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Design and development of a turmeric polisher

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Abstract

Dried turmeric rhizomes are generally polished to remove the outer dirty skins, roots and soil, and to transform them to relatively smooth, bright and yellowish rhizomes. In farm level, turmeric polishing is carried out manually following conventional methods, which are slow, tedious and labor-intensive operation. To overcome these problems, a medium-size turmeric polisher was designed and fabricated in Farm Machinery and Postharvest Process Engineering (FMPE) Division of Bangladesh Agricultural Research Institute (BARI) during 2013–14. Length, width and height of the polisher were 1040 mm, 850 mm and 1450 mm, respectively. Weight of the turmeric polisher was 90 kg. A 0.37-kW single-phase induction-type electric motor was used as the source of power for operating the polisher. The polisher was tested in FMPE Division, Regional Spices Research Station (RSRS), Magura and Hill Agricultural Research Station (HARS), Khagrachari. The polisher took 25 minutes to polish a batch of 30 kg dried turmeric. The price of the polisher was Tk 30000. The average cost of polishing by the polisher was Tk 1.42 per kilogram turmeric against the hand beating polishing cost of Tk 5.12 per kilogram. The polisher can save 81% time and 78% cost of polishing than that of hand beating method. Payback period of the polisher is 97 hours. Therefore, the polisher can be recommended for turmeric polishing in Bangladesh as well as for other turmeric growing countries.

Introduction

Bangladesh is one of the major turmeric (*Curcuma longa*, Linn.) growing countries in the world. The production of turmeric is 139877 metric tons per year in Bangladesh and cultivated area is 25107 ha (BBS, 2016). Turmeric is extensively used in South Asia for preparing tasty and colourful curried dishes (Powar *et al.*, 2015). Turmeric not only adds its typical flavour but also helps to bring out taste in curries. It has a wide use as spices as well as medicine. It is used as a colorant, cosmetic and drug, which is useful for a number of diseases. The post-harvest operations of turmeric are cleaning, curing, boiling, drying, polishing and grinding. Dried turmeric is polished to remove the outer dirty skin, roots and soil particles, and transformed into relatively smooth, bright and yellowish rhizomes. Polishing can be done by hand or by beating the rhizomes in a gunny bag. This operation is carried out manually, which is slow, tedious and labor-intensive. The quality of turmeric powder depends upon the initial quality of rhizomes and the practices adopted in various post-harvest operations. Washing and polishing are two primary processes for quality enhancement. Arora *et al.* (2007) reported that mechanically-washed turmeric rhizomes in a rotary machine were useful for efficient washing and bruising. At the rotational speed of 40 rpm for 20 minutes, the color improved from dark yellowish brown to desirable olive yellowish color with increase in the surface smoothness (Arora *et al.*, 2007). Polishing drums are being used at many places of the world for cleaning and polishing of various agricultural products. Turmeric is polished by abrasive hard surface and against rough perforated surface when the turmeric-filled drum rotates as well as by rubbing rhizomes against each other (Arora *et al.*, 2007). Moghe *et al.* (2013) developed a human powered polisher having a flywheel and motor bicycle-drive mechanism with speed-increasing gear pair, a flywheel and torque-increasing gear pair that drove the process unit with square jaw. But, dusts were spread with rotation that polluted the working environment. Sukumaran and Satyanarayana (1999) developed a mechanical turmeric polisher, which consisted of 880 mm diameter mild steel drum with wire meshes wrapped one above the other. The polisher rested on ball bearings at the two ends on a rectangular stand having 600-700 kg/h capacity. It was operated by a 2-hp three-phase electrical motor. Powar *et al.* (2015) evaluated a turmeric polisher operated by 35 hp tractor, 5 hp diesel engine and electricity. All of them were made with octagonal metallic drum. Pal *et al.* (2008) developed a pedal operated hexagonal drum polishing machine, which allowed raw skin of polish turmeric to spread in working environment. In Bangladesh, small and useful polisher is yet not available. Therefore, this study was undertaken to design and develop a low-cost and labor-saving turmeric polisher for turmeric growers and small entrepreneurs, and to evaluate its technical and economic performance. Performance of the polisher was tested in laboratory as well as in the field.

Materials and Methods

The physical properties, such as shape, size, bulk density and true density of a popular turmeric variety (BARI Halud-2) in Bangladesh were determined. The length

and diameter of 100 turmeric samples were measured by a vernier caliper. The bulk density was measured by weighing a rectangular box of known volume (0.5 m^3) of turmeric and true density was measured by water displacement method. The bulk density of turmeric was required for designing the volume of drum and discharge chute of a turmeric polisher.

Design and fabrication

A turmeric polisher was designed by using physical properties of turmeric. The sketch of a turmeric polisher (Fig. 1) was drawn with Solid works software 2014. The polisher was fabricated as per drawing at the workshop of the Farm Machinery and Postharvest Process Engineering (FMPE) Division of Bangladesh Agricultural Research Institute (BARI), Gazipur during the period of 2013-14. The schematic view of the turmeric polisher is shown in Fig. 2. The materials used for fabrication of different parts of the machine were: MS angle bar, MS flat bar, MS rod, MS sheet, MS shaft, rubber sheet, ball-bearing, and small spares, all of which are locally available. The functional parts of the machine are power source, power transmission, rotating drum, mainframe and collection tray. The pictorial view of the turmeric polisher is given in Fig 3.

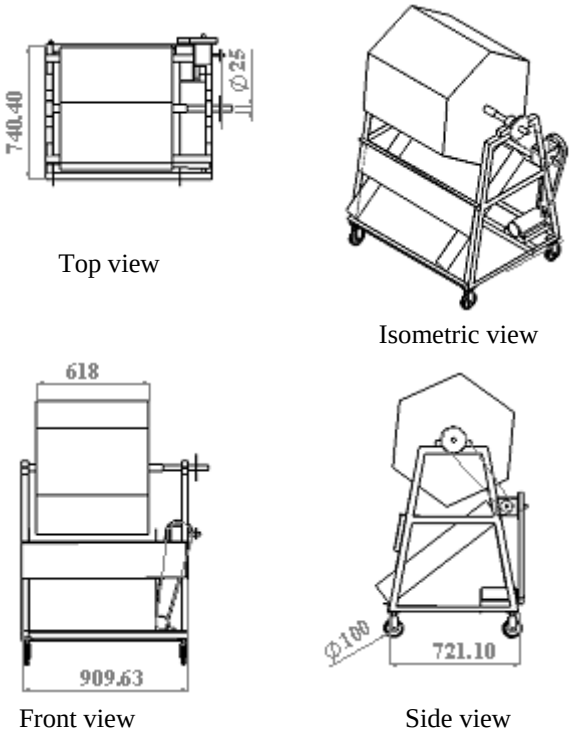

Fig. 1. Schematic views of turmeric polisher (all dimensions are in mm)

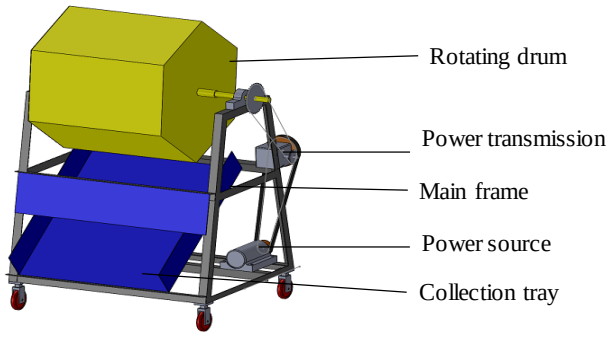

Fig. 2. The schematic isometric view of the turmeric polisher

Fig. 3. The pictorial view of the turmeric polisher

The functions of different parts of the turmeric polisher are briefly described below.

Power source: A 0.37-kW single-phase induction-type electric motor was used as the source of power for operating the polisher.

Power transmission: The flow diagram of the power transmission system is shown in Fig. 4. In the first step, speed of the motor was stepped down from 1400 to 583 rpm in the main shaft through gear box. The gear box ratio was 40:1 to reduce the speed from 583 to 14.5 rpm on the output shaft. The speed was further reduced to 27 rpm in rotary shaft of the rotating cylinder through chain and sprockets.

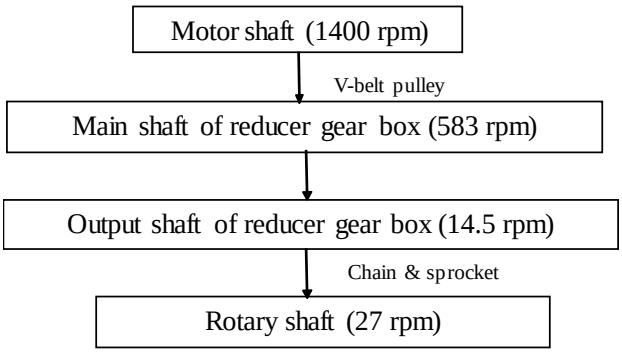

Fig. 4. Power transmission system of the turmeric polisher

Rotating drum: A rotating hexagonal drum of 610 mm length was framed with six polishing plates and two hexagonal plates. The material used was an MS sheet and an MS shaft. The shaft was of 25 mm in diameter and 1040 mm long. The entire cylinder was covered with six polishing plates of 350 x 610 mm size that were made with inner expanded wire mesh (6 x 7 mm). Radius of the hexagonal drum in circumscribing and inscribing circle were 690 mm and 590 mm, respectively. The cylinder was placed on two bearings on both ends of the shaft. Spikes (50 mm) in the polishing plates and the baffles on the shaft were provided for through mixing of turmeric and imparting additional rubbing action. For loading and unloading of turmeric, one polishing plate was used as the door hinged on the drum surface.

Mainframe: The mainframe was supported on four transport wheels. The main frame was made with two frame of 950 x 700 x 380 mm in dimension and the length of the connector was 900 mm. Electric motor, power transmission systems, rotary shaft, rotary cylinder and dropping cover were placed on the mainframe.

Collection tray: A collection tray of 800×720 mm dimension was made with MS sheet and MS flat bar to collect the polished turmeric.

Critical speed of polishing

During rotation inside the drum, the speed above which centrifuging occurred is called the critical speed. The speed of the polishing drum should be less than this critical speed, otherwise proper polishing of the rhizomes may not take place. Critical speed of the polisher was determined as (Pal *et al.*, 2008):

$$N_C = \frac{30}{\Pi}\sqrt{[\frac{g}{(R-r)}]} \quad \text{..... (1)}$$

where N_c is critical speed (rpm), g is acceleration due to gravity (9.81 m/s^2), R is radius of the drum (0.355 m) and r is radius of turmeric (m). It may be noted that for hexagonal drum, R was taken as the average radius of circumscribing and inscribing circles. The value of r was assumed to zero since it was very small compared to R. For proper stirring, designed critical speed (N_d) was taken as 60–80% of N_c (Kalra *et al.*, 2013). So, the designed critical speed was calculated using N_d as 60% of N_c, which was rounded to 30 rpm.

The specifications of the turmeric polisher are given in Table 1. The overall dimension of the designed polisher was 1040 mm x 850 mm x 1450 mm. The size of the polishing drum was determined from the physical properties of the turmeric. The drum was expected to be filled with maximum 50% of its holding capacity. It was rotated below the critical speed of 30 rpm to avoid centrifuging (Arora *et al.*, 2007). The polisher was movable due to its less weight (90 kg) and easily operable with single-phase electric connection of the farmers' house.

Table 1. Specifications of the turmeric polisher

Parameter	Dimension
Overall dimension	1040 mm x 850 mm x 1450 mm
Number of polishing drum	01
Length of the hexagonal drum	610 mm
Outer diameter of the hexagonal drum	690 mm
Inner diameter of the hexagonal drum	590 mm
Length of the main shaft	1040 mm
Power source	0.37 kW electric motor
Holding capacity of turmeric per batch	30 kg
Critical speed	30 rpm
Operating speed	27 rpm
Weight of the polisher	90 kg

Working principle

During rotation of the drum, polishing was done by rubbing the turmeric finger against the inside-expanded wire mesh surface. The outer skin, rubbed by polishing, fell through the perforation of the drum. The holding capacity of the turmeric polisher was generally kept 50% of volume of the drum to facilitate turning and proper mixing of dried rhizomes during polishing.

Performance evaluation

Testing and performance evaluation of the developed turmeric polisher were done during 2013-14. The results were compared with manual methods. The turmeric polisher was tested in laboratory of FMPE Division, BARI, Gazipur for evaluation of technical performance. The performance of the polisher was tested in two turmeric growing stations of BARI: Regional Spices Research Station (RSRS), Magura and Hill Agriculture Research Station (HARS), Khagrachari. To compare the performance with manual methods, manual polishing was done with the same sample in both the stations. The moisture content of the test samples was 11-12% (wb). The polisher was filled with 30 kg turmeric (Fig. 5). It was then operated for 10, 15, 20, 25 and 30 minutes. After every operating duration, the polished turmeric was discharged (Fig. 6) and the color was measured with chromameter to identify the optimum operating time. During polishing, machine speed, operating time, physical appearances, etc. were recorded.

Fig. 5. Feeding of turmeric in the polisher

Fig. 6. Discharging of turmeric from the polisher

Color analysis

The color of dried rhizome of turmeric samples was measured by a chromameter (CR-400, Minolta Co. Ltd., Japan) in CIE (Commission Internationale l'Eclairage) Lab chromaticity coordinates (Fig. 7). L^*, a^* and b^* represent black to white (0 to 100), green to red (-ve to +ve) and blue to yellow (-ve to +ve) colors, respectively. Out of five available color systems, the L*a*b* (Krokida *et al.*, 1998; Lozano and Ibarz, 1997; Maskan, 2001) and L*C*h^o (Zhang *et al.*, 2003) systems were selected since these are the widely used systems for evaluation of the color of dried food materials. The instrument was standardized each time with a white ceramic plate. Three readings were taken at each place on the surface of the samples and then the mean values of L*, a* and b* were calculated. The different color parameters were calculated following Camelo and Gomez (2004). The hue angle that indicates color combination is defined as

Hue angle = $\tan^{-1}(b^*/a^*)$ (when $a^*>0$) ..... (2)
Hue angle = $180°+ \tan^{-1}(b^*/a^*)$ (when $a^*<0$) .... (3)

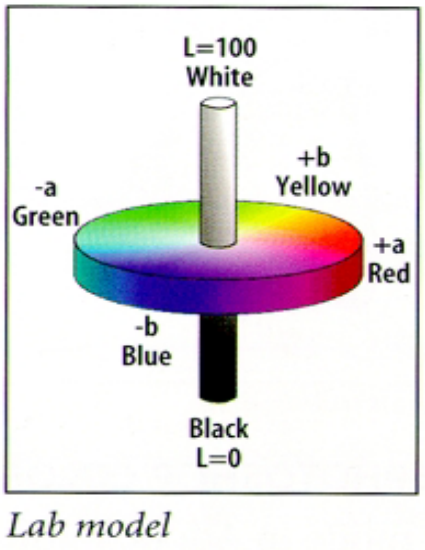

Fig. 7. CIE (Lab) chromaticity diagram

Machine output

The quantity of polished turmeric received in total time, including feeding, polishing and discharging time, was noted for machine output calculation as (Powar *et al.*, 2015).

$$M_0 = \frac{W_p}{t_p + t_c + t_{ul}} = \frac{W_p}{W_T} \quad \text{..... (4)}$$

where M_0 is machine output (kg/h), W_P is weight of polished turmeric (kg), W_T is total polishing time (t_p+t_c+t_{ul}, h), t_p is time of polishing (h), t_c is feeding time of raw turmeric (h) and t_{ul} is time of discharging of polished turmeric (h).

The capacity of the polisher was compared with traditional methods in the laboratory of FMPE Division. Two traditional methods of polishing turmeric fingers are found in Bangladesh. One puts 3–4 kg of turmeric in a sack and beats on cement floor by hand (Fig. 8); this is generally used in plain land of Bangladesh. Another method puts 5–7 kg of turmeric in bags and beaten by a simple paddle operated device; this method is used in hilly areas of Bangladesh (Fig. 9). The field performance of the machine was evaluated at Regional Spices Research Station, Magura and Hill Agricultural Research Station, Khagrachari.

Fig. 8. Hand-operated polishing method

Fig. 9. Paddle-operated polishing method

Economic analysis

Economic analysis of the turmeric polisher machine was done. Cost analysis included the operating cost of the machine that included both the fixed and variable costs. Fixed cost of the machine included depreciation, interest, and repair and maintenance. Annual interest (*I*) of bank was 14%. Variable costs included labor, electricity and materials. The price of the machine (*P*)

was Tk 30000 and machine life (L) was 5 years having working duration of 240 hours per year. Electricity cost was Tk 5.83 per kWh. One labor was required for operating the machine and the wage was Tk 400 per day. The cost of materials was 0.75 Tk/h. During cost analysis of the manual method, the price of the paddle-operated device was Tk 2500 and cost of materials was 0.75 Tk/h. For calculation of various costs: salvage value (S) = 10%P, depreciation = (P-S)/L, interest = ((P+S)/2)*(I/100), and repair and maintenance = 0.035P were used.

Results and Discussion

The physical properties of dried turmeric (BARI Holud-2) fingers (11% moisture content) are given in Table 2. Bulk density of turmeric was 492 kg/m^3 and porosity was 58%.

Table 2. Physical properties of turmeric

Physical properties	Range	Average value
Length, cm	3.25–5.50	5.12
Diameter, cm	1.00–1.30	1.20
Bulk density, kg/m^3	470–496	492.30
True density, kg/m^3	1130–1158	1148
Porosity, %	57–58	57.50

Color parameters of the polished turmeric at different polishing times are given in Table 3. It is revealed that lightness (L^*) and yellowness (b^*) of the polished turmeric significantly increased with the increase in polishing time, but there was no significant change in a^* value for 10 minutes although it changed after 15 minutes of polishing. The hue angle (h) of the non-polished fresh dried turmeric was significantly different from the polished turmeric, indicating justification of polishing the dried turmeric (Fig. 10). Color of the polished turmeric (both hue angle and b^* that represents yellowness) for 25 minutes (Fig. 11) was statistically similar with color of turmeric polished for 20 minutes, but there was significant difference between the color of turmeric polished for 25 and 30 minutes. So, polishing time was selected as 25 minutes for each batch. Moghe *et al.* (2012) reported that 20 minutes were required to polish a batch of turmeric.

Table 3. Color parameters of the un-polished and polished turmeric fingers at different polishing times

Polishing time (min.)	L*	a*	b*	h*
0 (un-polished)	18.59 e	0.93 a	14.53 d	86.33 d
10	24.48 d	0.93 a	21.61 c	87.53 c
15	24.94 d	0.74 c	22.57 c	88.12 b
20	30.38 c	0.81 bc	25.43 b	88.17 b
25	31.45 b	0.84 b	26.52 b	88.18 b
30	32.66 a	0.59 d	31.27 a	88.92 a
$LSD_{0.05}$	0.92	0.85	1.22	0.33

Fig. 10. Color of un-polished dried turmeric

Fig. 11. Color of turmeric polished for 25 minutes

Performance data of turmeric polisher obtained during the test in the laboratory of FMPE Division, BARI, Gazipur is given in Table 4. The Polisher took 25 minutes to polish a batch of 30 kg turmeric. After polishing of each batch, it required 5 minutes to discharge and refill in the polishing drum. During laboratory test, the capacity of the polisher was found to be 63.53 kg/h. Capacity of the manual polishing by hand beating was 8 kg/h, while it was 12 kg/h by paddle-operated beater using 4 kg and 6 kg in each batch, respectively. Thus, the use of the polisher saved 81% polishing time compared to the paddle-operated manual beating methods.

Table 4. Comparative performance of the turmeric polisher with manual polishing in the laboratory

Parameters	Machine	Manual method-1 (Hand beating)	Manual method-2 (Paddle beating)
Quantity processed, kg	60	60	60
Weight of turmeric per batch, kg	30	4	6
Operating time for 60 kg, min	57	450	300
Labor requirement, person	1	1	1
Capacity, kg/h	63	8	12
Time saving of polisher over hand beating, %		87	
Time saving of polisher over paddle-operated device beating, %		81	

Capacity of the turmeric polisher based on field and laboratory tests were found similar as compared in Table 5. During test at RSRS, Magura, the capacity of the polisher was found to be 63.53 kg/h. During field performance evaluation at HARS, Khagrachari, the capacity of the polisher was found to be 62.69 kg/h. The farmers expressed their satisfaction with the performance of the polishing machine.

Table 5. Field performance of the turmeric polisher

Parameters	Output at RSRS, Magura	Output at HARS, Khagrachari
Quantity polished, kg	90	120
Weight of turmeric per batch, kg	30	30
Operating time for tested quantity, min	85	115
Capacity of the polisher, kg/h	63.53	62.6
Labor requirement, person	1	1
Overall performance	Satisfactory	Satisfactory
Remark	Useful for polishing of turmeric at farm level	

Economic analysis was done considering the price of the polisher at Tk 30000 per unit. The cost of polishing was Tk 1.42 per kg (Table 6) and it is quite low compared to the production costs. On the other hand, for manual hand beating and bamboo made device, the polishing cost was Tk 6.34 and 5.12 per kg, respectively. Therefore, use of the polisher would reduce the cost of polishing by 77.60 and 72.27% compared to hand beating and paddle-operated device beating, respectively.

Table 6. Partial budget analysis of the turmeric polisher (as per fiscal year of 2017-18)

Price of the polisher	Cost by the polisher	Cost by hand beating	Cost by paddle-operated device
Price, Tk/unit	30000		2500
Life of the polisher, yr	5		1
Annual use, h	240		240
Annual fixed cost			
Depreciation, Tk/yr	5400		2250
Interest (14%), Tk/yr	2310		237.50
Repair and maintenance, Tk/yr	1050		87.50
Total fixed cost, Tk/yr	8760		2575
Total fixed cost, Tk/h	36.50		10.73
Operating cost			
Electricity, Tk/h	2.16		
Labor, Tk/h	50 .00	50.00	50.00
Material, Tk/h	0 .75	0 .75	0 .75
Total operating cost, Tk/h	52.91	50.75	50.75
Total cost, Tk/h	89.41	50.75	61.46
Polishing cost (63 kg/h machine capacity, 8 kg/h hand beating capacity and 12 kg/h paddle operated device beating capacity), Tk/kg	1.42	6.34	5.12
Payback period (Considering custom hiring rate as same as hand beating), h		96.79	

Conclusion

The proposed polisher was capable of polishing 30 kg dried turmeric fingers in 25 minutes. The polisher saved 81% and 87% polishing time over paddle-operated device beating and hand beating, respectively. The turmeric polisher saved 77.60% and 72.27% cost of polishing compared to hand beating and paddle-operated device beating, respectively. Considering custom hiring service as the same as hand beating (6.34 Tk/kg), the payback period of the turmeric polisher was 97 hours.

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