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Development of a Fruits Harvesting Machine

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ABSTRACT

Orange and pomegranate are two of the most important types of fruit crops grown in Egypt. Conventional harvesting method is inefficient in terms of both economy and time. So, machine harvesting systems are a partial solution to overcome and reduce the cost. The aim of this investigation is to modify a harvesting portable machine and study the feasibility of using it for picking the navel orange and pomegranate fruits. The modified machine was evaluated using various operating factors such as cutting height of 2, 3 and 4 m , two cutting head types of machine (toothed disc and scissor) and disc speeds of 3.14, 3.66 and 4.19 m/s. the results were compared to traditional manual method at the same operating factors. The results concluded that using the modified fruit harvesting machine for picking navel orange and pomegranate fruits with toothed disc head at disc speed of 3.66 m/s with all cutting heights exhibited an enhancement in performance rate and fruits damage ratio and decreased the specific energy and operational cost. The obtained results at optimum conditions were machine performance rate of 24.33 and 20 fruit/min, fruits damage ratio 9.66 and 9.25%, specific energy of 6.45 and 7.58 kW h/Mg and operational cost of 85.74 and 100.71 L.E./Mg at cutting height of 3 m for navel orange and pomegranate fruits, respectively.

Keywords: Orange fruit, pomegranate fruit, harvesting machine, picking device, harvesting methods, scissor and toothed disc speed.

1. Introduction

The total cultivated fruit tree area in Egypt was 1620,308 Fedden. From this area 80,098 Fedden are currently under pomegranate also, the area of citrus about 456,082 Fedden. The pomegranate average production between 8-9 tons/Fedden, also, The total pomegranate production was 6,449,909 tons and the average citrus production between 7-9 tons/Fedden with total citrus production was 4,245,684 tons of which 1,700,000 tons were exported (Ministry of Agriculture 2019).

Sanders (2005) mentioned that citrus harvesting accounts for 35-45% of the total production cost. Hence, improving the efficiency of this one process has a great impact on the feasibility and profitability of the enterprise. The traditional manual harvesting method is labor-intensive, and therefore expensive. Selection of high-quality fruit is highly desirable as it increases the price of fruit by providing the highest quality fruit, and none of the mechanical systems examined were found to match the high-quality selection ability of manual picking. Hence, it also includes the results of research into alternative ways of maximizing the productivity of manual picking to reduce the cost of manual picking.

Hermans, (2008) stated that over fifty years ago, the maturity stage was leading to harvesting using very tall/long ladders while carrying or carrying a basket. This carries a high risk of fatal injury through falls. Since the 1960s, low-stemmed trees have become the norm for some fruits. Trees with a lower leg provided a more efficient, faster harvest and a more comfortable working position compared to standing on a high ladder.

El-Iraqi *et al.* (2010) designed and manufactured a simple auxiliary tool for mechanical mango picking. These prototypes consist of a telescopic tube, a tube for collecting fruit and different cutting

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mechanisms. These mechanisms included one disc cutter with a gasoline engine, one disc cutter with an electric drive, electric shears and a lead hook. The results showed that the least damage of fruits was (3-4) %, (4-5) %, (5-6) % using electric shears, electric disc cutter, mechanical disc cutter respectively for harvesting Indian butter mango.

Roger *et al.* (2016) tested three types of manual mango picker, pull type, trigger type and modified trigger type equipped with a scissors blade controlled by a steel wire to cut the stems. Based on the results compared with a conventional mango picker with an average capacity of 22 fruits/min, the trigger and pull type scored a capacity of 12 fruits/min and 21 fruits/min, respectively.

Mohamed, (2017) indicated that the circular plan discs failed to cut the fruits stems. Also, the increasing of cutting saws disc linear speed increases the total cutting percentage, the picker success to pick mango fruits the optimum linear speed of 8.34 m/s with modified circular saws with 100 sharp edge teeth with double discs overlapping 5 mm and the counter blade position is under the discs that gave correct cutting percentage of 95% and only 5% undercut stems, using the innovated picker, indicated the average percentages of right harvested fruits, fallen fruits, injured fruits, and latex fruits were (2.28%, 2.43% 4.86% and 92.72 %.) respectively. Meanwhile, using the innovated picker decreased the fallen fruits ratio, injured fruits ratio, and latex fruit ratio by (84.89%, 64.55% and 84.25%) respectively and increased the right harvested fruits by 49.03%, comparing the average (productivity, total fruit injured ratio) for the manual picking and innovated picker there were (22 fruit/min, with damage ratio of 52.74%). Meanwhile, with the picker productivity was average (20 fruit/min with damage ratio of 7.28%, this means that the farmer would sell 52.74% from the crop with low price due to fruit injured. Using the picker is surely increasing the market value of the mechanically picked fruits due to low damage. The picker can be manufactured locally with cheap price for farmers. The total fabrication cost of the picker was 1500 LE with 2017 price level. The total operating costs was 21.37 LE/h. The rental value of mechanical was 22.82 LE/h. The picker indicated (NPV) of 844.3 LE at 14% interest rate. The picker payback period (PBP) was about 1.3 year.
The objectives of this study were:

- To use a manual harvesting machine to harvest both citrus and pomegranate fruits.
- To study some of the different operating factors affecting the portable harvester, such as harvesting-head type (toothed disc and scissor), heights and disc speeds.
- To evaluate the economics portable fruit harvesting machine after modification.

2. Materials and Methods

The main experiments were carried out during the season of 2021 at a farm in Bilbeis Center, El Sharkia governorate (31° 7' N Latitude, 30° 37' E Longitude) to harvesting fruits using a modified portable harvesting machine under Egyptian conditions.

2.1. Materials

2.1.1 The fruit harvesting machine

The harvesting machine type: Honda, model: small harvest, driven by hand, made in Japan with dimensions of 1650 mm length, 170 mm width, 230 mm height and weight of 10 kg consists of parts as shown in Fig. 1 as follows:

The first is a 2.5 hp two-stroke air-cooled petrol engine that carried on the farmer back. The engine speed is 1650 -1700 rpm and oil consumption of 0.8 L/h. Also engine has petrol tank volume about 2 liters. The second is fixed arm has length of 1500 mm with diameter 18 mm and was made of aluminum pipes that is controlled according to the position of the fruit on the tree. There is transmission shaft inside the fixed arm with diameter of 10 mm for transmit the motion from engine to toothed disc head or scissors harvesting head . The third is toothed disc that consists of three blades made of steel with 250 mm diameter for cutting crop.

Fig. 1: The machine before modification

For modification portable harvesting machine some parts were fabricated to fit fruit as follows:

1- Changing the fixed arm by telescopic arm with length of 3000 mm. It consists of three aluminum pipes with dimension of 1000 mm length, diameter 18 mm for the first pipe, and diameter 16 mm for the second pipe and diameter 12 mm for the third pipe By this telescopic carrier, it can be easily pick fruits from a height of about 5 meter.
2- Adding a flexible movable cable with length of 1000 mm to transmit the motion from engine to fixed arm and facilitate the control of the machine in all direction when operating. Also, increase the machine length.
3- Replacing toothed disc head by two another cutter head types that showed in figs. 2 and 3 as follows:

The first toothed disc has 100 teeth and 100 mm diameter. This cutter disc was fixed on the disc cutter base with a ball bearing which was fixed on the upper end of the telescopic carrier and transmission shaft. The toothed disc cutter was provided with metal cover to protect the disc cutter during rotating and protect the leaves and branches of tree. A part of the cutting circumference with length of 50 mm remains only without cover for cutting fruit twigs.

The second cutter type is harvesting scissors head that has two wings with 150 mm length, one of them is fixed and other is movable. Scissors for converting the rotational speed into reciprocating speed for mobile scissors to apply the cutting action on fruit twig.

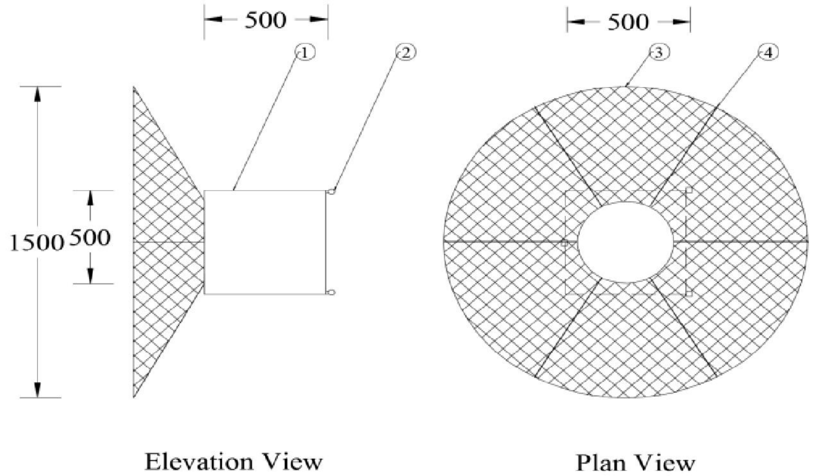
(a) **(b)**

Fig. 2: Photographs of the different cutter head types: (a) tooth disc (b) scissors

(a) **(b)** Dims.in mm

Fig. 3: Schematic views of the different cutter head types: (a) toothed disc (b) scissor

4- Adding fruit collection basket that showed in fig. 4 which consists of a basket of 50 cm in diameter and 50 cm in height and umbrella. It is installed on three wheels for easy movement between trees. An umbrella is installed on it with a diameter of 150 cm from the top to receive and collect the fruits harvested during the harvesting process. The umbrella consists of two parts connected by the opening and closing of the canopy. Each part consists of 3 skewers fixed in iron shears so that the skewers move up and down.

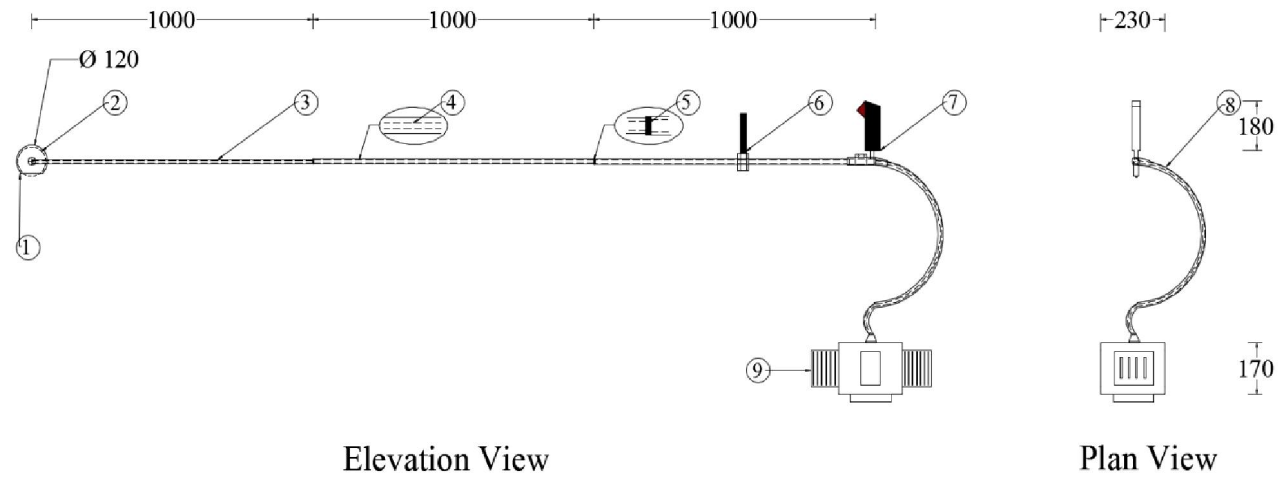


No.	Part name
1	Fruit basket
2	Wheels
3	Umbrella
4	Skewers

Dims.in mm

Fig. 4: Views of fruit collection basket

The modified portable harvesting machine that shown in Fig. 5 was modified especially for this work and constructed at a small workshop in Minya Al-Qamh City, Sharkia Governorate, Egypt (30° 30' N Latitude, 31° 20' E Longitude). This modification aimed to increase the performance rate (productivity), reduce damaged fruits, decreasing power requirements and minimizing the cost.



Dims.in

mm

No.	Part name	No.	Part name	No.	Part name	No.	Part name	No.	Part name
1	Disc cover	3	Telescopic arm	5	Break	7	Power switch	9	Petrol engine
2	Disc head	4	Transmission shaft	6	Arm holder	8	flexible cable		

Fig. 5: Views of the fruit harvesting machine

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Fruits

Experiments were carried out on a common cultivar of orange and pomegranate as follows:

-Navel orange

The height of maturity navel tree ranged between 4 - 5 m from the ground, tree spacing is 5 m, row spacing is 6 m and the average number of fruits in the tree is about 300- 350 fruit/tree spread on the tree. The main physical and mechanical properties of orange fruits under investigation that affect the performance of the designed harvesting tools were determined before picking fruits. Table 1 shows physical properties of navel orange. These data were measured for 20 fruit sample according to the standards set in (Sharifi *et al.,* 2007).

-Pomegranate

The height of maturity pomegranate tree ranged between 3 - 4 m, tree spacing is 3 m, row spacing is 4 m and the average number of fruits in the tree is about 150- 200 fruit/tree spread on the tree. It is grown mostly for its fruits and flowers. Physical and mechanical properties of pomegranate and navel orange that affect the performance of harvesting tools are shown in Table 1; it was measured and calculated for 20 fruit sample according to Jithender *et al.* (2017).

Table 1: Physical and mechanical properties of navel orange and pomegranate

Physical properties	Navel orange	Pomegranate
fruit (length, width, thickness, arithmetic and geometric mean diameter) mm.	84.06- 77.39- 75.54– 78.99 - 78.27 respectively.	76.56 - 68.81 - 72.61 - 72.66 - 72.39 respectively.
Average fruit volume cm^3	215.38	207.56
Average fruit mass (g)	201.32	208.52
Fruit density (g cm^{-3})	1.013	1.039
Bulk density (g cm^{-3})	0.443	0.651
Porosity (%)	49.39	33.48

Methods

The operation method of the modified portable harvesting machine under study is so simple whereas the worker selects the fruits on the branches during standing on ground and detaches it by placing the harvesting terminal to the fruit. Then the fruit is separated and dropped into the fruit collection net. While, traditional manual method used stairs made of aluminum and basket to pick the fruits. So, each treatment in the experiment was performed in three replicates and then data were collected during the harvesting.

Experimented procedures

The performance of the modified portable harvesting machine was experimentally evaluated under the following parameters:

(1) **Type of fruit crop**: Two types of navel orange and Pomegranate were tested.
(2) **Cutting methods:** Three cutting methods of traditional manual, the machine with toothed disc head and the machine with scissors head.
(3) **Cutting height:** Three cutting heights (picking heights) from ground 2, 3 and 4 m were tested.
(4) **Disc speed:** Three disc speeds of 600, 700 and 800 rpm or 3.14, 3.66 and 4.19 m/s, were tested.

Measurements

To study the effect of the variable factors and evaluate the fruit harvesting machine indicators the following measurements were carried:

Machine performance rate (productivity):

Total picking time and labor productivity were used to evaluate machine performance compared to the traditional method (manual harvesting). Total harvesting time for a full working day was recorded to determine average labor productivity using the different harvesting tools. The total time

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included selecting and cutting the fruits and the time required to transport the tools between the trees within the field.

Machine performance rate was determined by the following equation:

$$\text{P.R., fruit/min} = \frac{\text{No. of fruits}}{\text{T.}} \times 100$$

Where: P.R. is the performance rate; While. T is the time that was evaluated by calculating the average time of harvesting, moving between trees and climbing stairs (in manual method)

The fruits damage ratio:

The fruits damage ratio was evaluated by calculating the percentage of damaged fruits due to falling from the collection basket and the percentage of visible damage in the harvested fruits as a result of being cut with picking tools or falling on the ground.

The fruits damage ratio was determined by the following equation:

$$\text{D.R., \%} = \frac{\text{No. of damage fruits}}{\text{No. of total fruits}} \ 100$$

Where: D.R. is the fruits damage ratio.

Fuel consumption:

Fuel consumption per unit time was determined using a calibrated tank (refilling method) to measure the volume of fuel consumed during the operation time.

Required power:

The following formula was used to estimate the required power (Donnell, 1983):

$$\text{RP, kW} = 3.16 \text{ x fc}$$

Where: RP is the required power; fc is the fuel consumption, l/h.

Specific energy:

Specific energy was calculated by using the following equation:

$$\text{Specific energy, kW h/Mg} = \frac{\text{Power required, kW}}{\text{Machine productivity, Mg/h}} \times 100$$

Operational cost:

The modified machine hourly cost (H.C.) was calculated according to the conventional method of estimating both fixed and variable costs.

H.C., L.E/h = fixed cost (L.E/h) + variable cost (L.E/h)

Where: L.E. is the Egyptian pound; while worker wage is 20 L.E /h.

The operational cost was estimated using the following formula (Awady, 1978):

$$\text{Operational cost, L.E. /Mg} = \frac{\text{H. C., L.E /h}}{\text{Machine productivity, Mg/h}}$$

Results and Discussion

Some parameters that affect the operation performance of the fruits harvesting machine from a technological and economic point of view were studied and evaluated. So, the results were presented and discussed under the following headings:

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Effect of different operating parameters on machine performance rate:

Fig. 6 shows the effect of cutting height, cutting methods and disc speed, on machine performance rate. Results showed that machine performance rate increased by decreasing cutting height, increasing disc speed, and using toothed disc head for cutting the navel orange fruits and pomegranate fruits.

The maximum machine performance rate of 27.67 and 24.66 fruit /min were obtained at cutting height of 2 m and using toothed disc head with disc speed of 4.19 rpm for navel orange and pomegranate fruits, respectively. Meanwhile, the minimum machine performance rate of 8 and 6.33 fruit /min were obtained at cutting height of 4 m and using traditional manual method for navel orange and pomegranate fruits, respectively.

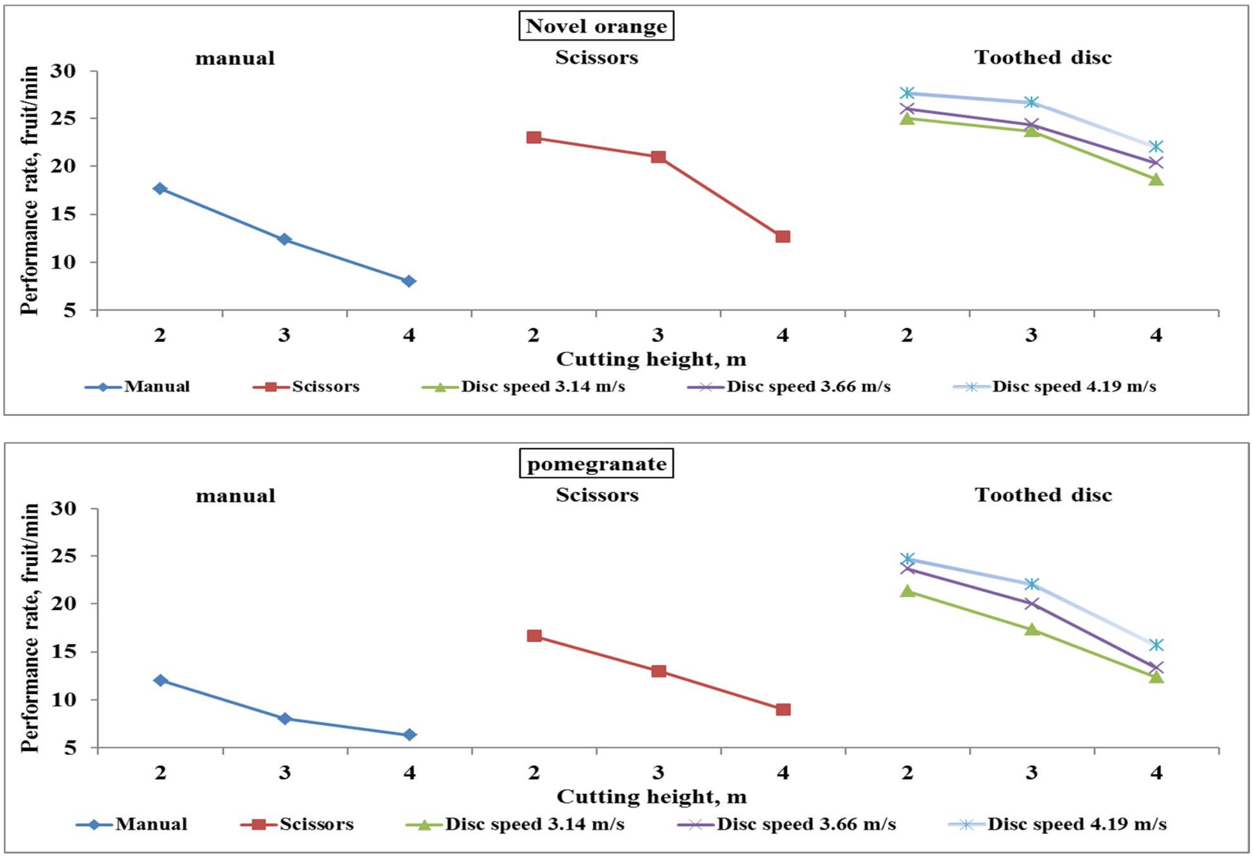

Fig. 6: Effect of some operating parameters on machine performance rate for harvesting navel orange and pomegranate fruits

Effect of different operating parameters on fruit damage ratio:

Fig. 7 displays the relation between cutting height, cutting methods and disc speed with fruits damage ratio for harvesting navel orange and pomegranate fruits. Hence, it appears that the fruits damage ratio increased by increasing cutting height and decreased by decreasing disc speed also fruits damage ratio increased at using machine with scissors head.

The results showed that, the minimum fruit damage ratio of 6.79 and 5.83% were obtained at cutting height of 2 m and using traditional manual method for navel orange and pomegranate fruits, respectively. The maximum fruit damage ratio of 12.63 and 12.22 % was recorded with cutting height of 4 m and using scissors head for navel orange and pomegranate fruits.

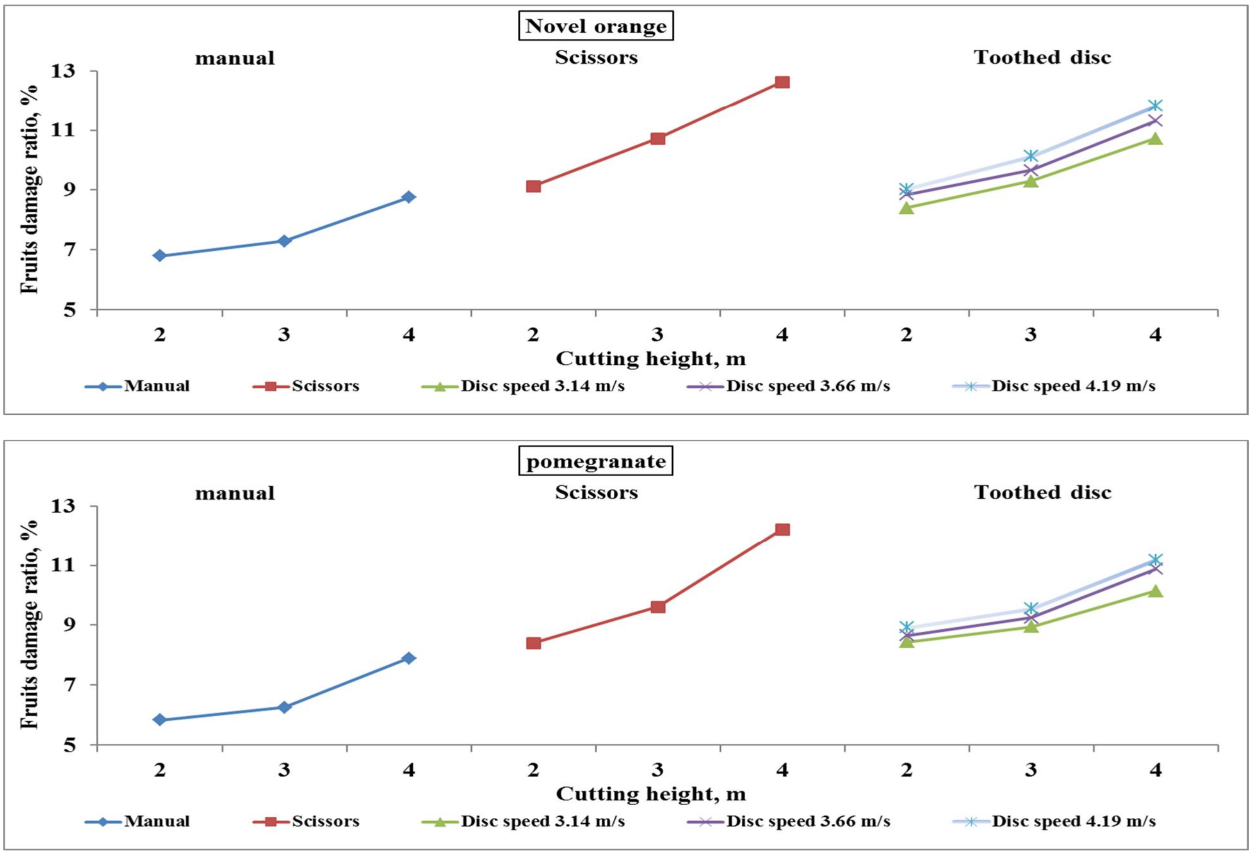

Fig. 7: Effect of some operating parameters on fruits damage ratio for harvesting navel orange and pomegranate fruits

Effect of different operating parameters on specific energy:

Results in Fig.8 showed the effect of fruit type, cutting height, cutting method and disc speed on specific energy. According to the obtained data it appears that the lowest specific energy was obtained at cutting height of 2 m but the highest specific energy was recorded at cutting height of 4 m, meanwhile the other parameter remained constant. The decrease in specific energy by decreasing cutting height can be attributed to the increase of the machine performance rate. The recorded results showed that the specific energy decreases with using toothed disc. Also results showed that specific energy increases by increasing disc speed from 3.14 to 4.19 m/s.

The results indicated that the lowest values of specific energy were 5.67 and 6.14 kW h/Mg at cutting height of 2 m and using toothed disc with disc speed of 4.19 m/s for navel orange and pomegranate fruits, respectively. Meanwhile, the highest values of specific energy were 11.77 and 13.89 kW h/Mg at cutting height of 4 m and using scissor head for navel orange and pomegranate fruits, respectively.

Effect of different operating parameters on operational cost:

The data presented in Table 2 cleared that the operational cost values decreased by decreasing cutting height. While the operational cost values decreased at using machine with toothed disc head for harvesting navel orange and pomegranate fruits. This result is attributed to increasing the machine performance rate by decreasing cutting height and using toothed disc. The results also revealed that the operational cost values for harvesting navel orange and pomegranate fruits decreased by increasing disc speed. This attributed to increase the machine performance rate.

The results showed that the lowest values of the operational cost were 75.41 and 81.66 L.E./ Mg at cutting height of 2 m and using toothed disc with disc speed of 4.19 m/s for navel orange and pomegranate fruits respectively. In addition to, the highest values of the operational cost were 206.97 and 252.41 L.E./Mg at cutting height of 4 m and using traditional manual method for navel orange and pomegranate fruits, respectively.

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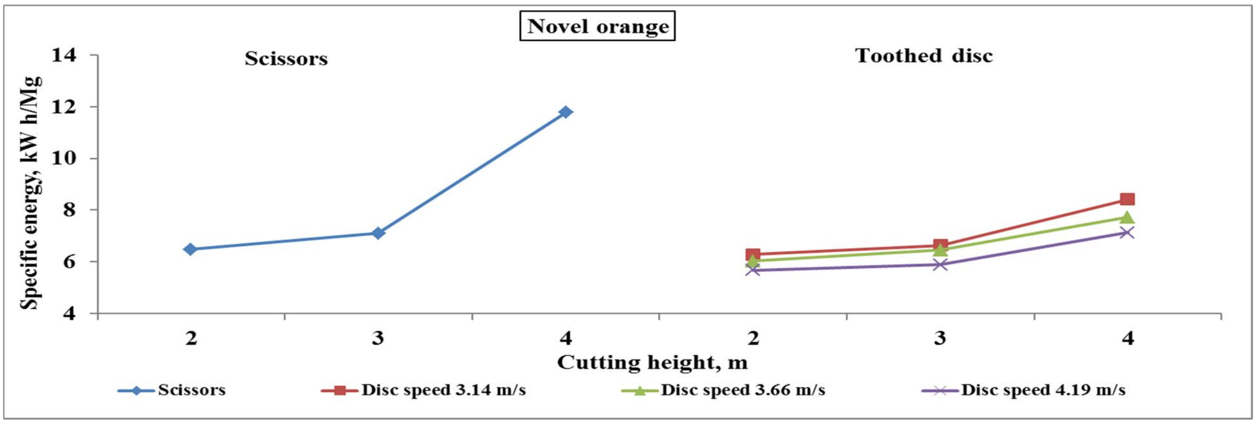

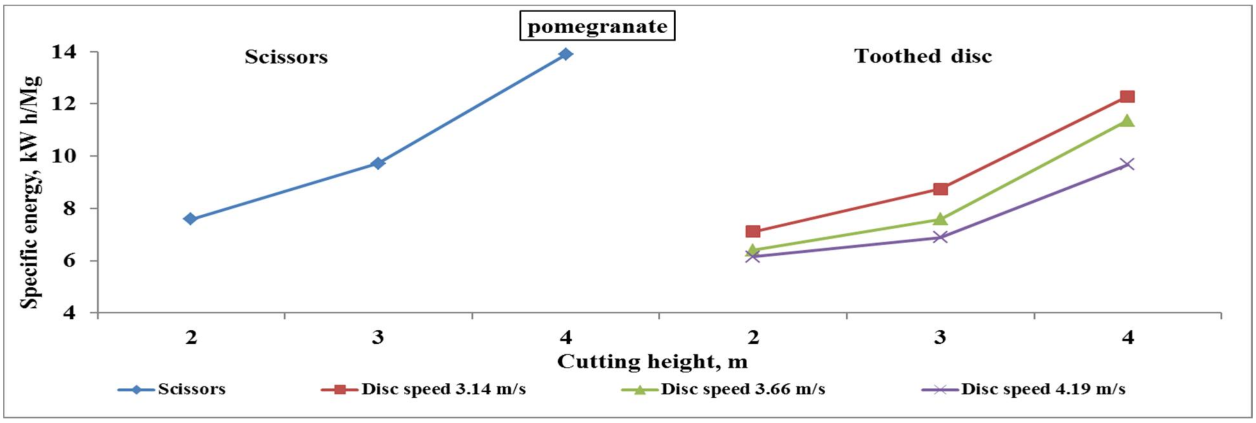

Fig. 8: Effect of some operating parameters on fruits damage ratio for harvesting navel orange and pomegranate fruits

Table 2: Effect of different operating parameters on operational cost

Type of fruits	Cutting height, m	Operational cost, L. E. /Mg				
		Cutting methods				
		Traditional manual	Scissors	Toothed disc Disc speeds, m/s		
				3.14	3.66	4.19
Navel orange	2	93.72	89.95	83.45	80.24	75.41
	3	134.25	98.52	88.15	85.74	78.23
	4	206.97	163.33	111.76	102.60	94.83
Pomegranate	2	133.21	117.49	94.42	85.11	81.66
	3	199.82	150.63	116.20	100.71	91.55
	4	252.41	217.27	163.31	151.06	128.57

Conclusions

It can be concluded that using the modified fruit harvesting machine for picking navel orange and pomegranate fruits with toothed disc head at disc speed of 3.66 m/s with all cutting heights exhibited an enhancement in performance rate and fruit damage ratio and decreased the specific energy and operational cost.

The obtained results at optimum conditions were machine performance rate of 24.33 and 20 fruit/min, fruit damage ratio 9.66 and 9.25% and specific energy of 6.45 and 7.58 kW h/Mg and operational cost of 85.74 and 100.71 L.E./Mg at cutting height of 3 m for navel orange and pomegranate fruits, respectively.

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