

Development and performance evaluation of a tomato grading machine

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Abstract: Grading is the process of categorizing fruits and vegetables on the basis of color, size, stage of maturity, or degree of ripening. Fruit and vegetable grading is an important process that influences quality, and handling can preserve the crop for later use and plays a major role in the food processing industries. In Bangladesh, tomato grading is done manually when needed. Manual grading is a labor intensive and inefficient process. Therefore, this study involves the design and fabrication of a low-cost tomato grading machine so that they can grade tomatoes easily, faster, and effectively. The proposed grader consisted of units including lifting system, conveyor system, grading unit, collector and electric motor. To run the machine with a controlled speed An AC electric motor was installed. The total fabrication cost of the tomato grader machine was US\$ 273.33. Compared with manual grading, the machine performs much better. Manual tomato grading in Bangladesh typically handles about 150 kg h⁻¹ per person, causes around 4%–6% damage, has a grading efficiency of about 60–70%, and costs roughly US\$ 0.009 per kg. In contrast, the machine achieved a much higher capacity (540 kg h⁻¹), lower damage (1.5%), higher grading efficiency (76%), and a significantly lower grading cost (US\$ 0.0026 per kg), demonstrating clear advantages in efficiency, product quality, and cost savings.

Keywords: tomato, grading capacity, fabrication cost, power consumption, damage

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1 Introduction

Tomato is a self-crossing annual crop. The popularity of tomatoes continues to grow in 2025, driven by their reputation as a "superfood" with extensive health benefits and versatility in global cuisines. Tomatoes are packed with antioxidants like lycopene and vitamins (C, A, K) and minerals (potassium), offering benefits for heart health, skin, immunity, digestion, and cancer prevention by reducing oxidative stress, supporting blood pressure,

boosting collagen, and protecting cells from damage, making them great for overall wellness, even potentially aiding vision and bone health (Rao and Agarwal, 2000). It is a short-duration vegetable crop (Heuvelink, 1996). According to data from FAOSTAT (2024), the world produced 190 million metric tons of tomatoes. Tomato cultivated in all parts of Bangladesh due to its adaptability to wide range of soil and climate and the production of tomatoes has increased in Bangladesh about 6.5 times after 1971

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(Haque et al., 1999). In 2018-2019, the total cultivation area of tomatoes was 2.82×10^4 ha, and the production was around 3.9×10^5 metric tons. In 2019 -2020 the production of tomatoes in Bangladesh increased to 4.15×10^5 metric tons. In 2019 -2020, 4.5×10^5 metric tons of tomatoes were grown by the farmers in our country with an area of 2.95×10^4 ha (BBS, 2022).

Tomatoes are not only seasonal but highly perishable and deteriorate very fast within 48hr after harvest resulting in huge losses (Muhammad et al., 2010). Sorting fruits and vegetables according to their color, size, maturity stage, or level of ripening is called grading (Lalam et al., 2025). Grading fruits and vegetables is a valuable activity that affects their quality and handling. It helps store the product for future use and plays a major role in the food processing industries. Foreign materials or undesirable elements can be removed significantly by applying a grading system on harvested crops.

A vital goal of agriculture is to produce and distribute fresh fruits and vegetables to local markets and vendors. To satisfy the growing need for sufficient food production and market supply, a number of innovative technologies have been developed and implemented in the food industry (Tripathi and Maktedar, 2020). Major retailers have indeed significantly expanded their fruit and fresh produce delivery services in recent years, driven by increased consumer demand for convenience and accelerated by the e-commerce boom during the COVID-19 pandemic. Retailers thus put pressure on suppliers to meet quality requirements (Clement et al., 2012). In industries such as agriculture or manufacturing, grading helps to minimize product rejection by aligning products with market demands and quality specifications. It gives a proper idea and the quality of the product. It helps to minimize the handling losses. World Trade Organization (WTO) demands high quality graded products that meet high quality standards. Graded products are highly demandable worldwide. Previous studies have shown

that centrifugal mechanisms can be effectively used in agricultural processing machines. A multipurpose centrifugal mechanism evaluated for nut processing demonstrated improved efficiency through integrated machine design (Alamooti and Mahmoodi, 2015).

In Bangladesh, tomato grading is traditionally done manually through visual estimation as part of routine postharvest handling practices to reduce loss and maintain quality (Khatun and Rahman, 2020). Manual grading is a time-consuming and costly operation (Daheriya et al., 2023). Also, manual agricultural tasks involving repetitive hand work lead to increased muscle fatigue and stress among workers (Benos, et al., 2020). Labors can have different perceptions and judgments to choose tomatoes equal in size. Human errors can be caused by a person's eye vision. Humans typically put in seven or eight hours a day at work. Extended work hours may cause workers to lose concentration, making it challenging for them to grade the tomatoes.

Furthermore, in the era of globalization, village people migrate from rural areas to urban areas. That creates a huge shortage of farmers. It is a big problem for future agriculture. During the peak time of cultivating tomatoes, a shortage of labor affected the manual grading system. Because of high labor cost, grading cost will be high. To get rid of these problems for grading tomatoes, modern mechanical technology can be helpful. A tomato grader machine can be useful to grade tomatoes effectively. Graded tomatoes will be more uniform, and accurate in size and ensure easy packaging and distribution. The farmers could sell their different sizes of tomatoes at a different rate of prices. Thus, the grading of tomatoes enhances the market value.

An efficient tomato grading machine can handle large quantities of tomatoes per hour, ensuring timely operation during peak harvesting periods. By reducing the dependence on manual labor, such a machine can address labor shortages, improve labor efficiency, and lower overall labor costs. Therefore, the fabrication and evaluation of a low-cost tomato

grading machine are necessary to provide farmers with a faster, more effective alternative to manual grading. Accordingly, the objectives of this study are to design and develop a tomato grading machine and to evaluate its technical and economic performance.

2 Materials and methods

2.1 Overall concept and major components of the machine

The physical properties of tomatoes were considered at the time of designing the grader machine, and materials were selected based on their availability and cost. The proposed tomato grading

machine consists of a frame, tomato lifting system, conveyor system, grading unit, collector and electric motor as shown in Figure 1 and with dimensions shown in Figure 2. The lifting system consisted of some tools such as bearing, chain, conveyor mat, and gear (sprocket type). The trays were used to collect the graded tomatoes which were made of MS sheets and covered with soft foam to prevent the tomatoes from damaging. With the help of chain and gear, power was transmitted from one grading chamber to the corresponding grading chamber. It also helped to operate the lifting system and gave rotary motion to the particular grading chamber.

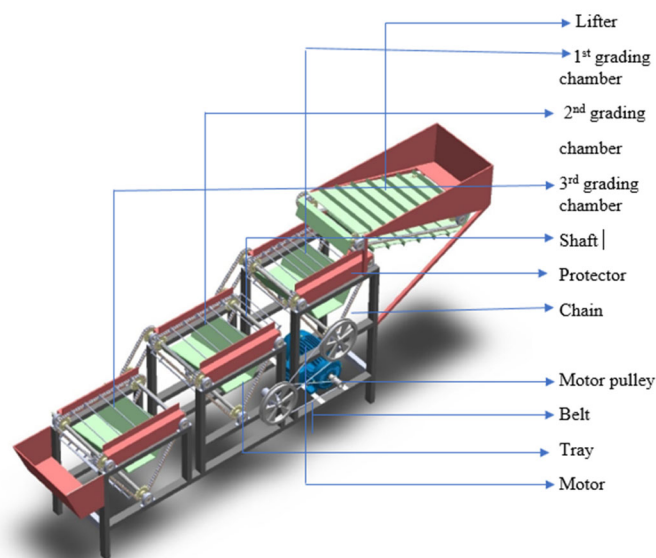


Figure 1 Graphical representation of the tomato grading machine

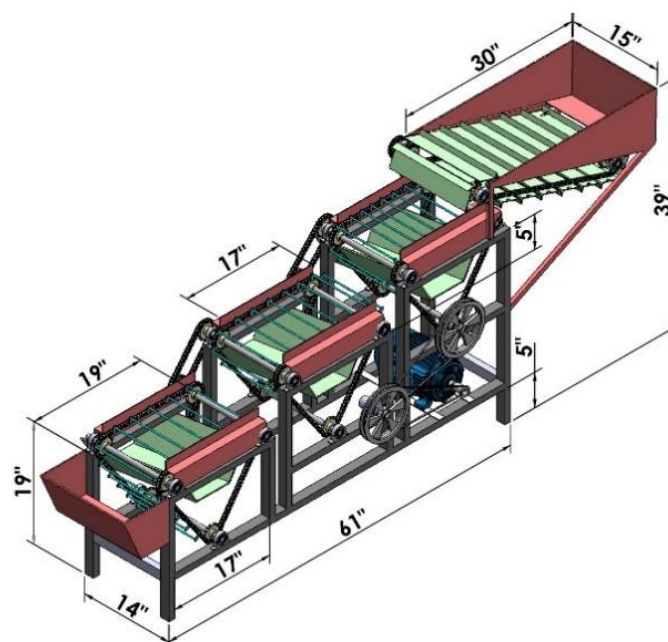


Figure 2 Schematic diagram of the machine with dimensions

2.1.1 Frame

The frame (Figure 3) is a critical component of the machine, as it withstands all applied loads and provides structural support, thereby protecting the other fragile components such as tomato lifting system, conveyor system, grading unit, and collector from breakage or damage.

2.1.2 Tomato lifting system

This system is made of bearing, chain, conveyor mat, and gear (sprocket type) (Figure 4). The machine is operated by an electric motor, which transmits power to the lifting chamber through a chain and pinion mechanism. During tomato lifting, step ladders

are used to gently carry the tomatoes into the grading chamber.

2.1.3 Circular shaft and collector/tray

The cylindrical shafts were made of mild steel rods and were mounted on bearings at both ends. These shafts transmit rotary motion to the grading chambers, enabling their rotation and allowing the tomatoes to be graded according to size. In the designed tomato grader, trays were used to collect the graded tomatoes which were made of ASTM 1020 MS sheets. The trays were covered with soft foam to prevent the tomatoes from damaging. Table 1 shows the specifications of shaft and collector.



Figure 3 Frame



Figure 4 Tomato lifting system

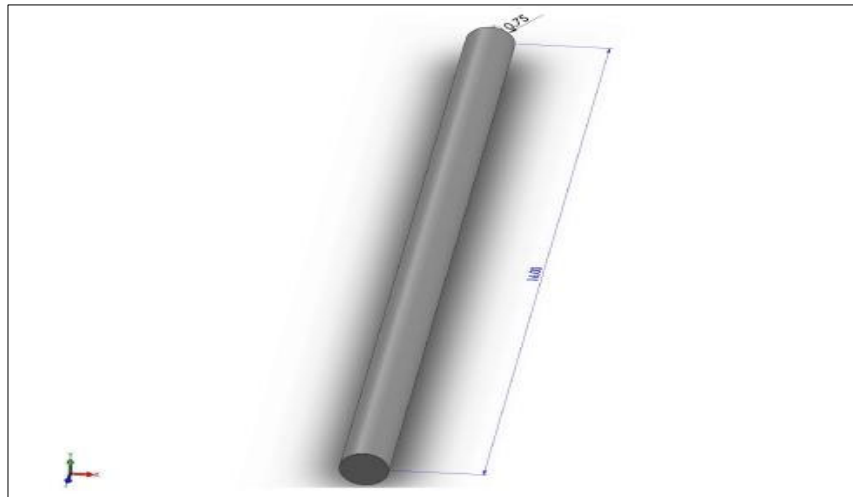


Figure 5 Circular shaft

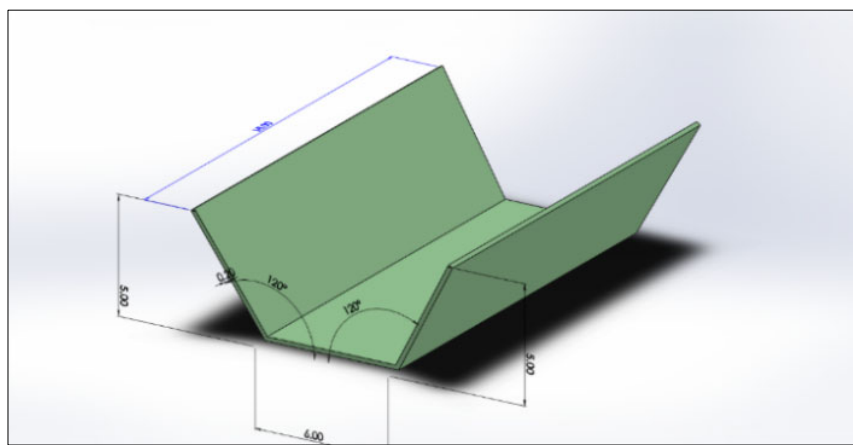


Figure 6 Tomato collection tray

Table 1 Specifications of a circular shaft and collector

Circular shaft	Collector/Tray
Material: Mild steel	Material: MS sheet
No of shaft: 12	Thickness of MS sheet: 0.098 inch
Length of the shaft: 17.5 inch	Dimension of frame: 22 inch × 18 inch
Diameter of the shaft: 0.75 inch	Manufacturing process: Welding

2.1.4 Chain and gear

The designed tomato grading machine employed chain and sprocket drive mechanisms to transmit power between successive grading chambers. These

drives facilitated the operation of the tomato lifting system and provided the required rotary motion to the respective grading chambers. The specifications of the chain and sprocket are presented in Table 2.

Table 2 Specifications of a chain and gear

Chain	Gear
Pitch(P):1.65 inch	Thickness :0.5 inch
Roller diameter(d_1):0.7505 inch	Pitch diameter :0.7 inch
Pin diameter (d_2): 0.225	Diametral Pitch: 3
Pin length(L):1.58 inch	No of teeth: 14
Plate thickness: 0.0985 inch	Material: 4140 steel
	Model: 14TTFE

2.1.5 Bearing and bearing holder

In the designed tomato grading machine, a total of 24 ball bearings were installed, each mounted within a bearing housing. These bearings facilitate smooth rotation of the shafts in each grading chamber and

minimize metallic friction between the shaft and the supporting steel bar. The bearing–housing assemblies were designed as modular units to simplify the installation and alignment of both the bearings and the shafts. Overall, 24 bearing holders were

incorporated into the tomato grader to ensure reliable operation and ease of maintenance. Table 3 shows the

specifications of a bearing and bearing holder.

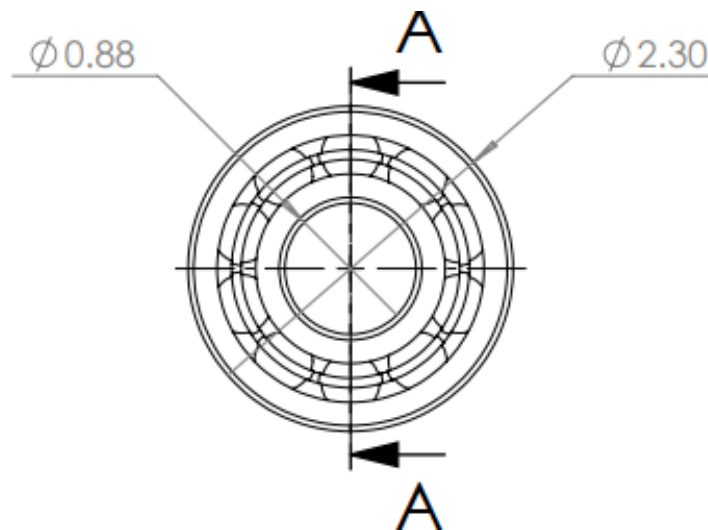


Figure 7 Bearing

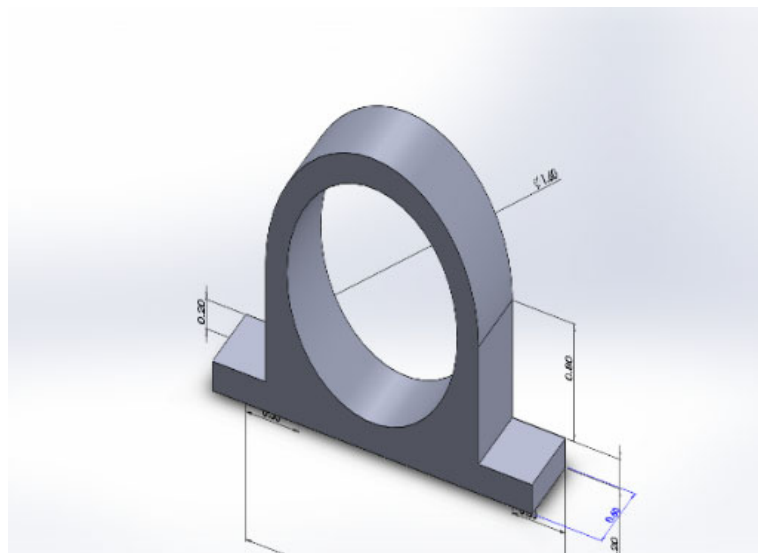


Figure 8 Bearing holder

Table 3 Specifications of a bearing and bearing holder

Bearing	Bearing holder
No of bearing -24 piece	Material: Iron
Manufacturer Name –MS MARSHAL	Inner Diameter: 1.8 inch
Inner Diameter -0.88 inch	Outer diameter: 2.2 inch
Outer Diameter-2.3 inch	
Width-0.625 inch	
End Type-Both sides sealed	

Table 4 Specifications of pulley

Types of pulleys	RPM	Diameter (inch)
Motor pulley	1400	1.6
Larger pulley	195	11.5
Smaller pulley	195	1.102
Machine pulley	23	9.5

2.1.6 Belt and pulley

In the designed tomato grader motor power was transmitted into grading by means of belt and pulley

mechanisms. It helped to convert electrical energy to mechanical energy and helped to operate the whole machine. There were two large pulleys and two small

pulleys. Specifications of pulley is shown in Table 4.

2.1.7 Grading chamber

In the tomato grader, there were three grading chambers. First chamber was designed to separate small size tomatoes (≤ 1.58 inch). Second chamber was designed to separate medium tomatoes (≤ 1.97 inch). Third chamber was designed to large size tomatoes (≤ 2.36 inch). Iron rods were connected in parallel with clips above the chains of each grading chamber. Iron rods were wrapped with soft flexible pipes to prevent damage of tomato skin during grading. The distance between two parallel rods in first chamber, second chamber was, and third chamber was 1.58 inch, 1.97 inch and 2.36 inch respectively.

2.1.8 AC motor

A 1hp single phase AC motor was used in the grader. The speed of the motor was 1 400 rpm and voltage were 220 volts. It helped to operate the machine with a controlled speed without any obstruction.

2.2 Power transmission unit

The power transmission unit was divided into two parts, (a) electric power and (b) chain-gear arrangement.

2.3 Design calculation

2.3.1 Power transmission

Power was required to be transmitted from motor to driven pulley which reduces rpm. From driven pulley power also transmitted to conveyor belt. The size of the pulley was determined by using following formula (Faires, 1965).

$$D_1 \times N_1 = D_2 \times N_2 \quad (1)$$

Where,

Motor to first pulley: Drive pulley diameter = D_1 (m);

Motor RPM = N_1 ;

Driven pulley diameter = D_2 (m);

Driven pulley RPM = N_2 , Co-efficient of friction for fabric belt, $\mu = 0.30$ and safe tension 10 N mm⁻¹ per width.

$$\text{Velocity of drive pulley, } V_1 = \frac{\pi D_1 N_1}{60} \quad (2)$$

$$\text{Velocity of driven pulley, } V_2 = \frac{\pi D_2 N_2}{60} \quad (3)$$

2.3.2 Power transmitted by belt

Power transmitted by belt and angle of lap was calculated from the following equations (Khurmi and Gupta, 2015)

Tight side of the belt = T_1

Slag side of the belt = T_2

Velocity of drive pulley = V_1

$$\text{Power transmitted by belt, } P = (T_1 - T_2) V_1 \quad (4)$$

$$\text{Angle of lap for belt drive, } \theta = 180 - 2\alpha \quad (5)$$

Where,

$$\alpha = \sin^{-1} \frac{D_2 - D_1}{2C};$$

C = center to center distance between two pulleys.

2.3.3 Belt tension ratio

Belt tension ratio was calculated from Equation 6 (Khurmi and Gupta, 2015).

$$\text{Belt tension ratio, } \frac{T_1}{T_2} = e^{\mu\theta} \quad (6)$$

Co-efficient of friction of fabric belt, $\mu = 0.14$;

Angle of lap = θ

2.3.4 Initial belt tension

Initial belt tension was calculated from Equation 7 (Khurmi and Gupta, 2015).

$$\text{Initial belt tension, } T_0 = \frac{T_1 + T_2}{2} \quad (7)$$

Where,

Initial belt tension = T_0 ;

Tight side of the belt = T_1 and Slag side of the belt = T_2 .

2.3.5 Length of the belt

Length of the belt was calculated from the following equation (Faires, 1965).

$$\text{Length of belt, } L = 2C + 1.57(D_1 + D_2) + \frac{(D_2 - D_1)^2}{4C} \quad (8)$$

Where,

Length of the belt = L ;

Drive pulley diameter = D_1 ;

Driven pulley diameter = D_2 ;

Center to center distance between two pulleys = C

2.4 Specifications of the tomato grader

The final characteristics of the machine after fabrication are displayed in Table 5

Table 5 Specifications of the fabricated tomato grader

Particulars	Specifications
Length of machine (inch)	80
Width of machine (inch)	20
Average height of machine (inch)	21
No. of grading unit	3
No. of tray	4
No. of lifter	1
No. of bearing	24
No. of shaft	12
Total length of chain (inch)	480
No. of pulley	4
No. of belt	2
Power source	Electric motor
Motor power	1hp



(a) Top view (b) Side view



(c) Photographic view of the fabricated tomato grader machine

Figure 9 Different views of the fabricated machine

2.5 Experimental procedure

2.5.1 Sample preparation for the performance test

Twelve kilograms of tomatoes were purchased from the Dinajpur local market. The sample did not include tomatoes with early damage such as abrasions,

scratches, or rot. As a result, the gadget did not sustain any initial damage while being tested. Small, medium, and big samples were split up into four groups, each weighing three kilograms. After grading, each tomato was physically measured for size using a

slide caliper and labeled for easy identification.

2.5.2 Laboratory experiment

As initially prepared each 3 kg of tomatoes were put into the lifter for grading and switched on the machine. Then, the non-graded tomatoes were successively fed into the lifter. When the non-graded were transported over the grading chambers, tomatoes were graded and deposited in separate trays according to their size. During grading, we counted the grading time by stopwatch. This helped in determining the grading capacity and grading efficiency of the machine. After four times of laboratory experiment the overall efficiency and damage rate of the machine was determined.

2.6 Technical evaluation

2.6.1 Grading capacity

Grading capacity of a tomato grader was determined on the basis of the amount of tomato graded within a specific period by using Equation 9 (Berhanu et al., 2024).

$$\text{Grading capacity (kg hr}^{-1}\text{)} = \frac{\text{total weight of tomatoes collected at outlet(kg)}}{\text{total time taken for grading(hr)}} \quad (9)$$

2.6.2 Grading system efficiency

Grading system efficiency of grading small, medium and large tomato was determined by the following equations (Valentin et al., 2016).

$$\eta_s = \frac{\text{number of correctly graded small tomatoes}}{\text{total number of small tomatoes in the sample}} \quad (10)$$

$$\eta_m = \frac{\text{number of correctly graded medium tomatoes}}{\text{total number of medium tomatoes in the sample}} \quad (11)$$

$$\eta_L = \frac{\text{number of correctly graded large tomatoes}}{\text{total number of large tomatoes in the sample}} \quad (12)$$

Where,

η_s = grading efficiency of small tomatoes;

η_m = grading efficiency of medium tomatoes;

η_L = grading the efficiency of large tomatoes.

The overall grading efficiency was calculated by the following formula (Mangaraj et al., 2010).

$$E_s = \frac{N_{to} - N_{tm}}{N_{to}} \times 100 \quad (13)$$

Where,

E_s = overall grading efficiency of the tomato grader, %;

N_{to} = Total number of the samples of all grade tomatoes;

N_{tm} = Total number of the misclassified tomatoes in all the samples.

2.6.3 Grading damage

The percentage of damaged tomato was taken by considering the total number of tomatoes with abrasion after the operation against the total number of tomatoes in the sample as shown in Equation 14 (Anawte, 2019).

$$\text{Damage tomato (\%)} = \frac{\text{Total number of tomatoes with abrasion}}{\text{Total number of tomatoes in the sample}} \times 100 \quad (14)$$

2.7 Operating cost of the machine

The total cost performed by this machinery in field operation is its operating cost. The operating cost includes :

(1) Fixed cost

(2) Variable cost

2.7.1 Fixed cost (FC)

Fixed cost includes:

(a) Depreciation (D): Equation 15 was used to calculate the depreciation of the machine by using straight line method (Barnard and Nix, 1979).

$$D = \frac{P-S}{L} \quad (15)$$

Where,

D = depreciation cost (US\$ yr⁻¹);

P = purchase price of the machine (US\$);

S = salvage value (US\$);

L = Life of the machine or obsolescence time (yr)

(b) Interest on investment (IOI): It was determined by using the following equation (Barnard and Nix, 1979).

$$\text{IOI} = \frac{P+S}{2} \times i \quad (16)$$

Where,

i = interest rate (decimal).

(c) Taxes, insurance and shelter (TIS)

2.7.2 Variable costs (VC)

It varies in proportion to the amount of machines

used. Variable cost consists of the following costs:

- (1) Labor cost (L)
- (2) Electric bill
- (3) Repair and maintenance cost (R & M).

So, the total cost is $TC = FC + VC$

Here, TC = total operating cost (US\$), FC = Fixed cost (US\$), VC = Variable cost (US\$).

All fixed costs and variable costs are converted into US\$ hr⁻¹.

2.7.3 Annual operating cost

The following equation was used to calculate the annual operating cost of the grader (Banu et al., 2022).

$$AC = FC + (VC \times U) \quad (17)$$

Where,

AC = annual cost (US\$);

FC = Fixed cost (US\$);

VC = Variable cost (US\$);

U = hours of use.

2.7.4 Power consumption

The power consumption was taken by simply of the rated size of drive pulley of the machine. In this study 1 hp motor was used. Power consumption was determined by the following equation.

$$P = \text{kilowatts} \times t, \text{ kwh} \quad (18)$$

Where,

t is the time of operation in hours.

$$\text{Electric energy of the motor, } E = \frac{P \times t}{1000} \text{ kwh} \quad (19)$$

$$\text{Current of motor, } I = \frac{P}{V \cos \theta} \text{ A} \quad (20)$$

3 Results and discussions

3.1 Collected tomato diameter range

Table 6 depicts the diameter range of the collected tomato of this experiment.

Table 6 Tomato diameter range(inch)

Small	Medium	Large
≤ 1.58	>1.58	> 1.97

3.2 Technical performance

Based on Equation 9, the developed grader achieved a grading capacity of 540 kg h⁻¹ at an operating speed of 23 rpm. The grading efficiencies recorded across four experimental trials were 65%, 85%, 79.31%, and 75%, yielding an overall average

grading efficiency of 76%. The mean mechanical damage observed during grading was limited to 1.5%, indicating satisfactory handling performance. The operational grading cost was estimated at US\$ 0.0026 kg⁻¹. Assuming an annual operating duration of 250 h, the corresponding electricity cost was calculated to be US\$ 8.46.

In comparison, Preetha et al. (2016) reported a grading efficiency of 80% at 15 rpm with a grading capacity of 175 kg h⁻¹, while Singh et al. (2016) achieved a higher grading efficiency of 94% with a grading rate of 2.7 t h⁻¹ using a different grading system.

3.3 Fabrication cost of the machine

Fabrication cost of the tomato grader machine was found US\$ 273.33 (Table 7). Cost of the machine can be minimized by commercially manufactured.

3.4 Operating cost of the machine

The cost of grading with the current grader was just US\$ 0.0026 per kilogram, as shown in Table 8. In small businesses, manual grading is frequently used to separate fruits, vegetables, eggs, and other food items. It costs more to operate than mechanical grading, but the initial investment is lower (Narvankar et al., 2005). Mechanical grading is necessary to grade huge amounts of fruits and vegetables in a short amount of time with great precision and dependability (Zhang et al., 2018). According to the World Trade Organization (WTO), new marketing trends call for premium goods. In order to reduce the manpower scarcity, save time, and enhance the quality of graded products, farmers are eager to acquire a suitable agricultural produce-grading equipment (Londhe et al., 2013).

3.5 Simple comparison between manual and mechanical grading

Using the data for manual grading of tomato by hand from the research work of Khatun and Rahman (2020), and in the sub-project completion report published by the Bangladesh Agricultural Research Council (BARC) (2022), a simple comparison

between manual and mechanical grading of tomato is shown in the Table 9.

Table 7 Fabrication cost of the machine

Materials	Cost (US\$)
Angle bar	32.34
MS sheet	8.25
Shaft bar	7.92
Ball bearing(24 nos)	19.80
Pulley (4 nos)	20.62
Belt (2 nos)	2.89
Chain	8.25
Gear	15.01
Sieve	3.09
Motor 1hp	41.25
Pipe	3.05
Tye lock	1.15
Foam	3.13
Fevical & Super glue	1.98
Rod	2.06
Tomato	12.37
Plastic angle	0.66
Weir + Plug	1.24
Making charge	86.21
Total cost	273.33

Table 8 The cost factors and items of the machine

	Cost factor/items	Units US\$ yr ⁻¹	US\$ hr ⁻¹
	Lifetime of the machine	7 years	
	Annual use	250 hours	
Fixed cost	i) Depreciation	34.88	0.14
	ii) Interest on Investment	14.92	0.06
	iii) Taxes, insurance and shelter (1% of P)	2.71	0.01
	Total fixed cost (i+ii+iii)	52.51	0.21
2. Variable cost	i) Repair and maintenance (0.0025% of P hr ⁻¹)	1.70	0.007
	ii) Labor cost (2 labor)	288.73	1.15
	iii) Electricity	8.46	0.034
	Total variable cost (i+ii+iii)	298.89	1.20
	Total cost = FC+VC	351.40	1.41
	Grading cost per kg	0.0026 US\$	

Table 9 Simple comparison between manual and mechanical grading

	Manual	Mechanical
Grading capacity, kg hr ⁻¹ person ⁻¹	150	540
Hours of operation per day	8	8
Cost of grading US\$ kg ⁻¹	0.009	0.0026

4 Conclusion

The developed tomato grader was designed on the basis of shape and size of tomatoes. It is able to separate non-graded tomatoes into three categories according to their size (small, medium and large). The overall grading efficiency of the grader was 76%. The optimum parameters of the machine were found at a speed of 23 rpm which can be able to grade 540

kg tomatoes in one hour with less amount of damage. The damage percentage was 1.5%. The initial cost of the tomato grader was US\$ 273.33. The machine is expected to last for 7 years. The annual use of the grader is approximately 250 hours. The grading cost of the machine can be affected by several factors such as depreciation, shelter, repair and maintenance, electricity also taxes at a current custom rate. The grading cost of the machine was found US\$ 0.0026

per kilogram. US\$ 8.46 electricity bill have to be paid annually for using the machine. In the future, this grader can be used to grade other fruits and vegetables by modifying some parts of the machine. Also, solar power can be incorporated so that it can operate anywhere.

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