean diameter, spherisity, shape index, weight, number of clove in garlic bulb, bulb to waste ratio of the garlic bulb were determined at 41.69% moisture content. The details were shown in Table 2. 3.2 Engineering properties of garlic clove

The engineering properties like: length, width, thickness, geometric mean diameter, sphericity, shape index, weight of one garlic clove, weight of 1000 clove, volume, bulk density, coefficient of friction, angle of repose, moisture content, compressive force, terminal velocity, husk to clove ratio and clove to waste ratio of the garlic clove were determined at 41.69% moisture content. The details were shown in Table 3.

Table 2 Engineering properties of garlic bulb

Engineering properties	Values		
	Min.	Max.	Mean ± S.D.
Length of garlic bulb (mm)	30.90	67.56	52.92 ± 13.16
Width of garlic bulb (mm)	34.70	49.13	41.03 ± 3.94
Thickness of garlic bulb (mm)	33.68	46.15	38.54 ± 3.36
Geometric mean diameter of garlic bulb (mm)	33.28	52.27	43.99 ± 5.41
Sphericity of garlic bulb	0.69	0.98	0.82 ± 0.10
Shape index of garlic bulb	0.75	0.97	0.86 ± 0.07
Weight of garlic bulb (g)	17.12	26.81	20.41 ± 9.69
Number of clove in garlic bulb	15.00	27.00	23.00 ± 3.78
Bulb to waste ratio	23.14	48.46	33.41 ± 6.88

Table 3 Engineering properties of garlic clove

Engineering properties	Values		
	Min.	Max.	Mean ± S.D.
Length of garlic clove (mm)	20.13	30.92	24.71 ± 3.66
Width of garlic clove (mm)	9.02	14.73	10.65 ± 1.76
Thickness of garlic clove (mm)	5.17	10.87	8.45 ± 1.56
Geometric mean diameter of garlic clove (mm)	9.96	16.54	13.01 ± 1.91
Sphericity of garlic clove	0.49	0.59	0.53 ± 0.03
Shape index of garlic clove	0.62	0.92	0.75 ± 0.1
Weight of one garlic clove (g)	1.67	0.98	1.31 ± 0.19
Weight of 1000 garlic clove (g)	1420	1480	1448 ± 0.02
Volume of one garlic clove (cm^3)	0.71	1.50	1.07 ± 0.29
Bulk density of garlic clove ($kg\ m^{-3}$)	429.73	435.65	432.4 ± 2.58
Co efficient of friction of garlic clove	0.79	0.82	0.811 ± 0.01
Angle of repose of garlic clove (°)	38.41	39.48	39.07 ± 0.44
Moisture content of garlic clove (%)	40.46	42.38	41.69 ± 1.07
Compressive force of garlic clove (kg)	11.29	14.31	12.82 ± 1.27
Terminal velocity of husk ($m\ s^{-1}$)	0.20	3.50	2.02 ± 1.23
Husk to clove ratio	0.05	0.15	0.08 ± 0.03
Clove to waste ratio	45.66	21.50	30.85 ± 9.34

3.3 Cost calculation of garlic peeling machine

The cost of rotary disc type garlic clove peeling machine includes cost of stainless sheet, labour charges for cutting and welding of S.S sheet, cost of electric induction motor, cost of blower, cost of food grade rubber, cost of nut bolts screw, cost of M.S angle Iron, labour cost of welding of M.S angle iron and cost of speed regulator. The total cost of machine was presented and calculated in Table 4. The manufacturing cost of peeling machine was calculated $ 137.

Table 4 Manufacturing cost of peeling machine

Sr. No.	Description	Rate	Material used	Total material cost ($)
1	Stainless steel (SS 203) sheet thickness 2 mm.	$ 4.04/kg	4.71 kg	19.0284
2	Labour charge for cutting and welding of stainless steel sheet	$ 10.78	-	10.78
3	Cost of 0.746 kW electrical induction motor	$ 56.58/unit	1 No.	56.58
4	Cost of blower	$ 29.64/unit	1 No.	29.64
5	Cost of food grade rubber	$ 5.39/kg	1 kg	5.39
6	Cost of nut bolt screw etc.	$ 0.040/unit	20 Nos.	0.80
7	Cost of M.S. angle (25 × 25 × 3 mm)	$ 0.81/kg	5.50 kg	4.455
8	Labour charge for M.S. angle welding	$ 0.61	-	0.61
9	Cost of speed regulator	$ 9.43/unit	1 No.	9.43
	Total cost of machine in US dollar ($)			136.71 ≈ 137

3.4 Calculation of cost of operation of garlic peeling machine

The fixed cost of rotary disc type garlic clove peeling machine includes cost of depreciation per hour, interest per hour and taxes, insurance and shelter charges per hour. The operating cost includes repair and maintenance cost per hour, labour cost per hour and cost of electricity per unit.

Assumptions:

Average annual use (H) = 730 h

Life of garlic peeler (L) = 10 years

Salvage value (S) = 10% of initial cost

A. Fixed cost	
Cost of garlic peeler with all accessories (C),	$ 137
Depreciation/h, $	$\frac{137-13.7}{10\times730}=0.0169$
Interest on investment/h (@ 10 per cent per annum), $	$\frac{137+13.7}{2}\times\frac{10}{730\times100}=0.000256$
Taxes, insurance and shelter charges/h (@ 2 per cent of initial cost per annum), $	$\frac{137\times2}{100\times730}=0.00375$
Total fixed cost/h, $	= 0.0169 + 0.000256 + 0.00375
	= $ 0.020908 ≈ 0.021
Fixed cost of the garlic peeler per hour, $	= 0.021
B. Operating cost	
Repair and maintenance cost/h (@ 5 per cent of initial cost per annum), $	$\frac{137\times5}{100\times730}=0.00938$

Assumptions:

I. One labour is required to utilize the full capacity of the peeler

II. Wage rate of $ 2.40 per man per day of 8 hours

Labour cost of one person h^{-1}	= $ 0.30
Cost of electricity of 1.0 kWh	= $ 0.067
Cost of electricity of 0.74 kWh	= $ 0.04958
Total operating cost h^{-1}	= $ (0.30 + 0.067 + 0.04598)
	= $ 0.417
Total cost of operation of peeler h^{-1}	= $ 0.438
Maximum capacity of garlic peeler kg h^{-1}	= 20
Cost of peeling, $ kg^{-1}	= 0.438/20
	= $ 0.0219 kg^{-1} ≈ $ 0.022 kg^{-1}

Fixed cost and operating cost of the garlic peeler per hour was calculated $ 0.021 and $ 0.417 respectively. The total cost of operation of peeler per hour was found $ 0.438 and cost of peeling was calculated $ 0.022 per kg.

3.5 Performance evaluation

During performance evaluation of rotary disk type garlic peeling machine, the following observations were found i.e. peeled garlic, unpeeled garlic, damaged garlic and husk content were found 83.90%, 7.71%, 3.10% and 5.29% respectively. The peeling efficiency of rotary disc type garlic clove peeling machine was found to be 89.43%. The power consumption and specific energy consumption were found 0.73 kWh and 0.049 kW/kg respectively during peeling process.

4 Conclusions

The developed garlic peeler was compact, portable and may be utilized in garlic processing industries, big restaurants, and hotels. This device can be protects the fingers from the health issues like irritation in fingers and nail breakings. This peeling machine also saves time of the user and providing better efficiency with low cost. The manufacturing cost of peeling machine was found to be $ 137. The total cost of operation of peeler per hour was found $ 0.438 and cost of peeling was calculated $ 0.022 per kg. The peeling efficiency of rotary disc type garlic clove peeling machine was found to be 89.43%.

References

Abalone, R., A. Cassinera, A. Gastón, and M. A. Lara. 2004. Some physical properties of amaranth seeds. *Biosystems Engineering*, *89*(1): 109-117.

Abd-Alla, H. E. 1993. Effect of coating process on seeds viability and some physio-mechanical properties of Egyptian cotton. *The Journal of Agricultural Science*, 18(8):2384-2396.

Abd-Alla, H. E., S. M. Radwan and E. H. El-Hanfy. 1995. Effect of some physical properties of rice grains on milling quality. *Misr Journal of Agricultural Engineering*, 12(1):143-155.

AOAC. 2000. *AOAC- Official Methods of Analysis*, Washington DC, USA: AOAC.

Bahnasawy, A. H. 2007. Some physical and mechanical properties of garlic. *International Journal of Food Engineering*, 3(6):1-18.

Bakhtiari, M. R., and D. Ahmad. 2015. Determining physical and aerodynamic properties of garlic to design and develop of a pneumatic garlic clove metering system. *CIGR Journal*,17(1):59-67.

Chandrasekar, V. and R. Viswanat. 1999. Physical and thermal properties of coffee. *Journal of Agricultural Engineering Research*, 3(6):227-234.

Cruess, W.V. 1958. Commercial fruits and vegetable products. USA: McGraw Hill Book Co. Inc.

Dhananjay, G.D., S. K. Choudhary and A.P. Ninawe. 2015. Methodology for design and fabrication of garlic peeling machine. *International Journal of Science and Research*, 2(11):2321-0613.

Haciseferogullari, H., M. Ozcan, F. Demir, and S. Calisir. 2005. Some nutritional and technological properties of garlic. *Journal of Food Engineering*, 68(4):63-469.

Horticultural Statistics at a Glance, 2018. Government of India, Ministry of Agriculture & Farmers' Welfare, Department of Agriculture, Cooperation & Farmers' Welfare, Horticulture Statistics Division.

Karababa, E. 2006. Physical properties of popcorn kernels. *Journal of Food Engineering*, 72(1):100-107.

Kaur, M., P. Kaur and M. Kumar. 2019. Development and fabrication of small capacity garlic peeler. *International Journal of Current Microbiology and Applied Sciences*, 8(8):619-634.

Manjunatha, M., 2007. Development and performance evaluation of garlic peeler. Ph.D. diss., Division of Agric. Eng., Indian Agric. Res. Institute, New Delhi.

Manjunatha, M., D. V. K. Samuel and S. K Jha. 2008. Studies on some engineering properties of garlic (Allium sativum), *The Journal of Agricultural Engineering,* 45(2):18-23.

Mohsenin, N. N. 1970. Physical Properties of Plant and Animal Materials. New York: Gordon and Breach, Sc. Pub.

Mohsenin NN 1986. Physical Properties of Plant and Animal Material, 2nd ed, New York: Gordon and Breach Pub.

Mudgal, V. D. and P. S. Chapawat. 2008. Influence of operating parameters on performance of air-assisted garlic clove peeler. *The Journal of Agricultural Engineering*, 45(3): 45-48.

Rajesh, K., M. K. Reddy, Y. Anusha, P. Haritha, D. Narendra, and S. Srujana. 2018. Design and fabrication of garlic peeler. *International Journal of Advanced Research in Science, Engineering and Technology*, 5(7): 165-170.

Sahay, K.M. and K. K. Singh, 1998. Unit Operations of Agricultural Processing, New Delhi: Vikas Pub. House Pvt. Ltd.

Sharma, S. K., B. L. Madhyan, 1988. Development and evaluation of green pea peeler. *Journal of Agricultural Engineering*, 25(3):63–68.

Singh, K. K. and T. K Goswami,. 1996. Physical properties of cumin seed. *Journal of Agricultural Engineering Research*, 64(2): 93-98.

Sitkei, G. 1976. *Mechanics of Agricultural Materials*: Sopron, Hungary: Department of Woodworking Machines, University of Forestry and Wood Science.

Zewdu, A. D., and W. K. Solomon. 2007. Moisture-dependent physical properties of tef seed. *Biosystems Engineering,* 96(1): 57-63.