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The Effects of Shaking Frequency and Amplitude on Detachment of Lime Fruit

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ABSTRACT- The aim of this study was to determine the most suitable shaking frequency and amplitude for shake harvesting lime fruit (*C. aurantifolia*). A tractor mounted limb shaker with adjustable shaking frequency and amplitude, powered by the tractor power-take-off shaft was designed and developed for this study. The rotating input power was transmitted to the shaker flywheel through a multiple sheave v-belt drive system where it was converted to reciprocating motion by a slider crank mechanism. The resulting vibrating motion could be transmitted to the tree limb through a telescoping boom and a special clamping device. A 3x3 factorial experiment arranged in a completely randomized design with three replications was conducted to investigate the effects of shaking frequency and amplitude on fruit detachment. Three levels of oscillating frequency (5, 7.5 and 10 Hz) and three levels of shaking amplitude (40, 80 and 120 mm) were investigated. Analysis of variance and mean comparison showed that the effect of shaking frequency on fruit detachment was significant. However, those of shaking amplitude and its interactions with frequency were not significant. The percentage of detached fruits significantly increased by increasing the shaking frequency, but the shaking frequency or amplitude had no significant effect on fruit damage. Complete fruit detachment (100%), was obtained by applying shaking amplitude of 120 mm at a frequency of 10 Hz, but considerable leaf removal at this combination of shaking frequency and amplitude was a limiting factor. Therefore, shaking the limbs at 80 mm amplitude and 10 Hz frequency with about 98.5% fruit detachment and negligible leaf shattering was found to be the most suitable combination. In order to determine the bonding strength of lime fruits, a series of tests were conducted in which, the average pulling force required for detaching ripe and unripe fruits as well as fruit mass and geometric mean diameter were measured. The average static force required for removing ripe fruits was found to be about 14.2% of that required for removing unripe fruits. The average ratio of tensile force required for removing a fruit to its weight (F_s/W) was measured as 6.9 and 61.8 for ripe and unripe fruits, respectively. The two indices suggest utilizing a limb shaker as a valuable approach for selective harvesting of ripe fruits. This is especially true for fruit varieties with non-uniform ripening characteristics.

Keywords: Fruit harvesting, Mechanical harvesting, Tree shaking, Citrus harvesting, Limb shaker

INTRODUCTION

Lime (*C. aurantifolia*), is a major crop in the southern part of Fars province, Iran. Lime, which is mostly used for juice either in post-harvest processing plants, in local traditional mills or directly by the final consumer is still completely manually harvested. At present, citrus crops in Iran, including oranges, tangerines, sweet lemons and

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grapefruits are still picked entirely by hand. Manual picking of limes is not practical due to the thorny branches and small size of the fruits. So, the crop is manually harvested either by beating the limbs and branches with long willowy poles or shaking the limbs by securing a hook to a long pole. This traditional practice is costly, and requires tremendous amounts of labor and time. Factors such as rising wage rates, scarcity of labor and the increasing size of annual fruit crop are incentives for producers to seek appropriate approaches for mechanizing their fruit harvesting operations. Mechanical harvesting provides a significantly higher harvesting rate as compared to manual picking. A comprehensive review of literature on citrus harvesting systems indicate that the maximum picking rate of manual pickers is 0.5 t/h, whereas the picking rate of trunk shaking harvesters is 10 t/h and for canopy shakers it is 25 t/h. Hence, a mechanical harvester can replace 20-50 manual pickers (15). Two broad approaches have been considered for citrus harvest mechanization (17): a, mass harvesting and b, individual fruit harvesting or alternatively "mass-removal harvesting" and "contact removal harvesting". Mass harvesting considerations have been oscillating air blast (7, 12, 19, 21, 22 and 24) trunk and limb shakers (1, 2, 5, 6, 8, 11 and 20) and oscillating tines or canopy shakers (1, 4, 14 18 and 22). The canopy shaking technique is carried out by inserting a number of flexible horizontal rods into tree canopy by direct contact of the branches with the inserted rods (15). Individual fruit harvest considerations, as alternatives to mass harvest, have been combing and pulling (1, 3 and 13), vacuum twist (17), rotating cut-off devices (2 and 3) and rotating spindle selective picking head (16). Contact removal harvesting doesn't seem to be potentially practical for harvesting limes because of the small size of the fruits and intermingling of the foliage and branches in the canopy.

One of the pioneers in the mechanization of shake harvesting of trees was Fairbank (10), who equipped a farm tractor with an eccentric shaft that powered a cable attached at one end to a tree limb. The cable shaker applied a large amplitude vibration to the limb, but the shaking frequency was limited by the resonant frequency of the limb. Later, some manufacturers developed the boom shaker, which used a tension/compression member supported by a rigid boom, to replace the cable (13). Although boom shakers had the advantage of being a one-man worker operation, their adaptability to some orchard conditions was limited by tree shape and ground conditions.

Hand–carried shakers were developed as a replacement for the poles used to shake small limbs (13). A double-acting air piston was connected to a long rod extended to a C-clamp hook that the worker placed over each limb to be shaken. The success of hand-carried shakers has been very limited because they are slower and harder to operate than other mechanical shakers.

Along with the development of tree shaking equipments, engineering research was undertaken to determine empirical relations among stroke, frequency and fruit removal. Experience with many tree fruits has indicated that high frequencies (25-40 Hz) and short strokes (20-25 mm) are generally most effective when tree structure and fruit attachment are relatively rigid (9). Long strokes (100-120 mm) and low frequencies (1.5-6 Hz) have been found superior for willowy trees with long branches that hang down under the mass of the fruits (13).

Coppock and Hedden (8) described the design requirements of a citrus limb shaker to be characterized by a long stroke (100-125 mm), low frequency (1.6-6 Hz) and a high degree of maneuverability. These findings are mainly based on the experimental shake harvesting of oranges and grapefruits and may not hold true in the case of lime trees which have significantly smaller size fruits.

No attempt has been reported to investigate the effects of shaking frequency and amplitude on the percentage of fruit removal in lime trees. So, the objectives of the present research were: (a) To investigate the effects of shaking frequency and amplitude on lime fruit detachment, (b) to determine the optimum shaking frequency and amplitude for effective fruit detachment and (c) to determine the fruit detachment force/weight ratio (F/W).

MATERIALS AND METHODS

Development of an Experimental Limb Shaker

A tractor-mounted limb shaker with adjustable shaking frequency and amplitude was designed and developed for conducting the field experiments (Fig. 1). The shaker consisted of six main parts, including the frame, power transmission, mechanical clutch, oscillating motion mechanism, shaker boom and clamping device. The frame, which supports the other components, was made of structural steel square tubing. The shaker frame was equipped with an A-frame to be mounted on the tractor three point hitches.

The shaker was powered by the tractor power-take-off shaft through a telescoping universal joint. Variable speed ratio was provided by employing a multiple sheave V-belt drive. A combination of two triple sheave pulleys with pitch diameters of 220, 270 and 310 mm, mounted on two parallel shafts provided three speed ratios of 1:1, 1.5:1 and 2.2:1, respectively. This stepwise speed reduction system as well as tractor engine throttle control could provide desired oscillation frequencies ranging from 5 to 20 Hz.

A mechanical single disk friction clutch was mounted on the drive line over the input shaft to the shaking mechanism. By the utilization of this clutch, quick power engagement, disengagement and maintaining desired frequency during each shaking test were made possible.

A slider-crank mechanism with variable crank length was used to generate an oscillating motion at the desired amplitudes. A 340 mm diameter, 30 kg disk type cast iron flywheel was used as the crank (input) member of the shaking mechanism.

This could reduce speed fluctuations due to the reciprocating masses. Shaking amplitudes of 20, 40, 60, 80 and 100 mm were accessible by connecting the shaking boom to various points located at radial distances of 10, 20, 30, 40, and 50 mm from the flywheel center of rotation, respectively.

A cardan universal joint was used for this connection to provide enough spatial flexibility for the shaker boom

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Figure 1. The tractor-mounted limb shaker with adjustable shaking frequency and amplitude

The telescoping shaker boom was made of thin-walled steel tubing in two pieces with a length ranging from 1.2 to 2 m to account for variability of shaker distance to the tree limb to be shaken. A new clamp was designed to provide the necessary attachment between the shaker boom and tree limb. The clamp was equipped with three self-locking, spring-loaded gripping fingers (Fig. 2). With this arrangement and the employment of a cable and ratchet mechanism, the clamp fingers could be controlled, adjusted and attached to tree limb from a distance of about 1 to 2 m without the need to have direct access to the limb.

Shaking Tests

The experiment was conducted in the city of Jahrom, a major lime growing area in Fars province, Iran. Twenty seven lime trees at the same age and growing conditions were selected for mechanical harvesting. The experimental design was a 3x3 factorial experiment with a completely randomized design in three replications. Three levels of shaking frequency (5, 7.5 and 10 Hz) and three levels of shaking amplitude (40, 80 and 120 mm) were investigated. For each replication, the shaker boom gripping fingers were clamped to a randomly pre-selected fruit bearing limb at an accessible and convenient location along the limb. After adjusting the shaking frequency and amplitude according to the scheduled treatment, the shaker clutch was engaged to shake the limb at the preset frequency and amplitude for about 5 to 10 seconds. After shaking, the detached fruits and those remaining on the limb were collected, counted and weighed. The percentage of fruit detachment for each test was calculated as:

$$\text{Fruit detachment (\%)} = \left(\frac{N_h}{N_h + N_r}\right) \times 100 \qquad (1)$$

Where:

N_h = Number of harvested fruits by shaking

N_r = Number of fruits remaining on limb after shaking

The detached fruits were then kept in room temperature for 24 hours before being inspected for any visible sign of skin damage including, bruising, cutting and scuffing. The percentage of fruit damage for each test was calculated as:

$$\text{Fruit damage (\%)} = \left(\frac{N_d}{N_h}\right) \times 100 \qquad (2)$$

Where:

N_d = Number of damaged fruits in each test

Figure 2. Self-locking gripping fingers of the shaker boom

Determination of the Fruit Detachment Force/Weight Ratio (F_s/W)

In order to measure the fruit detachment force, a spring balance with a range of 20 N and a resolution of 0.1 N was used. Before conducting the shaking tests, 20 ripe and 20 unripe lime fruits were randomly selected to measure detachment force measurement. The free end of the spring scale was attached to the selected fruit by a light weight gripping device and a pulling force was gradually increased until the fruit was detached. The maximum force developed was measured and recorded as the static detachment force. Each detached fruit was then weighed and its dimensions along the three principal axes were measured and recorded.

Dynamic Force Imparted on an Average Size Lime Fruit (F_d)

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

$$F_d = mr\omega^2 \qquad (3)$$

Where:

F_d: Dynamic force, N
m: Fruit mass, kg
r: Shaking amplitude, m
ω: Shaking frequency, rad s^{-1}

Assuming that all lime fruits along the test limb were shaken at the same frequency and amplitude imparted by the shaker boom, the average dynamic force applied on the fruit-stem junction was calculated by using the Eq. [3].

RESULTS AND DISCUSSION

Results of the analysis of variance for the effects of different levels of shaking frequency and amplitude on lime fruit removal and damage is shown in Table 1. For fruit removal, the results indicated highly significant differences ($p<0.01$) among different levels of shaking frequency, but the effect of amplitude and the interactive effects of frequency and amplitude were not significant. Regarding fruit damage, none of those two factors had any significant effect on fruit damage caused by shake harvesting.

Table 1. Analysis of variance of data on lime fruit removal (%) and fruit damage (%) at different levels of frequency and amplitude

Source	Degree of freedom	Mean Squares	
		FR	FD
Frequency, F	2	1442.95^{**}	0.59^{ns}
Amplitude, A	2	48.55^{ns}	0.48^{ns}
A×F	4	100.79^{ns}	1.29^{ns}
Error	18	109.08	0.57
Total	26		

^{ns} Non significant, ** Significant at $p<0.01$, FR Fruit removal, FD Fruit damage

Comparison of mean values of the total number of detached fruits for each frequency-amplitude combinations are shown in Table 2. At higher frequency levels, significantly ($p<0.05$) higher fruit detachment has occurred, while increasing the shaking amplitude at different levels of frequency has not increased fruit detachment significantly.

The reason could be attributed to the fact that the dynamic force imparted to the fruit-stem or stem-branch junction by the forced vibration is proportional to the second power of frequency, while it is only a linear function of amplitude. Furthermore, the frequency of oscillation does not change along the tree limb from the point of shaker attachment to the fruit bearing secondary branches, while oscillation amplitude does not remain constant and normally decreases along the limb due to the flexible and limber nature of the lime tree branches. Diener et al. (9) defined the ratio of the limb stroke at the end of the limb to the shaker stroke as limb transmission efficiency and reported values of 25-130% over a range of frequencies and stroke.

Table 2. Comparison of mean values of lime fruit detachment (%) at different levels of shaking frequency and amplitude

	Amplitude (mm)			
Frequency, Hz	**40**	**80**	**120**	**Mean**
5	**63.38[c†]**	**76.03[bc]**	**77.90[bc]**	**72.44[C‡]**
7.5	**83.71[abc]**	**84.75[abc]**	**90.51[ab]**	**86.33[B]**
10	**94.67[ab]**	**98.50** *[a]*	**100.00[a]**	**97.72 [A]**
Mean	**80.59[A]**	**86.43 [A]**	**89.47 [A]**	

[†]Means followed by common lower case letters within each row or column are not significantly different at p=0.05 (DMRT)
‡ Means followed by the same capital letters are not significantly different at p=0.05 (DMRT)

At shaking frequency of 10 Hz, and shaking amplitudes of 40, 80 and 120 mm, about 95, 98.5 and 100 percent of fruits were detached, respectively Table 2. A shaking amplitude of 120 mm with the frequency of 10 Hz is not recommended even though it has resulted in 100% fruit removal, because at this combination, leaf shattering and foliage breakage was excessive. Fig. 3 shows the percentages of fruit damage due to shake harvesting at different levels of shaking frequency and amplitude. The damage ranging from 3 to 9 % with an average of about 5.5 % has not been significantly affected by shaking frequency or amplitude. Therefore the damage was solely due to the collision and impact forces that fruits have received after detachment.

Detachment Force

Table 3 lists the mean values of measured lime fruit geometric mean diameter, mass, weight (W), detachment force (F) and F/W ratios for ripe and unripe fruits.

F/W ratio is a good indicator of ease of fruit detachment. Table 3 shows that this ratio decreased from 61.90 for unripe fruits to 6.9 for ripe fruits. This is attributed to the weakening of the stem-calyx junction, as the natural abscission layer develops under the normal ripening process.

Table 4 lists the calculated dynamic (inertial) forces imparted on an average size ripe fruit at different levels of shaking frequency and amplitude investigated in this study. We may simply expect fruit detachment to occur as the inertial force due to the imparted vibration and sudden redirection of momentum exceeds the static tensile force required for fruit detachment (1.93 N and 13.61 N for ripe a nd unripe fruits, respectively as listed in Table 3).

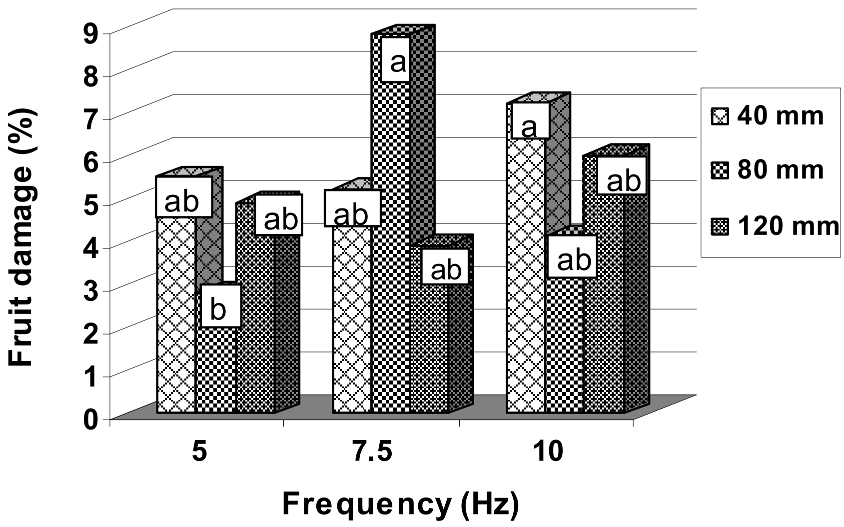

Figure 3. The effects of shaking frequency and amplitude on fruit damage Similar letters indicate no significant difference at p=0.05 [DMRT]

Table 3. Physical characteristics and average static forces applied for detaching ripe and unripe lime fruits

Fruit condition	Geometric mean diameter (mm)	Mass (g)	Weight W (N)	Detachment force F (N)	F/W ratio
Ripe	**35.70**	**28.51**	**0.28**	**1.93**	**6.90**
Unripe	**34.90**	**21.60**	**0.22**	**13.61**	**61.90**

A comparison of Tables 3 and 4 reveals that in 5 out of 9 shaking treatments, the calculated dynamic force is greater than the measured static force required for ripe fruit detachment. Therefore, one would have expected almost complete detachment of ripe fruits in those five treatments and little or partial fruit detachment at the other four shaking treatments. A comparison of Tables 2 and 4 shows that for the five treatments in which the calculated values of dynamic force was greater than the measured static detachment force, between 85 to 100 % of fruits have been removed by shaking, which is in good agreement with the expectation. Also observed was a little over 63 to about 84 % fruit removal in the other four treatments. The reason for this unexpected high fruit removal is the fact that fruit detachment by shaking is a complex phenomenon in which several factors including, inertial axial, bending and torsional stresses, as well as fatigue failure due to cyclic stresses are involved (13), whereas the measured static detachment force could only be related to the inertial axial force. Also, even at the highest shaking frequency and amplitude combination, the calculated dynamic force was smaller than the measured static force required for unripe fruit detachment. This indicates that we should not have expected detachment of unripe fruits at the shaking trials of this experiment. In fact, inspection of the detached fruits revealed that the number of unripe fruits among them was very few.

Table 4. Calculated dynamic force (N) imparted on an average size ripe fruit at different levels of shaking frequency

Frequency (Hz)	Amplitude (mm)		
	40	80	120
5.0	0.51	1.02	1.53
7.5	1.16	2.32	3.48
10.0	2.06	4.12	6.18

CONCLUSIONS

The results of this study revealed that:

1. Lime fruit can be harvested by limb shaking.
2. At any specific amplitude, increasing the shaking frequency resulted in higher fruit detachment.
3. At any specific frequency, increasing the amplitude did not cause any significant fruit detachment.
4. The most efficient fruit detachment occurred at 10 Hz frequency and 80 mm amplitude. Further increasing of shaking amplitude causes excessive leaf shattering and foliage breakage.
5. Increasing shaking frequency or amplitude did not increase fruit damage in a significant manner.
6. The F/W ratios for ripe and unripe fruits were found to be 6.9 and 61.9, respectively. This means that the force required to remove ripe fruits is only about 11 % of that required to remove unripe fruits. Therefore, limb shaking can be used for selective harvesting of ripe fruits.

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REFERENCES

1. Brown, G. K. 2002. Mechanical harvesting systems for the Florida citrus juice industry. ASAE Paper No. 02-1108, ASAE, St. Joseph, MI 49085.
2. Brown, G. K., P. F. Burkner and C. E. Schertz. 1969. Mass harvest problems in California citrus. Proc. Int. Citrus Symp. 2:667-674.

3. Burkner, P. F. and G. K. Brown. 1969. Evaluation of a roller head for mechanical harvest of fresh market Citrus. ASAE Paper No. 69-120. St. Joseph, MI 49085.
4. Castillo, A., G. E. Gomez and M. J. Del Valle. 1996. Foliage shaker to harvest Valencia oranges in Cuba. Proc. of AgEng96 Conference, Madrid, Spain.164-165.
5. Coppock, G. E. 1967. Harvesting early and midseason citrus fruit with tree shaker harvest systems. Proc. Fla. State Hort. Soc., 80:98-104
6. Coppock, G. E. 1974. Development of a limb shaker for harvesting Florida citrus. Trans. of the ASAE, 17(2):262-265.
7. Coppock, G. E. and J. R. Donhaiser. 1981. Conical scan air shaker for removing citrus fruit. Trans. of the ASAE , 24(6):1456-1458.
8. Coppock, G. E. and S. L. Hedden. 1968. Design and development of a tree-shaker harvest system for citrus fruits. Trans. of the ASAE, 11(3):339-342.
9. Diener, G. E., J. L. Levin and R. T. Whittenberger. 1969. Relation of frequency and length of shaker stroke to the mechanical harvesting of apples. ARS U. S. A., 42-148.
10. Fairbank, J. P. 1946. Mechanical tree shaker and such. Diamond Walnut News, 23(4): 4-6.
11. Hedden, S. L., D. B. Churchill and J. D. Whitney. 1984. Orange removal with trunk shakers. Proc. Fla. State Hort. Soc. 97:47-50.
12. Jutras, P. G. and G. E. Coppock. 1963. Harvesting citrus fruit with an oscillating air blast. Trans. of the ASAE, 6(2):192-194.
13. O'Brien, M., B. F. Cargill and R. B. Fridley. 1983. Principles & Practices for Harvesting Fruits and Nuts. Westport, CT: AVI Publishing Co., Inc. 469pp.
14. Peterson, D. L. 1998. Mechanical harvester for processed oranges. Applied Engineering in Agriculture 14(5):455-458.
15. Sanders, K. F. 2005a. Orange harvesting systems review. Biosystems Engineering 90(2):115-125.
16. Sanders, K. F. 2005b. Selective picking head for citrus harvesting. Biosystems Engineering 90(3):279-287.
17. Schertz, C. E. and G. K. Brown. 1968. Fundamental considerations in citrus harvest mechanization. Paper No. 66-131. 59th Annual Meeting Amer. Soc. Ag. Eng.
18. Sumner, H. R., J. D. Whitney and S. L. Hedden. 1975. Foliage shaker for citrus harvesting. Part I: Design and kinematics of shaker drive system. Trans. of the ASAE, 18(1):66-69.
19. Whitney, J. D. 1968. Citrus fruit removal with an air harvester concept. Proc. Fla. State Hort. Soc. 81.58-62.
20. Whitney, J. D. 1999. Field test results with mechanical harvesting equipment in Florida citrus. Applied Engineering in Agriculture, 15(3):205- 210.

21. Whitney, J. D. and J. B. Patterson. 1972. Development of a citrus removal device using oscillating forced air. Trans. of the ASAE, 15(5):849-855.
22. Whitney, J. D. and D. R. Schultz. 1975. Analysis of air shaker principles to remove citrus fruit. Trans. of the ASAE, 18(6):1061-1064.
23. Whitney, J. D., H. R. Sumner and S. L. Hedden. 1975. Foliage shaker for citrus harvesting. Part II: Harvesting trials. Trans. of the ASAE, 18(1):70-73.
24. Wilson, W. C., J. R. Donhaiser and G. E. Coppock. 1979. Chemical and air shaker orange removal in South Florida (LABELLE). Proc. Fla. State Hort. Soc. 92:56-58.

تاثیر بسامد ودامنه ارتعاش برجداسازی میوه لیمو ترش

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چکیده- هدف از اجرای این تحقیق تعیین مناسبترین بسامد و دامنه ارتعاش برای برداشت ارتعاشی میوه لیمو ترش (*C. aurantifolina*) بود. یک دستگاه شاخه تکان سوار بر تراکتور با بسامد و دامنه نوسان قابل تغییر و تنظیم که توان مورد نیازش از طریق محور توان دهی تراکتور تامین می گردید، برای اجرای این تحقیق طراحی و ساخته شد. توان دورانی ورودی دستگاه از طریق یک سیستم رانش تسمه ای به فلایویل شاخه تکان منتقل و درآنجا با استفاده از مکانیزم لنگ و لغزنده به حرکت رفت و برگشتی تبدیل می شد. حرکت ارتعاشی حاصل از طریق یک تیرک تلسکوپی و یک گیره مخصوص به شاخه درخت منتقل می گردید. یک آزمایش فاکتوریل درقالب طرح کاملا تصادفی با سه تکرار برای بررسی تاثیر سطوح مختلف بسامد و دامنه ارتعاش بر جداسازی میوه به اجرا گذاشته شد. سه سطح بسامد (۵، ۷/۵ و ۱۰ هرتز) و سه سطح دامنه ارتعاش (۴۰ ، ۸۰ و ۱۲۰ میلی متر) مورد مطالعه قرارگرفت. تجربه واریانس و مقایسه میانگین ها نشان داد که تاثیر بسامد ارتعاش بر جداسازی میوه معنی دار است ، درحالی که تاثیر دامنه ارتعاش و اثر متقابل آن بر بسامد معنی دار نبود. با افزایش بسامد ارتعاش ، درصد میوه های جداشده بطور معنی داری افزایش یافت، ولی بسامد و دامنه ارتعاش تاثیر معنی داری بر میزان آسیب دیدگی میوه نداشت . جداسازی کامل میوه (۱۰۰٪) با اعمال ارتعاشی با دامنه ۱۲۰ میلی متر و بسامد ۱۰ هرتز حاصل گردید، ولی با این ترکیب دامنه و بسامد ، ریزش قابل توجه برگ عامل محدودکننده بود . از این رو تکانیدن شاخه با دامنه ۸۰ میلی متر وبسامد ۱۰ هرتز با جدا سازی ۹۸/۵٪ میوه و ریزش ناچیز برگ، مناسب ترین ترکیب شناخته شد. برای تعیین استحکام اتصال میوه به شاخه، مجموعه آزمون هایی انجام گردید که طی آن میانگین نیروی کششی لازم برای جداسازی میوه های رسیده و نارس و همچنین جرم و میانگین قطر هندسی میوه اندازه گیری شد. میانگین نیروی لازم برای جداسازی میوه های رسیده درحدود۱۴/۲ درصد نیروی لازم برای جداسازی میوه های نارس بود. میانگین نسبت نیروی کششی لازم برای جداسازی میوه به جرم آن (F/W) برای میوه های رسیده و نارس به ترتیب برابر با ۶/۹ و ۶۱/۸ اندازه گیری شد. این دو کمیت اخیر را می توان به عنوان شاخصی از امکان بالقوه بکارگیری شاخه تکان برای برداشت انتخابی میوه های رسیده درمورد ارقامی از میوه های با خصوصیت رسیدگی غیر یکنواخت قلمداد نمود.

واژه های کلیدی: برداشت میوه, برداشت ماشینی, درخت تکان, برداشت مرکبات و شاخه تکان

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