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Manufacturing and Evaluating the Performance of Shaking Machine for Harvesting the Lime (*Citrus aurantifolia*)

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ABSTRACT

Limes are manually picked all over the worldwide. To reduce the number of labour, time and reduce harvest costs of Egyptian lime. The machine was manufactured to operate an electric motor with different masses to give four frequencies during different shaking time for shaking harvesting. During shaking main branches, a certain amount of ripe lime couldn't be detached primarily due to an insufficient level of transferred energy. Harvesting tests showed that about 91 % of ripe lime without any fell of small green lime or flowers were detached under the recommended frequency of 45 Hz for the main branch shaking, shaking time 20 s and the mass of blocks W3 =365 g fastened on either side of the electric motor shaft. Recommended parameters during the shaker harvesting work as selective harvesting did not harvest unripe small green lime or fallen flowers just fell only ripe lime (yellow lime and greenish yellow lime). The study provided baseline knowledge and information for improving the lime harvesting to obtain high lime detach efficiency, save time, cost and labours for harvesting lime by manufactured an electric shaker.

Keywords: Lime; Detach efficiency; Frequency; Vibration; Shaker; Harvesting; Productivity; Operating cost.

INTRODUCTION

Harvesting with shaking is one of the widely spread methods for harvesting tree fruit mechanically. Unaffordable and time-consuming hand picking is the main problem in traditional lime harvesting. In the last half, a century shaking methods of harvesting has been considerably grown. Egypt lemons and limes production in 2016, nearly 369.6 thousand tons and exports nearly 34.1 thousand tons (FAO, 2017).

During shaking, trees respond otherwise to completely different excitation frequencies and amplitudes, and fruit may be removed with one or combined motions of pendulum apparatus motion, tilting motion, twisting motion, and beam-column motion (Cooke and Rand, 1969; Diener *et al*., 1965). Meanwhile, it absolutely was additionally found that stem fatigue throughout a continual bending motion contends a crucial role in fruit detachment removal (Rand and Cooke, 1970). Input vibrations at higher frequencies lead to higher fruit removal potency, however, they're typically related to a larger probability of harm to the fruit and tree (Norton *et al*., 1962). Although presently commercially out there harvesting systems might increase labour productivity by 5-15 times and scale back the price of harvesting up to 50 % (Brown, 2005). The frequency of excitation vibration is generated in multiple ways in which, all of that have an effect on transmission among the tree. The vibration will be made by the rotation of an eccentric mass, a drum with sticks, the deflectors of an air fan or a crankshaft-rod device (Whitney, 1977; Whitney and Sumner, 1977). This forced vibration is applied to the tree with a constant value of amplitude and frequency, that is troublesome to change while not extra engineering. As a result, the vibration at a given excitation frequency worth is transmitted by the trunk through main branches to bearing branches wherever it detaches the fruit. The proportion of fruit removed additionally depends on the fruit detachment force and mass (Sumner and Coppock, 1982), the canopy of the tree position (He *et al*., 2013) and period or range of vibration events (Blanco-Roldan *et al*., 2009).

Low harvest potency values aren't solely due to high FRF (Fruit Removal Force, N), however alternative variables like tree training, tree structure additionally play an important role in harvest potency and that they additional that it's necessary to prune trees in such the simplest way that facilitates a good vibration transmission to any or all elements of the tree canopy (Castro-García *et al*., 2014). The maximum fruit removal percentages were obtained average values of 99, 100,100 for upright limb position, short limb length, and small tree size, respectively (Erdogan *et al*., 2003).

The fruit mass increases during the ripening season lead to a reduction of FRF (Sessiz and Özcan, 2006). Tsatsarelis (1987), through an experiment, designed dependencies between the time required for olive detachment and forcing vibration characteristics. The basic principle of shaking harvest is to transmit an acceptable quantity of mechanical energy to fruiting branches to induce a detaching force on the fruit stem interface that then removes the fruit from the trees (Erdogan *et al*., 2003). Tsatsarelis *et al*. (1980), reported that the factors that affect the fruit detachment are attachments force, fruit weight, maturity, variety geometry of the fruit and volume.

The average FRF between 1.5-6.5 N for olive fruit with average mass 3.3 g (Hoshyarmanesh *et al*., 2017). The pull force to fruit weight quantitative relation, stem length, shaking frequency and damping quantitative relation affecting citrus detachment (Ghonimy, 2006).

Coppock *et al*. (1985), harvested Valencia oranges late within the harvest season once selectivity is that the most troublesome. With a mean mature fruit removal of 96 %, the average sequent yield loss was 15 % and the average shake time was 1.8 min/tree. Torregrosa *et al*. (2014), studied the motion of citrus attributable to undulation excitation employing a slow-motion camera in laboratory condition. The motion of the fruit was calculable exploitation its centre of mass, linear speed/acceleration and tilt angles and that they found that short strokes and low frequencies were weak to remove some fruit. Quality of the lime choice is extremely fascinating as a result of it achieves the maximum lime worth through the availability of the very best lime quality. Tree of the lime with a special case for harvesting because of the lime production nearly all over the year, especial main flowering in the spring, so that it must be carefully harvesting cause of care of fallen flowers from the tree and small fruits not ripping during many times harvesting all over the year. Tree of the lime has a lot of thorns that harmful to operator picking by handling and it forbade him to reach the lime on high branches or overlap branches.

As the fruit additional ripens, the harvest amount rate grows extremely (Ferguson *et al*., 2010). The frequency period ought to be made at an amplitude which will turn out sufficiently high acceleration while not damaging the branches of trees. The frequency duration response of an individual lime was dependent on the stage of maturity. The maximum displacement and stress amplitude occurred at the stem nodes that facilitate lime detachment while avoiding damage formation in branches.

The objective of this study is to provide new an electric shaker for lime detachment, determine the frequency response of ripe fruits and unripe fruits fell under forced shaking to operate it as a selective shaking harvesting method did not harmful tree or damaged branches or fallen flowers or fallen small green fruits.

MATERIALS AND METHODS

Materials

Experiments were carried out at Mit-Ghamr, Dakahlia Governorate, Egypt during the season of 2018 using available local materials to manufacturing an electric shaker system for harvesting lime fruits by shaking main branches.

The vibration of the shaker device is generated by a multi-double eccentric block exciter, which provides an exciting force for the branch, as shown in Fig. 1. Exciter is fastened with the clamping device. because it clamped, exciting force is employed for main tree branches to move it. When the limes have enough acceleration, the purpose of separating the limes is achieved. Using two equal unbalanced eccentric masses each one fastened on either side of the motor shaft and within the same direction rotating.

The variable force applied to the fruit creates a momentum leads to a failure stress riser at the stem node, and if the force is giant enough, the fruit will be detached. Attachment force of the stem to small branches depends on the different stages maturity of fruit ripening.

Machine specification:

Harvesting system in this study was manufacturing an electric shaker for harvesting lime fruits and works by two operators. One for shaking branches by shaker another one for handling gasoline generator and control it by turning on or off.

An electric shaker was consisting of a catching unit, shaker unit, and power unit, as shown in Fig. 1.

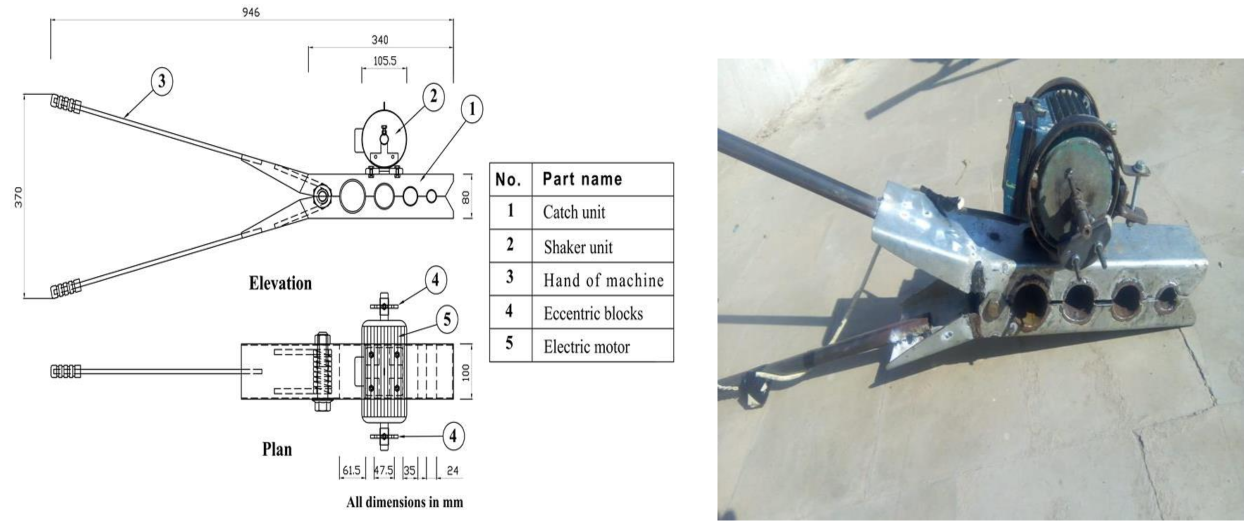

Fig. 1. An electric system for shaking

(a) Catch unit:

Catch unit constructed of iron sheet metal with 4 mm thickness. Dimensions of the catch unit were 370 mm for height, 946 mm for length and 100 mm for width. Catch unit have different size rings fits with diameters of lime branches and their diameters (24, 35, 47.5 and 61.5 mm). Machine hands made from two pipe iron metal with dimensions of 3 mm thickness, 20 mm diameter and 500 mm length, it's fixed with catch unit

(b) Shaker unit:

Shaker unit was consisting of electric motor power of 0.37 kW at 3000 rpm rotating speed, alternating current (AC), 220 V, 1.8 A, and eccentric blocks. Eccentric blocks fixed on the electric motor shaft with a diameter of 18 mm. Dimensions of eccentric blocks were 65 mm for length and 64 mm for width. It made from plate iron metal with 6 mm thickness.

Based on the preliminary test, an excitation force ranged from 10-30 N was required to detach the fruit from the branch. Eccentricity is a block that center is not on rotated point, which is generally referred to as a round wheel. It becomes eccentric once the circle doesn't revolve around its center. An eccentric block adopted semicircle type is divided into two groups, which are respectively fastened on either side of one output shaft.

It is noticed that at field experiments parallel blocks on the motor shaft give the maximum frequency, as shown in Fig. 2.

(c) Power unit:

Consisting of gasoline generator with a power of 1 kW and key to change the motor speed. Physical and mechanical properties of the lime tree and lime fruits are provided in Table 1.

Methods:

Experimental conditions:

The shaker system unit was studied under the following parameters:

- Four frequencies: 35, 40, 45 and 50 Hz,
- Four shaking time:15, 20, 25 and 30 s,
- Four eccentric masses (mass of blocks): W1= 215, W2= 300, W3 = 365 and W4 = 430 g fastened on either side of the motor shaft.

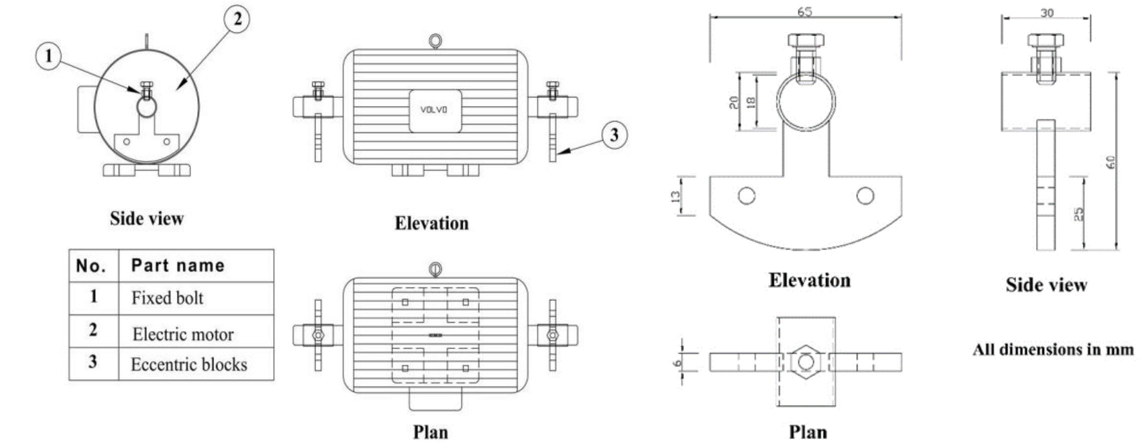

Fig. 2. parallel blocks on the motor shaft and rotating within the same direction.

Table 1. Physical and mechanical properties of the lime trees and lime fruits.

Tree characteristic	Average value	Lime characteristic	Average value
Tree height, mm	3500	Lime diameter, mm	32
Tree trunk diameter, mm	800		
Tree age, year	17		
Maine branches numbers	3		
Tree distance in the same row, mm	4000	Lime length, mm	39
Distance between rows, mm	4000	Mass of one lime, g	30
Length of the main branch, mm	2200	Force for remove one ripe lime, N	12.5
The length between catching point and the trunk on the main branch, mm	1400	The ratio between the removal force and lime mass	42.47
Branch diameter at vibration catching point, mm	60		
Tree yield, Kg/year	36		

Instruments:

The shaker system unit was evaluated using the following devices and equations:

Electrical balance:

The category was OHAUS, made in the U.S.A measuring lime fruits mass. The maximum balance was 2610 g with 0.1 g accuracy.

Tachometer:

Measuring the revolution per minute of the electric motor in the range from 0.05 to 19999 rpm with ± 0.05 % accuracy.

Stopwatch:

Consumed time for each treatment was measured by using a digital stopwatch (Casio JHS) with 1/100 second accuracy was used to record the time.

Clamp meter and voltmeter:

Measuring the current intensity and voltage. The specification of the used clamp meter and voltmeter are as following: Made in: Japan; Category: Super 600 V~AC 50 Hz; Measurement: AC amperage, AC voltage, and resistance.

Measurements:

Machine productivity:

Shaker system unit productivity was calculated from the following formula:

$$S_p = M_d / T \quad (1)$$

Where: **S_p is shaker system unit productivity, kg h^{-1}; M_d is mass of detached ripe lime, kg; T is consumed time, h.**

Detach efficiency:

The Detach efficiency was calculated derived from using the following formula (Erdogan *et al*., 2003):

$$D\ \% = (m_{hr} / (m_r + m_{hr})) \times 100 \quad (2)$$

Where: **D is the detach lime percentage, %; m_{hr} is the mass of harvested ripe lime, kg; m_r is a ripe lime mass on the tree did not have fallen, kg.**

Power and Specific energy requirement (SER):

Estimating the power as provided by Hunt (1983):

$$P = (FC/c) \times (\eta_{th}/100) \times HV \quad (3A)$$

Where **P is the power required, kW; FC is the consumption fuel, kg h^{-1}; η_{th} is the thermal efficiency, %; HV is the heating value of fuel, kJ kg^{-1}; and c is equal 3600.**

Estimating the power consumed as provided by Ibrahim (1982):

$$P = I \times V \times \cos\theta \times \frac{1}{1000} \quad (3B)$$

Where **P is the required power, kW; I is current intensity, Ampere; V is voltage, Volt; cos θ is power factor, 0.84.**

Calculating the requirements of the specific energy for shaker:

$$SER\ (kW\ h\ t^{-1}) = (P, kW) / (S_p, t\ h^{-1}) \quad (4)$$

Operating cost:

Shaker system unit hourly cost was determined by El Awady (1978):

$$C = p/h\ (1/a + i/2 + t + r) + (1.2\ W.F.\ S) + m/144 \quad (5)$$

Where **C is cost for working one hour, EGP h^{-1}; P is the machine price, EGP; h is working hours during the year, h y^{-1}; a is the machine life expectancy, y; i is rate of interest for one year, %; t is ratio of taxes overheads, %; r is ratio of repairs and maintenance, %: W is the power consumed, kW; F is price of the fuel, EGP l^{-1}; S is consumption of the specific fuel, l kW^{-1} h^{-1}; m is monthly salary for operator, EGP; 1.2 is factor including oil consumption and oil filter prices as a percentage of the fuel consumption price; 144 is the average number of working hours in one month; h.**

$$Operating\ cost\ (EGP\ t^{-1}) = C, EGP\ h^{-1} / S_p, t\ h^{-1} \quad (6)$$

RESULTS AND DISCUSSION

Shaker productivity

Frequency, the mass of blocks and shaking time are principal parameters governing the productivity of the harvester shaker. The obtained results for the lime shaker indicated that, at the frequency of 45 Hz by increasing the mass of blocks from 215 to 430 g, productivity increased from 25.27 to 32.39, and from 28.19 to 35.56 Kg h^{-1} at shaking time of 15 and 20 s, respectively, as shown in Fig. 3.

After shaking time of 20 s productivity decreased at shaking time of 25 s and more productivity decreased at shaking time of 30 s.

At the frequency of 45 Hz by increasing the mass of blocks from 215 to 430 g, productivity increased from 26.46 to 33.23, and from 24.47 to 30.66 Kg h^{-1} at shaking time of 25 and 30 s, respectively.

When the mass of blocks increases from 215 to 430 g the productivity increase due to increasing vibration by increasing the mass of blocks and productivity increased with increased frequency from 35 to 50 Hz for all shaking times.

It is noticed that after 365 g and 45 Hz at 20 s shaking time, more immature small green lime fallen and more flowers fell until 30 s frequency, so the mass of blocks 365 g and 45 Hz at 20 s shaking time are recommended because gives high productivity without any losses (small green unripe lime fallen and flowers fallen).

Results showed that productivity increased with increasing shaking time from 15 to 20 s, the big mass of fallen lime of most mature lime and vice versa the decreased productivity with increasing the separation time from 20 to 30 s occurs because of the fewer number of trees shaking in one-hour and big spare time lose without Significant increase of fallen ripe lime.

These results agree with Polat *et al.* (2017), found that harvesting potency values in harvesting tests using 40 Hz frequency and 20 mm were 93.27 % for pistachio variety of Siirt and 87.06 % for pistachio variety of Kirmizi.

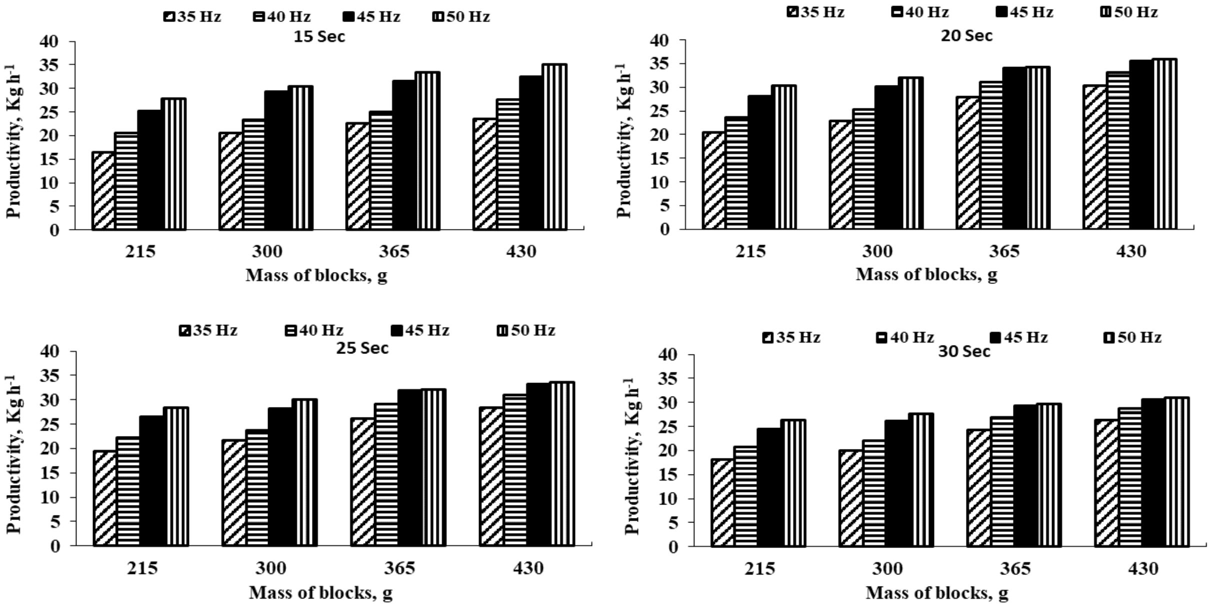

Fig. 3. Effect of frequencies, the mass of blocks and shaking time on productivity.

Short shaking time is not enough to g*et al*l ripe lime fallen down due to attenuation of transmitted waves of vibrational. Long shaking time leads to a severe loss of infected tree leaves and did not damage any small twigs.

Finally, Productivity increased with a trend from 215 to 430 g and from 35 to 50 HZ, the small green unripe lime and flower of lime begin falling down after 365 g and 45 Hz at 20, 25, 30 s with ripe lime, so the losses increased and made shortage yield for next the shaker harvesting.

Detach efficiency

The obtained results for the lime shaker indicated that, at frequency of 45 Hz by increasing, the shaking time from 15 to 30 s, and mass of blocks from 215 to 430 g, detach efficiency increased from 60.17 to 77.13, from 75.18 to 94.83, from 76.70 to 96.30, and from 77.64 to 97.35 % at shaking time of 15, 20, 25 and 30 s, respectively, as shown in Fig. 4.

Detach efficiency increased with the mass of blocks increases from 215 to 430 g, shaking time increase from 15 to 30 s and frequency increase from 35 to 50 Hz the detach efficiency increase due to increase mass of fallen ripe lime (yellow lime + greenish yellow lime).

These results agree with Erdogan *et al.* (2003), reported that apricot removal percentages increased with increasing frequency and increasing amplitude as well.

These results agree with He *et al.* (2013), found that mechanical shaker in sweet cherry harvesting removal efficiency increased with increasing of accumulative excitation time. A relationship between vibration frequency and proportion of mature fruit removal may be affected by differences in trunk diameter, tree size, fruit mass, and maturity (Moreno *et al.*, 2015; Whitney, 2003).

The detach efficiency increases from the shaking time of 15 to 30 s, as a result of the descent of most mature lime by increasing detach time. Calculate detach efficiency for only rip lime (yellow lime + greenish yellow lime) and did not consider any losses (small green lime fell and flowers fell) that begin falling down after 365 g and 45 Hz at 20, 25 and 30 s with ripe lime fallen.

The lime is an especial case in harvesting because of it flowering during the most of the year so, the tree of the lime is sensitive to any vibration or mechanical harvesting.

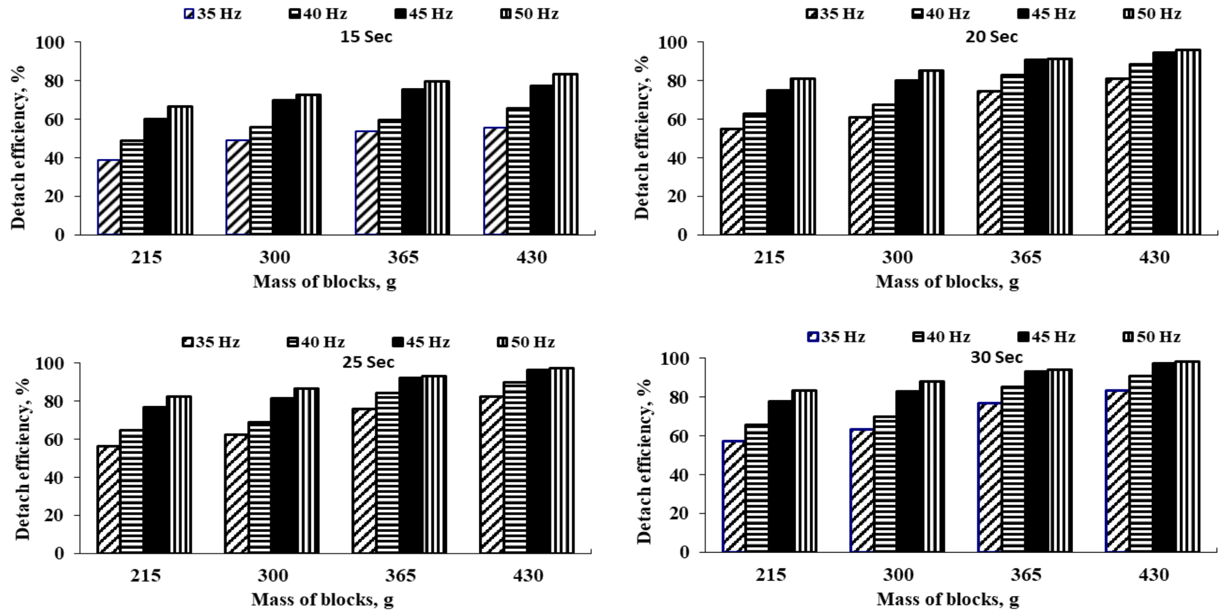

Fig. 4. Effect of frequencies, the mass of blocks and shaking time on detach efficiency.

Specific energy requirement

Results in Fig 5. Indicated that, at frequency of 45 Hz by increasing, the shaking time from 15 to 30 s, and mass of blocks from 215 to 365 g, specific energy requirement decreased from 9.51 to 8.75, from 9.03 to 8.68, from 10.02 to 9.56, and from 11.12 to 10.99 kW h t^{-1} at shaking time of 15, 20, 25 and 30 s, respectively.

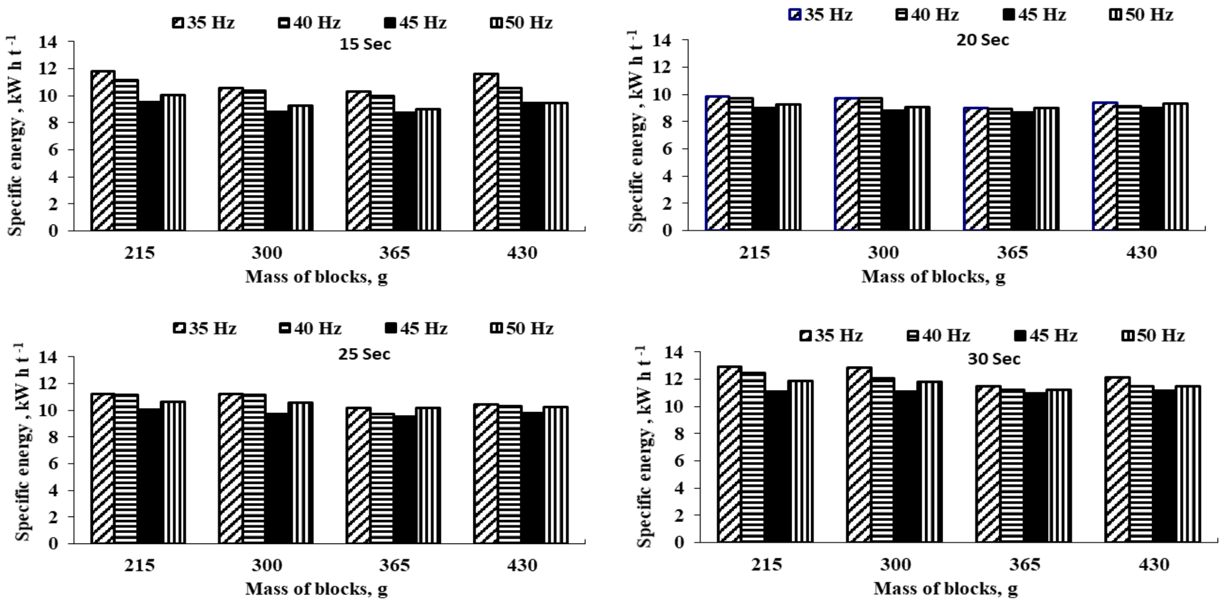

Fig. 5. Effect of frequencies, the mass of blocks and shaking time on Specific energy requirement.

At frequency of 45 Hz by increasing the shaking time from 15 to 30 s, and mass of blocks from 365 to 430 g, caused increase in the specific energy requirement from 8.75 to 9.44, from 8.68 to 8.97, from 9.56 to 9.78, and from 10.99 to 11.17 kW h t^{-1} at shaking time of 15, 20, 25 and 30 s, respectively. When the mass of blocks increases from 215 to 365 g the specific energy requirement decreased, but begin to increase after 365 to 430 g due to mass increase on the motor occurs in reverse resistance used more power not a parallel increase of productivity. Therefore, recommend mass 365 g at 20 s because it gives acceptable detach efficiency, productivity and lowest specific energy of 8.68 kW h t^{-1}.

It is noticed that the specific energy requirement decreased with increased frequency from 35 to 45 Hz for all shaking times, but after that from 45 to 50 Hz, it increases. It attributes to 45 Hz gives acceptable productivity and detach efficiency without losses which happen at 50 Hz at long shaking times.

The highest specific energy requirement about 12.89 kW h t^{-1} observed at shaking time 30 s at the mass of 215 g and 35 Hz frequency and the lowest specific energy requirement about 8.68 kW h t^{-1} observed at shaking time 20 s at the mass of blocks 365 g and 45 Hz frequency. So, the best shaking time 20 s at the mass of blocks 365 g and 45 Hz frequency cause of lowest specific energy requirement.

The specific energy requirement of the lime shaker was lowest at 45 Hz, 365 g and shaking time of 20 s because of higher productivity without losses was obtained at these parameters. An increase in the requirement of the specific energy from 45 to 50 Hz, for lime shaker is due to an increase in power that was proportion greater than an increase in shaker productivity.

These results agree with He *et al*. (2013), found that the energy consumption at 18 Hz was considerably more than that at 14 Hz with an equivalent accumulated excitation time. The 18 Hz excitations consumed 3.0 kJ extra energy during the initial 5 s cycle and 11.7 kJ extra for the total 20 s of shaking compared to the energy consumption with 14 Hz excitations.

Operating cost

Relating the use of harvester shaker results in Fig. 6. Indicated that, at the frequency of 45 Hz by increasing, the shaking time from 15 to 20 s, and the mass of blocks from 215 to 430 g, operating cost decreased. The operating cost decreased with increased frequency from 35 to 50 Hz for all shaking times.

This can be attributed to the high productivity at shaking time 20 s, 365 g, and 45 Hz without losses and by increasing frequency from 35 to 50 Hz productivity increased also vice versa operation cost decreased.

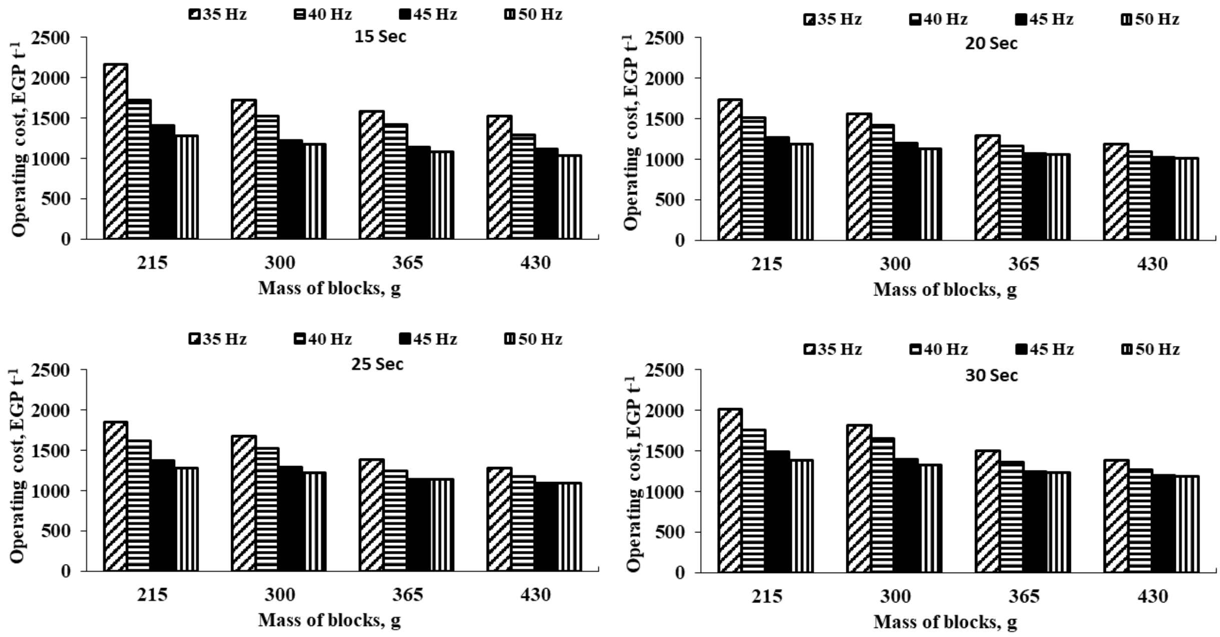

Fig. 6. Effect of frequencies, the mass of blocks and shaking time on operating cost

Average manual harvesting for one operator about 40 Kg/day of lime and average operating cost for manual harvesting about 2500 EGP t^{-1}. So, the shaker harvesting by two operator saves nearly 57 % of the average manual operating cost because of the operating cost of the shaker harvesting about 1066.27 EGP t^{-1}. It was found that the shaker harvesting of the lime saved energy, time and money, as shown in Table 2. It is noticed that the shaker harvesting saves nearly 60 % of labour used in manual harvesting and faster than manual harvesting within the same number of labour by nearly 2.5 times. Harvesting by an electric motor one tree needs nearly 2.33 min to harvest lime. These results are consistent with the findings of Roka and Hyman (2012), mechanical harvesting systems could reduce harvesting costs by 50 %.

Table 2. Comparison between the shaker harvesting and the manual harvesting of lime.

	The average value of the shaker harvesting	The average value of the manual harvesting
Productivity, Kg h^{-1}	34.05	6.65
Detach efficiency, %	91	90
Harvesting number of the tree during working day, tree/day	150	30
The operating cost, EGP t^{-1}	1066.27	2500

CONCLUSION

It may be recommending that using an electric shaker for harvesting the lime at 20 s, 45 Hz, and an optimum block mass W3=365 g fastened on either side of the motor shaft. The productivity of the shaker harvesting was 34.05 Kg h^{-1}, the detach efficiency was 91 %, specific energy requirement was 8.68 kW h t^{-1}, and the operating cost of 1066.27 EGP t^{-1}. The shaker harvesting saves nearly 57 % of the operating cost of manual harvesting.

This shaker harvesting if work at recommended results it may be considered the selective machine to harvesting the lime with a special case of harvesting lime. It was found that the shaker harvesting of the lime saved energy, time, cost and labours. Prefer to training lime tree to have vigour branches and big distance between each other to facilitate the shaker harvesting.

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تصنيع وتقييم أداء آلة هز لحصاد الليمون البنزهير

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[١] قسم الهندسة الزراعية – كلية الزراعة – جامعة الزقازيق

[٢] قسم الهندسة الزراعية – كلية الزراعة – جامعة طنطا

يتم حصاد الليمون البنزهير اختياريا ويدويًا حول العالم وتتميز مصر بالليمون البنزهير ومن صفاته أنه صغير الحجم وذو حموضة عالية للثمار. تهدف الدراسة إلى تصنيع هزاز كهربائى لحصاد الليمون البنزهير لتقليل الاعتماد على العمالة الموسمية وتقليل تكاليف الحصاد والسرعة فى عملية الحصاد وتوفير الوقت ، والهز الميكانيكى من طرق الحصاد لأشجار الفاكهه وقد تم تصنيع آلة لهز الأفرع اعتمادا على استخدام أوزان لا مركزية مختلفة لإعطاء سرعات مختلفة للاهتزاز. خلال اهتزاز الفروع ، لا يمكن فصل كمية معينة من الليمون البنزهير في المقام الأول بسبب عدم كفاية مستوى الطاقة المنقولة. كان الهدف الأساسي من هذه الدراسة هو تصنيع هزاز كهربائى واستخدامه فى حصاد الليمون البنزهير ذو طبيعة خاصة حيث أنه يزهر تقريبا طول أيام العام والحصاد يتم وتوجد زهور على الشجرة وايضا يتم التحقق من كفاءة الآلة في فصل الليمون البنزهير من فروع الأشجار الرئيسية فى أزمنة هز مختلفة وأظهرت النتائج التوصية بتشغيل الهزاز الكهربائى أثناء فصل الليمون البنزهير تحت اهتزاز مقداره ٤٥ هرتز ، و وقت الفصل ٢٠ ثانية و الكتل اللامركزية الثالثة =٣٦٥ جرام على كل طرف لعمود الموتور الكهربائى . قدمت الدراسة المعرفة الأساسية ومعلومات لتحسين حصاد الليمون البنزهير للحصول على انتاجية ٣٤.٠٥ كيلو جرام\ الساعة و كفاءة عالية للفصل مقدارها ٩١ % وذلك بإستخدام طاقة مقدارها ٨.٦٨ كيلووات . ساعة \ طن وتكاليف حصاد ١٠٦٦.٢٧ جنيه\ طن وهذا يوفر نحو ٥٧ % من تكاليف الحصاد اليدوى ويوفر العمالة وبذلك يوصى باستخدام الهزاز الكهربائى فى حصاد الليمون البنزهير ويفضل تربية شجر الليمون البنزهير للحصول على فروع قوية ومسافة كبيرة بين بعضها البعض لتسهيل الحصاد بالهزاز الكهربائي .