

EFFECTS OF SHAKING MODE, FREQUENCY AND AMPLITUDE ON 'SHAHANI' DATE FRUIT DETACHMENT, II: FIELD EXPERIMENT

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ABSTRACT

One of the major problems in date (*Phoenix dactylifera* L.) harvesting is variable maturity. Selective hand-picking of individual ripe fruits from each bunch is the most expensive and time consuming cultural operation. A $2 \times 5 \times 3$ factorial experiment with a completely randomized design in three replications was conducted to investigate the effects of shaking mode, frequency and amplitude on date fruit detachment. Five levels of shaking frequency (200, 300, 450, 600 and 750 cpm) and three levels of shaking amplitude (20, 40 and 60 mm) were investigated at two modes of fruit bunch vibration (vertical and hanging). The experiment was conducted on 'Shahani' dates fruit bunches. The effects of shaking mode, frequency and amplitude were significant on fruit detachment. The most effective detachment of ripe fruits with minimum unripe fruit detachment occurred at 300 cpm frequency and 60 mm amplitude. Also the results showed that the vertical shaking mode was more effective in detaching ripe fruits than hanging mode and in the vertical shaking mode the amount of detached fruits with calyx attached was less than in the hanging mode. The amount of detached fruits without calyx attached increased at the higher frequency and amplitude levels. Fruit pull tests showed that the average axial tensile force required to remove ripe fruits was about 35% of that needed for removing unripe fruits. Bunch

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shaker was capable of removing marketable ripe dates from the bunch without imparting any significant rubbing or bruising damage to the fruits.

Key words: Bunch shaker, Date harvesting, Fruit detachment 'Shahani' dates, Shaking.

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تأثیر فرم بسامد و دامنه ارتعاش بر جداسازی میوه خرماي 'شاهانی'

بخش دوم: آزمون مزرعه ای

محمد لغوی و محمد ابونجمی

به ترتیب، دانشیار و دانشجوی پیشین بخش ماشین های کشاورزی دانشکده کشاورزی دانشگاه شیراز، شیراز، جمهوری اسلامی ایران.

چکیده

یکی از مشکلات عمده در برداشت میوه خرما (*Phoenix dactylifera* L.) عدم یکنواختی در رسیدگی محصول است. برداشت دستی میوه های رسیده از هر پنگ، پرهزینه ترین و وقت گیرترین قسمت عملیات برداشت است. به منظور بررسی اثرات فرم بسامد و دامنه ارتعاش بر جداسازی میوه خرما، یک آزمایش فاکتوریل (۲×۲×۵) در قالب طرح کاملاً تصادفی با ۳ تکرار اجرا شد. پنج سطح بسامد ارتعاش (۲۰۰، ۳۰۰، ۴۰۰، ۶۰۰ و ۷۵۰ دور در دقیقه) و سه سطح دامنه نوسان (۲۰، ۴۰ و ۶۰ میلی متر) در دو فرم ارتعاش پنگ (عمودی و آویخته) با سه تکرار بر روی پنگ های خرماي 'شاهانی' انجام شد. تجزیه واریانس تیمارها نشان داد که پارامترهای دامنه، بسامد و فرم ارتعاش بر جدا سازی میوه اثر

معنی داری داشتند. درسامد ۳۰۰ دور در دقیقه و دامنه ارتعاش ۶۰ میلی متر بهترین نتیجه در جدا سازی خرماي رسیده 'شاهانی' با کمترین ریزش خرماي نارس در کمترین مدت زمان (کمتر از ۱۰ ثانیه) به دست آمد. نتایج نشان داد که برای جدا سازی میوه رسیده، ارتعاش عمودی پنگ نسبت به ارتعاش در حالت آویخته مؤثرتر بود. همچنین درصد خرماي جدا شده کلاک دار نیز کاهش یافت. نتایج آزمون نشان داد که نیروی کششی لازم برای جدا سازی خرماي رسیده (رطب و خرما) نزدیک به ۳۵ درصد نیروی محوری لازم برای جدا سازی میوه های نارس (خارک) می باشد. دستگاه ارتعاش دهنده پنگ قادر به جدا سازی خرماي رسیده بازار عاری از آسیب هایی مانند زخمی شدن و له شدن محصول می باشد.

INTRODUCTION

The date palm (*Phoenix dactylifera* L.) is native to Iran, Iraq, Saudi Arabia and many oases in the desert areas of northern Africa. It has been a staple food in those regions since the first recorded history (9). For more than 4000 years people have been cultivating date along banks of Karoon and Karkheh, two big rivers in Iran (5). Yearly production of date in Iran is about 900000 tons (3).

During the past decades, increasing interest in mechanical harvesting of date fruits has led to the development of date harvesting aids and machines (2, 5, 6). As date do not mature uniformly, therefore selective harvesting is necessary. Hand picking has gradually decreased due to the shortage of available farm laborers and increase in their wages during the harvest season.

Following the design and development of an experimental bunch shaker (1), the need for determining the optimum frequency, amplitude and vibration mode for date fruit detachment was recognized. The need for an efficient date harvester that could remove the ripe fruits from the bunch was perceived by Perkins and Brown (6). Who reported that the vertical shaking

mode had the best effect on ripe date detachment. According to these results a rigidly mounted shaker applying 40 mm strokes at 1400 cpm and a hand-carried shaker applying 40 mm and 80 mm strokes at 700 cpm, respectively, were built and tested (for removing ripe Deglet Noor date fruits). Sarige *et al.* (8) designed and developed a hydraulically powered tractor mounted date bunch shaker that delivered a 9.5 cm stroke vibration at 67 Hz for removing Hiani ripe date fruits (8). Later, Sarige (9) used an inertia type shaker for shaking the whole palm. It consisted of a counter rotating-weight mechanism imparting multi-directional vibration to the palm. The power required for clamping and shaking was provided by an augmented hydraulic system of the prime mover. Clamping the shaker to the lower quadrant of its height (about 2.5-3 m) yielded the optimal rate of fruit removal (about 90%).

The objectives of the present research were: (a) Investigation of the effects of shaking mode, frequency and amplitude on date fruit detachment, (b) Determination of the optimum 'shaking' frequency and amplitude for ripe 'shaking' dates harvesting and (c) Determination of fruit detachment force/weight ratio (F/W).

MATERIALS AND METHODS

The experiment was conducted on 'Shahani' date palms in Jahrom, one of the major date growing regions in Fars province. Fifteen 'Shahani' date palms at the same age and growing condition were selected. The experimental design was a 5×3×2 factorial experiment with a completely randomized design in three replications. Five levels of shaking frequency (200, 300, 450, 600 and 750 cpm) and three levels of shaking amplitude (20, 40 and 60 mm) were investigated at two modes of fruit bunch vibration (vertical and hanging).

Shaking Test

'Shahani' date fruit bunches with equal size and maturity were randomly cut from the palms. Each fresh sample was weighed and then attached to the clamping device of the shaker to be shaken either in vertical or hanging mode. Every effort was made to simulate the on-tree orientation of each bunch. In the vertical shaking mode the base of the fruit bunch stalk was

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clamped to the shaker frame and the end of the shaker boom was also clamped to the fruit stalk. Then the shaker mechanism was turned on to reciprocate at the preset frequency and amplitude. In the hanging shaking mode, the base of the fruit bunch stalk was attached to the clamping device at the end of the rocking arm of the shaker. Detached fruits at each shaking mode were collected by a special collecting curtain (Fig. 1). Each bunch was shaken for ten seconds. After shaking, total detached fruits were weighed and then the number of ripe, unripe, damaged and fruits with their calyx attached were counted. Ripe and unripe fruits that remained on the

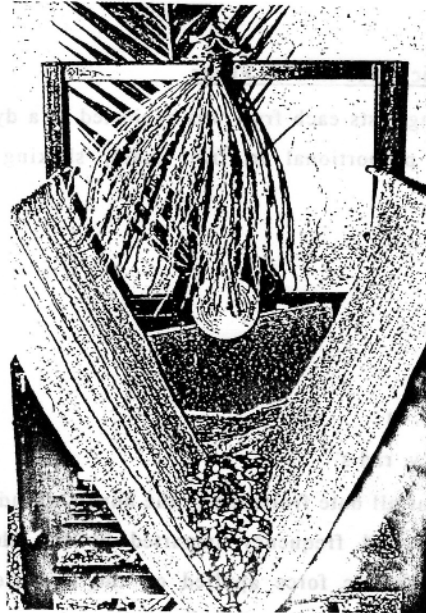


Fig. 1. Collection of detached fruits

RESULTS AND DISCUSSION

bunch after shaking were also counted. After shaking test, a sample of 40 dates from each bunch was randomly selected and weighed to find the average fruit weight. Finally the weight of each stripped fruit bunch was measured.

Determination of Fruit Detachment Force /Weight Ratio

In order to measure the detaching force between each fruit and its strand, a spring balance with 20 N range and 0.1 N resolution was used. The free end of the spring scale was attached to the randomly selected fruits by a special clamp and a pulling force was applied along the longitudinal axis of the fruit. The pulling force was gradually increased until the fruit was separated from its strand. The maximum force developed was read and recorded as the static detachment force. This test was done for both ripe and unripe fruits. Finally, each fruit was weighed and its dimensions along the three principal axes were measured and recorded.

Estimation of Dynamic Force on Date Fruits

During the shaking tests each fruit was subjected to a dynamic (inertial) force F_d which is proportional to fruit mass, shaking amplitude and frequency, such that:

$$F_d = m r \omega^2 \quad [1]$$

where:

F_d : Dynamic force, N

m : Fruit mass, kg

r : Shaking amplitude, m

ω : Shaking frequency, rad s^{-1}

Assuming that all date fruits along the bunch strands were shaken at the same amplitude and frequency imparted by the shaker boom, the estimated average dynamic force applied on the fruit-stem junction was calculated by using the Eq. [1]. All data collected were analyzed using MSTATC software, and then mean values were compared by DMRT.

RESULTS AND DISCUSSION

Analysis of variance for response of 'Shahani' date fruits to different levels of frequency, amplitude and 'shaking' mode for detaching ripe fruits (Table 1), indicated that there were highly significant differences ($P < 0.01$) among these factors for total detached fruits, detached unripe fruits,

detached ripe fruits, detached fruits with calyx and remained ripe fruits remaining on the bunch.

Table 1. Analysis of variance of data on 'shaking' date fruit removal at different levels of amplitude, frequency and shaking mode.

Source	df	Mean squares				
		R _{dt}	R _{ut}	R _{ret} [†]	R _{det}	R _{rt}
F	4	7593**	10514**	0.874**	313**	4909**
A	2	14893**	22380**	2.087**	472**	10854**
S	1	3540**	3044**	0.395**	551**	3730**
FA	8	353**	1552**	0.061**	41 ^{ns}	471**
FS	4	578**	436 ^{ns}	0.088**	115**	984**
AS	2	2052**	2157**	0.060**	49 ^{ns}	123 ^{ns}
FAS	8	429**	452**	0.050*	91**	300*
Residual	60	111	30	0.0130	34	137

[†] The mean in log transformed value.

* Significant at P≤0.05.

** Significant at P≤ 0.01.

ns Non significant.

F = Frequency A = Amplitude S = Shaking mode.

R_{dt} Ratio of total detached fruits to total fruits on the bunch (%).

R_{ut} Ratio of detached unripe fruits to total unripe fruits (%).

R_{ret} Ratio of remained ripe fruits to total ripe fruits (%).

R_{det} Ratio of detached ripe fruits with calyx attached to total detached ripe fruits (%).

R_{rt} Ratio of detached ripe fruits to total ripe fruits (%).

Effects of Frequency, Amplitude and Vibration Mode on Date Fruit Detachment

Fig. 2 compares the mean values of the total detached fruits for the frequency-amplitude combinations. Both frequency and amplitude had significant effect on total detached fruits. At the higher frequency and amplitude levels, highest fruit removal has occurred. From Figs. 3 and 4 it

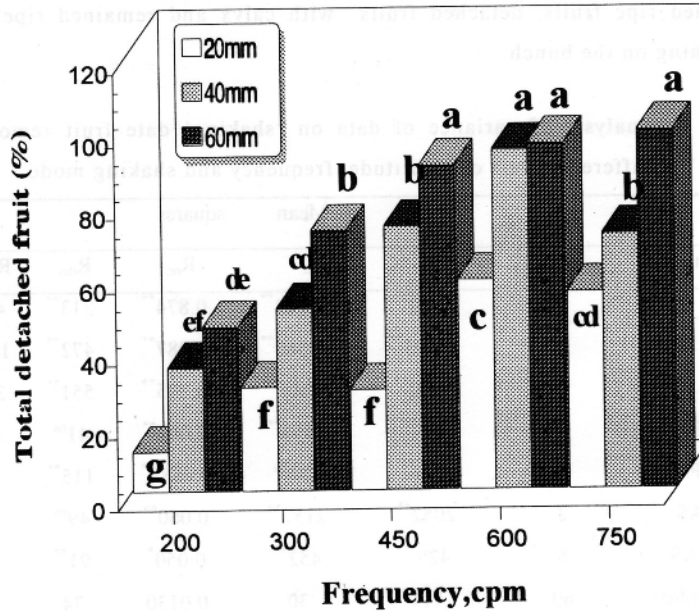


Fig. 2. Effect of frequency on total detached fruits at different amplitude levels. Similar letters indicate no significant difference at 5% probability level using DMRT.

can be concluded that the most suitable frequency and amplitude for ripe fruit detachment are at 300 cpm and 60 mm, respectively. In this treatment, significantly lower unripe fruit removal occurred while detachment of ripe fruits was about the same as the higher frequency treatments. At higher frequency and amplitude levels, detachment of unripe fruits increased highly which is generally undesirable. Figs. 5 and 6 show that in general, the vertical shaking mode was more efficient in detaching ripe fruits than the hanging mode, although in some treatments no significant difference was found between the two shaking modes. Fig. 7 shows that significant fruit detachment occurred at 40 and 60 mm amplitude levels, especially at vertical shaking mode. This is probably attributed to the fact that in the vertical shaking mode, bending moment about the point of fruit attachment to strand is more effective than the axial tensile stresses which are believed to be the main cause of fruit detachment in the hanging mode. The other effective factor may be the whipping motion of the strands in the vertical

shaking mode which magnifies the vibration amplitude comparing with the hanging mode.

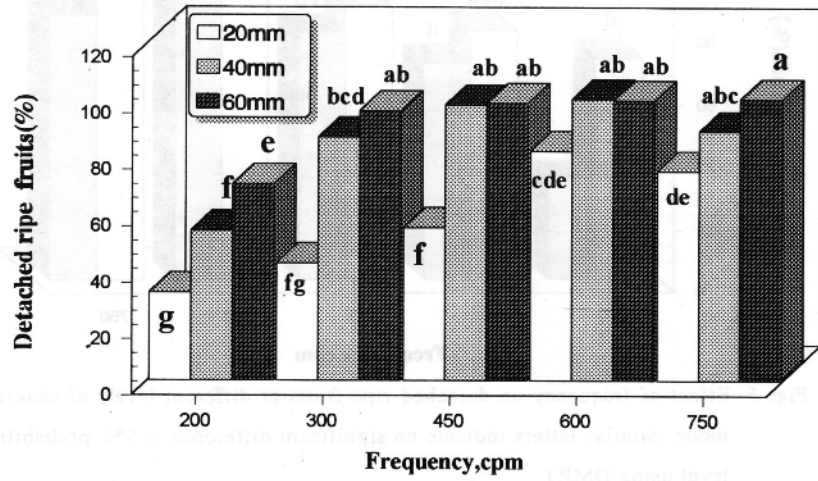


Fig. 3. Effect of frequency on detached ripe fruits at different amplitude levels. Similar letters indicate no significant difference at 5% probability level using DMRT.

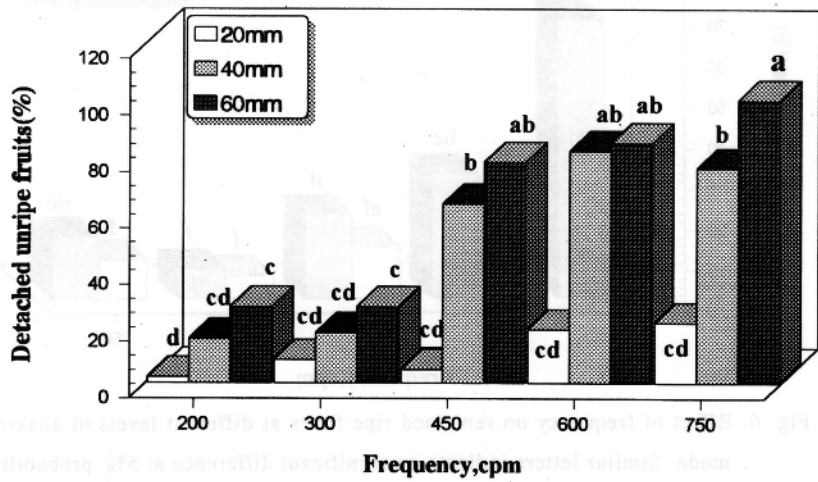


Fig. 4. Effect of frequency on detached unripe fruits at different amplitude levels. Similar letters indicate no significant difference at 5% probability level using DMRT.

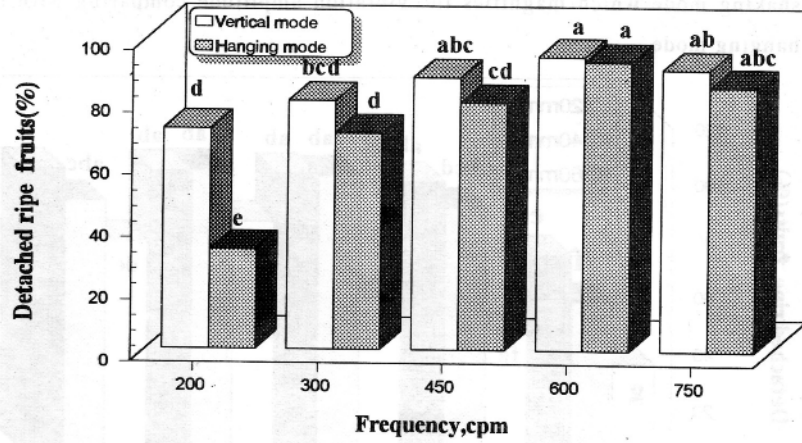


Fig. 5. Effect of frequency on detached ripe fruits at different levels of shaking mode. Similar letters indicate no significant difference at 5% probability level using DMRT.

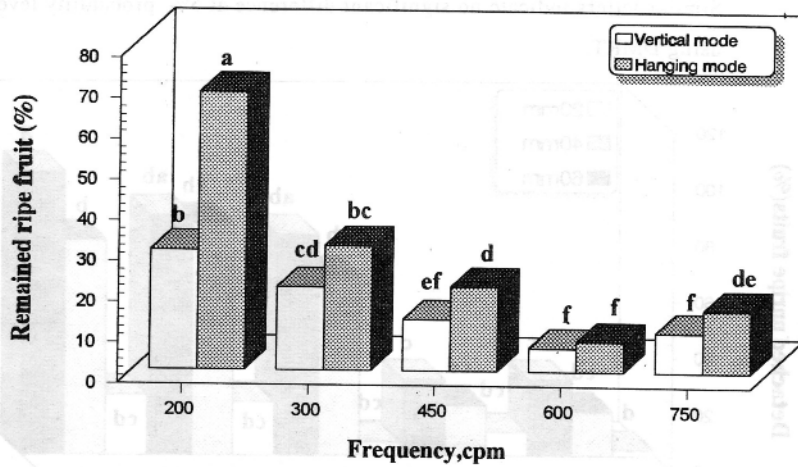


Fig. 6. Effect of frequency on remained ripe fruits at different levels of shaking mode. Similar letters indicate no significant difference at 5% probability level using DMRT.

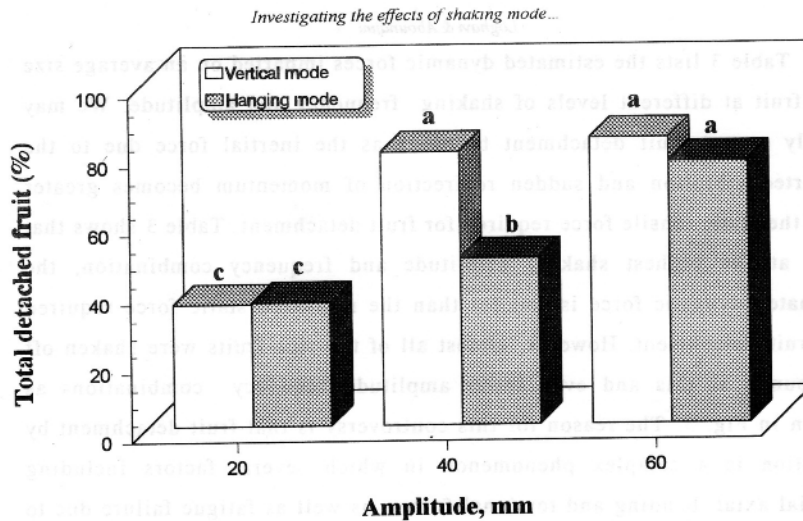


Fig. 7. Effect of amplitude on total detached fruits at different levels of shaking mode. Similar letters indicate no significant difference at 5% probability level using DMRT.

Static Detachment Force

Table 2 lists the mean values of measured date fruit geometric mean diameters, mass, weight, static detachment force and F/W ratios for ripe and unripe fruits.

Table 2. Physical characteristics and average static forces applied for detaching ripe and unripe fruits.

Fruit condition	Geometric mean dia.(mm)	Mass (g)	Weight W(N)	Detachment Force F(N)	F / W ratio
Ripe	27.4	10.3	0.10	2.5	25
Unripe	27.1	13.2	0.13	7.2	55

F/W ratio is a good indicator of ease of fruit detachment. This ratio decreased from 55 for unripe fruits to 25 for ripe fruits. This is attributed to the fact that under normal ripening process, the strand-calyx junction becomes weaker as the natural abscission layer develops.

Table 3 lists the estimated dynamic forces imparted on an average size ripe fruit at different levels of shaking frequency and amplitude. We may simply expect fruit detachment to occur as the inertial force due to the imparted vibration and sudden redirection of momentum becomes greater than the static tensile force required for fruit detachment. Table 3 shows that even at the highest shaking amplitude and frequency combination, the estimated dynamic force is smaller than the measured static force required for fruit detachment. However, almost all of the ripe fruits were shaken off the bunch at this and even lower amplitude-frequency combinations as shown in Fig. 3. The reason for this controversy is that fruit detachment by vibration is a complex phenomenon in which several factors including inertial axial, bending and torsional forces, as well as fatigue failure due to cyclic stresses are involved. One of these factors may become dominant depending on the fruit-stem geometry and physical properties, shaking mode, frequency and amplitude combinations.

Table 3. Estimated average dynamic force (N) imparted on ripe fruits at different frequency and amplitude levels.

Amplitude (mm)	Frequency (cpm)				
	200	300	450	600	750
20	0.045	0.102	0.230	0.409	0.638
40	0.090	0.204	0.460	0.818	1.276
60	0.135	0.306	0.640	1.227	1.914

CONCLUSIONS

1. The results of this study revealed that at 300 cpm frequency and 60 mm amplitude the most efficient detachment of 'shaking' ripe date fruits occurred.
2. The vertical shaking mode had more significant effect on detaching ripe fruits than the hanging mode. Also at the vertical shaking mode the percentages of remained ripe fruits and detached fruits with calyx attached were less than those of the hanging mode.
3. Increasing shaking time (more than 10 seconds) in hanging mode at high frequencies (600 and 750 cpm) and large amplitudes caused damage to

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the detached and remained fruits on the bunch (predetachment damage), but at low frequencies (300 and 450 cpm) no fruit damage was encountered.

4. At any specific frequency, increasing amplitude caused higher fruit removal.
5. At any fixed amplitude, increasing frequency caused higher fruit removal.
6. At higher amplitudes and frequencies, the percentage of detached fruits with calyx attached was significantly decreased.
7. The F/W ratios for ripe and unripe fruits were found to be 25 and 55, respectively. This means that the force required to remove most of ripe fruits is about 35% of that needed to remove unripe fruits.

Suggestions for Further Study

The following suggestions might be useful for obtaining further information necessary to develop and improve the performance of the shaker type based date harvesting system.

1. Conducting mechanical shaking tests on other major Iranian date varieties such as 'Kabkab' and 'Mazafti' to find the best shaking amplitude and frequency for detaching ripe fruits.
2. Development of a hydraulically-operated clamp in order to facilitate shaking operations.
3. Development of a hydraulically or pneumatically powered hand carried shaker, for harvesting short palms.
4. Installation of the shaker on recently developed date towers or hydraulic arms developed earlier to investigate the feasibility of selective date fruit harvesting.
5. Utilization of the experimental shaking machine as a part of an integrated harvesting, sorting and packaging system.

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