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Vibration and Shock Analysis of Fruit and Vegetables Transport

—Cherry Transport from Yamagata to Taipei—

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Abstract

Vibration and shock data was collected using accelerometers placed in corrugated fiberboard containers of cherries transported from Yamagata, Japan to Taipei, Taiwan. Vibration during airplane transport differed from that of transport by trucks, with much high-frequency vibration and the highest peak frequency measured at 80 Hz. Vibration features of Japanese trucks differed from those of Taiwanese trucks. Cherries loaded on trucks in Yamagata and undergoing customs procedures and inspection at Narita International Airport (Narita) showed fewer shocks and lower acceleration, < 10 G. Packaged cherries loaded on planes at Narita and unloaded at Taiwan Taoyuan International Airport (Taoyuan) showed the highest shocks. Maximum shock acceleration of 60 G throughout transport was detected in loading at Narita. Shock acceleration during quarantine and customs procedures at Taoyuan was also high like at Narita. Cherries transported by truck in Taipei underwent a maximum shock acceleration of 20 G, exceeding that in Japan truck transport.

Disciplines: Food / Postharvest technology
Additional key words: airplane, cherry, export

Introduction

Vibration and shock during transport injures fruit and vegetables, especially fruit with a soft pericarp. Mechanical damage in truck transport, including abrasions and bruises, reduces quality to a level where truck transport may become problematic. Losses in fresh fruit rose by 17% and in vegetables 10% during transport and distribution in 2006 in Japan[8]. Fruit must thus be packaged in cushioning sufficient to protect it from vibration and shock. This is especially true of perishable fruit and vegetables such as pears[2,11,12,16,17], loquats[1], peaches[15], potatoes[13], tangerines[7], and oranges[10]. Domestic fruit is mainly transported by truck using many types of containers, including corrugated fiberboard containers and cushioning materials. Fruit for export may also be packaged using the same material and design as in distribution in Japan, causing problems in mechanical damage and internal quality, necessitating the development of better packaging for exported fruit.

The export of cherries, a major product of Yamagata Prefecture, while currently low, is gradually increasing. Taiwan is a major destination for Yamagata cherries despite the expensiveness of Japanese cherries. Due to their delicacy[3], examples of damaged Japanese cherries in Taiwan supermarkets and department stores are numerous. To lower cherry damage during export, packaging materials and design must be improved to raise protection quality, but information on how cherries are affected by vibration and shock during export is still insufficient for optimizing packaging. Many attempts have been made to evaluate mechanical damage to fresh produce during truck transport[4–6], but almost no reports have been made on vibration and shock to cherries during export including airplane transport. We evaluated mechanical damage by recording and analyzing vibration and shock data on cherries during truck transport to Narita International Airport (Narita), at quarantine and customs processing at Narita, in air transport from Narita to Taiwan Taoyuan International Airport (Taoyuan), at quarantine and customs processing at Taoyuan, and during truck transport to final destinations in Taipei.

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Materials and methods

1. Vibration measurement during transport

Vibration and shock were measured using 130 × 90 × 62 mm digital 3-dimensional (3D) acceleration recorders (Der-mini, Shinyei Technology Ltd., Japan) that weighed about 800 g including batteries.

Shock data collection was triggered by acceleration exceeding 3 G. Conditions studied included a sampling rate of 1.0 ms, a data length of 512, A/D conversion of 12 bits, and maximum recordable wave numbers of 2,400.

Vibration data was continuously collected once every 5 minutes triggered by acceleration exceeding 0.3 G. Conditions studied included a sampling rate of 2.0 ms, a data length of 1,024, A/D conversion of 12 bits, and maximum recordable wave numbers of 1,200.

Cherry samples weighing 500 g were packaged in 2 polypropylene containers per corrugated fiberboard container, with vibration and shock recorders placed inside of the corrugated fiberboard container instead of a cherry container (Fig. 1(a)). Corrugated fiberboard containers were tied in place using polypropylene bands (Fig. 1(b)).

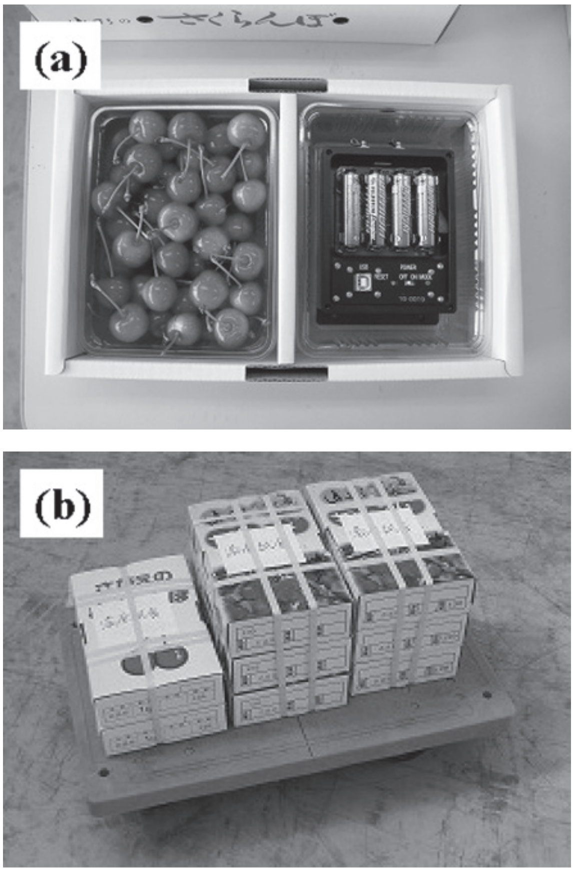

Fig. 1. Cherry packaging container with accelerometer
(a) Accelerometer in packaging container, (b) Corrugated fiberboard container for export to Taipei

2. Transport scheduling

Cherries transport scheduling was roughly as follows:

- Trucks carrying corrugated containers of cherries left Yamagata at 19:00 on June 19, 2007
- Trucks arrived at Narita at 09:00 on June 20.
- Quarantine and customs processing lasted from 14:00 to 15:10 on June 20.
- Exports departed by plane at 20:00 on June 20.
- Exports arrived at Taoyuan in Taiwan at 23:55 on June 20.
- Quarantine and customs processing lasted from 13:00 to 18:00 on June 21.
- Trucks bearing cherries departed the airport 18:30 on June 21.
- Trucks arrived at destination department stores in Taipei at 20:30 on June 21.

3. Drop tests for packaged cherries

Drop tests for packaged cherries were made using DTS-50 (Shinyei Technology Ltd., Japan), which dropped containers perpendicularly from a height of 10–50 cm. Containers contained digital 3D accelerometers (Fig. 1(a)). Data was collected at a sampling rate of 1.0 ms, a data length of 512 and A/D conversion of 12 bits.

4. Vibration and shock analysis

Data was analyzed using Der-mini-PSD Ver. 1.3 vibration software (Shinyei Technology Ltd., Japan) and Der-mini-SH Ver. 1.3 shock software (Shinyei Technology Ltd., Japan). Vibration acceleration during transport was converted to power spectral density (PSD) data using Hanning window process and Fast Fourier Transformation (FFT).

Results

Cherries harvested in Yamagata were transported from there to department stores in Taipei, Taiwan. Transport from Yamagata to Narita was by truck, mostly on highways. Transport from Narita to Taoyuan was by plane. From the airport to department stores, transport was by truck. Typical transport acceleration data is shown in Fig. 2(a) from Yamagata to Narita, (b) from Narita to Taoyuan and (c) from Taoyuan to department stores in Taipei. Vibration acceleration during plane transport was very much lower than by truck transport. No significant difference was seen between Japan and Taiwan truck transport. Vibration acceleration was determined using PSD (Fig. 3). Truck transport vibration acceleration in Japan peaked at 15 Hz (Fig. 3(a)). Vibration during airplane transport differed significantly from

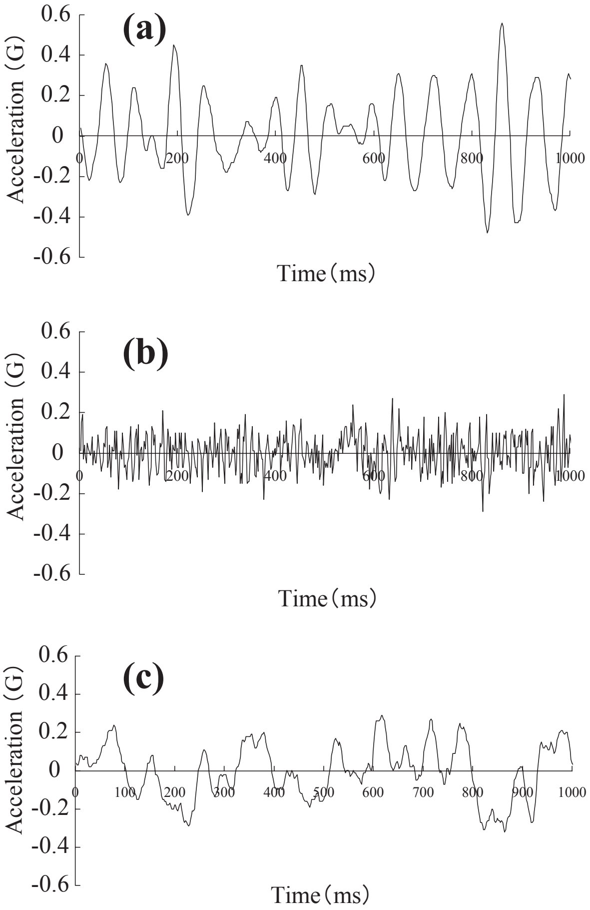

Fig. 2. Vibration during transport

(a) Truck from Yamagata to Narita, (b) Airplane from Narita to Taoyuan, (c) Truck from Taoyuan to Taipei

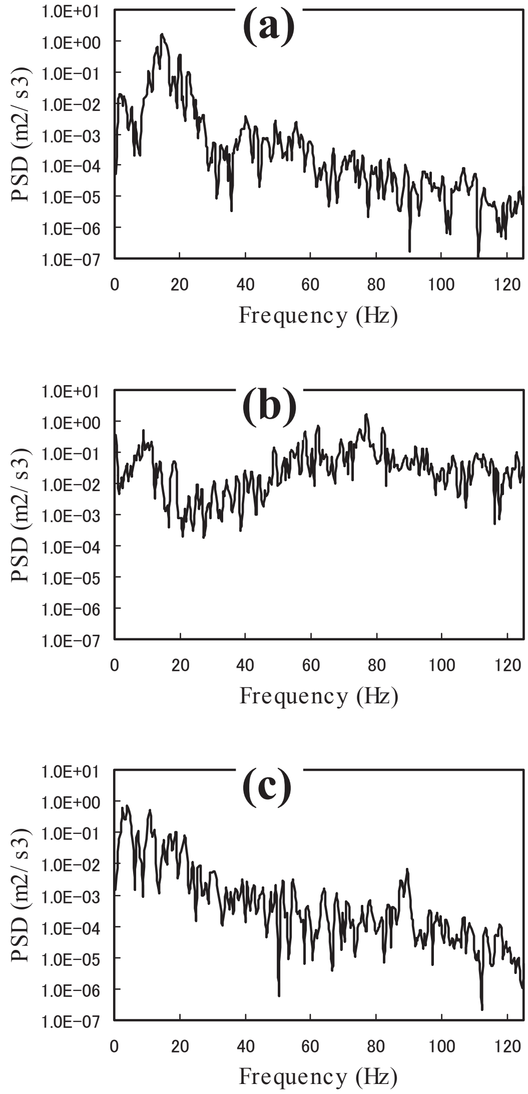

Fig. 3. PSD spectra of vibration

(a) Truck from Yamagata to Narita, (b) Airplane from Narita to Taoyuan, (c) Truck from Taoyuan to Taipei

truck transport (Fig. 3(b)), containing considerable high-frequency elements with a peak frequency at 80 Hz. In Taiwan truck transport, the peak frequency was 2–3 Hz and higher frequency elements other than this peak decreased with frequency.

In shock acceleration exceeding 3 G during overall transport (Fig. 4), most shock was recorded when cherries were loaded and unloaded from airplanes. Maximum shock acceleration of 60 G during overall transport occurred during loading at Narita. Maximum shock acceleration while cherries were transported by truck in Taipei was 20 G. No shock acceleration exceeding 3 G was detected during Japanese truck and airplane transport.

Shock frequency recorded during transport from Yamagata to Taipei was separated into 6 periods -- handling and loading at Yamagata, quarantine and customs processing at Narita, loading on airplanes at Narita, unloading at Taoyuan, quarantine and customs processing at Taoyuan, and truck transport in Taipei (Table 1). Shock frequency was analyzed for each period and it was determined whether containers fell or not. Moreover, maximum shocks in each period are shown in Fig. 5. Shock frequency events recorded during truck loading in Yamagata and in quarantine and customs processing at Narita were few and low, less than 10 G. No shocks distinguished as “falls” were produced, for example, by throwing containers. It was suggested that containers were handled comparatively carefully during these periods. Containers underwent most frequent shocks during airplane loading and unloading. Fifty-nine shocks exceeding 3 G, including 2 exceeding 20 G and 4 of 10–20 G, during loading at Narita and 129 shocks exceeding 3

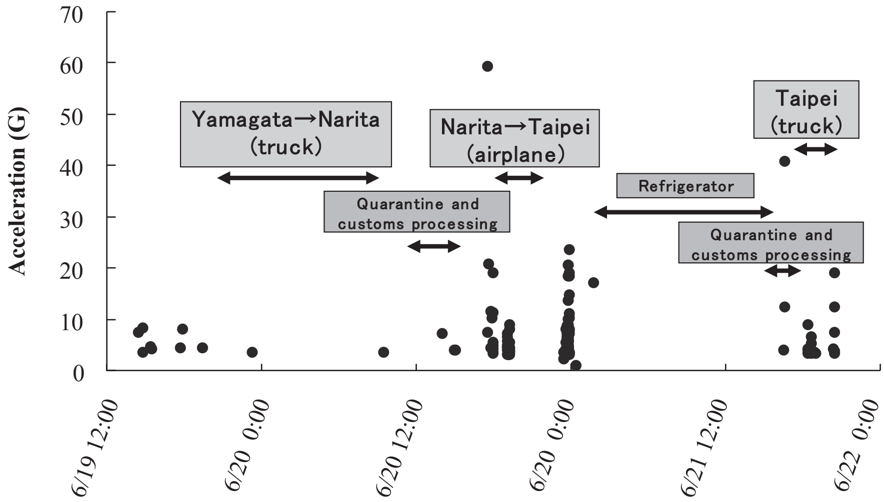

Fig. 4. Shock during transport from Yamagata to Taipei
Dots indicate shock occurrence and acceleration.

Table 1. Acceleration frequency during transport

	Accelaration						
	3-5G	5-10G	10-20G	20G	Total	Fall	Shock
Yamagata	6	4	0	0	10	0	10
Quarantine and customs processing at Narita	2	2	0	0	4	0	4
Loading onto airplane	43	10	4	2	59	1	58
Unloading from airplane	88	30	9	2	129	4	125
Quarantine and customs processing at Taoyuan	1	0	1	1	3	2	1
Transport in Taipei	15	8	3	0	26	0	26

G, including 2 shocks exceeding 20 G and 9 of 10–20 G, during unloading at Taoyuan were recorded. Shocks distinguished as “falls” produced by throwing containers were recorded 5 times during loading and unloading. Drop tests for packaged cherries dropped containers perpendicularly from a height of 10–50 cm. Figure 6 shows shock acceleration when the container was dropped from a height of 20 cm. Maximum shock acceleration (Fig. 5(c)) was 60 G and about the same as a fall from a 20 cm height (Fig. 6). This was the maximum shock during transport. No shocks occurred during airplane transport, but many large ones did occur before and after airplane transport, including those not recorded during Japan truck transport. Shocks during quarantine and customs processing at Taoyuan were recorded only 3 times, but were relatively large. Two shocks were distinguished as falls, leaving the impression that containers were handled comparatively roughly. A total of 26 shocks were recorded during Taiwan truck transport and maximum acceleration was 20 G, making handling in Taiwan truck transport rougher than that in Japan truck transport. By type, shock due to falls occurred only 7 times, with the other 131 shocks generated by other impact.

Packaging materials and design for export, e.g. the corrugated fiberboard containers in this study, were usually the same as those used in Japan. No cherries were usually damaged in Japan truck transport, but many suffered significant damage by the time they had arrived at department stores in Taipei (Fig. 7), indicating that damage was mainly caused by shock in loading at Narita and unloading at Taoyuan.

Discussion

An analysis of PSD spectra from Japan and Taiwan truck transport showed a peak at 15 Hz in Japan truck transport and at 2–3 Hz in Taiwan transport. Vibration higher than the peak decreased with frequency in PSD

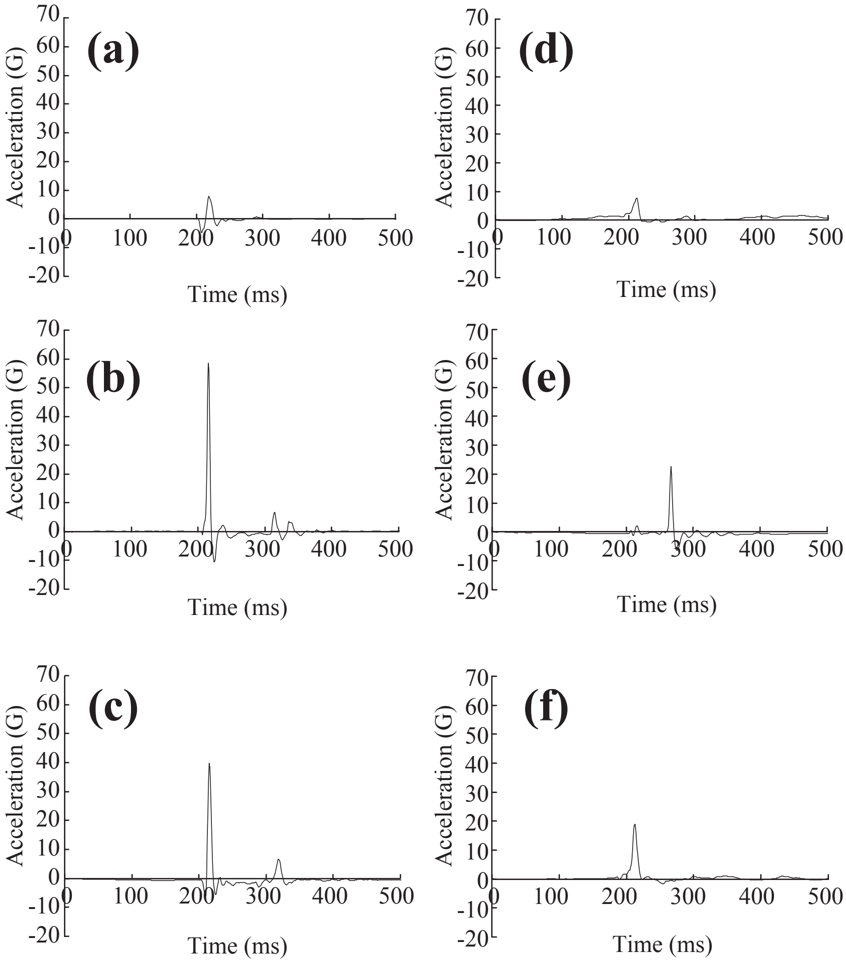

Fig. 5. Maximum acceleration during transport

(a) Yamagata, (b) Quarantine and customs processing at Narita, (c) Loading on airplane, (d) Unloading from airplane, (e) Quarantine and customs processing at Taoyuan, (f) Transport from Taoyuan to Taipei

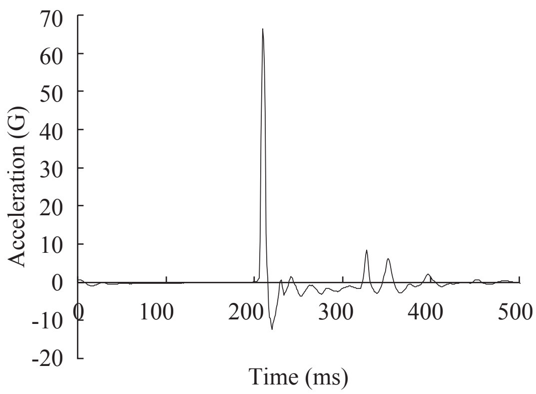

Fig. 6. Shock in fall from 20 cm height

spectra for both. Usuda et al. (2006)[14] reported that vibration in trucks with leaf-spring suspension peaked at 3 Hz and that in new trucks with air-ride suspension peaked at 3 Hz, with another large peak at 13 Hz. Our study indicated that Japan truck transport usually involved air-ride suspension and that in Taiwan leaf-spring suspension. Shock recorded during transport in Taiwan was frequent and larger than that during transport from Yamagata to Narita. These differences appear due both to handling and to truck suspension.

Airplane transport vibration peaked at 80 Hz and included relatively higher frequency, but contained few frequency vibrations at 20 Hz. Nakamura et al. (2007)[9] reported that acceleration transmissibility was maximum at 20 Hz in a strawberry vibration test, and that packaged strawberries have a resonance frequency at this peak where vibration intensified. Airplane vibration is generally low or very low at the resonance frequency, suggesting that airplane transport involves less damage than truck transport. Vibration differs widely between straw-

Fig. 7. Damage to packaged cherries after transport from Yamagata to Taipei

berries and cherries, however, requiring very precise analysis of factors such as resonance frequency.

We distinguished between shock in falls and in other handling throughout transport, finding that falls caused shock in only 7 cases, with other factors as causes in the other 224 cases. We calculated the fall height based on shock waveforms, finding that the maximum fall height was 10 cm. These results suggest that corrugated fiberboard containers used to package cherries were handled rather carefully during transport.

Maximum shock acceleration recorded before and after airplane transport occurred 6–7 times as often as in truck transport, so cherries using packaging materials common in Japan were severely damaged. Packaging materials for cherries must therefore be improved by using better cushioning materials.

While most airplane passengers have the impression that severe shocks occur on landing, our results suggest otherwise, i.e. landing shock acceleration is a comparatively low level.

Our study was limited in that it focused on cherry transport from Yamagata to Taipei, and shock acceleration naturally differs with the transport route, transported item and packaging materials. More detailed data on different routes, transported items and packaging material must thus be collected so that packaging design can be appropriately optimized.

Acknowledgments

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References

1. Barchi, G. L. et al. (2002) Damage to loquats by vibration-simulating intra-state transport. *Biosyst. Eng.*, **82**, 305–312.
2. Berardinelli, A. et al. (2005) Damage to pears caused by simulated transport. *J. Food Eng.*, **66**, 219–226.
3. Hinsch, R. T. et al. (1993) Vibration of fresh fruits and vegetables during refrigerated truck transport. *Trans. ASAE*, **36**, 1039–1042.
4. Iwamoto, M. et al. (1977) Engineering approach to simulated transportation test for fruits and vegetables (I) – Vibrating characteristics and in-transit mechanical injury of lettuce filled in carton-boxes stacked high–. *Nogyo kikai gakkaishi* (*J. JSAM*), **39**, 343–349 [In Japanese with English summary].
5. Iwamoto, M. et al. (1978) Engineering approach to simulated transportation test for fruits and vegetables (I) – Definition of in-transit mechanical injury and determination of vibrating acceleration level for simulated transportation test-. *J. JSAM*, **40**, 61–67 [In Japanese with English summary].
6. Iwamoto, M. et al. (1980) Engineering approach to simulated transportation test for fruits and vegetables (I) – Evaluation of power-spectrum density of vibrating acceleration affecting the in-transit mechanical injury–. *J. JSAM*, **42**, 369–374 [In Japanese with English summary].
7. Jarimopas, B. et al. (2005) Measurement and analysis of truck transport vibration levels and damage to packaged tangerines during transit. *Packag. Technol. Sci.*, **18**, 179–188.
8. Ministry of Agriculture, Forestry and Fisheries (2008) Food balance sheet. http://www.maff.go.jp/j/zyukyu/fbs/index.html [In Japanese].
9. Nakamura, N. et al. (2007) Effects of vibration frequency and direction on damage of strawberries. *Nogyo shisetsu gakkaishi* (*J. Soc. Agric. Strutc., Jpn.*), **38**, 109–115 [In Japanese with English summary].
10. Peleg, K. & Hinga, S. (1986) Simulation of vibration damage in produce transportation. *Trans. ASAE*, **29**, 633–641.
11. Slaughter, D. C. et al. (1993) Assessment of vibration injury to Bartlett pears. *Trans. ASAE*, **36**(4), 1043–1047.
12. Slaughter, D. C. et al. (1995) Packaging Bartlett pears in

polyethylene film bags to reduce vibration in transit. *Trans. ASAE* , **41**, 107–114.

13. Turczyn, M. T. et al. (1986) Potato shatter bruising during laboratory handling and transport simulation. *Trans. ASAE*, **29**, 1171–1175.
14. Usuda, H. et al. (2006) Basic study on the vibration analysis for development of three dimensional transport simulation model for produce. *J. Soc. Agric. Struct., Jpn*, **36**, 215–222 [In Japanese with English summary].
15. Vergano, P. J. et al. (1991) Peach bruising: susceptibility to impact, vibration, and compression abuse. *Trans. ASAE*, **34**, 2110–2116.
16. Zhou, R. et al. (2007) Effect of transport vibration levels on mechanical damage and physiological responses of Huanghua pears (*Pyrus pyrifolia Nakai*, cv. Huanghua). *Postharvest Biol. Technol.*, **46**, 20–28.
17. Zhou, R. et al. (2008) Effects of cushioning materials on the firmness of Huanghua pears (*Pyrus pyrifolia Nakai* cv. Huanghua) during distribution and storage. *Packag. Technol. Sci.*, **21**, 1–11.