Development and evaluation of a mechanical carrot washing machine

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Abstract: Vegetable production in Bangladesh has increased substantially (3 million tons) and ranked third position in the world. Root vegetable need to be cleaned before transporting from field to market. A base line survey was conducted on vegetables production, sorting, washing, and packaging in four vegetable growing districts such as Narsingdi, Bogura, Jashore, and Pabna district to generate baseline indicators which helped in developing a mechanical device for carrot washing. In all locations, root crops (carrot and radish) were washed manually by farmers to get better price. Manual method is drudgery, time consuming and unhygienic. A batch type carrot washing machine with holding capacity of 120 kg was designed and fabricated with locally available materials at Bangladesh Agricultural Research Institute, Gazipur. It was operated by an electric motor of 2.1 kW. Centrifugal water pump of 1.1 kW was used for water supplying. Washing period ranged from 5 to 7 minutes per batch. Washing and cleaning efficiency of the machine were 98% and 99% respectively. Washing improved the microbiological quality and safety of carrots. Washing cost of carrot was found to be 0.29 BDT kg^{-1}. Payback period and break-even points of the washing machine were 39 days and 145 h yr^{-1}, respectively. Benefit cost ratio of washing was found to be 2.44. The price of the washing machine was BDT 220000.0 (US$2500). Machine saved by 67% cost and 47% time compared to conventional manual carrot washing method. Farmers and traders would be benefited using the vegetable washing machine in custom hire basis.

Keywords: benefit cost ratio, carrot, colour, capacity, microbial load

Citation: Amin, M. N. and M. A. Hossain. 2021. Development and evaluation of a mechanical carrot washing machine. Agricultural Engineering International: CIGR Journal, 23 (3):111-120.

1 Introduction

Bangladesh ranks third position in vegetable production (3.0 million) in the world. Vegetable produce all-round the year in Bangladesh. Proper post-harvest processing and handling are essential factor of agricultural production. Post-harvest processes include the integrated functions of harvesting, cleaning, grading, cooling, packaging, storing, transporting and marketing. The adoption of improved post-harvest practices can reduce a substantial amount of food losses, improve overall food quality and safety, enhance consumers' acceptance, and thus add to the value of the marketable products (Matin et al., 2016). Various chemicals are widely used to reduce the incidence of post-harvest pest and diseases. Although it is effective, this method is discouraged or even discarded in recent years due to economic, environment and health concerns. The longer shelf-life and less post-harvest infestation of vegetables are needed to store and transport for marketing in the super market at different distant places. Post-harvest losses of important fruits and vegetables at different levels (growers, traders, wholesalers and retailers) were ranged from 23.6% to 43.5% (Hassan et al., 2010).

Washing is a standard postharvest handling operation for all root vegetables to remove soil, dirt, dust and

Received date: 2019-12-23 **Accepted date:** 2021-06-07

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external pathogenic structures. Unfortunately, in Bangladesh vegetables are hardly washed before entering into the marketing channel, and this contributes to poor quality and considerable losses of the produce.

In Bangladesh, after harvesting, vegetables are generally transported in the market without sorting, grading and washing. There are many micro-organisms, and dust on the surface of the vegetables. The products are infected by micro-organisms easily. Unhygienic products are sold in the markets. Some traders wash products with impure water of local ponds or canals. These washed products are harmful for human health that causes different diseases. Sanitation is a great concern to produce handlers, not only to protect the produce against post-harvest diseases, but also to protect the consumers' food borne illnesses. *Escherichia coli* 0157:H7, salmonella, Chryptosporidium, Hepatitis, and Cyclospera are among the disease-causing organisms that have been transferred via fresh fruits and vegetables (Burditt, 1982; Mitcham et al., 1997). Fruits and vegetables cleaning machine is used to remove impurities (field soil, dust and surface microorganism, fungicide/insect, sap and black spot) in freshly harvested vegetables. The capacity of the machine was 20 kg/batch of vegetables and rpm of it was 20-30. The machine is a multifunctional fruit and vegetable cleaning equipment with bubbles, spraying and brush available in cleaning with features such as highly cleanness, energy-saving, water-saving, stable and reliable. This equipment is suitable for cleaning fruits and vegetables. It is easy to operate, convenient maintenance and wiring (TNAU, 2017).

Zhengzhou Aslan Machinery Company Limited, Henan, China is fabricating and marketing stainless steel vegetable spray washing machine. The dimension of the machine was 4130×1010×1550 mm. Power required was 2.57 kW and capacity was 1500 kg per hour (Anon, 2010).

Dawn and Annamalai (2013) developed a batch type root vegetable washer like carrot and radish. The holding capacity of the washer was 10 kg. It consisted of a detopper, a stainless steel washing drum, centre shaft with holes for water spraying etc. The washing drum was provided with different matting namely 5 mm thickness rubber, 1.5 and 3.5 mm thickness plastic, respectively for effective cleaning of the vegetables. The washing and cleaning efficiency were 97 and 91% for carrot and 96 and 90% for radish, respectively using 3.5 mm thickness plastic matting. Kenghe et al. (2015) developed a prototype of fruit washer which consisted of cleaning unit, body and lid, rotor assembly, main frame and power transmission unit. The capacity of the washing the fruit varied from 340 kg h^{-1} to 892 kg h^{-1} and washing efficiency of the machine varied between 96.36% to 98.18% for all rotors used for potato washing. In Panjab, Sehgal and Arora (2006) designed and fabricated a stainless steel, portable, electric power (0.38 kW) operated vegetable washing machine. The inner rotary drum of the washer was made of stainless steel with 1.5 mm thickness, 760 mm length and 620 mm diameter. Washing efficiency ranged from 90.2% to 95.5% and capacity varied from 100-600 kg h^{-1} depending upon the types of vegetables washed. Capacity for the carrot was 350-400 kg h^{-1} and washing time was 8 minutes at the speed of 40 rpm.

Carrot vegetables is grown under soil and contaminated with muds, dust and idrt. For making them consumable, the need to wash properly. Large scale washing of carrot in Bangladesh is carried out manually using labours' feed and hands. This is very unhygienic and stinks. The study was conducted to develop a simple mechanical washing machine for vegetables to reduce postharvest losses and marketing hygienic products. In Bangladesh, there is no prototype of mechanical washing machine for washing of vegetables. In commercial purpose, a vegetable washing machine is needed for getting hygienic fresh vegetable in local and export markets.

2 Materials and methods

2.1 Baseline survey

Four vegetable growing districts such as Narsingdi, Bogura, Jashore, and one major carrot growing area Pabna were purposively selected during 2017-18 to collect baseline data and information on vegetable production and postharvest treatments. Two upazila from three districts and one upazila from Pabna were selected with the consultation of vegetable scientists of Bangladesh Agricultural Research Institute (BARI). The selected areas were listed in Table 1.

Table 1 Selected study areas for primary data collection

District	Upazila
Jashore	Jashore Sadar and Bagharpara
Bogura	Bogura Sadar and Shibgonj
Narsingdi	Raipura and Shibpur
Pabna	Ishwardi

Total of 121 respondents, among them 71 were vegetable farmers, 30 *Paiker* (Intermediary) and 20 retailers was randomly selected for interviewing to collect primary data and information. Primary and secondary markets in the study area were taken into consideration.

Survey questionnaire was developed by incorporating indicators for fulfilling the study objectives. The draft questionnaire was modified with the help of Agricultural Economics Division, BARI through pre-testing in the project area at Palpara bazar and Bramandi village in Shibpur upazila under Narsingdi district during 2017. Trained enumerators and scientists of the project collected primary data from selected farmers and traders using structured questionnaire through personal interview. Secondary data were also collected from journal papers, reports and internet.

2.2 Design of the root crop washing machine

The root crop washing machine was designed on the basis of base line survey results.

The mechanical vegetable washing machine was designed with following consideration

1) The capacity of the machine should be 0.5-0.75 ton per hour for root vegetables

2) It should be portable (for easy movement)

3) Fabrication cost should be minimum as possible

4) Water circulation should be controlled

5) Root vegetables should be cleaned properly

6) Power transmission system should be easy

7) Minimum power should be used

The sketch of the machine was drawn using AutoCAD and Solid Work 17 software showing different parts with dimensions.

2.2.1 Brief description of root crop washing machine

A mechanical root crops washing machine was designed and fabricated at Farm Machinery and Postharvest Process Engineering Division, BARI, Gazipur during September to December 2017. It was fabricated with MS sheet, MS flat bar, nylon shaft, brush, MS shaft, FL bearing, chain-sprocket, wheel, motor, gear reducer, magnetic contact, and Off-On switch etc. The main parts of it are: i) Half circle tank; ii) Nylon brush roller; iii) Power transmission system; iv) water circulation system; v) delivery chute; vi) Electric system. An isometric view of the machine is shown in Figure 1. The top, front and side views of the root crop washing machine are presented in Figure 2. A photographic view of the machine is shown in Figure 3.

2.2.2 Description of main parts of the machine

2.2.2.1 Half circle tank

A half circle tank was made of MS sheet and MS angle bar which was welded to a separate frame of MS angle bar. The frame was made of MS angle bar. The tank had conveyor brush rollers, bearing, casing, delivery chute and water spray pipe and electric board etc.

2.2.2.2 Brush type roller

Conveyer brush rollers are key functional part of the root vegetables machine. It includes fibre shaft, MS shaft, nylon brush, FL and PL bearing, chain, sprocket, clamp etc. Conveyer brush roller was made of fibre shaft along with nylon brush. Each end face of the fibre shaft was blinded with metal plate that was attached with screw, and MS shaft was inserted through the fibre shaft. The shaft was welded with the metal plate. The sprocket was welded with the MS shaft. The other end of the shaft was inserted into the bearing that fixed with tank to rotate easily. The conveyer brush rollers were rotated by means of chain and sprocket. Power was transmitted to shaft of the roller from motor by chain and sprocket. All (Ten) brush rollers were rotated clockwise. It was used to clean of mud from the root vegetables and convey the vegetables from one end of the machine to another.

2.2.2.3 Power transmission system

Electric motor as a prime mover was used for rotating the washing machine. Motor speed was stepped down from 1450 to 115 rpm using gear reducer and belt-pulley. Power was transmitted to the shaft of the brush rollers from shaft of gear reducer by chain and sprocket.

2.2.2.4 Water supply system

It is one of the essential parts of the washing machine to supply water for cleaning vegetables. Electric water pump was used to supply water for washing of vegetables. A single perforated pipe was placed horizontally that was fixed on the longitudinal sides over the machine. Water flow was maintained by a regulator valve.

2.2.2.5 Electric system

A magnetic contact and off-on switch were used to control the motor and pump.

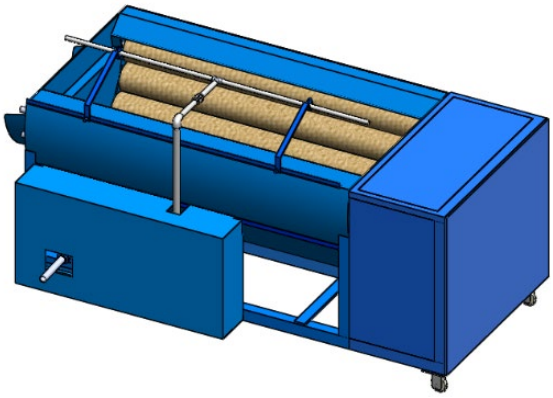
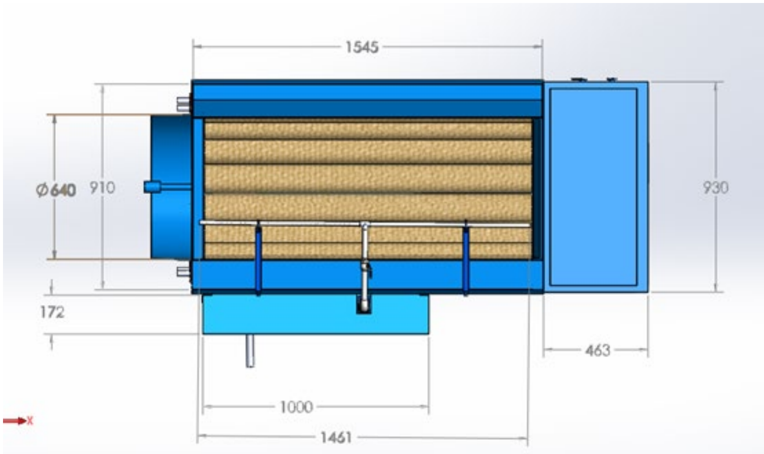
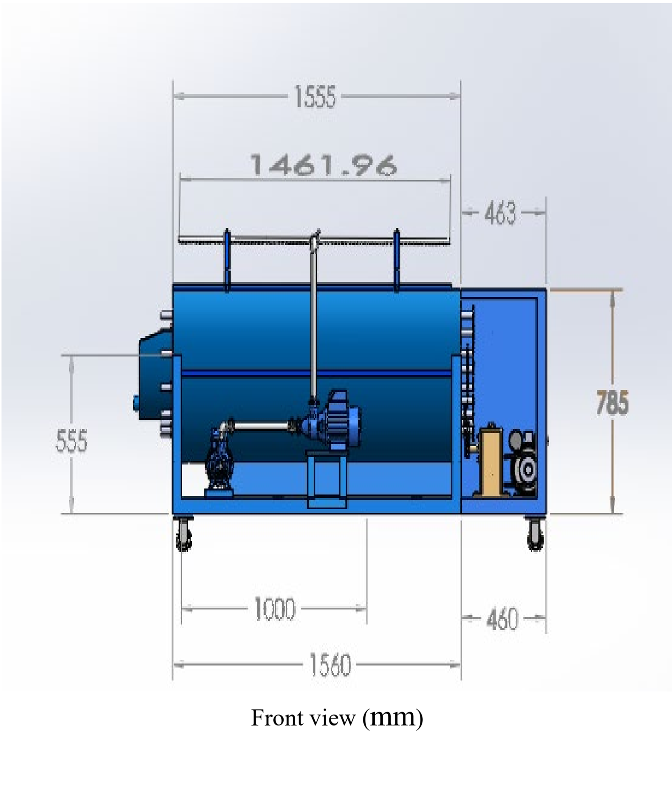


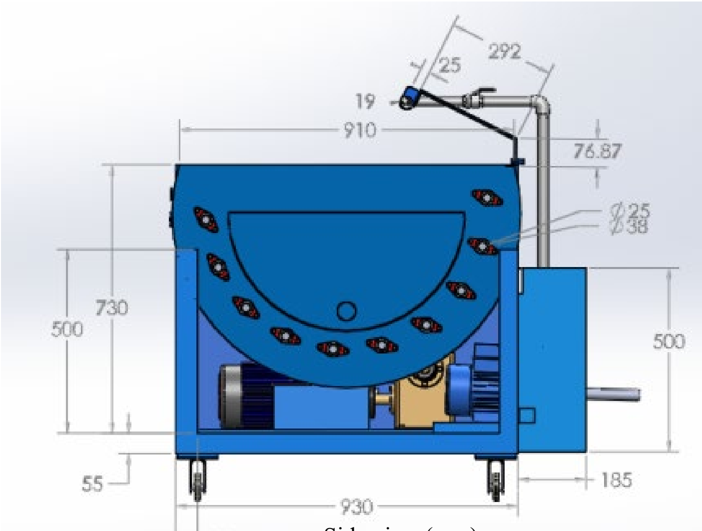
Figure 1 Isometric view of root crop washing machine



Top view (mm)



Front view (mm)



Side view (mm)

Figure 2 Front, top, side and isometric views of the root crop washing machine

Figure 3 A photographic view of root crop washing machine

2.3 Working principle

First, the machine is placed on plane surface and shady place near water and electric source. The water tank is filled with fresh water. Then the motor is started to run the conveyer brush and pump is started to supply water through perforated pipe. Harvested root crops are directly fed inside brush roller of the machine. About one to two minutes after operation, water supply is started for removing mud. They are rolling slowly among them by 5-7 minutes. Later on, water is sprayed and the washed vegetables are collected in a plastic crate or jute sack through delivery chute. This process is continued. Finally, the washed vegetables are carried out to the drying place to get their surface dry.

2.4 Performance parameters

The performance of the developed vegetable washing machine was evaluated regarding on the washing efficiency and cleaning efficiency as Equation 1 mentioned below.

$$\text{Washing efficiency} = \frac{\text{Weight of the carrot after washing}}{\text{Weight of the carrot before washing}} \times 100 \tag{1}$$

Cleaning efficiency is the removal of fibrous roots from the rootstalk. In a sample, the number of cleaned tubers free of the fibre refers to the extent of cleaning as given in Equation 2.

$$Cleaning\ efficiency = \frac{\text{No of cleaned roots free of fibres}}{\text{Total number of roots}} \times 100 \tag{2}$$

2.5 Determination of colour

The peel colour of carrots was measured using a chroma meter. An 8 mm diameter measuring head mounted on the meter was calibrated each time with a standard white plate. Colour measurements were recorded using Hunter L*, a* and b* scale (Hunter, 1975; Francis, 1980). The "L*" coordinate is a measure of lightness (white-black and ranges from no reflection L=0 to perfect diffuse reflection *L=100), the a* scale ranges from negative values for green to positive values for red and the b* scale ranges from negative values for blue to positive values for yellow. The L*, a* and b* values were converted to hue value and chroma (McGuire, 1992). The C* represented the vividness of colours with values ranging from 0=least intense to 60 =most intense. The h° is actual or perceived colour that used to classify the kind of colour, which vary continuously from 0° to 360°. A h° of 0° corresponded to h° of 270. The colour was measured using CIELAB scale at D65 (Daylight–Neutral) illuminant as shown in Figure 4. Three readings were taken at three points on the surface of each carrot and the mean values of L*, a* and b* were calculated.

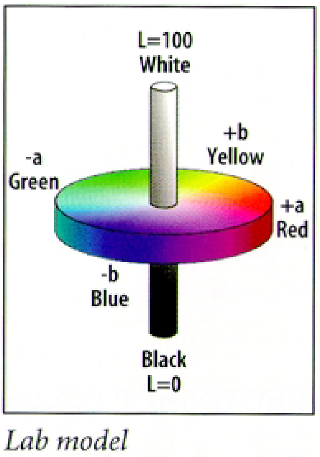


Figure 4 CIE (Lab) chromaticity diagram

Hue value ($h°$) and chroma ($C*$) were calculated using the following equations (Lopez-Camelo and Gomez, 2004).

$$\text{Hue angle} = \tan^{-1}\left(\frac{b*}{a*}\right) \text{ (when } a*>0) \quad (3)$$

$$\text{Hue angle} = 180° + \tan^{-1}\left(\frac{b*}{a*}\right) \text{ (when } a*<0) \quad (4)$$

$$\text{Chroma} = (a*^2 + b*^2)^{0.5} \quad (5)$$

2.6 Laboratory test

Fresh carrot was harvested from experiment field of Farm Machinery and Postharvest Process Engineering Division, Joydebpur, Gazipur to conduct preliminary test of the machine for checking functional parts of the machine. Quantity of vegetables, washing time, speed of conveyor and brush roller, electric energy use, water use, water pressure and injury of vegetables after washing were recorded during operation of the machine. Quality of washed and non-washed carrot was observed in FMPE postharvest laboratory. Microbial load (TABC, TCC, E.Coli, Salmonella spp. and yeast & molds count) of washed and unwashed carrots was determined in research laboratory of WAFFEN (Water Food Feed Environment) research laboratory, Dhaka.

2.6.1 Field performance test

Fresh carrots were harvested from farmer's field at Musurikhola, Saver, Dhaka to test the machine. Quantity of vegetables, washing time, speed of conveyor and brush roller, water use, water pressure and injury of vegetables after washing were recorded during operation of the machine. Quality of washed and non-washed carrot was observed in FMPE postharvest laboratory.

2.7 Economic analysis

2.7.1 Cost estimation for fabrication of vegetable washing machine

The fabrication cost of the machines was calculated including cost of materials, labour, overhead, incidental expenses.

2.7.2 Washing cost estimation of root vegetable machine

Economic analysis of the vegetable washing machine was done as per standard procedure. Currency in this study is expressed in BDT (Bangladeshi Taka) (US$ 1.00= BDT 85.00). Operating cost of the machine included the fixed cost and variable cost. Fixed of the machine included capital consumption and shelter. Variable costs included labour, electricity, water, materials, repair and maintenance (R&M). The price of the machine is BDT 220000.00 and machine life is five years. Working duration is 175 days per year. Two labours are required for operating the machine. Four hundred litres of water is required for washing of one ton of carrot. Labour wage is BDT 500 per day and water charge is 100 BDT/h and materials cost is 1.00 BDT h^{-1}. Interest rate of investment is 12%.

Fixed cost of the machine included annual depreciation, interest on investment, and shelter. Capital consumption included depreciation and interest.

1) Capital consumption (CC)

$$CC = (P - S)CRF + S \times i \quad (6)$$

Where, *P*=Purchase price (BDT); *S*=Salvage value (BDT); *CRF*= Capital recovery factor and *i*= Rate of interest.

$$CRF = \frac{i(1+i)^L}{(1+i)^L - 1} \tag{7}$$

where, L=Life of machine (year).

2) Shelter, T=3.0% of purchase price of the machine (BDT).

Total fixed cost per year

$$FC = CC + T \tag{8}$$

Where FC= Fixed cost (BDT year^{-1}).

Variable Cost

In calculation of variable cost (VC), the following relations were assumed

1) Labour cost per hour, L_b=BDT man-h^{-1}

2) Electricity cost per hour, E=Lit h^{-1}

3) Repair and maintenance *(R&M)* cost per year =3.5% of purchase price of the machine

4) Water charge, BDT h^{-1} (0.03 BDT L^{-1} × 3000 L h^{-1})

5) Materials cost (plastic crate, bowl, triple, pipe, pedestal fan etc)

Total variable cost

$$VC = L_b + E + R\&M \tag{9}$$

Annual cost/operating cost

$$AC = FC + VC \tag{10}$$

3 Results and discussion

3.1 Base line study

The study revealed that vegetable washing is generally practiced by farmers and Paikers and it varied from location to location (Table 2). Sorting and grading of vegetables were done either farmers or Beparis/Piakers. In all locations, red amaranth and root crops (carrot and radish) were washed by farmers to get better price. Farmers and traders used bamboo basket, plastic crate, plastic bag, and jute sack for packaging of selected vegetables. Washing and grading of vegetables was a profitable activity to the farmers.

Table 2 Sorting, washing and packaging status of vegetables in Narshingdi, Bogra, Jashore and Pabna districts

Parameters	Narshingdi		Bogra		Jessore		Pabna	
	Farmers	Traders	Farmers	Traders	Farmers	Traders	Farmers	Traders
Sorting manually								
Carrot	-	-	100%	50%	0%	20%	50%	-
Red amaranth	0%	33%	100%	1%	66%	0%	-	-
Brinjal	22%	66%	100%	43%	100%	20%	-	-
Washing manually								
Carrot	-	-	87.5%	50%	0%	20%	87%	-
Red amaranth	22%	33%	87.5%	57%	100%	0%	-	-
Brinjal	22%	28.5%	87.5%	43%	0%	40%	-	-
Packaging							-	-
Carrot	-	-	Plastic bag, bamboo basket	Plastic Bag, plastic crate, Jute sack	No produce	Jute sack	Plastic bag, Jute sack	-
Red amaranth	bamboo basket	bamboo basket	Bamboo basket	bamboo basket	Bamboo basket	bamboo basket		
Brinjal	Jute bag, Bamboo basket	Plastic bag, Jute bag,	Bamboo basket, Plastic bag	Plastic Bag, plastic crate, Jute sack	Bamboo basket	Plastic Bag, Jute sack	-	-

3.2 Performance test

The performance result of the machine is presented in Table 3. The rotation of rollers in same direction was better performance than anti direction of roller due to carrots were higher rolling and more friction between carrots surface. The higher capacity was found in same rotational direction of all rollers than that of anti-rotational direction of half of the total rollers. Washing time was required seven minutes per batch in same direction of rollers. The higher capacity (0.986 ton per hour) and cleaning efficiency (99%) of the washing machine was found in same direction of rollers than those of anti-direction of rollers. The efficiencies of washing and cleaning of the machine in same direction was found to be 98% and 99% respectively. No injured carrots were observed. Zhengzhou Asian Machinery Company Limited, Henan, China fabricated similar vegetable washing machine having capacity of 1.5 t h^{-1}.

Table 3 Performance test of the machine for carrot

Rotational direction of roller	Weight of harvested carrots, kg	Weight of washed carrots, kg	Washing time/batch, min	Roller Speed, rpm	Quantity of water, L	Capacity, kg h^{-1}	Washing efficiency,%	Cleaning efficiency, %
Same direction of all rollers	115.0	113.0	7.00	113.0	16.0	986	98	99
Anti direction of half of the total rollers	117.5	115.5	9.30	112.3	30.0	758	98	98

3.3 Colour comparison between washed carrot by machine and unwashed carrot

Different colour parameters of the carrots washed by machine and unwashed are shown in Figure 5. It was observed that *a** indicated that washed carrots was better in red colour and *b** indicated that higher yellow colour of washed carrots than that of unwashed carrot. Hue angle (h) indicated that machine washed carrots were reddish-yellow colour than that of unwashed carrot. It prevails that machine washed carrot was glossy (C=44) and attractive that fetch higher price and consumer acceptance.

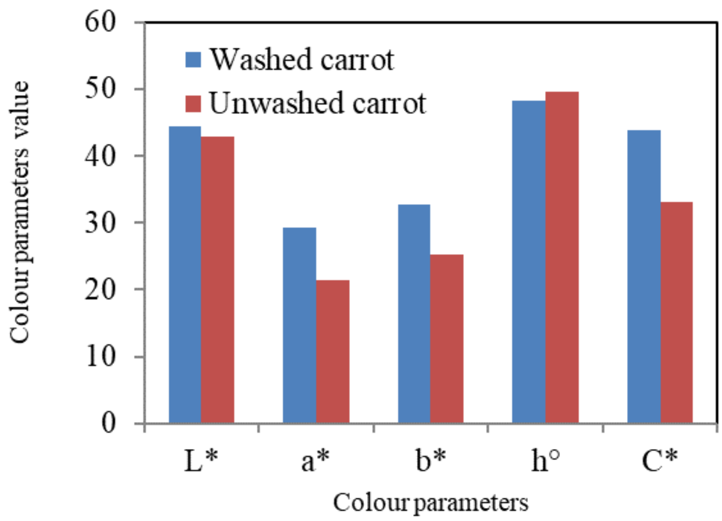


Figure 5 Colour comparisons between washed carrots by machine and unwashed

3.4 Profitability analyses

The washing cost, payback period and BCR, of washing machine is shown in Table 4. Profitability analysis revealed that the method of carrot washing incurred fixed and variable costs. The lion share of cost was estimated for variable cost for the method. Fixed cost included two cost items namely capital consumption and shelter, whereas variable cost included labour, electricity/fuel, R & M, materials and water charge. The washing cost carrot was 0.29 BDT kg^{-1}. It saved 67% cost and 47% time compared to conventional manual carrot washing method.Table 4 Economic analysis of the vegetable washing machine

Cost item	Value
Machine price, BDT	220000
Machine life, yr	5
Fixed cost (FC)	
1. Capital consumption (CC), BDT yr^{-1}	57567.00
2. Shelter (T), BDT yr^{-1}	1100
Sub-total, BDT yr^{-1}	58667.00
Sub-total, BDT. h^{-1}	42.00
Variable cost (VC)	
Labour, BDT h^{-1}	125
Electricity, BDT h^{-1}	18
Fuel cost, BDT h^{-1}	0
Lubricant, BDT h^{-1}	0
R&M, BDT h^{-1}	6.00
Materials, BDT h^{-1}	1

Water cost, BDT h^{-1}	100
Sub-total	250.00
Total cost (FC+VC), BDT h^{-1}	292.00
Capacity of the machine, t h^{-1}	1.0
Washing cost (Total cost/capacity), BDT t^{-1}	292.00
Payback period, days	39
BCR	2.44

Note: Use BDT interest of Taka 1 US$=85BDT

3.4.1 Break-even point

Break-evenpoint of root crop washing machines is presented in Figure 6. It is observed that BEP's of the root crop washing machine was 145 h per year. Therefore, vegetable washed by the machine could be profitable to traders when the annual use of the machine exceeds 145 hours.

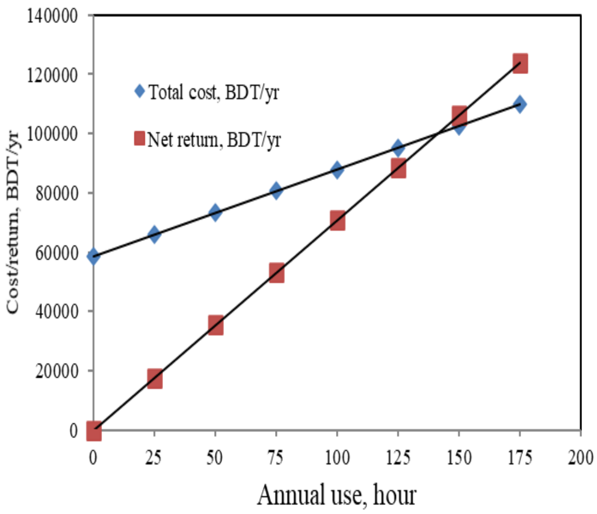


Figure 6 Break-even point of root crop washing machine

3.5 Microbiological test results

Microbial load of washed and unwashed carrots was presented in Table 5.

Table 5 Determination of microbial load of unwashed and washed carrots

Parameters	Unwashed carrots		Washed carrots	
	BE(CFU g^{-1})	AE	BE	AE
Total aerobic bacterial count	4.41×10^5	ND	1.83×10^5	ND
Total coliform count	7.50×10^4	ND	4.83×10^4	ND
E. coli	4.71×10^3	ND	<10	A
Salmonella spp.	<10	A	<10	A
Yeast & mold count	2.67×10^4	ND	7.14×10^3	ND

Note: BE:Before enrichment; AE: After enrichment; ND: Not done; A: Absent; Detection limit: 10 CFU g^{-1}.

The unwashed carrots were found contaminated with E. coli, an indicator bacterium of faecal origin. In addition, the total aerobic count, total coliform count and total yeast and mold count was within the maximum permitted level (ICMSF, 2000). On the contrary, water washed was able to completely eliminated E. coli from the carrots. In addition, approximately 1.0 log CFU g^{-1} of reduction of APC, TCC and TYF count was recorded in washed carrots.

4 Conclusion

A root crop washing machine was developed operated by an electric motor of 2.1 kW. Overall dimension of the machine is 227×910×920 mm. The capacity of the machine was 120 kg per batch. Washing and cleaning efficiencies were about 98% and 99% respectively. Surface colour of carrot washed by the machine was better than (reddish-yellow) that of unwashed carrots. Washing cost was found to be 0 0.29 BDT kg^{-1}. Payback periods root crop washing machine was 39 days. Breakeven point of the washing machines was 145 h yr^{-1}. Benefit cost ratio of the machines were comparatively higher so washing of vegetables is a profitable activity to the traders. Microbial load was eliminated through washing the carrot with water. The farmers could not effort the machine but traders or community able to purchase the machine for commercial purpose. Therefore, there is a good opportunity for farmers and traders to increase income and generate employment using the machine. Carrot washing may be recommended for washing carrot for hygienic marketing and consumption.

Acknowledgement

The authors are very thankful and acknowledge to Bangladesh Agricultural Research Council, Farmgate, Dhaka for financial supports under "Research Grant Project" to conduct the study and develop the machine. The authors are also grateful to BARI for providing physical and logistic supports to carry out the study successful.

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