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Design, fabrication and performance evaluation of a simple mango harvester

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ABSTRACT

Harvesting is one of the most important agricultural and horticultural operations. In Bangladesh, mango harvesting is done traditionally by shaking, plucking with bamboo, picking by hand, by climbing on the tree and from the ground using bamboo stick. The traditional manual harvesting is very labor intensive and thus expensive. There are some risk factors such as the mango could be physically damaged when fall to the ground, sometimes it may fall on the people under the tree and cause accidents. Sometimes people fall from the tree on the ground and cause accidents and even die. This work concerns the development a simple manually operated mango harvester. Two different prototypes of the harvester was designed and manufactured. One is telescopic using different diameter stainless steel pipe and another fixed height using aluminum pipe. The harvester consists of cutting tool, spring, clutch wire, clutch, wheel, pipe and collecting net. The main mechanism used in this concept was simple braking mechanism for cutting operation by using share force of cutting part. The capacity of first prototype (telescopic) and second prototype (second height) was 37.77 kg hr^{-1} and 40.95 kg hr^{-1} respectively. The percentage of damaged mango was lower than the manual method. The machine fabrication cost is affordable to the farmers and the harvesting cost of first prototype (telescopic) and second prototype (second height) was same US$ 0.01 kg^{-1}. The simple mango harvester would be an easy solution for mango harvesting.

INTRODUCTION

Bangladesh ranks first in per hector fruit production in the World. A total of 70 different fruits are being produced in the country while mango is the second largest producing fruits in the country while banana tops the list (The Daily Industry, May 10, 2020).

Mango production was 2.37 million metric tonnes in FY 2017-18; it was 2.2 million metric tonnes in FY 2018-19 (BBS, 2019). Bangladesh occupied the 8th place as a mango producing country around the world (The Daily Star, June 26, 2020). The plucking of the most juicy summer fruit mango is start in the middle of May with its Guti varieties in northern region and other improved varieties in Sathkharia and hill tracts.

Harvesting is one of the most important agricultural and horticultural operations. The traditional manual harvesting is very labor intensive and thus expensive. Although Hill et al. (1981) found that mechanical harvesting was not always cheaper than hand harvesting. Therefore, spending money to improve the harvesting operation leads to the quantitative and qualitative growth in yield and income. Since the cost of harvesting represents 35–45% of total operating cost, there is potential for a significant reduction in total fruit production costs through the improvement in the efficiency of this operation (Sanders, 2005).

Mangoes are generally harvested at physiologically mature stage and ripened for optimum quality. Fruits are hand-picked or plucked by bamboo poles. It is a tedious task. During harvesting, the latex trickles down the fruit surface from the point of detachment imparting a shabby appearance to it upon storage. Sometimes latex fall on the face and causes scars. Therefore,

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the fruits should be harvested with a 10-20 mm stem attached to it (Humble, 2014). Also plucking process of mango involves high risk that there are chances of falling from the tree. It may cause severe physical and health problems.

In Bangladesh, mango harvesting is done traditionally by shaking, plucking with bamboo, picking by hand, by climbing on the tree and from the ground using bamboo stick. There are some risk factors associated with the traditional methods such as the mango could be physically damaged when fall to the ground, sometimes it may fall on the people under the tree and cause accidents. Many times people fall from the tree on the ground and cause accidents and even die. The latex from mango stem fall on the face and body may cause harmful effects. Also getting available labor during that period is not easy. Therefore, a mango harvesting machine is necessary for mango harvesting.

Since harvesting is one of the most important agricultural and horticultural operations but the traditional manual harvesting is very labor intensive and thus expensive, the use of properly designed harvesting tools not only prevents undue mechanical damage but it also appreciably reduces the cost of production of tree fruits. Although mechanical harvesting with tractor operated hydraulic elevator type fruit harvester have not yet been commercially applied in Bangladesh, many researches were conducted towards the design and application of manually operated fruit picker around the world. Some of these are low cost pear harvesters (Hussain et al., 2012), pepper plucking equipment (Rahul et al., 2012), peach fruits harvesting (Hamam et al., 2011), manually operated drumstick harvester (Patil et al., 2015) etc.

The primary goal of the study is to design and development of mango plucking equipment to facilitate mango harvesting in the agricultural sector. So in order to avoid climbing and to solve the problems related in this field it is essential to have mango plucking equipment.

MATERIALS AND METHODS

Design considerations and machine construction

A manually operated mango harvester was developed according to tree, implement and operator parameter. The tree height generally varies from 8m to 9m with its canopy diameter ranges 5m to 6m. The prototype mango harvester uses a cutting and detaching principle. Before the conduction of the test, two different prototypes of this modified fruit harvester. One is telescopic using different diameter stainless steel pipe and another fixed height using aluminum pipe. The harvester was made of locally available materials to keep the cost low. Efforts were made to keep the mechanism and operation of the machine as simple as possible. Figure 1 and Figure 2 shows the conceptual design of the mango harvester that was initially fabricated. The harvester consists of the following parts:

Cutting tool: It was actually used for cutting mango stem. In first prototype, cutting plier was used as cutting tool. It was made of iron and weight was 350 gm. Scissors as a cutting tool was used in second prototype.

Spring: A 64mm spring was used for connecting and compressing two blade of the cutting tool.

Clutch wire: It connected the movable blade with the clutch. The length of the clutch wire was different for two prototypes.

Clutch: Clutch was used for pressing the movable blade towards fixed blade for cutting operation. It actually pulled the clutch wire which was connected to the movable blade.

Wheel: In the first prototype, when telescopic pipe was folded, the excess clutch wire was intertwined in the wheel.

Collecting net: It was 4m long collecting net made of black cloth. Two rings were attached at two openings of it.

Pipe: Stainless steel pipe was used for the first prototype and 20mm diameter aluminum pipe was used for the second prototype. In the first prototype three different diameter pipes were used for telescopic function and those pipes diameter was 20mm, 16mm and 12 mm.

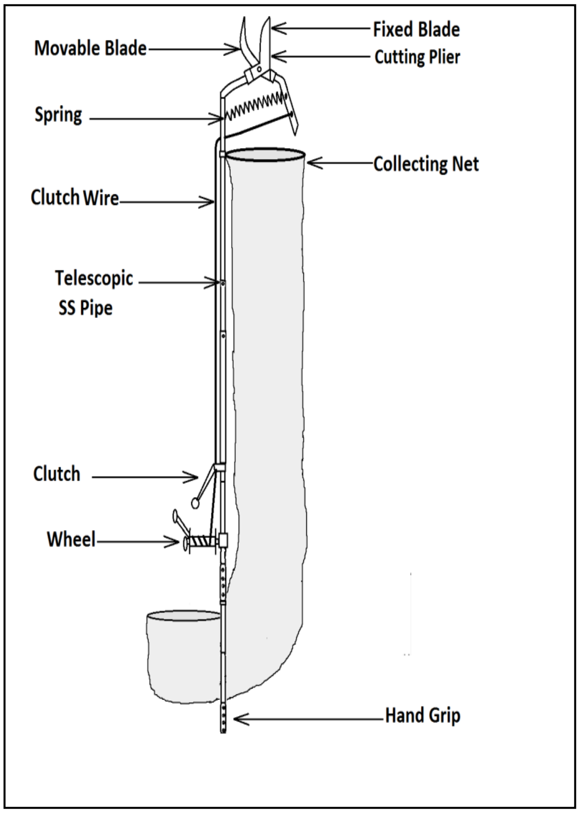

Figure 1: Simple mango harvester of first prototype (telescopic)

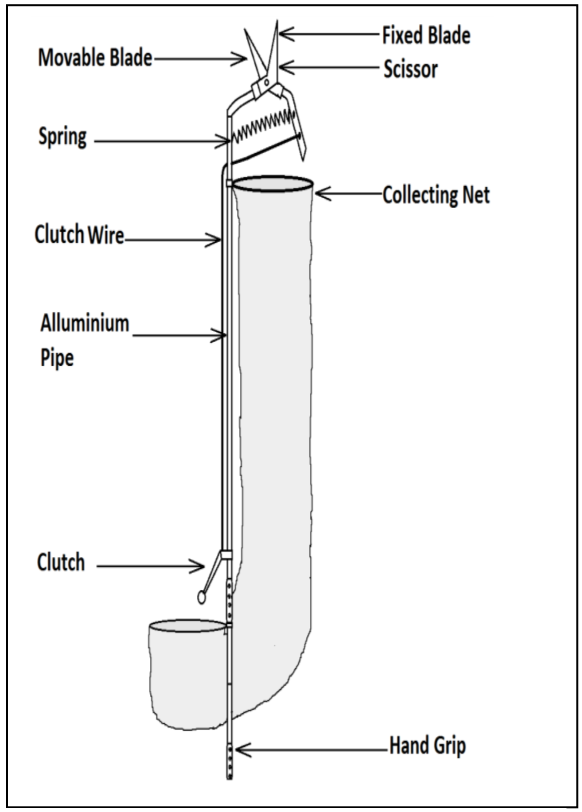

Figure 2: Simple mango harvester of second prototype

Working principle

The main mechanism used in this concept was simple braking mechanism for cutting operation by using share force of cutting part. The top portion or the cutting part of the equipment consisted of two sharp blades. The blade which was inserted into the pipe was fixed and the other one was the movable. The movable blade was attached with a clutch by using clutch wire. A spring was attached between the movable blade & fixed portion of the equipment. The hand lever or clutch for operating the equipment was given at the lower portion. While pressing the clutch from the bottom, the clutch wire pulled back & the spring got compressed and the movable blade moved toward the fixed blade and done the cutting job. After cutting, the mango fell through a collecting net & it can be collected without any bruising or rapture in mango skin.

Forces and moment acting on the handle of the mango harvester

Moment is a turning effect of a force. It is an expression involving the product of a distance and a physical quantity, and in this way it accounts for how the physical quantity is located or arranged. Moments are usually defined with respect to a fixed reference point; they deal with physical quantities as measured at some distance from that reference point. In principle, any physical quantity can be multiplied by distance to produce a moment; commonly used quantities include forces, masses, and electric charge distributions.

In mango harvester, moment acts on handle due to weight of scissors and collecting net which is attached in top portion of the harvester. Total weight of the harvester is also responsible for creating moment on the handle. So there is a resultant force (R) that acts between these two forces which is mainly responsible for creating moment at the point A of handle as shown in figure 3.

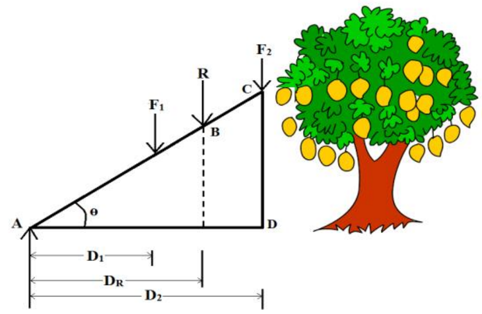

Figure 3: Moment acting on the handle of the mango harvester

In the figure Moment,
M = F × d
= R × d
= R × D_R
= ($F_1 + F_2$) × AB cosθ
Where,
F_1= Force due to Aluminum pipe weight, Kg
F_2 = Force due to scissors & collecting net weight, Kg
R = Resultant force, Kg
D_1= Distance of force F1 from point A, ft
D_2= Distance of force F2 from point A, ft
D_R = Distance of resultant force R from point A, ft
θ = Harvesting Angle, degree

Performance test

To study the efficiency of the two prototypes of the harvester, a local mango orchard in Uttar Sadipur near HSTU, Dinajpur was selected. A mango tree was selected, we were harvested mango for one hour and the weight of harvested mango for each prototype was recorded. Three trials were made of the same procedure and the weight of harvested mango for each trial was recorded. Manual harvesting is also done for one hour and the data was recorded. Harvesting capacity and percentage of damaged mango was calculated using the following equations:

$$\text{Harvesting capacity (kg. hr}^{-1}\text{)} = \frac{\text{weight of harvested mango}}{\text{Total harvesting time}} \quad (2)$$

Percentage of damaged mango (%) =

$$\frac{Weight\ of\ damaged\ mango}{\text{weight of harvested mango}} \times 100 \quad (3)$$

Cost analysis of the mango harvester

A Simple cost analysis was done for the mangoharvester. The analysis included the actual cost of the device, annual fixed cost and variable cost. The annual fixed cost included depreciation, interest and shelter cost. Variable cost included repair and maintenance cost and labor cost. Assumption was made as interest 13%, shelter 0.1% per year; repair and maintenance cost 0.1% per hr, operation per day 8 hrs, annual use 400 hrs and estimated life span 10yrs of the machine.

The cost was calculated using following formulas:

The annual depreciation was calculated as
$D = P - S/L(4)$
Where, D is the depreciation, P is the purchase price of the machine, S is the salvage or selling price and L is the time between buying and selling.
Interest on investment was calculated as
$I = [P + S/2] \times i(5)$
Where, I is the interest on investment, P is the purchase price of the machine, S is the salvage or selling price, i is the current interest rate.

Total cost per year calculated as
Total cost = Annual fixed cost + Variable cost (6)

RESULTS AND DISCUSSION

Different features of the mango harvester

The details of features of the two prototype mango harvester are shown in Table 1. The table included the details about source of power, skill of operator, weight of implement, maximum height of implement, clearance between scissors and lever. Table 1 shows that the weight of fixed height prototype is less than the telescopic prototype because of the different material is used for construction. Scissor is also used instead of cutting plier in the fixed height prototype which is also reduced the weight of the harvester.

Moment acting on the handle of the mango harvester

As described in the methodology moment acting at different position of the harvester for different harvesting angle was calculated and shown in figure 4. From the figure we show that the moment acting on the handle of the first prototype is higher than the second prototype because of it heavy weight. So because of the higher moment acting on the handle it's difficult to control the balance of the harvester during harvesting and takes more time than second prototype for harvesting.

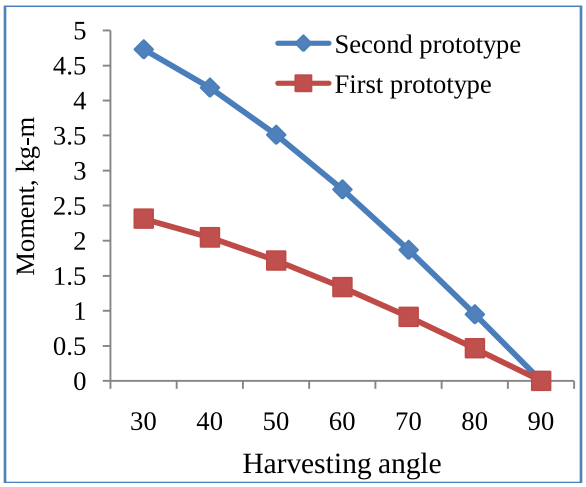

Figure 4: Figure 4: Moment acting on the handle of the Mango harvester

Performance test

The capacity and the damaged percentage of mango from the performance test of the harvester and manual method are shown in table 2. From the table it shows that the capacity of the first prototype (fixed height) and manual harvesting are approximately same. The capacity of the second prototype (telescopic) is less than the fixed height prototype and manual method. Because of the heavy weight of the telescopic prototype, it's found difficult to harvest mango and very time consuming. The percentage of damaged mango by the harvester is lower than the manual method. In traditional harvesting, mango gets physically injured that results shorter storage life which is a major problem for storage and low market price. Latex sometimes falls on face and causes wound. Normally mango harvesting is done by climbing and shaking tree brunches which is risky for climber. But local people do not pay too much attention in these problems. The simple mango harvester can easily solve these problems. Scissors in this harvester cuts stem along with mango thus eliminates latex problem. Harvested mango falls through a collecting net, therefore rapture problem does not happen and storage life of harvested mangoes extend.

Table 1: Different Features of the manually operated mango harvester

Particulars	Specification	
	Telescopic	Fixed height
Source of power	Human muscle	Human muscle
Material	Stainless steel pipe	Aluminum pipe
Weight of the implement (including scissors and net)	2.30kg	1.08kg
Weight of collecting net	0.25kg	0.25kg
Weight of scissors or cutting plier	0.44 kg	130gm
Height of implement	3.66m	3.66m
Scissors blade length	80mm	70mm
Collecting bag holder diameter	210mm	210mm
Clearance		
Scissors blade	15mm	15mm
Lever	60mm	60mm
Skill of operator	Not necessary	Not necessary

Table 2: Result of the performance test

Method	Capacity (kghr-1)	Damaged mango (%)
1st prototype (telescopic)	37.77a	0.69b
2nd prototype (fixed height)	40.95a	0.67b
Manual	40.73a	2.46a

Economics of the mango harvester

The mango harvester was designed and fabricated in such a way to keep its cost low. Table 3 shows the cost factors and items of two prototypes of the mango harvester. From the table, it can be seen that the manufacturing cost of the first prototype and second prototype respectively are US$ 13.27 and US$ 9.80. The harvesting cost of the first prototype and second prototype was same US$ 0.01 per kg. From the table, it also saw that the major portion of the cost is related to the labor cost and not to the machine cost.

Table 3: Cost analysis of the mango harvester

Cost factors/items	Unit	First prototype (telescopic)	Second prototype (fixed prototype)
A. Cost of the mango harvester	US$/Unit		
Pipe	US$	3.55	2.50
Clutch wire (12 ft)	US$	2.00	2.00
Collecting net	US$	2.00	2.00
Scissors/cutting plier	US$	1.77	1.00
Wheel	US$	0.95	-
Construction cost	US$	3.00	2.30
Total Cost	US$	13.27	9.80
B. Life of the mango harvester	Year	10	10
C. Annual use	Hrs	400	400
D. Annual fixed cost			
a. Depreciation	US$/yr	1.19	0.88
b. Interest on Investment (13%)	US$/yr	0.73	0.70
c. Taxes, Shelter, Insurance (0.1%)	US$/yr	0.01	0.01
Total	US$/yr	1.93	1.59
Total	US$/hr	0.005	0.004
E. Variable Cost			
a. Repair and maintenance (0.10%)	US$/hr	0.01	0.01
b. Labour (one labour, 3.5US$/day)	US$/hr	0.45	0.45
Total	US$/hr	0.46	0.46
F. Total cost	US$/hr	0.47	0.46
G. Cost of harvesting	US$/kg	0.01	0.01

CONCLUSION

This study introduced a simple mango harvesting device which is low cost and easily affordable to the farmers. The mango harvester design was desired to have a telescopic mechanism. At first it was fabricated as telescopic version but due to heavy weight it was further modified. During further modification of it, due to unavailability of various diameter SS pipe in the local market, the second prototype was made with single pole aluminum pipe not a telescopic version as first prototype. The harvesting capacity of the first and second prototypes was 37.77 kg hr^{-1} and 40.95 kg hr^{-1} respectively. The harvesting cost of the prototypes was same US$ 0.01 kg^{-1}. The percentage of damaged mango was 0.69% and 0.67% respectively for first and second prototypes which is lower than the manual method (2.46%). The design and fabrication of this kind of simple mango harvester is the possible solution of increasing self-life, saving harvesting time, reducing labor and harvesting cost.

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