Engineering Journal issn: 0125-8281

*Article*

# The Design of Bunch Shaker and the Date Fruit Detachment Force

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**Abstract.** In this work, the design and construction of a tractor-mounted shaker used for the removal of date fruits from the bunch is presented. The dynamic force developed by this shaker is calculated and the tensile force required to detach the date fruit at subsequent stages of fruit maturity is measured with the prospect of relating the two forces. Such a relation would facilitate the design of shaker stroke and frequency which would develop a dynamic force equivalent to the detachment force requirement for any type of date variety. The experimental results confirmed that the detachment force decreased significantly with the progress of fruit maturity. The average tensile detachment force at the final stage of fruit maturity was 6.8 N which is 20% of the average tensile detachment force at the first stage of fruit maturity (33.4 N). However, the dynamic force developed by the bunch shaker at different shaking frequencies, which ranged from 0.42 N to 2.68 N, is much lower than the tensile detachment force. This implies that dates removal from the bunch by a bunch shaker cannot be attributed to the development of a dynamic force which exceeds the tensile detachment force requirement. Consequently, the tensile fruit detachment force cannot be utilized as a criterion for the design of a date bunch shaker.

**Keywords:** Date bunch shaker, mechanical date harvest, date fruit detachment force.

**ENGINEERING JOURNAL** Volume 25 Issue 8
Received 24 June 2019
Accepted 5 August 2021
Published 31 August 2021
Online at https://engj.org/
DOI:10.4186/ej.2021.25.8.127

DOI:10.4186/ej.2021.25.8.127

## 1. Introduction

Date palm (Phoenix dactylifera L.) is one of the oldest trees that has been cultivated in the Middle East and Northern Africa for 5000 years. The origin of this tree is most likely Mesopotamia (Iraq), where archaeological findings revealed that date palm trunks were used for constructing houses 3000 BC [1].

The date palm may reach a maximum height of 15-20 m before being cut down due to decline in yield and difficulty to reach the tree crown to perform cultural operations [2]. Traditionally, skilled laborers climb the tree trunk barefoot which is dangerous, very difficult and slow. Climbing the tree trunk may be facilitated by scooping out footholds in the tree trunk, using a rope, or a climbing belt wound around the worker and the tree [3].

Date growers in the United States use different types of aluminum ladders to reach the tree crown. As the date palms grow taller, ladders with increased lengths are used. For date palms with over 10 m height, extension aluminum ladders are favored. Sometimes, a 3-6 m length ladder is permanently attached below the tree crown of extra high date palms to avoid carrying around very long ladders [4]. Although using ladders to reach date palm crown is considered much safer than climbing tree trunk, it is still tedious and dangerous. This, in addition to the shortage of skilled labor, prompted research work to employ date palm mechanization in the USA during the 1960's. Different types of machines were developed to position workers near the tree crown. These machines include tractor-pulled towers, forklift towers and truck-mounted hydraulic cranes [5].

Work elsewhere since the 1980's followed similar lines in developing and field-testing machines to reach the date palm crown [6]. Some investigated conditions of local date palm plantations in terms of tree spacing, presence of other crops in spacing between palm trees, irrigation channels, and borders which obstruct machine mobility and date mechanization requirements [7-9]. Others, investigated the physical properties of date palms related to mechanization [10, 11], the design of date palm trunk climbing machines [12, 13] and self-propelled ladder [14].

In Saudi Arabia, work on modifying industrial equipment to be suitable for work in date palm orchards was reported [15]. The work involved the modification of a hydraulic lift which reaches a height of 10 m and an aluminum platform utilizing a dual chain system to reach a working height of 11 m. A specially developed hydraulic lift with a U-shaped platform which facilitates work at the tree crown without additional movement of the platform was also field tested. The hydraulic lift was mounted on a four-wheel drive truck and equipped with full control capability from the platform [16].

In Iraq as well, different types of machines for date palm mechanization were tested [17]. Evaluation of field performance tests of some of these machines which include hydraulic lifts with a working height in excess of 12 m were reported [18].

In United Arab Emirates, a hydraulically-operated service machine for date palms mounted on a tractor was developed. It lifts a worker to a relatively limited height of 4.5 m. Field tests of this machine verified its higher productivity, in addition to providing a safe and comfortable work conditions as compared to manual practice [19].

In Iran, evaluation of locally available machines for date palm mechanization revealed that most lifting machines were not suitable and recommended guidelines for modifying these machines [20]. Ten different types of lifters were also evaluated and classified to determine the most suitable lifter [21].

Harvesting date fruits is the most expensive process in date production. It represents 45% of total cost of production [22] which puts emphasis on harvesting dates mechanically with the aim of reducing cost and overcoming shortage of specialized hand labor. In general, date fruit harvesting involves reaching the date palm crown to cut mature date bunches and lower them down, and then removing the dates from the bunch.

The mechanical harvest of dates was first investigated during the 1960's in the United States on the semi-dry Deglet Noor date variety which represents over 90% of local date production [22]. The widely used mechanical harvesting system utilizes a truck-mounted crane to reach the tree crown, cut the mature date bunches and lower them down to remove the dates using a hydraulically driven bunch shaker. The truck drawn bunch shaker produces a vertical stroke of 82.5 mm at 700 cycle/minute to remove all dates from the bunch within 2 s without causing fruit damage [22]. The wide adoption of harvesting dates mechanically in the United States led to a reduction of 75% in harvesting labor and 50% in harvesting cost [5]. However, it was reported that the use of this shaker resulted in dropping mature as well as immature dates, which created sorting problems during date processing and packing. Proposed methods to overcome this problem involved modifying the shaker stroke and frequency and suggesting post-harvest fruit separation methods [23].

Innovative research work on mechanical harvest of dates includes the development of a portable date bunch harvesting machine which allows the operator from ground level to cut bunches at a height of up to 8 m and lower them down [24]. The bunches are cut by a rechargeable electric-chainsaw fitted on the top of a telescopic mast that can be raised using two manually operated winches. Preliminary field tests showed the machine capability to cut bunches at a height of 6.5 m and lower them down. However, there might be some issues related to the relatively long time required to set the machine and its heavy mass (42 kg) which makes it difficult to handle by one operator.

In a more futuristic approach, an investigation which involves steps towards an attempt to introduce a robotic manipulator into date fruit harvesting was conducted

[25]. The investigation presents the geometric calculations required for the manipulator control. The manipulator which is part of a date harvesting machine is equipped with a cutting tool which cuts date bunches without the need to lift a worker to the tree crown. The manipulator was designed, constructed and successfully tested.

It is noteworthy that investigators have focused on developing methods and machines to reach the date palm crown, which is understandable since it facilitates performing other cultural operations as well as harvesting. Whereas the removal of date fruits from the bunch did not attract similar attention, although it is used in the USA to remove dates from the bunch even when ladders are used to cut bunches and lower them down with ropes. In fact, there are only three reported attempts to develop and successfully test a date fruit bunch shaker since the 1960's and only one of them, developed in USA [22], was mass-produced.

In 2001, an investigation was carried out to design and develop a prototype date bunch shaker, driven by an electric motor, to remove the semi-dry Iran Shahani date fruits variety. The work involved experimenting different types of bunch shakers, shaking modes, shaking strokes and frequencies. It was concluded that a shaker with a vertical stroke of 60 mm at a frequency of 300 cycle/min provides the most effective results in terms of dropping ripe dates with minimal removal of unripe fruits at a relatively short time (5-7 s) [26]. In a follow-up to this investigation, the fruit detachment force to remove Shahani date fruits was measured using a spring scale with 20 N range and 0.1 N resolution equipped with a special clamp to hold the date fruit. The detachment force for ripe dates was found to be 2.5 N, which is approximately 35% of the detachment force for unripe dates (7.2 N) [27].

In 1986, an experimental work was carried out to establish a possible criterion for the design of a bunch shaker which selectively drops only mature Zahdi date fruits, the main local semi-dry date variety in Iraq [28]. The work involved investigating the effects of different biophysical and physical properties of Zahdi date fruit on date fruit detachment force. Fruit maturity, weight, length, diameter, and strand diameter were measured and correlated to fruit detachment force. Results indicated that fruit detachment force decreased significantly with maturity. The average detachment force at the four stages of fruit maturity considered, Chimiri, Khalal, Rutab and Tamar, was 3.31 kg (32.5 N), 3.19 kg (31.3 N), 1.99 kg (19.5 N) and 0.77 kg (7.55 N) respectively. These results indicate that the significant reduction in detachment force with maturity could be utilized as a criterion for the design of a selective bunch shaker which drops only the mature dates. This work was followed up with the development of a tractor-mounted date bunch shaker driven by the tractor's power take off (PTO) shaft (Fig. 1). It has a vertical stroke of 50 mm and can be operated at a shaking frequency of up to 1000 cycle/min. It was successfully tested in removing Zahdi date fruits from bunches at shaking frequencies of 300, 450 and 600 cycle/min. Test results indicated that a shaking frequency of 450 cycle/min was the most effective in dropping only the mature dates at a short time (3.5-5 s) without causing fruit damage [29].


Fig. 1. Tractor-mounted bunch shaker [29].

In the present work, details of the design and construction of the tractor-mounted date bunch shaker, referred to above [29], are presented. In addition to that, the dynamic force developed by the date bunch shaker is calculated and compared with the fruit detachment force to verify whether the two forces correlate. Such a relation, if present, would provide a generalized formula for the design of date bunch shaker stroke and frequency on the basis of detachment force requirement for any type of date variety without the need for field experiments. To achieve this objective, the detachment force required to remove Zahdi date fruit from its strand at subsequent stages of fruit maturity is measured. Date fruit mass is also measured as it is required for calculating the date bunch shaker dynamic force.

## 2. Materials and Methods

### 2.1. Design of Tractor-mounted Bunch Shaker

One of the most important considerations in the design of power-driven mechanical systems is the selection of suitable prime mover. In the case of date fruit shaker system, it is believed that it would be

DOI:10.4186/ej.2021.25.8.127

advantageous in several ways if the shaker system is designed as a tractor-mounted system. This would reduce the cost of the system, makes it more practical and enables its use and adoption by farmers and date growers, since it would be considered as another tractor-mounted implement.

In addition to that, tractors are suited for work in farms and date palm orchards, this would facilitate the use of the shaker system in the field, its transport from and to the date palm orchards and moving it from one place to another inside the orchard. Tractors are equipped with a power take-off shaft to provide implements with rotational power at a speed range of 0-1000 rpm, which is suitable for the propulsion of the shaker system.

The most essential part of the shaker-system is the slider-crank mechanism which converts rotational motion into reciprocating motion. For this purpose, a slider-crank with a 50 mm stroke, as shown in Fig. 2.

Fig. 2. Slider-crank mechanism.

Fig. 3. Clamp for holding the date bunch during shaking.

A clamp for holding the bunch in position during shaking was designed and manufactured (Fig. 3). The clamp is made of mild steel and is bolted to the slider-crank mechanism. The clamp is spring-loaded and its inner faces were roughened to maintain its grip on the bunch stalk and prevent its slip during shaking. The clamp is pressed on the bunch stalk by a bolt tightened with a handle.

The slider-crank was bolted on a frame of tractor mounted mower (Fig. 4) in order to hitch it on the tractor's three-point hitch system.

A specially manufactured adapter (Fig. 5) was used to connect the rotating end of the slider-crank mechanism to the universal joint propeller shaft which in turn is attached to the tractor's PTO shaft.


Fig. 4. Frame of tractor-mounted mower.

DOI:10.4186/ej.2021.25.8.127


Fig. 5. Adapter for connecting the slider crank mechanism to the propeller shaft.

The whole shaker system assembly mounted on a tractor is shown in Fig. 6. Details of design dimensions and specifications of the slider-crank and bunch-holding clamp utilized as a date bunch shaker are listed in Table 1 and their CAD modeling is shown in Fig. 7.


Fig. 6. Date bunch shaker mounted on tractor.

Table 1. Design dimensions and specifications of date bunch shaker.

| | |
|---|---|
| Shaker stroke | 50 mm |
| Shaking frequency | 0-1000 cycle/min |
| Crank throw | 25 mm |
| Length of slider-crank connecting rod | 50 mm |
| Dimensions of slider mechanism | 160×60×15 mm |
| Length of bunch-holding clamp | 65 mm |
| Thickness of bunch-holding clamp | 4 mm |
| Material of slider mechanism | Cast Iron |
| Material of Crank mechanism | Carbon steel |
| Material of bunch-holding clamp | Carbon steel |

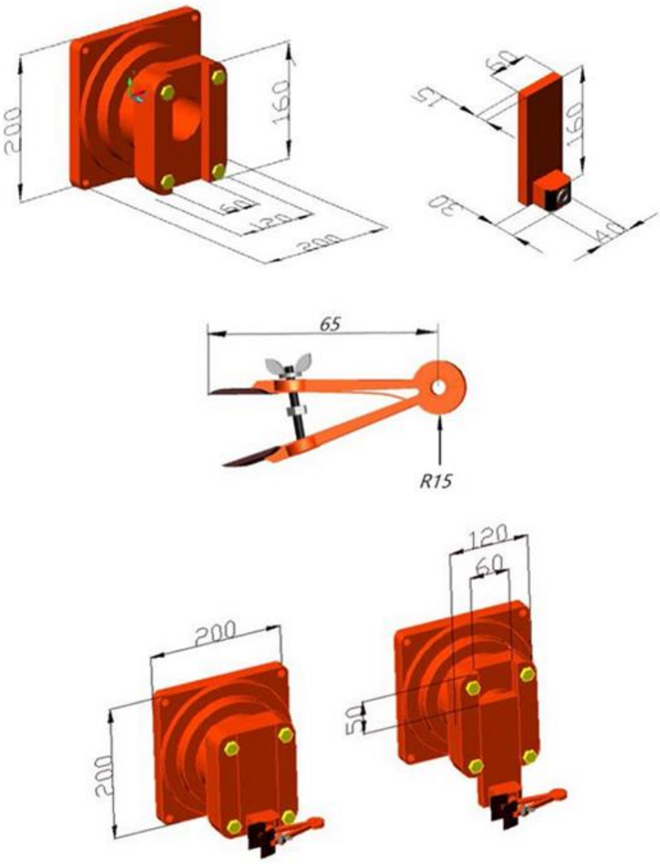


Fig. 7. CAD Modeling of bunch shaker.

DOI:10.4186/ej.2021.25.8.127

### 2.2. Measurement of Static Tensile Detachment Force and Date Fruit Mass

Zahdi date fruits at subsequent stages of maturity were collected from Zafaraniya Date Palm Orchard-Baghdad at successive intervals during the summer of 2017. Fruit maturity was classified according to color and form into Chimri, Khalal, Rutab and Tamar; the four subsequent stages of fruit maturity (Fig. 8).

Fig. 8. The four subsequent stages of Zadhi dates fruit maturity.

For each stage of fruit maturity 25 test specimens were subjected to a static tensile test using a Universal Testing Machine Type Zwick 1445 to determine the fruit detachment force as shown in Fig. 9(a). A test specimen (Fig. 9(b)) is a single date fruit with approximately 50 mm of the strand on each end clipped from date bunches. The test procedure involved holding the date fruit and its strand in adjacent adapters manufactured especially for this purpose (Fig. 9(c)). Then, the axial tension is applied by the movement of the Universal Testing Machine crosshead until the fruit is totally separated from its strand. A constant crosshead speed of 20 mm/min was employed during detachment tests as in similar procedures [28]. The detachment force for each tested specimen is plotted on the x-y plotter as a load-extension curve.


Fig. 9. Static tensile detachment force setup: (a) Universal Testing Machine; (b) test specimen; (c) adapters.

The fruit mass of each tested specimen was measured using a Camry electronic scale Model EHA701 which has an accuracy of 0.01 g (Fig. 10).


Fig. 10. Camry scale used for measuring date fruit mass.

### 2.3. Modeling and Simulation of Dynamic Bunch Shaker Force

The vertical date bunch shaker applies a dynamic (inertia) force which is a function of fruit mass, shaker stroke and angular velocity. It is originally derived from Newton's Second Law of Motion and can be expressed as follows [27]:

$$F_d = mr\omega^2 \quad (1)$$

where:

$F_d$ : dynamic bunch shaker force (N)
$m$: date fruit mass (kg)
$r$ : shaker stroke (m)
$\omega$ : angular velocity (rad/s)

The angular velocity ($\omega$) is:

$$\omega = \frac{2\pi N}{60} \quad (2)$$

where:
N: shaker frequency (cycle/min)

Substituting Eq. (1) into Eq. (2) yields the general formula which relates the dynamic bunch shaker force to fruit mass, shaker frequency and stroke:

$$F_d = (\frac{2\pi N}{60})^2 \, m \, r \quad (3)$$

The above equation can be used to predict the dynamic force developed by a bunch shaker at any given shaker stroke and frequency and for any date fruit variety having any mass. For simulation, the three types of date fruit varieties considered in previous work for mechanical shaker experiments; namely Zahdi, Shahini and Degelt noor can be taken into consideration for this purpose. These varieties have an average fruit mass of 8.5, 10.3 and 12.6 g respectively [28, 27, 3]. For a bunch shaker with a stroke of 50 mm and operating at different shaking frequencies of 200-1000 cpm, the dynamic bunch shaker force for the three aforementioned date varieties are presented in Table 2.

Table 2. The dynamic bunch shaker force calculated for three date varieties with different fruit masses, and at various shaking frequencies.

| Date variety | Mass (kg) | Frequency (cpm) | Shaker force (N) |
|---|---|---|---|
| Zahdi | $8.5 \times 10^{-3}$ | 200 | 0.186 |
| | $8.5 \times 10^{-3}$ | 400 | 0.746 |
| | $8.5 \times 10^{-3}$ | 600 | 1.678 |
| | $8.5 \times 10^{-3}$ | 800 | 2.983 |
| | $8.5 \times 10^{-3}$ | 1000 | 4.660 |
| Shahani | $10.3 \times 10^{-3}$ | 200 | 0.226 |
| | $10.3 \times 10^{-3}$ | 400 | 0.904 |
| | $10.3 \times 10^{-3}$ | 600 | 2.033 |
| | $10.3 \times 10^{-3}$ | 800 | 3.614 |
| | $10.3 \times 10^{-3}$ | 1000 | 5.647 |
| Deglet Noor | $12.6 \times 10^{-3}$ | 200 | 0.276 |
| | $12.6 \times 10^{-3}$ | 400 | 1.105 |
| | $12.6 \times 10^{-3}$ | 600 | 2.487 |
| | $12.6 \times 10^{-3}$ | 800 | 4.421 |
| | $12.6 \times 10^{-3}$ | 1000 | 6.908 |

## 3. Results and Discussion

### 3.1. Static Tensile Detachment Force

Results of the static tensile detachment force of Zahdi dates at the four stages of fruit maturity are shown in Fig. 11. Each value represents the mean of 25 replicates.

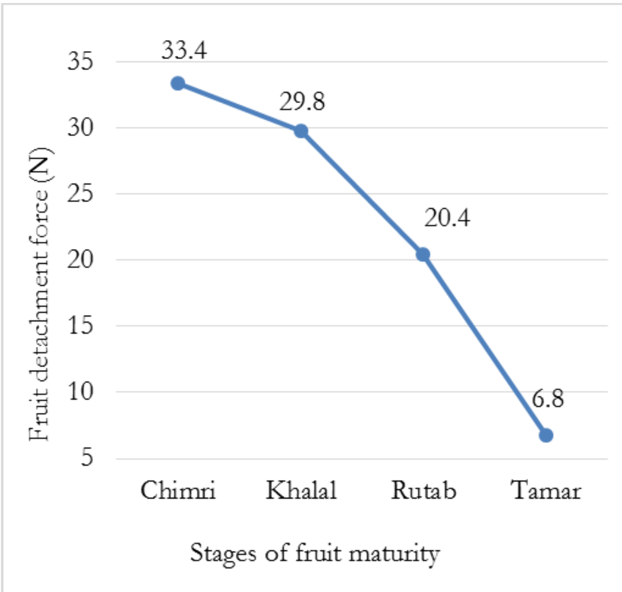


Fig. 11. Zahdi date fruit detachment force at subsequent stages of maturity.

It is noted that the detachment force decreased progressively with maturity. The mean value of detachment force at the first stage of fruit maturity (Chimri) was 33.4 N, which dropped to 29.8 N at the second stage of fruit maturity (Khalal). With the advance of fruit maturity to the third stage (Rutab) the detachment force decreased even further to 20.4 N. The final stage of fruit maturity (Tamar) witnessed the highest reduction in detachment force which had an average of value of 6.8 N. These results are in good agreement with previous work on Zahdi date fruits [28]. However, the detachment force for Zahdi date fruits are extremely higher than those reported for Iran Shahani date fruits which ranged from an average of 7.2 N for unripe fruits to 2.5 N for ripe fruits [27]. This might be attributed to the fact that these are two different date varieties with different physical and biophysical properties and cultivated in two different environments. Moreover, the techniques employed for measuring the detachment force are different which might affect accuracy and lead to discrepancy of results.

### 3.1. Fruit Mass

In general, date fruit varieties differ in size and mass, however, the common thing between all date varieties is that the maximum fruit size and mass is reached during Khalal stage [3]. The mean values of Zahdi date fruit mass at different stages of maturity are shown in Fig. 12.

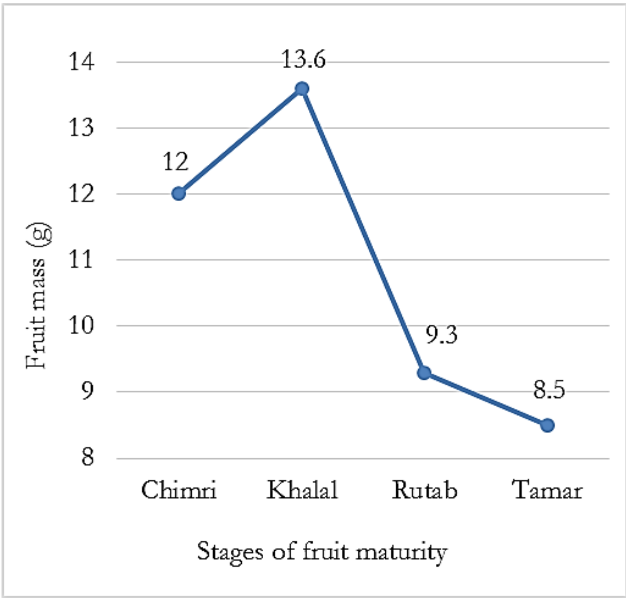


Fig. 12. Zahdi date fruit mass at subsequent stages of maturity.

As shown in figure, the mean value of Zahdi date fruit mass increased from 12 g at Chimri stage to reach a maximum value of 13.6 g at Khalal stage. Then, it dropped to 9.3 g at Rutab stage and finally to 8.5 g at Tamar stage. This is in good agreement with the general trend referred to above, as well as results of previous work on Zahdi date fruits [28]. It also showed similar trend to that of Iran Shahani date fruits [27] which reported that the mean value of unripe fruit mass was 13.2 g dropping to 10.3 g for ripe fruit.

### 3.2. Correlation between Date Fruit Tensile Detachment Force and Dynamic Shaker Force

The design requirements and constrains for selective harvesting of date fruits can be summarized by the fact that there will always be mature and immature dates on the same bunch. Therefore, the bunch shaker should be characterized by being selective in producing a dynamic force high enough to drop only the mature dates and leave the immature ones on the bunch. One way to approach this problem of differentiating between mature and immature dates removal force requirement is to measure the static detachment force at different stages of fruit maturity. If the force required to remove mature dates is much lower than that for immature ones it could facilitate the design parameters of the bunch shaker by selecting a shaking stroke and frequency to produce a dynamic force equivalent to the mature date fruit removal force.

Hypothetically, this can be achieved if the shaking frequency and stroke of the bunch shaker are selected to produce an inertia force equivalent to the force required to drop (detach) the mature dates. However, this can only be verified if the dynamic force developed by the bunch shaker is correlated to the static detachment force.

The dynamic shaker force for Zahdi date bunches having fruits at different stages maturity, as expressed by their respective masses, using a 50 mm shaker stroke at frequencies of 300, 450 and 600 cpm, as employed in previous work [29], can be calculated using Eq. (3). The results of these calculations as well as the fruit detachment force at different stages of fruit maturity are shown together in Fig. 13 for comparison.

It is evident that the fruit detachment forces at all stages of maturity are extremely higher than the dynamic inertia force developed by the shaker. The values of the dynamic shaker force at the three shaking frequencies had a range of 0.67-2.68, 0.59-2.37, 0.46-1.84, and 0.42-1.68 N given respectively for the four subsequent stages of fruit maturity. These values are only a fraction of the detachment force requirement. Even the simulated values of dynamic shaker force presented in Table 2 which included an extremely excessive shaking frequencies were much lower than the detachment force. Bearing in mind that the field experiments in previous work [29], confirmed that a shaker with 50 mm vertical stroke can drop mature dates even at a frequency of 300 cpm. The most effective fruit removal was achieved at 450 cpm which produces a force of only 0.94 N; much lower than the 6.8 N detachment force required to remove mature dates from the bunch. Whereas the use of 600 cpm shaking frequency, resulted in dropping mature as well as immature dates despite producing a dynamic force of only 1.68 N.

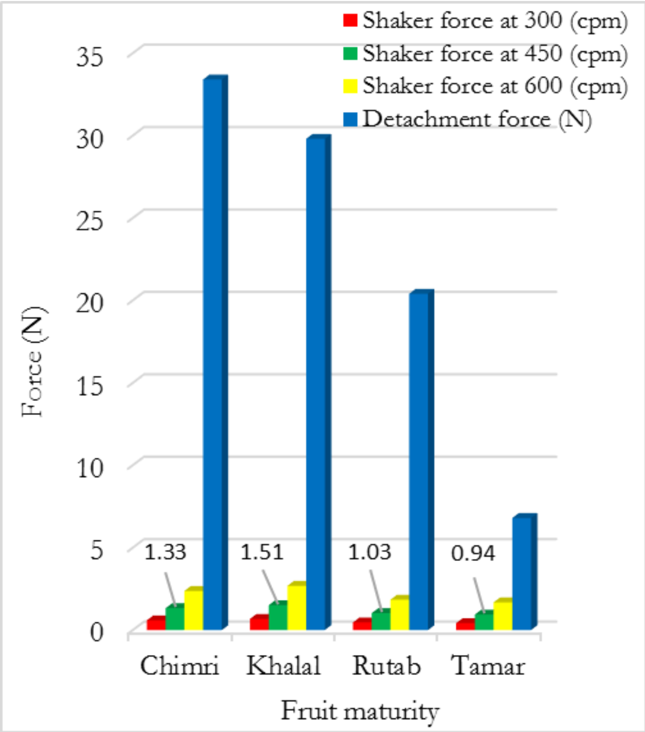


Fig. 13. The fruit detachment force and the dynamic shaker force for Zahdi dates at subsequent maturity.

This implies that the removal of the dates from the bunch cannot be attributed to the development of a dynamic force higher than the static tensile detachment force. In fact, shaking dates by a vertical bunch shaker cannot impose a tensile force on the date fruit due to the nature of date fruit attachment to its strand. The date fruit is perpendicularly attached to its strand because it does not have a stem; the calyx is directly connected to the strand as shown in Fig. 9 (b). Therefore, a shaker with a vertical stroke actually applies a force perpendicular to the main axis of the date fruit; i.e. parallel to strand axis, which results in shear not tension. This, in addition to the cyclic fatigue loading involved in shaking led to the removal of dates from the bunch at a much lower force than the static tensile detachment force requirement.

In view of the above findings, the fruit detachment force cannot be utilized as a criterion for the design of date bunch shaker. Although, in practical terms, shaking at different frequencies and/or strokes does achieve selectivity in dropping mature dates only and leaving immature ones on the bunch as reported in previous work [27, 29]. However, a general theoretical form to design a shaker stroke and frequency to drop only mature dates from the bunch on the basis of static tensile detachment force does not seem feasible.

## 4. Conclusions

1. The tensile force required to detach date fruits from the strand decreases significantly with the progress of fruit maturity. For Zahdi date variety, this force had a maximum value of 33.4 N for immature dates (Chimri) and a minimum of 6.8 N for fully mature dates (Tamar).
2. The calculated dynamic force produced by a vertical shaker with a 50 mm vertical stroke at 300-600 cpm for Zahdi dates had values of 0.42-2.68 N which are much lower than the tensile detachment force.
3. The most effective removal of mature Zahdi dates from the bunch, as reported by previous work [29], was achieved at a frequency of 450 cycle/min. This produces a dynamic force of only 0.94 N, whereas the tensile detachment force requirement is 6.8 N.
4. From above, it is evident that date fruits removal from the bunch by a vertical shaker cannot be attributed to the development of a dynamic inertia force higher than the tensile force required to detach date fruits.
5. A combination of forces including shear, as well as cyclic fatigue is believed to be the cause of fruit removal from the bunch by a vertical shaker
6. Accordingly, the tensile fruit detachment force cannot be utilized as a criterion to specify date bunch shaker design parameters; shaker stroke and frequency.
7.

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