Vibration-Assisted Tight-Filling Machine for Tangerine

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Abstract

This research was to test and evaluate the vibration-assisted tight-filling machine (VATFM). Both engineering and economical aspects were considered. The machine comprised three parts, i.e., feeder and weighter (550 mm wide by 750 mm long by 350 mm high), controller and vibrator (410 mm wide by 580 mm long by 315 mm high).

Tests were conducted with constant amplitude (6 mm) and constant duration of 5 seconds of vibration. Control factors of vibration included 4 frequencies and 5 fruit packing methods. Two sizes of tangerine (no.2 and 00) and 2 replications were used for each combination of the control factors. Two vibrational properties, i.e., settling index (H_m) and damage percentage were investigated.

Results showed vibration with constant 8.7 Hz frequency and vertical pressure of 478.7 N/m^2 was suitable for the tested tangerines. Corresponding packing error and fruit damage were less than 0.5 and 0.9%, respectively. Packing rates for tangerine no. 2 and 00 were 463.8 and 538.8 kg/hr.

After vibration there was some space available at the top of package due to fruit settling. The packages of tangerine no.2 and 00 could be filled up with additional fruits of 3.49 and 2.55 kg/package, respectively. Economic analysis indicated that the VATFM had the break even point at 13,040 packages and pay back period of 77 days.

Key words : Tangerine, filling machine, vibration

Introduction

For the present economics of Thailand, agricultural produce becomes essential to generate income to farmers and the country. In order to provide good produce quality to the consumers, postharvest technology is brought into use. During transportation, the packed fruits are subjected to sagging (Peleg,1985). Since fruits stay in package loosely and out of order, they can be easily shaken inside the packages when subjected to vibration during shipping. The fruits hit one another or hit package walls, resulting in fruit damage. Tangerine fruit sagging averaged 7.3% (Jarimopas, 2001). Vibration before shipping helps fruit settling and increases packing density. Besides, it reduces sagging and damage. More fruits can be added to each container, thereby reducing transportation cost. Hinsch et al. (1993) reviewed literatures and reported 15-68% of market value loss due to distribution and transportation process. O'Brien et al. (1960, 1965) studied fruit vibration during transport. They simulated packed fruits in two kinds of packages—bulk bin and lug box. For 100 miles of travel, it was found that the tested fruits of different layers in a package exhibited unequal damage. Maximum fruit dam age (23.9%) appeared at the top layer of lug box and 19.8% at that of bulk bin. This finding was substantiated by Gentry et al. (1965). Slaughter et al. (1993) studied fruit damage by means of vibration on tight and loosened packaging. Result showed that the color of fruits of tight packaging changes less than that of the loosened packaging. However, too tight packaging could incur damage to fruits due to compression. Thai fruits are currently suffering from this kind of damage a lot (Siripanich, 1995). Siripanich (1995) wrote that fruit sagging in wholesale packages was due to the fact that the fruits were loosely packed with large void spaces and with small number of contact points among fruits. Vibration during transportation causes the fruits to move into the void spaces, resulting in sagging, and the high pressure exerted at contact points on fruits in the lower layer tends to cause fruit damage. Fruit sagging psychologically reflected the feeling that some fruits were taken away although package weight remains constant.

To solve the problem of fruit sagging a vibration assisted jumble filling machine was developed for orange (Peleg, 1985). The machine helped increase packing density and reduce sagging. Fruit damage could be kept at minimum if appropriate vibration parameters were controlled. Vibration factors affecting fruit injury were amplitude and frequency (Gentry et al., 1965). Besides, duration and direction of motion had to be included (Peleg, 1985). Performance evaluation was denoted by settling index which is a function of count, height of package and clearance amongst fruits and package bottom (Peleg, 1985). To minimize transit injury, Guillou (1963) developed a method of packing known as "tight-fill" pack. In this method the fruit container was vibrated from 5 to 10 seconds in a vertical plane at a frequency of 600 to 900 cycles per minute with a stroke adjusted to give a maximum acceleration of 2 g. A closing pressure of about 478.7 N/m2 also applied on top of the pad of the container. Tight fill pack gave as good result as packing expert did (Gentry et al., 1965). Phoomto (2000) studies vibration properties of Thai mandarin and found that appropriate vibration characteristics were 10 Hz frequency, 2 mm Amplitude, and 5 second duration. Direction of motion was horizontal with 0.8 g. acceleration. Mandarin injury can be identified by the appearance of deformed and flat outside surface. Currently, vibration-assisted tight-filling (VATF) technique is still unavailable for tangerine. Therefore, it was necessary to develop a VATF machine that is suitable for Thai tangerines.

Materials and Method

Materials and Equipment : Materials and equipment used included a variable speed motor (Mitsubishi, ½ hp), a vibration meter (Rion, 0-10 g), a tachometer (Yokogawa), an air compressor, a digital balance (0-150 kg), a vernier caliper, and a tangerine plastic basket (370 mm x 570 mm x 320 mm).

Method : The prototype VATF machine is shown in Fig. 1. The VATF comprised three parts: a vibrator, a feeding and weighing unit, and a controller. The vibrator was made of 2.5-cm rectangular steel pipe frame, lined with 1 mm. thick steel plate. Under the vibrator are 4 wheels at each corner to facilitate movement. Vibration was generated by a driving link attached to an eccentric bearing at the motor drive. A lid with a weight–plate was used to apply vertical pressure on the fruits. The feeding and weighing unit (550 mm wide by 750 mm long by 350 mm. high) was made of 1-inch L beam as a frame. Inside is lined with zinc plate and 5 mm. thick polyethylene foam. Under the frame is a spring scale (0-30 kg). At the top of the frame is a pneumatic–cylinder for automatic feeding control. The controller consisted of a solenoid valve, a 240/24 v. transformer, a microswitch, a timer (Omron 0-30 second), and a speed controller (Speecon 7200 M3, 0.55-11 kw) Electro-mechanical equipment is connected altogether to control the motor and opening-closing of the feeder. Experiments were divided into three parts:-

a) Determination of appropriate vibration frequency

In this test the amplitude and duration of test were kept constant at 6 mm and 5 seconds, respectively. Four different frequencies (5, 10, 15, 20 Hz) and two sizes of tangerine (no. 2 and 00) were tested.

Test procedures were as follows: First, the diameters D of randomly selected 10% of the fruits from a 25-kg commercial basket were measured. Then the 25 kg of tangerines no.2 were automatically loaded by the feeding and weighing unit into the vibrator. The desired vibrating frequency, e. g., at 5 Hz , was set by the motor speed controller. After being vibrated for 5 seconds, the tangerines were removed from the vibrator and left in the ambient air for 2 days. Then, the clearance of each fruit, hi, to the top of tangerine basket was measured, and fruit injury was evaluated and recorded. Percentage of damage was determined by ratio of the injured fruit to total fruits in a basket, multiplied by 100. Inspection was subjectively made to identify the injured fruit felt deformed, flat and softer than the fruit that was a control. The same procedures were repeated with 2 replications for each frequency of 5, 10, 15, and 20 Hz. Similar experiments were conducted with the no. 00 tangerines. Settling index Hm can be analyzed from the equation $Hm = c/[\frac{1}{N}\sum_{i=1}^{N} Z_i]$; where N = number of count, Z_i = vertical distance of fruit center form the basket bottom (mm) = $C-h_i-D/2$, C = basket height (mm.) (Fig.2).

Fig. 1 Prototype of Vibration-assisted Tight Filling Machine for Thai Tangerine.

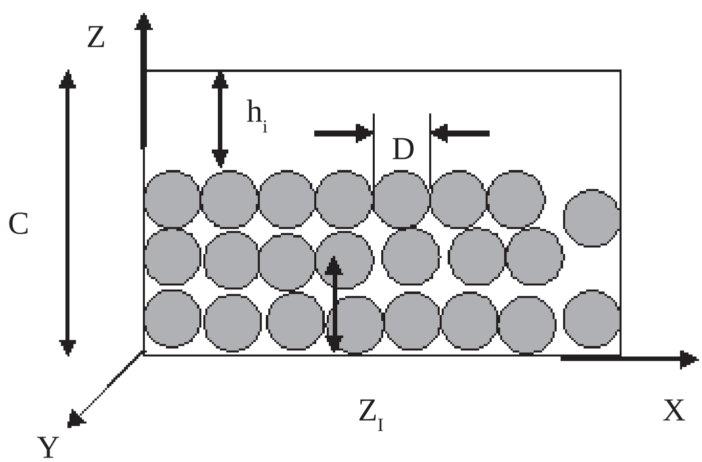

Fig. 2 Settling index measurement.

b) Determination of suitable vibration-assisted filling method for tangerine

Five methods of vibration-assisted filling were tested: i) frequency-increasing vibration, ii) constant frequency vibration, iii) constant frequency vibration with vertical pressure 293.4 N/m^2 ,iv) constant frequency vibration with vertical pressure 478.7 N/m^2, v) constant frequency vibration with vertical pressure 957.4 N/m^2. Testing procedures were similar to that of experiment a) except for the testing method iii, iv and v, where padded flat steel plates (360 mm x 560 mm) of different thickness (to meet different pressure) were placed on top of the fruits in the basket on the vibrator.

c) Performance test of the VATF machine continuously

The same vibration-assisted filling of experiment b) was applied to the prototype of VATF machine for continuous operation with 5 tangerine baskets for each fruit size. Hm, damage, filling error, additional tangerine, vibration acceleration (g) and capacity (kg/hr) were measured and analyzed.

Results and Discussion

Appropriate Frequency

Table 1 shows results of H_m and percent damage for vibration of various frequencies at constant amplitude and duration. H_m of tangerine no. 2 (smaller size) is greater than that of no.00 for a certain frequency. This implied more sagging and more space to be filled up. This agrees with what Peleg (1985) wrote that the smaller spheroidal fruits can be packed more densely than the bigger ones. For tangerine of the same size, an increase in frequency caused an increase in H_m and damage. This is because increasing frequency accelerated fruit movement to fill up gap amongst fruits. Fruits of upper layer descend, which means more sagging (higher H_m) and more dynamic loads on the fruits. Consequently, more damage took place.

Table 1 Settling index Hm and damage of Tangerine vibrated at constant amplitude of 6 mm, 5 seconds duration, and varying frequencies.

Tangerine no.	Frequency (Hz)	H_m	Damage (%)
	5	2.47	0.52
	10	2.57	0.93
2	15	2.62	2.21
	20	2.75	3.62
	5	2.28	0
	10	2.52	1.16
00	15	2.58	3.16
	20	2.72	4.96

Fig. 3 shows that Hm and damage increase linearly with frequency (R^2>0.94) for both sizes of tangerines. The appropriate frequency for keeping the damage below an acceptable damage level of 1% would be 8.7 Hz for both the No. 2 and No. 00 tangerines.

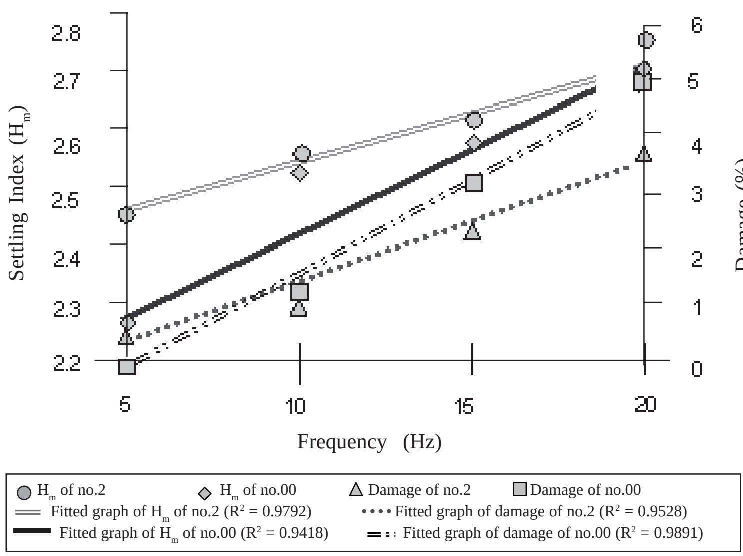

Fig. 3 Graphs fitted by linear regression between Hm and damage.vs. frequency.

Appropriate vibration-assisted filling

Table 2 shows average values of Hm and damage incurred by different ways of vibration-assisted filling based on the following vibration conditions: amplitude = 6 mm, frequency = 8.7 Hz, and duration = 5 sec.

Table 2 Comparison among various vibration-assisted tight filling methods.

Tangerine no.	VATF	H_m	Damage %
2	Increasing frequency (0-8.7 Hz)	2.35^{BC}	0.27^{B}
	Constant frequency 8.7 Hz	2.32^{D}	0.26^{B}
	Constant frequency 8.7 Hz with vertical pressure 239.4 N./m^2	2.36^{B}	0.27^{B}
	Constant frequency 8.7 Hz with vertical pressure 478.7 N./m^2	2.41^{A}	0.40^{B}
	Constant frequency 8.7 Hz with vertical pressure 957.4 N./m^2	2.43^{A}	0.65^{A}
00	Increasing frequency (0-8.7 Hz)	2.24^{C}	0.56^{B}
	Constant frequency 8.7 Hz	2.21^{C}	0.59^{B}
	Constant frequency 8.7 Hz with vertical pressure 239.4 N./m^2	2.37^{B}	0.58^{B}
	Constant frequency 8.7 Hz with vertical pressure 478.7 N./m^2	2.42^{AB}	0.87^{B}
	Constant frequency 8.7 Hz with vertical pressure 957.4 N./m^2	2.47^{A}	1.49^{A}

Note : The values of H_m or damage that have the same superscript in its column for a certain tangerine number have no statistical difference at 95% level of confidence.

Regarding DMRT statistical analysis at 95% level of confidence , the VATF with constant frequency of 8.7 Hz and vertical pressure of 478.7 N./m^2 is the most appropriate method because it imparted high H_m (ie. high sagging which helped add more tangerines) and very small damage (less than 0.9%).

Test of Continuous Operation of the VATF Machine

Applying result of the previous experiment of the most appropriate filling, VATF machine was operated continuously to fill up 5 baskets of tangerine for each size. Test results showed that H_m was 2.38 and 2.27 for tangerine no. 2 and 00, respectively (Table 3). This is realistic because smaller fruits can settle more densely than the larger ones. Damage was less than 0.9% average for both sizes which complied with the previous experiment and not exceeding the design limit from the first experiment. Filling error was quite small (less than 0.5%) while the capacity was 463.8 and 538.8 kg./hr. for fruit no. 2 and 00, respectively. Associated acceleration of vibration was 0.9 g. This fairly agreed with the work of Gentry et al. (1965) that acceleration of top layer fruit staying randomly in a vibrated package during transit was 1 g. The amounts of fruits that could be added to each already-vibrated basket were 3.49 and 2.55 kg for fruit no. 2 and 00, respectively.

Table 3 Results of VATF Performance Test.

Parameters	**Tangerine fruit no.**	
	2	**00**
Hm	2.38	2.27
Damage (%)	0.49	0.88
Filling error (%)	0.41	0.45
Capacity (kg/hr)	463.8	538.8
Acceleration (g)	0.9	0.9
Additional tangerine (kg)	3.49	2.55

Engineering Economics Analysis

In practice, four VATF machines will be used at the outlet of each perforated cylinder sizing machine. Total construction cost is 65,200 baht (Table 4). After vibration, 2.5 kg of tangerine can be added per basket. According to Bupha shop in Talad Thai wholesaler, 170 baskets of tangerines per day can be sold out with profit of 2 baht per kilograms.

Break Even Point (BEP) can be determined as followed (Rijirawanich and Ploymeekha,1994):

R (revenue) = E (expenses), where R = pP, p = profit per unit production, P = number of production, but E = 65,200 baht and R = 2.5 x 2 x P baht. At the BEP 2.5x2xP = 65,200 baht. Therefore, P = 13,040 baskets. Bupha shop has to put investment on wholesaling of 13,040 baskets of tangerines. Afterwards he will start getting profit. Pay Back Period can be calculated as followed:-

R = E where R = (2.5x2x170) M, (M= number of days to be paid back), and E = 65,200 baht . Therefore (2.5x2x170)M = 65,200 baht. M = 76.71 = 77 days.

Table 4 Construction cost of a VATF machine of tangerine.

Descriptions	Price (baht)
1. 2- Pneumatic cylinders 1,500 baht each.	3,000
2. 2- Solenoid valves 2,500 baht each	5,000
3. 2- microswitches 100 baht each.	200
4. Spring balance	600
5. ½ Hp electric motor	1,500
6. Gear reducer	500
7. Ball bearing	100
8. Control box	400
9. Air compressor	8,000
10. Transformer	500
11. Steel and accessories	1,500
12. Labor	1,000
Total	**22,300**

Conclusion

A prototype of VATF machine was developed. As a result of testing and evaluation with different combinations of settings of vibration parameters and vertical pressure, the following appropriate settings for the vibration filling procedure were selected: constant frequency of 8.7 Hz, amplitude at 6 mm, duration of 5 sec., and vertical pressure of 478.7 N/m^2. Application of this most appropriate filling technique to pack 5 baskets of tangerines continuously gave the following results: i) capacity of 463.8 and 538.8 kg/hr for fruit no. 2 and 00, ii) filling error not exceeding 0.5%, and iii) mechanical damage not exceeding 1% as previously designed. The estimated cost of the prototype was 22,300 baht per unit. Engineering economic analysis indicated break even point and pay back period were 13,040 baskets and 77 days, respectively.

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References

Gentry, J.P., Mitchell, F.G. and Sommer, N.F. (1965), Engineering and quality of deciduous fruits packed by volume-filling and hand-placing methods. *Trans. of the ASAE*. 8(4) : 584-589.

Guillou, R. (1963), Settling packed fruit by vibration. *Trans. of the ASAE*. 6(3) : 190-192,194.

Hinsch, R.T.et al. (1993), Vibration of fresh fruits and vegetables during refrigerated truck transport. *Trans. of the ASAE* 36(4) : 1039-1041.

Jarimopas, B (2001), *Postharvest Machinery and Packaging of Fruits.* (Bangkok : Funny Pub. Co.)

O'Brien, M., Gentry, J.P. and Gibson, R.C. (1965), Vibrating characteristics of fruits as related to in-transit injury. *Trans. of the ASAE* 8(2) : 241-243.

O'Brien, M., Claypool, L.L. and Leonard, S.J. (1960) Effects of mechanical vibrations on fruit damage during transportation. ASAE Paper No. 60-311, *Am. Soc. Agr. Engrs.* (Michigan : ASAE)

Peleg, K. (1985), *Produce Handling, Packaging and Distribution.* (Connecticut : AVI Pub.Co.Inc)

Phoomto, N. (2000), *Study of Vibration Properties of Tangerine*. Unpub. M.Eng. Thesis (Nakornpathom : Department of Agricultural Engineering, Kamphaengsaen Engineering Faculty, Kasetsart University, Kamphaengsaen)

Siripanich, J. (1995), *Physiology and Postharvest Technolgy of Fruits and Vegaetables.* (Nakornpathom : Office of Agricultural Entension Press, Kasetsart University, Kamphaengsaen)

Slaughter, D.C., Hinsch, R.T. and Thompson, J.F. (1993), Assessment of vibration injury to Bartlett pears. *Trans. of the ASAE* 36(4) : 1043-1047.

Rijirawanich, W.and Ploymeekha, C. (1994) *Engineering Economics.* (Bangkok : Chulalongkorn Printing Co.)