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Development and evaluation of a battery operated ginger (*Zingiber officinale*) washer for small and marginal farmers

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ABSTRACT

Ginger (*Zingiber officinale* Rosc.) is a commercial crop grown for its aromatic rhizomes which is used both as a spice and medicine. Being a root crop and owing to its physical structure, ginger rhizomes contain heavy soil load which makes washing as an important and prime post-harvest operation. Manual washing of ginger is a laborious and time consuming process. An experiment was conducted at the ICAR-Indian Agricultural Research Institute, New Delhi during 2020 with an objective to develop a continuous rotary drum type battery operated ginger washer and to evaluate its performance.The machine consists of the frame, feeding and discharge chutes, rotary drum with internal flights, pressure pump and nozzle assembly, battery and a drive unit. The developed washer was evaluated at different feed rate and residence time to appraise the washing efficiency, microbial washing efficiency, bruise index and colour of washed ginger. Increase in feed rate significantly reduced the washing and microbial efficiencies but increased mechanical damage. Washing and microbial efficiencies increased with increase in residence time.Significant difference in the colour was found between washed and unwashed ginger.The best set of conditions under which the washer could be operated was 150 kg/h and 25 sec, at which the machine was found to have mechanical washing efficiency of 92.48%, microbial washing efficiency of 93.18% and 4.54% bruise index. Besides eliminating drudgery of washing operation, the developed washer was found to save time, water and operating cost as compared to manual washing.

Keywords: Bruise index, Ginger, Microbial efficiency, Washing, Washing efficiency

Ginger (*Zingiber officinale* Rosc.) is one of the most important spices grown in India. It is harvested by uprooting or digging; and hence contain heavy soil load.To reduce soil load in freshly harvested ginger, a common practice followed is to allow uprooted rhizome on the field long enough to dry the adhering soil and gently shaking the rhizomes. This practice is not efficient in removing all impurities. Presence of dirt and soil reduces market value and affects quality during storage and transportation (Hordofa and Tolossa 2020). Berza *et al.* (2012) reported that unwashed and bagged ginger initiates mould growth that further facilitates spoilage of fresh ginger. Besides improving market price and maintaining quality, washing of ginger substantially reduces transportation and storage costs.

There are several ways of washing such as soaking in still or running water, use of water sprays and drum/brush/shuffle washers. The best washing procedure employs two or more methods selected based on the nature of the produce. In case of ginger, pressure washing is recommended to reduce soil and microbial loads. On-farm washing practices followed by farmers include manual washing, washing in crates, tubs, ponds or small water storage and sometimes use of low pressure water pumps (Emers 2012, Ghuman *et al.* 2014). These methods are tedious, labour intensive, induce mechanical injury to produce and are inefficient. Many researchers have developed small capacity manual/mechanical fruit and vegetable washers (Ambrose and Annamalai 2013, Adegbite *et al.* 2018, Verma and Karwasra 2018, Kumar and Azad 2020). There are limited studies focused on either developing or modifying existing washer for ginger (Pal *et al.* 2008, Jayashree and Visvanathan 2010, Kumar and Azad 2020). Further, present day researchers are focusing on developing solar powered or battery operated small agricultural machinery (Aradwad *et al.* 2018, Singh *et al.* 2019). Existing washer are batch type and not affordable by small and marginal farmers because of high initial cost, electricity requirement and their non-adoptability/portability for hilly terrain. Considering the above constraints, the present study was undertaken to develop a continuous type, battery operated rotary drum washer for ginger suitable for small and marginal farmers.

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MATERIALS AND METHODS

Present study was carried out at the Division of

Agricultural Engineering, ICAR-Indian Agricultural Research Institute, New Delhi during 2020.

Raw material: Unwashed raw ginger was procured from wholesale local vegetable market (Azadpur mandi), New Delhi. Material procured in gunny bags was stored at room temperature and used for evaluation purpose within 24 h.

Engineering properties of ginger rhizome: Engineering properties of agricultural material plays an important role in the design, development and operation of equipment employed in their processing (Arun Kumar *et al.* 2014). Therefore, some engineering properties of ginger rhizome, relevant to washer development were determined by the methods described and was used by various researchers (Arun Kumar *et al.* 2013, Ajav and Ogunlade 2014). Properties determined in the study include moisture content, linear dimensions, static coefficient of friction, bulk density and angle of repose (Table 1).

Selection of fabrication material: Continuous washers come in contact with muddy water; hence materials having adequate resistance towards muddy water were used in the fabrication of main drum and its components. The drum size was chosen to have a maximum capacity of 150–200 kg/h so that it could be affordable to small farmers (Fig 1). Main frame and other components were fabricated using mild steel for better strength and stability. Local availability, dead weight and cost of items and materials used for fabrication were given due consideration with the ultimate aim of utilizing the cheapest available materials, yet satisfying all strength requirements.

Table 1 Engineering properties of ginger rhizome

Property	Mean value
Moisture content (w.b)	88.6 ± 1.16
Length (mm)	94.8 ± 9.3
Width (mm)	24.2 ± 4.1
Thickness (mm)	17.6 ± 3.3
Bulk density (kg/m^3)	467 ± 42.9
Coefficient of friction	Plywood: 0.52 ± 0.14 GI: 0.47 ± 0.09 Stainless steel: 0.39 ± 0.10 Perforated plastic: 0.59 ± 0.21
Angle of repose (degree)	35.8 ± 2.1

Step-wise development process

Rotary drum: HDPE drum, 580 mm diameter and 930 mm height, was used. Sufficient numbers of holes (5 mm) were drilled on the drum surface to drain wash water. Screw flights (100 mm wide, 230 mm pitch) made of 2 mm HDPE acrylic sheet were provided along the internal length of the drum for forward movement of ginger. Dimensions of the screw flights were selected based on the engineering properties of ginger rhizome (Table 1).

Spray nozzles and pump: Different types of nozzles were procured and evaluated for their flow rate and coverage area using a spray patternator. Solid cone nozzle having 60° angle of distribution and 1 L/min flow rate was selected. Total of 8 nozzles were fitted on the central support rod of the drum. Two diaphragm water pumps of 12 V, 72 W and 10.5 kg/cm^2 pressure were connected to sprayers (4 sprayers per pump) to get total discharge of 7–9 L/min.

Selection of motor: Rotary drum was fitted with torque sensor and handle crank mechanism to assess the torque requirement for selecting drive unit. Under load condition, required torque at 25 rpm was calculated as 5.5 Nm. Therefore, a 12 V DC gear head motor of 24 W having a torque of 9 Nm was selected.

Battery requirements: Size of the battery was selected on the basis of run time required to operate selected water pump and motor for 6 h.

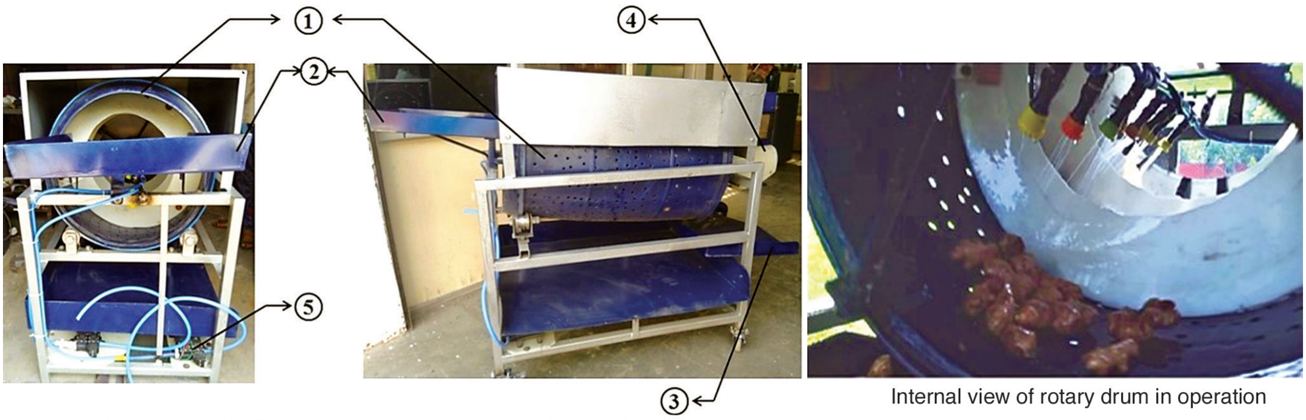
Battery Ah capacity = Current consumed × battery run time

Current consumed = 5.5 A (observed)

Battery Ah capacity = 5.5 × 6 = 33 Ah

Therefore, two 12 V 18 Ah batteries connected in parallel were found adequate for operating the washer for 6 h. Solar energy can be an alternate to grid power; considering 50% panel efficiency, a 200 W solar panel can charge two 12 V 18 Ah batteries in less than 3 h.

Frame: Mild steel square pipes and sheet of suitable gauge were used for fabrication of support frame and



Internal view of rotary drum in operation

1 – rotary drum assembly; 2 – feeding tray; 3 – outlet; 4 – drive unit; 5 – pressure pump

Fig 1 Battery operated ginger washer.

other parts such as feeding discharge chute, etc. Overall dimensions of the washer were 175 × 75 × 125 cm (L×B×H).

Performance evaluation of developed washer: Developed washer was operated at different feed rate (200, 150, 100 kg/h) and residence time (15, 20 and 25 s) for analyzing its performance. Feed rate was controlled by hand, by taking a known sample of rhizome in feeding tray. Residence time was maintained by adjusting the rpm of the drum using DC regulator. Ginger rhizomes were soaked in water for 10 min before they were fed into the washer. Experiments were performed in triplicate and the average was reported as final results.

Washing efficiency (η_w): It indicates the ability of a washer in removing soil/dirt adhering to the surface. Mechanical washing efficiency of ginger washer was determined as per the method described by Jayashree and Visvanathan (2010):

$$\text{Washing efficiency } (\eta_w), \% = \frac{W_{UW} - W_W}{W_{UW}} \times 100$$

where W_{UW}, weight of soil in 100 g of unwashed ginger, g; W_W, weight of soil in 100 g of washed ginger, g.

Microbial washing efficiency (η_m): The samples were analyzed for surface microbial load in terms of total plate count (Colony forming units, cfu) before and after washing and determined by serial dilution technique as described by Ranganna (1986).Whole rhizome was immersed in a beaker containing 1 L distilled water and shaken in a rotary shaker for 1 h, microbial load of extract water was estimated and expressed as cfu/cm^2 after calculating surface area of rhizome. Surface area of the rhizome was measured by assuming cylindrical shape; overall height was calculated by measuring height of each finger using vernier calipers and equivalent radius from the volume measured by water displacement method.

$$\text{Microbial washing efficiency } (\eta_m), \% = \frac{I_{ML} - F_{ML}}{I_{ML}} \times 100$$

where I_{ML}, initial microbial load, cfu/cm^2; F_{ML}, final microbial load, cfu/cm^2.

Bruise index (BI): It is a technique in which visual damage is quantified. About 1 kg of washed ginger was assessed for injuries such as scraping, cut and breakage and multiplied by scaling factor (Jayashree and Visvanathan 2010)

$$\text{Bruise index (BI)}, \% = 0.5\,(S_1) + 1\,(S_2) + 1.5\,(S_3) + 3\,(S_4) + 8\,(S_5) + 2\,(S_6)$$

Where S_1, scraping or surface abrasion (no depth); S_2, scraping depth between 0 to 5 mm; S_3, scraping depth between 5.1 to 10 mm; S_4, scraping depth between 10.1 to 20 mm; S_5, scraping depth > 20 mm; S_6, broken tip 25 mm in diameter or larger.

Colour: Surface colour of the samples was measured using colour reader (model: CR20, make: Konica Minolta) in terms of L*, a* and b*.

Statistical analysis: Two-factor completely randomized design was followed to determine the effect of varying feed rate and residence on the depended parameters. Analysis of variance was performed using SAS Version 9.3 available at ICAR-IARI, New Delhi. Pearson's correlation coefficients were also calculated.

RESULTS AND DISCUSSION

The developed ginger washer was evaluated at different feed rates and residence times to check the influence performance indices and was also compared with manual washing. Tests were carried out to optimize the best operational combination (Table 2).

Washing efficiency: Washing efficiency ranged between 95.87% (100 kg/h and 25 s) and 79.5% (200 kg/h and 15 s). Statistical analysis showed that feed rate and time had significant ($P<0.01$) individual influence on η_w, however their interaction effect was found non-significant ($P>0.05$) (Table 2). At a given residence time, $\eta_w$decreased with increase in feed rate. Similarly, for a given feed rate, the $\eta_w$was observed to increase with residence time. At higher feed rate, more rhizomes were fed into the washing drum at a given time resulting in overlapping and reduced flips of rhizomes within the drum. A similar influence of washing time on $\eta_w$was reported for batch type ginger (Jayashree

Table 2 Statistical analysis of the performance tests

	η_w	η_m	BI
Model F-value	50.99 (<.0001)	22.10 (<.0001)	185.0 (<.0001)
Feed rate (F)			
F_1	92.22	92.96	4.86
F_2	89.30	90.71	6.59
F_3	83.24	87.88	10.17
SEm±	0.372	0.321	0.115
CD (P=0.05)	1.126	0.97	0.347
F-value	151.182 (<.0001)	62.83 (<.0001)	556.62 (<.0001)
Residence time (T)			
T_1	84.42	88.50	9.51
T_2	88.37	90.37	6.94
T_3	91.96	92.67	5.17
SEm±	0.372	0.321	0.115
CD (P=0.05)	1.126	0.970	0.347
F-value	102.48 (<.0001)	42.33 (<.0001)	360.06 (<.0001)
Interaction (F × T)			
F-value	0.845 (0.5169)	1.762 (0.1858)	4.24 (0.0156)
CD (P=0.05)	NS	NS	0.601
CV	1.26	1.06	4.77

η_w, washing efficiency; η_m, microbial washing efficiency; BI, bruise index; NS, non-significant; value in parenthesis represent probability (P).

and Visvanathan 2010) and turmeric (Arora *et al.* 2007) washer. Maximum η_w observed in the developed washer is higher than that reported by Kumar and Azad (2020), 78%, for ginger. Washing efficiency of 91.17% was observed in manual washing with maximum possible capacity of only 40 kg/ha-person.

Microbial washing efficiency: The initial surface microbial load of unwashed ginger rhizome was found to be 3.36×10^4 cfu/cm^2. The $\eta_m$of ginger increased with increase in washing time but decreased with feed rate, and varied from 85.31% at 200 kg/ha for 15 s washing to 94.69% at 100 kg/ha for 25 s of washing. Individual influence of feed rate and time were significant ($P<0.05$), however interaction effect was non-significant (Table 2). As residence time decreased and feed rate increased, chance of rhizome to get exposed to jet of pressurized water decreased; consequently decreasing η_m. Manual washing was found to give 92.35% η_m; however, capacity observed in manual washing (40 kg/h) was very low. Observed results indicate that the developed washer meets threshold of minimum 80% η_m for a commercial washer as per WHO standards. Jayashree and Visvanathan (2010) also reported that the effect of washing time was significanton η_m of ginger in a mechanical washer. Arora *et al.* (2007) reported η_m of 87.20% for mechanical washing of turmeric rhizomes.

Bruise index: The effect of feed rate and time on BI of ginger indicated that the independent parameters had a significant influence ($P<0.05$; Table 2) on tested parameter. Interaction effects were also observed to be significant ($P<0.05$) on BI (Table 2). The value of BI varied from 3.25 to 12.88 for washing ginger at 100 kg/h for 15 s and 200 kg/ha for 25 s, respectively. At a given feed rate, the BI increases with decrease in residence time. Shorter residence time, in other way, higher peripheral speed of rotating drum causes more lift of ginger rhizomes along the inner side of the drum and more impact of fall; consequently more mechanical damage. Contrary, slow speed of drum or longer residence time results in sliding of rhizomes instead of lifting causing minimum damage during washing. Increase in BI with increase in feed rate could be due to high density of rhizomes with the drum and rhizome to rhizome rubbing and impact action. BI of about 5.10 was observed during manual washing, this could be due to agitation and rubbing of gingers by force of action of hand. Results observed in the current study are on par with observation of Jayashree and Visvanathan (2010) where authors reported significant influence of peripheral speed and washing time on BI. However, Arora *et al.* (2007) reported contrary results in mechanical washing of turmeric that bruising decreases with washing speed and time. This could be due to difference in surface and mechanical properties of turmeric and ginger.

Colour: The colour of ginger rhizome samples in terms of 'L', 'a' and 'b' are presented in Table 3. Colour values 'L', 'a' and 'b' of unwashed ginger rhizome were 35.28, 8.72 and 16.05, respectively. After machine washing, these values varied from 47.78–52.77, 7.43–7.93 and 18.80–20.58, respectively; corresponding values for manual washing were 49.37, 7.9 and 19.53. Significant ($P<0.05$) difference in the colour was observed between washed and unwashed ginger; however slight or no difference was noticed between manual and machine washing (Table 3). It was observed that values of 'L' and 'b' improved upon washing, both manual and machine, whereas 'a' values slightly decreased. Results showed that the feed rate had positive influence on 'a' values and negative influence on 'L' and 'b'; on the other hand, washing time had opposite influence on these values.

Table 3 Colour values of washed and unwashed ginger

		L	a	b
Unwashed		35.28^{a}	8.72^{c}	16.05^{a}
Manual washing		49.37^{b}	7.90^{b}	19.53^{cd}
Machine washing				
Feed rate	Residence time			
100	15	51.17^{c}	7.75^{ab}	19.38^{bcd}
	20	52.07^{c}	7.62^{ab}	19.56^{cd}
	25	52.77^{c}	7.43^{a}	20.58^{e}
150	15	49.20^{b}	7.79^{ab}	19.22^{bc}
	20	51.34^{c}	7.65^{ab}	19.38^{d}
	25	51.79^{c}	7.57^{ab}	19.97^{bcd}
200	15	47.78^{b}	7.93^{b}	18.80^{b}
	20	48.58^{b}	7.82^{ab}	19.27^{bcd}
	25	49.31^{b}	7.85^{ab}	19.54^{bcd}

Means in columns with different superscripts are significantly different at $P\leq0.05$.

Optimum operating conditions: The best suitable feed rate and residence time of washing of ginger for the developed washer was selected mainly based on the microbial washing efficiency. Minimum of 80% efficiency is desirable for any commercial mechanical washer (Dauthy 1995). Hence, the feed rate of 150 kg/h with residence time of 25 s corresponding to microbial washing efficiency of 93.18% was considered as the optimum machine parameters. At the optimum washing condition, the mechanical washing efficiency and bruise index were 92.48% and 4.54%, respectively. The colour values 'L', 'a' and 'b' of ginger washed at optimized conditions were 51.79, 7.57 and 19.97, respectively. Rated capacity (150 kg/h) of the developed continuous washer is higher than the capacity of the batch type ginger washer (60 kg/h) developed by Punjab Agricultural University and evaluated by Jayashree and Visvanathan (2010).

Cost economics: The estimated cost of the machine was ₹25,000 per unit including a set of 12V 18 Ah batteries. Considering washing capacity of 150 and 40 kg/h for machine and manual, respectively; labour cost of ₹500/day of 8 h and recharge life of batteries as 100 times with 4 h of operation, the calculated cost of operation, time and water requirement for developed washer are ₹50, 40 min and 300 L, respectively, per quintal; corresponding values for manual washing are 156, 150 and 900. Compared to manual washing, developed washer, besides eliminating drudgery of operation, cuts down water requirement, time and cost of operation to a tune of 66%, 73% and 67%, respectively.

A battery operated continues type of ginger washer was developed and evaluated. The results of the study showed that, residence time and feed rate affected the washing efficiency, microbial washing efficiency, bruise index and colour. Statistical analysis revealed that there was a significant difference on the performance parameters among the different feed rate and washing time. The optimized operating parameters were 150 kg/h feed rate and 25 s residence time, which gives, 92.48% washing efficiency, 93.18% microbial efficiency and 4.54% bruise index. Compared to manual washing, developed washer saves more than 60% time and operation cost besides saving 65% time.

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