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Development and feasibility assessment of garlic clove peeling machine

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ABSTRACT

Peeling garlic cloves is a major energy and time consuming operation that sometime cause allergy to skin when done manually. A prototype electric motor powered garlic clove peeling machine was developed that worked on the principle of application of abrasion, friction and compressive forces on the cloves to remove peels from the cloves. It consisted of a cylinder made of nitrile rubber covered with steel mesh of 64 perforations per square inch, a concave made of steel mesh of 9 perforations per square inch, a blower and a power transmission unit. The cylinder-concave clearance was tapered with 20 mm near the inlet to 10 mm near the outlet. The cylinder-concave assembly was kept inclined at an angle of 35° from the horizontal. The cylinder was operated at 40 rpm. The garlic cloves were dried to the moisture content of 38–39% (w.b.) and fed at the rate of 40 g/min. The output capacity of the machine was 1.50 kg/h with peeling efficiency of 71% and percent damage of 18.24%. Cleaning efficiency of the machine was 99.23% with no blower loss. Labour and electrical energy requirement of the machine were 0.67 man-h and 1.61 kW-h/kg, respectively. The mechanical peeling saved 60% time and labour over conventional manual peeling. The machine has to be operated for about 275 h/year to justify mechanical peeling over manual peeling. The machine was found to be suitable for use in small canteen and processing centres.

1. Introduction

India is the second largest producer of garlic (*Allium sativum* L.) in the world. Garlic is consumed in fresh as well as dried form to enhance the flavor of curries, chutneys, pickles etc. Due to the widely fluctuating cost of fresh garlic, there is a need for a simple processing technology to prepare quality garlic products with long shelf life for their use in off-season.

Garlic cloves contain thin paper-like inedible outer skin which needs to be removed before processing or consumption. Typical size of the cloves makes peeling a tedious and time consuming operation (Mudgal, 2005; Mudgal and Champavat, 2011). Raw garlic releases oil containing chemical diallyl disulphide (DAD), allyl propyl disulphide and allicin, which causes allergy. Several indigenous and improved methods have been followed for peeling of garlic cloves (Prasad, 2013). Though these methods alleviate the drudgery involved in conventional hand peeling, lack of hygienic conditions, increased cost and restriction of processing activity have prevented the use of processed garlic cloves for commercial purposes. Several attempts have been made to develop suitable devices for the mechanical peeling of garlic cloves. They may be categorised into two, viz., those which used abrasive materials (Mudgal, 2005; Prasad, 2013; Manjunatha *et al.*, 2014) and those which used pressurized air (Mudgal and Champavat, 2008; Mudgal and Champavat, 2011; Prasad, 2013) for the peeling of garlic cloves.

Mudgal (2005) developed a manually operated garlic clove peeling machine that consisted of a cylinder

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inclined to horizontal by 8º and provided with lining material such as rubber, coir mat, emery etc., and a top cover and a concave both covered with lining material to impart abrasive action. Garlic cloves were conditioned to moisture content of 50–55% (w.b.) before feeding. The output capacity of the machine was 5 kg/h. Prasad (2013) reported the development of a peeling machine for dehydrated garlic flakes. It had a scrubber that rotated at 160 rpm inside a barrel with clearance of 8 mm. As the flakes moved down in the clearance, the abrasion and friction forces removed the peels. The output capacity of the machine was 50 kg/h with 80–85% peeling efficiency in two passes. Manjunatha *et al.* (2014) developed a power operated garlic peeler with a cylinder covered with 10 mm thick rubber and a concave made using 8×8 mesh. Peeling efficiency, percent yield, percent unpeeled, percent damage and percent peel separation were 86.6, 86.2, 4.7, 9.15 and 96%, respectively with throughput capacity of 27 kg/h and energy requirement of 1.15 kW-h. The mechanical garlic peeling devices that worked on the principle of abrasion, friction and compression required dried garlic cloves and facilitated continuous feeding.

Mudgal and Champawat (2008) studied the influence of operating parameters (height of peeling chamber, garlic clove bed depth, air jet pressure and position of air jet) on the performance of a batch type air assisted garlic clove peeler, and reported a peeling efficiency of 97-98%. Mudgal and Champawat (2011) developed a garlic clove peeler with a pressure chamber which was connected at the top to a diffuser to separate the thin husk from the peeled material. The air flow pipe from the compressor was provided at a height of 60 mm from the top surface of the garlic bed. A batch of 500 g garlic cloves were peeled in 70 s with peeling efficiency of 97.6%. Prasad (2013) reported the development of a garlic clove peeling machine that consisted of a cylindrical chamber in which 500-750 g conditioned cloves were filled, and compressed air was injected for 45 to 60 s. Output capacity of the machine was 18–22 kg/h with no significant damage to cloves. The peeling efficiency was 96–98%. The mechanical devices that used pressurised air for garlic clove peeling were of batch type with high output capacity and peeling efficiency, and very low damage to cloves.

Kaur *et al.* (2019) developed a low capacity garlic peeler. They reported a recovery rate of 39.40% peeled cloves at 400 rpm of the roller. The maximum peeled clove recovery was recorded 33.45% for a controlled sample. During evaluation of the performance of the machine, the capacity was found to be 15 kg/h. At the same speed of the roller, the maximum peeling efficiency of 48.13% observed was with hot air pretreated samples.

Commercial garlic peeling machines are batch type, and have high output capacity (greater than 50 kg/h), but are expensive. For small canteens and processing centres, a small capacity garlic clove peeling machine which may be operated for half an hour to one hour for fulfilling the daily requirement is required. The garlic peeling machine which used abrasive materials on cylinder-concave clearance allowed continuous feeding and did not have any pre-requisite machine requirements like air compressor etc. However, the efficient working of the machine depends on the physical properties of garlic cloves. Therefore, in the present work, physical properties of garlic cloves most available and sold in the local market were measured, a garlic clove peeling machine was developed and its performance and feasibility of use were assessed.

2. Materials and Methods

2.1 Physical properties of garlic cloves

Garlic bulbs were collected from a local market. The cloves were separated from the bulbs and kept in room temperature under ambient conditions. Various physical properties of garlic cloves relevant to mechanical peeling in a cylinder-concave clearance were measured (Table 1). One hundred garlic cloves were randomly selected from the bulk, and their length, breadth and thickness were measured using a digital vernier calliper (Mitutoyo make and measuring range 0 to 150 mm). The geometric mean diameter and sphericity of the cloves were calculated (Mohsenin, 1986). Based on the geometric mean diameter, width and thickness of cloves, it was decided to have tapered clearance between the cylinder and concave with 20 mm clearance near the inlet to 10 mm clearance near the outlet. The tapered clearance imparted abrasion, shear and compressive forces on the cloves resulting in the peeling of cloves.

2.2 Development of garlic clove peeling machine

The garlic clove peeling machine worked on the principle of application of abrasion, friction and compression forces on the garlic cloves. It consisted of a cylinder, a concave, a blower, and an electric motor and a speed reduction unit. An exploded view of the cylinder-concave assembly is shown in Figure 1. The cylinder was of 450 mm length made with a mild steel core of 70 mm diameter. The core was overlapped with 15 mm thick nitrile rubber. The outer surface of the rubber cylinder was covered with steel mesh of 64 perforations per square inch. The concave was made of steel mesh of 9 perforations per square inch, and it completely surrounded the cylinder. The cylinder-concave clearance varied from 20 mm near the inlet to 10 mm near the outlet. The upper side of the concave was covered using stainless steel sheet of 1 mm thickness. The complete assembly of cylinder and concave was kept inclined at an angle of inclination of 35° from the horizontal which was more than the angle of repose of the garlic cloves. A hopper

Table 1. Physical properties of garlic cloves

Sl. No.	Physical property	Number of samples	Range	Mean ± Standard deviation
1.	Length, mm	100	18.27–40.10	29.64±5.51
2.	Width, mm	100	5.89–14.40	11.44±2.52
3.	Thickness, mm	100	4.33–12.06	6.81±1.93
4.	Geometric mean diameter, mm	100	8.28–17.42	13.21±2.35
5.	Sphericity	100	0.37–0.54	0.45±0.06
6.	Bulk density, kg/m^3	500 g	406.98–426.83	416.86±8.11
7.	True density, g/cm^3	500 g	972.22–1166.67	1101.87±91.66
8.	Porosity	500 g	58.14–64.29	61.95±2.72
9.	Angle of repose, °	1.0 kg	30.21–31.53	30.75±0.56

was provided to feed the garlic cloves in the cylinder-concave clearance at the inlet end of the cylinder. A 40 W blower with 200 mm sweep, 1300 rpm speed and 30 m^3/min rated air delivery was used to blow away the peels towards the outlet of the peeling machine.

The cylinder was operated using a 1.5 kW, 3-phase induction motor with rated speed of 1410 rpm. A speed reduction unit comprising 3 sets of chain drives with total velocity ratio 35:1 was used to power the cylinder from the electric motor. A universal coupling was used to connect the cylinder shaft to the output shaft of the speed reduction unit. The schematic diagram of the garlic clove peeling machine is shown in Figure 2, and its overall view is presented in Figure 3.

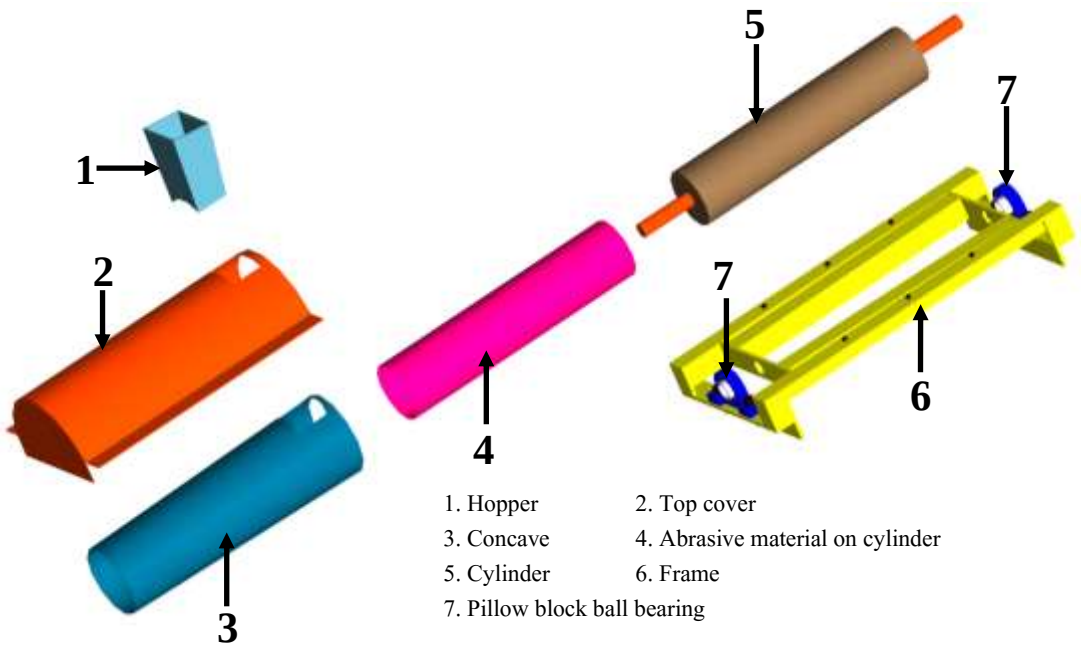

Figure 1. Exploded view of the cylinder-concave assembly of the garlic clove peeling machine

1. Electric motor
2. Chain drive velocity ratio, 2:1
3. Chain drive, velocity ratio, 5:1
4. Chain drive, velocity ratio, 3.5:1
5. Universal coupling
6. Feed hopper
7. Cylinder top cover
8. Outlet
9. Blower fan

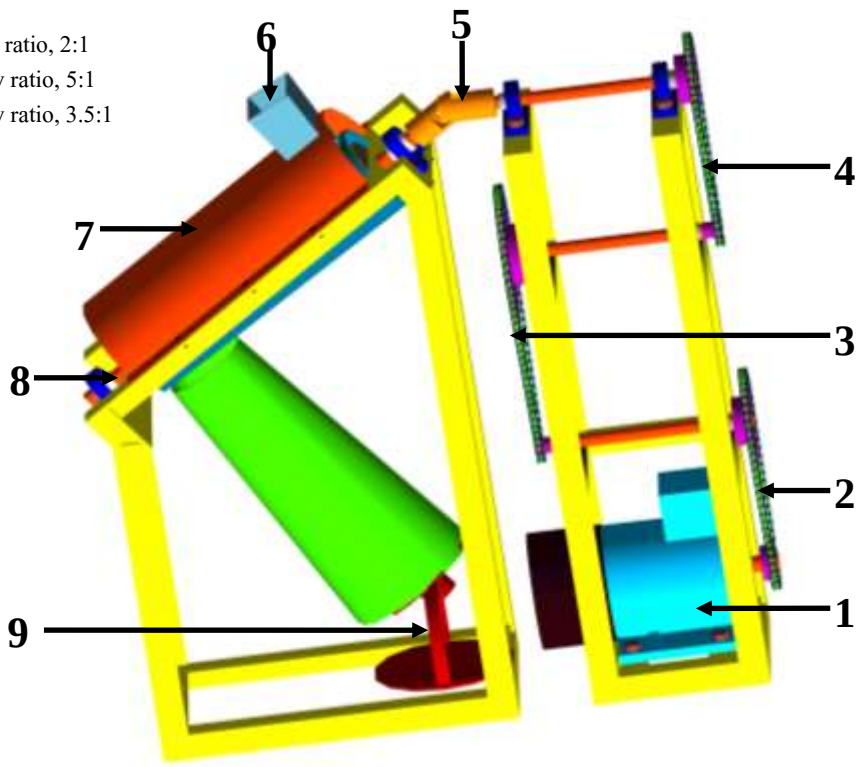

Figure 2. Schematic diagram of garlic clove peeling machine

1. Electric motor, 2. Peeling unit, 3. Blower, 4. Speed reduction unit

Figure 3. Overall view of garlic clove peeling machine

2.3 Preliminary trials

Preliminary trials were conducted to make necessary adjustments in the machine to obtain maximum peeling efficiency and minimum damage to the cloves, and to identify the most suitable design and operating parameters for the effective peeling of garlic cloves. It was observed that the fine skin removed from the garlic cloves and broken pieces of cloves adhered to the concave mesh in due course of time. The release of oil from the bruises on the cloves increased the adhesion of peels and broken pieces, and resulted in clogging of the cylinder-concave clearance. Therefore, the concave mesh had to be cleaned using brushes at certain time intervals. Conditioning of the cloves in the hot air drier or solar drying to moisture content of 38–39% (w.b.) was found to be necessary for effective peeling. A rotary speed of 40 rpm for the cylinder and the uniform continuous feed rate of 40 g/min were found to be suitable for the effective peeling.

2.4 Performance evaluation of machine

The garlic clove peeling machine was set at the identified design and operating parameters. The following procedure was followed for the evaluation of the performance of the developed garlic peeling machine:

(i) The garlic cloves were separated from the bulbs, and dried in a hot air oven at 60º C for 3 hours. The cloves were kept in ambient conditions ready for mechanical peeling.

(ii) The electric motor was started, and the cylinder was operated at 40 rpm. The blower was switched on.

(iii) The cloves were fed to the hopper at the rate of 40 g/min. A total of 300 g garlic cloves were fed to the machine in each trial.

(iv) The material flowing out at the outlet was collected in a steel container and weighed. The material was segregated into wholesome fully peeled (WC_o), wholesome partially peeled (PC_o), damaged and broken (DC_o) cloves and peels (P_o). Each segregated material was weighed.

(v) The material blown by the blower fan was collected and weighed. The material was segregated into wholesome fully peeled (WC_b), wholesome partially peeled (PC_b), damaged and broken (DC_b) cloves and peels (P_b). Each segregated material was weighed.

(vi) The material loss (peels and pieces of garlic cloves) inside the machine was computed by subtracting the sum of weights in step (iv) and (v) from total weight of the cloves fed to the machine in step (iii).

Various performance indices were developed to quantify the performance of the garlic clove peeling machine.

Feed rate of garlic cloves, $A = B + C + D$ (1)

where, A = feed rate of garlic cloves,

B = total weight of materials collected at the outlet per unit time

C = total weight of materials blown by the blower fan per unit time

D= material loss (peels and pieces of garlic cloves adhered to cylinder concave) inside the machine per unit time

Total weight of materials at the outlet per unit time, $B = WC_o + PC_o + DC_o + P_o$ (2)

where, WC_o = wholesome fully peeled garlic cloves at the outlet per unit time

PC_o = wholesome partially peeled garlic cloves at the outlet per unit time

DC_o= damaged cloves at the outlet per unit time

P_o = garlic peels at the outlet per unit time

Total weight of materials blown per unit time, $C = WC_b + PC_b + DC_b + P_b$ (3)

where, WC_b = wholesome fully peeled garlic cloves blown by the blower fan per unit time

PC_b = wholesome partially peeled garlic cloves blown by the blower fan per unit time

DC_b= Damaged cloves blown by the blower fan per unit time

P_b = garlic peels blown by the blower fan per unit time.

$$\text{Feed rate of garlic cloves} = \frac{\text{Total quantity of garlic cloves fed}}{\text{Total time taken}} \quad (4)$$

Feed rate is expressed in g/min or kg/h.

$$\text{Peeling efficiency} = \frac{(WC_o + WC_b)}{A} \times 100 \quad (5)$$

$$\text{Percent partially peeled cloves} = \frac{(PC_o + PC_b)}{A} \times 100 \quad (6)$$

$$\text{Percent damaged cloves} = \frac{(DC_o + DC_b)}{A} \times 100 \quad (7)$$

$$\text{Cleaning efficiency} = \left(1 - \frac{P_o}{B}\right) \times 100 \quad (8)$$

$$\text{Percent blown cloves} = \frac{(WC_b + PC_b + DC_b)}{A} \times 100 \quad (9)$$

$$\text{Percent material loss inside the machine} = \frac{D}{A} \times 100 \quad (10)$$

$$\text{Output capacity of the machine} = \frac{WC_o}{\text{Total duration of operatin of machine}} \quad (11)$$

Output capacity is expressed in kg/h.

Actual output capacity of the machine was calculated by assuming 20% time loss. Three trials were conducted, and the average values of performance indices were reported.

2.5 Assessment of the feasibility of use of machine

Labour requirement (man-h/kg) and electrical energy consumption (kW-h) for the operation of the machine (with actual output capacity) were determined. The machine required a trained labourer to feed the garlic cloves. The machine utilized electrical energy for the operation of cylinder and blower.

Initial cost of the machine was calculated by adding together the cost of raw materials used for fabrication, price of electric motor and the blower fan, and labour charges for the fabrication. Initial cost of garlic clove peeling machine was found to be INR 35000. Useful life of machine was assumed to be 10 years. Annual rate of interest was assumed to be 12%. Annual insurance and taxes of 2%, annual housing cost of 1% and annual repair and maintenance cost of 6% of initial cost was assumed. Rates of INR 7.50 per kW-h of 3-phase electrical energy and INR 4.50 per kW-h of single phase electrical energy were considered. The wage of INR 280 for the unskilled labourer per day of work (8 hours) was considered. Overall time loss of 20% of total duration of operation of the machine was considered.

The cost of mechanical peeling of garlic cloves was compared with cost of operation of conventional manual peeling. The minimum hours of annual use required to justify owning the developed machine was identified graphically. The machine was operated for efficient use for one hour several times to check the durability and reliability of machine components and use under actual processing conditions.

3. Results and Discussion

3.1 Performance of the garlic clove peeling machine

The abrasive steel mesh on the cylinder and perforated concave imparted the required abrasion, friction and slight compressive forces on the conditioned cloves for peeling, and the blower separated the peels from the cloves. Feed rate, output capacity, performance indices and energy requirement for the mechanical peeling of garlic cloves using the prototype machine in three trials are presented in Table 2.

3.1.1 *Feed rate and output capacity*

The average feed rate of the garlic clove peeling machine was 2.63 kg/h. The low feed rate of the machine facilitated the application of sufficient abrasive, friction and compressive forces on the cloves while they were sliding down the tapered cylinder-concave clearance towards the outlet. The average actual output capacity was found to be 1.50 kg of wholesome fully peeled garlic cloves per hour. In general, machines which used abrasive material had lower throughput capacity and peeling efficiency, and higher damage as compared to the machines which used compressed air for garlic clove peeling. Further, slight bruise to the garlic cloves released the oil which made the peels and pieces of cloves to stick to the abrasive surfaces of cylinder and concave. This reduced the effectiveness of cylinder-concave surfaces and necessitated frequent cleaning of the surfaces, hampering continuous operation of the machine.

Table 2. Performance indices and energy requirement of prototype garlic clove peeling machine

Parameters	Trial-1	Trial-2	Trial-3	Average
Feed rate of garlic cloves, kg/h	2.54	2.70	2.64	2.63
Peeling efficiency, %	71.33	69.87	72.12	71.11
Percent partially peeled cloves, %	3.67	7.33	5.13	5.38
Percent damaged cloves, %	19.77	17.27	17.69	18.24
Cleaning efficiency, %	99.23	99.18	99.29	99.23
Percent blown cloves, %	0.00	0.00	0.00	0.00
Percent material loss inside machine, %	3.12	3.13	2.88	3.04
Output capacity of machine, kg/h	1.81	1.89	1.90	1.87
Actual output capacity, kg/h	1.45	1.51	1.52	1.50
Labour requirement, man-h/kg of peeled garlic		0.67		
Electric energy consumption, kW-h/kg of garlic		1.61		

3.1.2 *Peeling efficiency, percent partially peeled cloves and percent damaged cloves*

Peeling efficiency of the garlic clove peeling machine was in the range of 69.87–72.12% with average value of 71.11%. There was no control on the pattern and speed of flow of individual garlic cloves in the cylinder-concave clearance. Hence, the cloves were subjected to varying degrees of abrasion and friction forces. The cloves subjected to adequate magnitude of forces for sufficient duration remained unbroken and got their peels removed fully, while those subjected to higher or lower magnitude of forces and duration of application resulted in either damaged or partially peeled cloves. The average partially peeled cloves were 5.38%, and damaged cloves were 18.24%. However, past researchers (Mudgal, 2005; Prasad, 2013; Manjunatha *et al.,* 2014) have reported the maximum peeling efficiency and percent damage of 86.6 and 9.15%, respectively. Further, a recent research (Kaur *et al.,* 2019) reveals a maximum peeling efficiency of 48.13% at 400 rpm of roller speed.

An overall view of 60 g sample collected at the outlet of the machine in one of the trials is shown in figure 4. The garlic cloves which did not flow smoothly in the cylinder-concave clearance particularly near the outlet were subjected repeatedly to higher magnitude of abrasion, friction and compression forces, and they got broken in the process.

3.1.3 *Cleaning efficiency, percent blown cloves and percent material loss*

The average cleaning efficiency of the garlic clove peeling machine was 99.23%. Further, there was no blower loss. Release of oil from the bruises of the garlic cloves held the peels and broken cloves on the abrasive surfaces, and it accounted for 2.88–3.13%. It was observed that the accumulation of materials on the abrasive surfaces led to clogging in about 25 minutes of operation, resulting in significant reduction in peeling efficiency, yield of peeled garlic cloves and output capacity of the machine. Abrasive surfaces have to be cleaned using brushes leading to loss of productive time. Mudgal (2005) also reported the adhesion of fine skin removed from cloves to the lining material.

3.2 Feasibility of use of garlic clove peeling machine

Labour requirement and total electrical energy consumption for the operation of the prototype machine was found to be 0.67 man-h and 1.61 kW-h per kg of peeled garlic cloves, respectively. The plot of variations in cost of mechanical garlic peeling with annual use up to 300 hours is shown in figure 5. It indicates that the cost of mechanical peeling operation decreased with increase in annual use of machine. Further, the machine has to be operated for about 275 h/year to have the cost of mechanical peeling operation less than the manual peeling, and justify the use of the prototype garlic clove peeling machine over manual peeling. This annual use amounts to peeling of 412 kg garlic cloves per year and daily mechanical peeling for about one hour. This resulted in the saving of one hour for peeling one kg garlic. The cost of mechanical peeling operation for 275 h/year was INR 58/h or INR 39/kg. At this rate of annual use, the developed garlic clove peeling machine saved 60% time and labour over conventional manual peeling of garlic cloves. An unskilled trained worker may be engaged for one hour daily besides his regular duties in a small canteen or processing centres for mechanical peeling of garlic cloves. Thus, the developed electric motor powered garlic clove peeling machine suits well to the requirements of small canteen and processing centres.

Figure 4. Overall view of a sample collected at the outlet of the machine

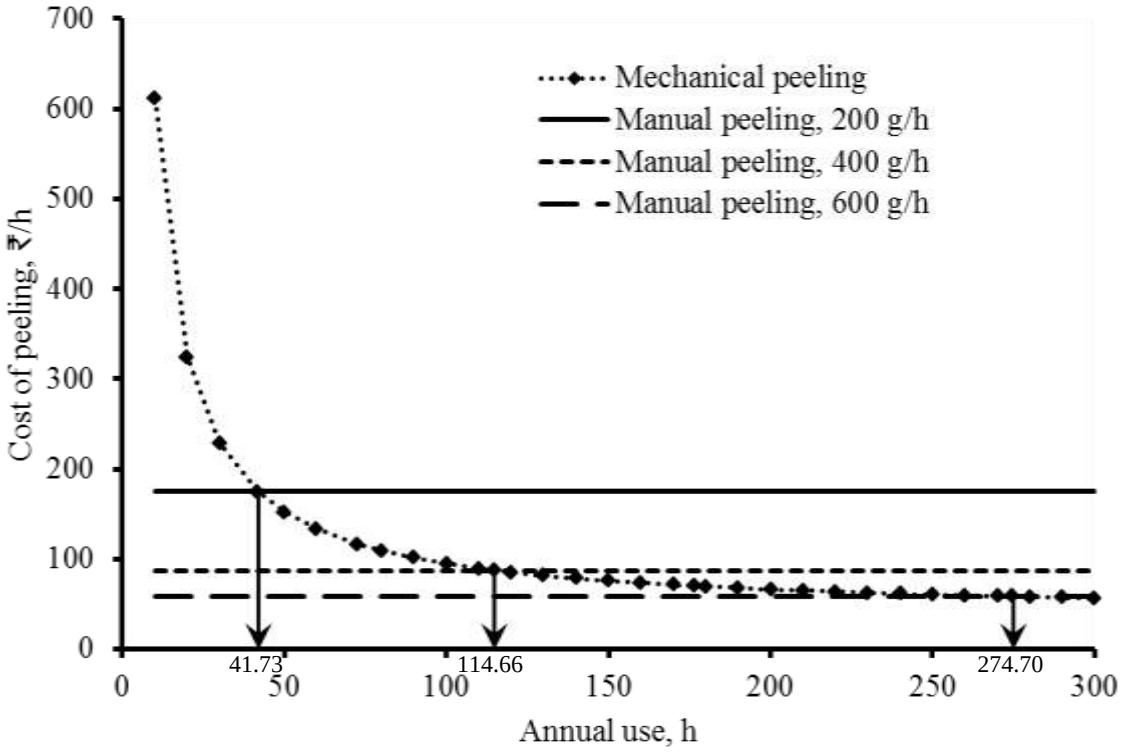

Figure 5. Cost of mechanical peeling of garlic cloves at various rates of annual use and its comparison with manual peeling

4. Conclusions

The prototype machine that removed peels from garlic cloves based on the principle of application of abrasion, friction and compression forces on the cloves in the tapered abrasive cylinder-concave clearance was found to have the potential for use in the small canteens and processing centres. The efficient operation of machine required drying of cloves to moisture content of 38–39% (w.b.) and continuous operation for about 25 minutes and then cleaning with brush to prevent clogging of the cylinder-concave clearance. Daily use of machine by a worker for atleast one hour is necessary to justify the use of machine for garlic clove peeling. Use of machine saved one hour for peeling one kg of garlic as against conventional method. There was saving of 60% of labour and time compared to manual peeling of garlic.

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