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Measurement and Analysis of Physical Environmental Load during Handling and Distribution of Domestic Fruits -Focused on Seongju Korean Melon

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Abstract The proportion of agricultural products handled through the Agricultural Products Processing Center (APC) is also steadily increasing every year, and in the case of Seongju Korean melon, a total of 10 APCs of Nonghyup and farming association corporations are in operation, and the distribution ratio is about 60% based on total production. In this study, Seongju Korean melon was selected as a target to analyze the environment load during carrying (production farm ~ APC) in the production area and the transport environment load during distribution of domestic fruits, and to analyze the environmental load for handling at APC. The vertical average vibration intensity (overall G_{rms} of 1~250 Hz) of truck transport measured at three transport routes from Seongju Korean melon producer ~ APC, Seongju ~ Seoul and Seongju ~ Jeju was about three times larger than that in the lateral direction and 4.5 times larger than that in the longitudinal direction, respectively. The frequency of occurrence of high-amplitude events (G) in the vertical direction compared to the measuring time was deeply related to pavement conditions in the order of unpaved farm-roads, concrete-paved farm-roads, and asphalt-paved main-roads, but overall G_{rms} for the entire frequency band is believed to have a greater impact on vehicle traveling speed than road conditions. On the other hand, the difference in the size and direction of the vibration intensity measured by the forklift truck's main-body and the attachment (fork carrier) during handling at Seongju Korean melon APC was clear, and the vibration intensity of the forklift truck's main-body was largely affected by the stiffness of the fork and the mast according to the handling weight. Based on the field-data of the transport environment during domestic distribution measured through this study, it is believed that it is possible to develop a lab-based simulation protocol for appropriate packaging design.

Keywords Korean melon, Transport environment load, Power Spectral Density, Appropriate packaging design, Vibration & Shock

Introduction

With the opening of the global distribution market and agricultural product market, Korea's distribution conditions are rapidly changing, and global consumers' purchasing patterns have also become more advanced and diversified, placing importance on the quality and safety of agricultural products. However, agricultural products are uneven, variable, and moreover, they are bulky compared to the price and their original characteristics continue to change during distribution, making it difficult to handle them in terms of logistics compared to general industrial products[1)].

In order for Korea's agricultural products to become stable farm income crops with overseas export strategies, it will be necessary to improve the distribution system and develop various processing technologies after harvest, but among them, the agricultural packaging field is an urgent task.

After harvesting, fruits and vegetables go through processing processes such as storage, screening, auction, and transportation until they are delivered to consumers, and physical damage may occur in the process. In particular, since various vibrations and shock phenomena that occur during transport cause the most damage in the resonance frequency band of the fruit or fruit package itself, measures should be taken to minimize product damage during transport. In general, damage caused

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by mechanical damage during the distribution of harvested agricultural products varies depending on crops, but cannot be overlooked, and it is most important to reduce the mechanical shock during post-harvest processing to reduce this loss[2]. Research on mechanical damage to agricultural products caused by vibrations during transport has been steadily conducted at home and abroad: tomatoes[3,4], potatoes[5,6], peaches[7,8], apples[9-13], pears[14-17], grapes[18], and orange[19].

In Korea, cargo trucks are mainly used for the transport of fruits, and environmental factors such as temperature and humidity and physical factors such as vibration and shock introduced by the interaction between cargo trucks and roads. Among these factors, the vibration and shock levels measured in transport trucks are directly related to fruit damage, and it is very important to identify the handling load in APC (Agricultural Products Processing Center) as well as the size and characteristics of the fruit's transport environment load in the production area and distribution to reduce fruit damage through appropriate packaging design.

Research has been steadily conducted at home and abroad to analyze the transport environment load through PSD (Power Spectral Density) analysis based on the vibration and shock measured by cargo trucks during transport according to the transport route and method of agricultural products[20-27]. These measurement data have been widely used to reduce economic losses by minimizing mechanical damage during transport and to develop appropriate packaging designs for agricultural products, but most of the test data are concentrated in the transport process of agricultural products in distribution, and data measured during carrying in the production area or handling at APC is very insufficient.

In this study, Seongju Korean melon was selected as the target to analyze the carrying environment load in the production area (producer ~ regional APC) of domestic fruits, the handling environment load at APC, and the transport environment load during distribution. Seongju Korean melon accounts for more than 80% of domestic Korean melon production, and the distribution ratio through local APC among the production is more than 60%[28]. Therefore, the specific purpose of this study is as follows.

1. to analyze the environmental load during carrying from Korean melon producer to regional APC
2. to analyze the environmental load during handling by forklift truck in APC
3. to analyze the transport environment load during distribution of Seongju Korean melon, and develop the PSD-based simulation protocol based on this field-data

Experimental Design and Methods

1. Experimental design

In the case of Seongju Korean melon, a one-ton truck is mainly applied to the carrying between producer ~ nearby APC. In order to measure the environmental load for this carrying process, the test course was set as shown in Table 1 through an on-site survey. The total distance of the test course was 41.7 km, and based on the distance, the asphalt-paved main-road accounted for about 66%, the concrete-paved farm-road accounded about 32.8%, and the unpaved farm-road accounted about 1.2%, and the average traveling speed on these three roads (Fig. 1) was 65 km/hr, 35 km/hr, and 25 km/hr, respectively. Two field recorders were used to measure the field-data, one for measuring the frequency-domain vibration, SAVER 3 × 90 (Lansmont Corporation, Monterey, CA, USA)[29] with a tri-axial piezoelectric accelerometer (200G), and the other for measuring time-domain vibrations, SLAM STICK (LOG-0002-100G-DC-2GB-AL, enDAQ, USA)[30]. These field recorders were firmly fixed to the central position behind the load platform of the truck (Hyundri PORTER II, 1-ton).

The Korean melons collected by APC go through the process of commercialization such as screening, cleaning, and packaging, and are sold to large retailers and wholesale markets through auctions there. Before shipping, melons packaged in APC are handled by forklift trucks, such as multi-stage stacking, carrying, and trucking. The electric forklift truck (TOYOTA 1.5 Geneo-B 10) in Fig. 2 was used to measure the environmental load for this handling process, and the field-data was measured at one location of the forklift truck's main-body and attachment, respectively. The main body's measuring position was the front axle (Sensor #1 in Fig. 2), and the attachment's measuring position was the fork carriage (Sensor #2 in Fig. 2) that moved along the mast with the fork mounted. The measuring time was about 1.5 hours, and the data recorders applied to the measurement were the same as when measuring the environmental load for carrying in the production area.

Two transport routes were selected to measure the transport environment load on the distribution of Seongju Korean melon. That is, as shown in Fig. 3, Seongju ~ Seoul and Seongju ~

Table 1. Details of the test course applied to measurement of environmental load for carrying Seongju Korean melon in the production area

Items	Asphalt-paved main-road	Concrete-paved farm-road	Unpaved farm-road
Traveling distance	27.5 km	13.7 km	0.5 km
Ave. traveling speed	65 km/hr	35 km/hr	25 km/hr
Traveling time	25.4 min	23.4 min	1.2 min
% (total 41.7 km)	66%	32.8%	1.2%

(a) Asphalt-paved main-road (b) Concrete-paved farm-road (c) Unpaved farm-road

Fig. 1. Types of roads included in the test course.

Fig. 2. Forklift truck applied to measure environmental loads for handling in APC, and the attachment position of the field recorders.

Fig. 3. GPS coordinates for the test routes (red line: Seongju ~ Seoul, yellow line: Seongju~Jeju).

Jeju, the longest transporting distance from Seongju to the north and the south, respectively, were set as test routes. Details of these test routes are shown in Table 2. Here, the field recorders applied to measure the field-data are the same as

Table 2. Details of the test route applied to measure transport environment load during distribution of Seongju Korean melon

Items	Seongju ~ Seoul	Seongju ~ Jeju
Traveling distance	- 277 km - Highway, 264 km (95.3%); national road, 13 km (4.7%)	- 428 km - Highway, 185 km (43.2%); national road, 40 km (9.4%); sea 203 km (47.4%)
Payload	- 20 ton (tare weight 10,700 kg included)	- 19 ton (tare weight 11,700 kg included)
Vehicle	- 4.5 ton wing-body truck, 3-axle - Daewoo NOVUS SE, 2016 model - Leaf-spring suspension	- 8.5 ton wing-body truck, 3-axle - Daewoo MAXEN, 2023 model - Leaf-spring suspension - 20,000-ton Ferry (Yeosu~Jeju)

Fig. 4. Truck applied to measure the transport environment load during distribution of Seongju Korean melon and the attachment position of the field recorders.

when measuring the environmental load for carrying in the production site. and these field recorders were firmly fixed to the central position behind the load platform of the truck (Table 2) as shown in Fig. 4.

2. Measuring method and parameters of field-data

The field recorders used to measure three environmental loads were SAVER 3 × 90 to measure frequency-domain vibration, and SLAM STICK to measure time-domain vibration. The measurement parameters of these field recorders are shown in Table 3. In addition, GPS (Gper, SPACOSA, Korea)[31] with an error range of 5~20 m was used to determine location information when measuring the transport environment load during distribution.

Table 3. Measurement parameters of the field recorders applied to measure the field-data

Saver	Slam Stick
Signal-triggered data -Signal-triggered threshold level, 0.5G -Sampling rate, 1000 Hz -Record time, 2 s Timing-triggered data -Sampling rate, 1000 Hz -Record time, 2 s	-Sampling rate, 512 Hz -Acceleration trigger, no -Triaxial accelerometer, 100G

3. Data acquisition and analysis

In order to reduce storage memory and battery consumption, SAVER's long-term field-data acquisition method calculates and records G_{rms} from acceleration (G) generated by sampling length when an event occurs at a certain time interval or above a certain level. In this study, events less than 0.02 G_{rms} were filtered to remove undesirable events from the analysis, such as non-vibration-related movements due to stop or very slow traveling speeds.

Time-domain vibration data (G_{rms}) recorded in SAVER is displayed as frequency-domain PSD based on FFT using Saver Xware Software (Lansmont Corporation, Monterey, CA, USA)). In this study, the frequency range of 1~250 Hz was indicated by the PSD level. The PSD profile is a graph of energy (vibration intensity) versus frequency, which is commonly used to measure and compare vibration levels. The square root of the integral of the PSD profile in the entire frequency band is overall G_{rms}, which represents the average vibration level of the entire spectrum and is also deeply related to vibration fatigue for long periods of vibration.

The PSD for a specific frequency bandwidth was calculated as follows[19,22-27].

$$PSD = \frac{1}{BW}\sum_{i=1}^{N}(rmsG_i^2)/N \tag{1}$$

$$\mathrm{rmsG} = \sqrt{\frac{1}{\mathrm{N}}\sum_{i=1}^{N}a_i^2} \tag{2}$$

where rms G_i (G_{rms}) is the sampled root-mean-square acceleration measured within a bandwidth of frequencies (BW), N is the total sample number of vibration signals for a given segment of vibration history, and a_i is the acceleration G measured directly by the accelerometer.

The corresponding PSDs are then plotted against the center frequency of the bandwidth to develop the power density spectrum for the data set. In this study, 1 Hz was selected for the bandwidth.

Results and Discussion

1. Environmental load for carrying Korean melon from the production area

Fig. 5 shows the time-domain vibration signal measured at the test course (Table 1) for carrying (producer ~ nearby APC) Seongju Korean melon in the production area. In addition, the PSD analysis results for the entire test section are shown in Fig. 6(a), and the PSD analysis results for each section by road type are shown in Fig. 6(b) to (d), respectively. In the entire test course (Table 1), the high-amplitude event occurred mainly in the vertical direction. In the PSD analysis results of the entire

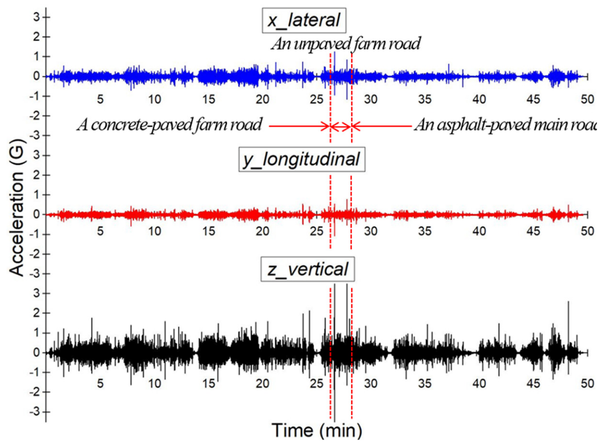


Fig. 5. Time-domain vibration signal generated when carrying Korean melon from the production area.

transport section, the PSD profile in the vertical direction was higher than the PSD profile in other directions [Fig. 6(a)], and the overall G_{rms}, which represents the average vibration level for the entire frequency band (1~250 Hz), was about 2.9 times larger than the left and right direction and about 5 times larger than the front and back, respectively. In particular, the difference in vibration levels between vertical and other directions in the frequency band of 20 Hz or less was more pronounced (Table 4).

As shown in Fig. 5, the frequency of high-amplitude events in the vertical direction compared to the measurement time was deeply related to the pavement conditions in the order of unpaved farm-road, concrete-paved farm-road, and asphalt-paved main-road, and the maximum vibration measured in the unpaved farm-road was about 3.5G in the vertical direction. However, the overall G_{rms}, the average vibration intensity for the entire frequency band, was the smallest in the asphalt-paved main-road, but there was no difference between the concrete-paved and the unpaved farm-road. It is judged that such a result is very closely related to the traveling speed of the vehicle. In other words, the worse the road condition, the lower the average traveling speed of the vehicle (Table 1), and the lower the speed of the vehicle is believed to have affected the average vibration intensity by compensating for vibration caused by the road condition.

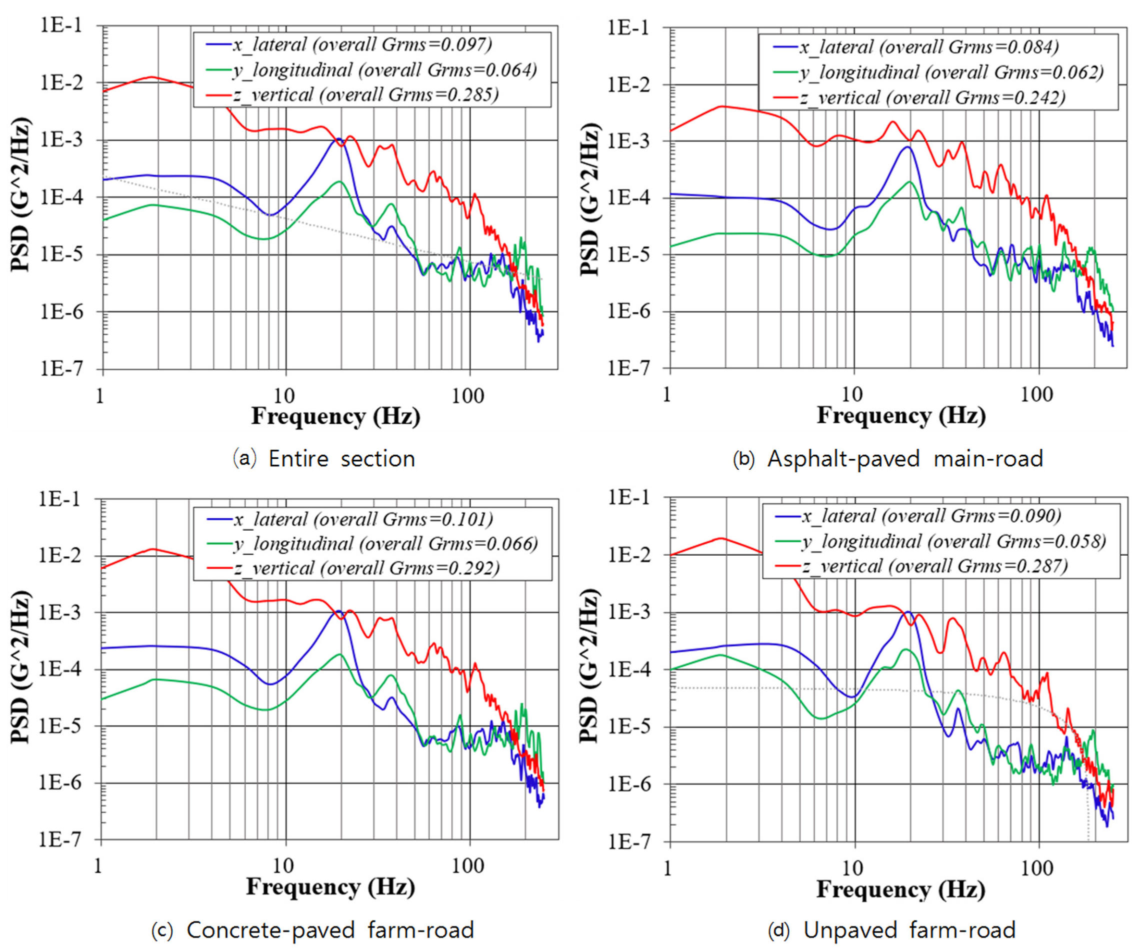
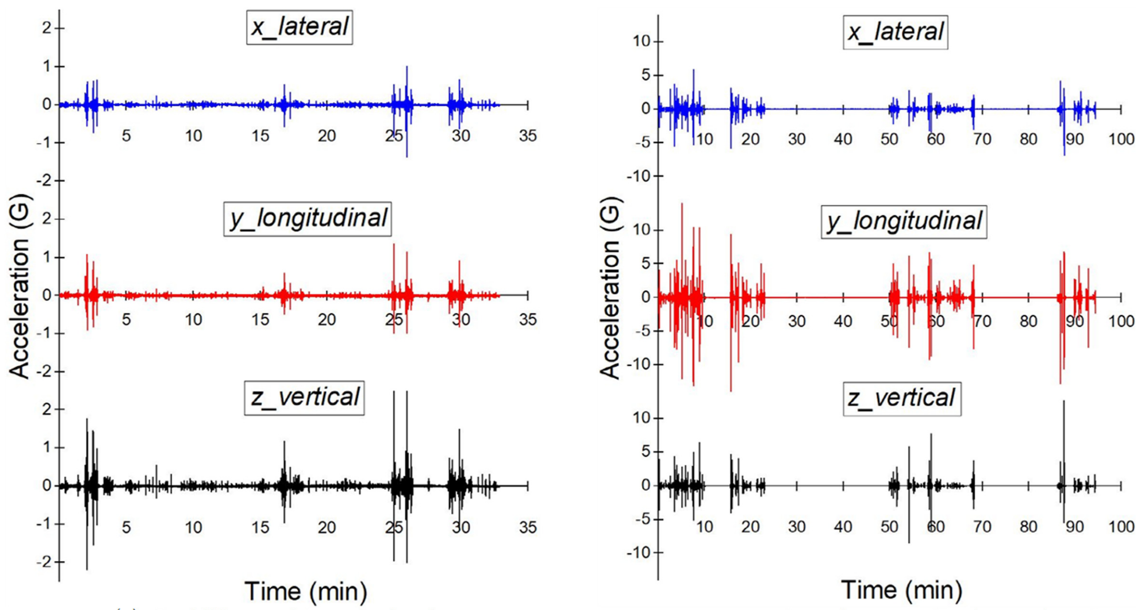


Fig. 6. PSD profile by road type when carrying Korean melon from the production area.

Table 4. Overall G_{rms} of the PSD profile by road type

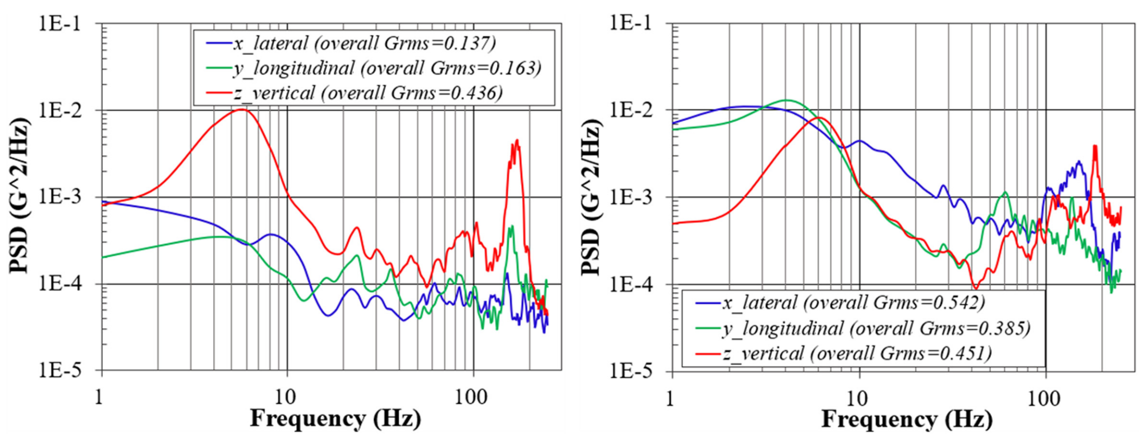
Transport stage	1~250 Hz			Under 20 Hz		
	x (G)	*y* (G)	*z* (G)	*x* (G)	*y* (G)	*z* (G)
The entire section	0.097	0.064	0.285	0.077	0.037	0.236
-Asphalt-paved main-road	0.084	0.062	0.242	0.063	0.033	0.176
-Concrete-paved farm-road	0.101	0.066	0.292	0.037	0.037	0.242
-Unpaved farm-road	0.090	0.059	0.287	0.074	0.042	0.254

Note: *x*_lateral, *y*_longitudinal, *z*_vertical



(a) Forklift truck' main-body (b) Attachment (Fork carriage)

Fig. 7. Time-domain vibration signal generated when handling in APC.



(a) Forklift truck's main-body (b) Attachment (Fork carriage)

Fig. 8. PSD profile when handling in APC.

2. Environmental load for handling in APC

Korean melons packaged in APC are handled by logistics devices (mainly forklift trucks) such as multi-stage stacking, carrying, sorting and trucking. In this process, the time-domain vibration signals measured by the forklift truck's main-body and the attachment (fork carriage) are shown in Fig. 7, respectively. In addition, the PSD analysis results based on the field-data measured at these two locations are shown in Fig. 8.

The frequency of occurrence of vertical high-amplitude events in the forklift truck's main-body was higher than that in other directions, and the maximum vibration size was about 3G in the vertical direction and about 1.2G in the other direction. However, the frequency of occurrence of high-amplitude events in the attachment was similarly high in the vertical direction and the longitudinal direction, and the maximum vibration size in this direction was found to be more than 10G.

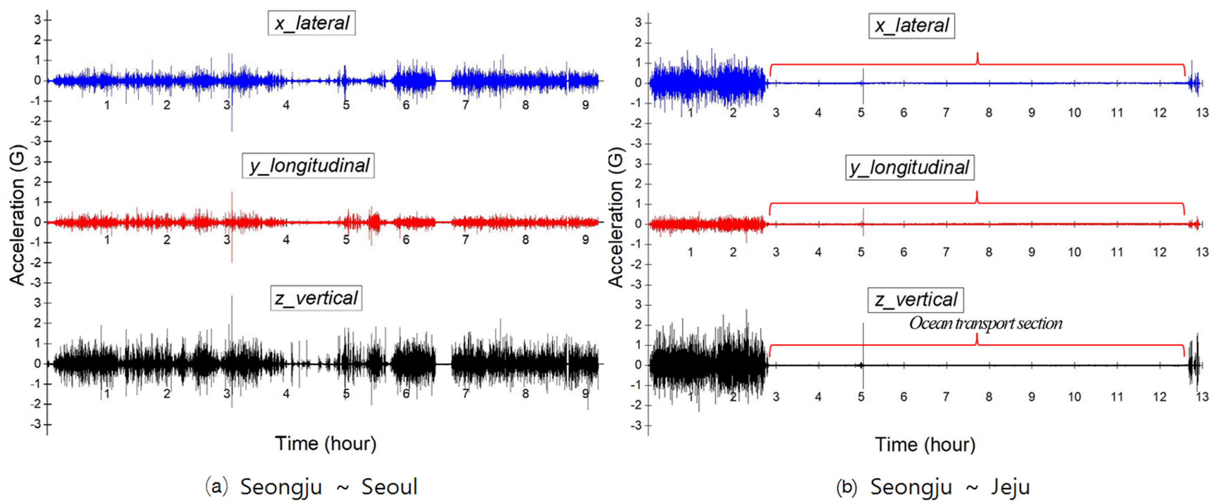


Fig. 9. Time-domain vibration signal for each transport route in distribution.

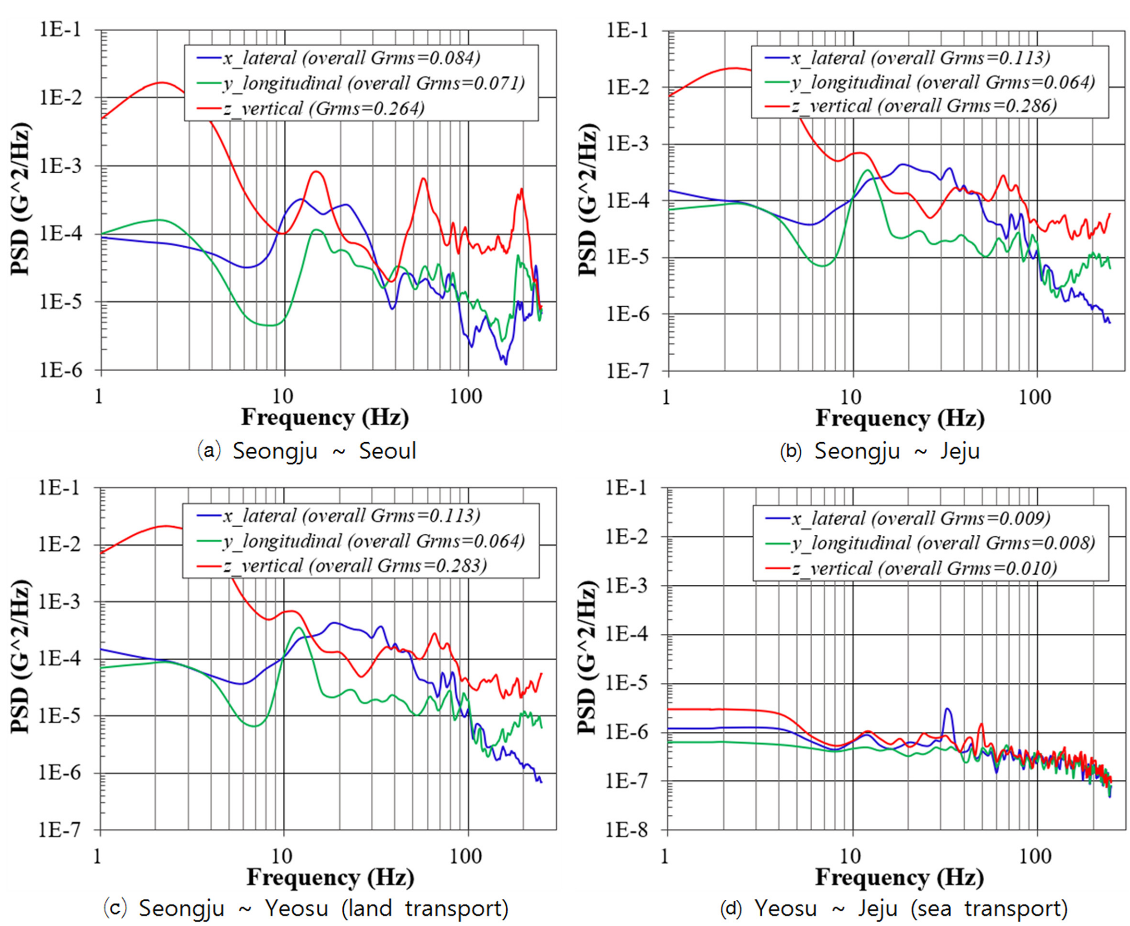


Fig. 10. PSD profile for each transport route in distribution.

Table 5. Overall G_{rms} of PSD profile for each transport route in distribution

Transport route	1~250 Hz			Under 10 Hz		
	x (G)	y (G)	z (G)	x (G)	y (G)	z (G)
Seongju ~ Seoul	0.084	0.071	0.264	0.025	0.020	0.194
Seongju ~ Jeju	0.064	0.113	0.286	0.021	0.026	0.251
-Seongju ~ Yeosu	0.064	0.113	0.283	0.020	0.025	0.249
-Yeosu ~ Jeju	0.008	0.009	0.010	-	-	-

Note: x_lateral, y_longitudinal, z_vertical

The overall G_{rms} for the entire frequency band (1~250 Hz) in the forklift truck's main-body was also about 2.7 to 3.2 times higher in the vertical direction than that in other directions, but the overall G_{rms} in an attachment was the largest in the lateral directions, followed by vertical and longitudinal directions. Therefore, the vibration intensity at the forklift truck's main-body was greatly affected by the road condition, but the vibration intensity at the attachment was found to be largely affected by the rigidity of the fork and mast according to the handling weight.

3. Transport environment load during distribution

Fig. 9 shows the time-domain vibration signal measured at each of the Seongju ~ Seoul and Seongju ~ Jeju routes, the longest distance in the direction of the south and the north, respectively, centering on Seongju among the distribution routes of Seongju Korean melon. In addition, the PSD analysis results are shown in Fig. 10, respectively, based on the field-data measured at these routes.

As shown in Fig. 9, based on the frequency of occurrence of the high-amplitude event, the vertical vibration was the largest, followed by the lateral direction and the longitudinal direction. The maximum vibration in the vertical direction was about 3G. According to the PSD analysis results of the entire transport section shown in Fig. 10(a) and (b), the overall G_{rms}, the average vibration intensity for the entire frequency band, was 2.5~3.1 times larger in the vertical direction than that in the lateral direction, and 3.7~4.5 times larger than that in the longitudinal direction, respectively. The difference in overall G_{rms} between these directions was more pronounced in the low-frequency band of 10 Hz or less (Table 5). These results were well consistent with the results measured by Park et al.[7)] on the transport route of Daegu ~ Sangju ~ Seongju ~ Jinju ~ Masan with a 5-ton truck of leaf-spring suspension. Having a high vibration energy level in the vertical direction at a frequency of 2~3 Hz is judged to be the response of the truck's leaf-spring suspension[23], and the results showing a high vibration energy level in the lateral directions in the 10~30 Hz frequency band were well consistent with the research results of Zhou and Wang[32].

According to the PSD analysis results [Fig. 10(c) and (d)] conducted by dividing the Seongju ~ Jeju route [Fig. 10(b)] into land and sea sections, the vibration level of sea transport was very low compared to land transport, and there was no clear difference between directions. However, this study is the result of measurement on the 20,000-ton ferry, and in general, container ships are known to show differences in vibration levels depending on where the container is located in the bow, stern, top or bottom[33)].

Conclusions

The first step in developing an appropriate packaging design for agricultural products is to develop a lab-based simulation protocol that can reproduce this transport environmental load in a lab after measuring the transport environment load on the distribution route and method of the agricultural products. In this study, Seongju Korean melon was selected as a target to analyze the environment load during carrying (producer ~ APC) in the production area and the transport environment load during distribution of domestic fruits, and to analyze the environmental load for handling at APC. The results of this study are summarized as follows.

1. The average vibration intensity (overall G_{rms} for 1~250 Hz) in the vertical direction of the 1-ton truck measured between Seongju Korean melon producer ~ nearby APC (asphalt-paved main-road 66%, concrete-paved farm-road 32.8%, unpaved farm-road 1.2%) was about 2.9 times larger than that in the lateral direction and 4.5 times larger than that in the longitudinal direction, respectively, and the difference was more pronounced in the frequency band of 20 Hz or less. In addition, the frequency of occurrence of high-amplitude events (G) in the vertical direction compared to the measuring time was deeply related to the pavement condition in the order of unpaved farm-roads, concrete-paved farm-roads, and asphalt-paved farm-load.

2. The frequency of occurrence of vertical high-amplitude events in the forklift truck's main-body during handling at the local APC of Seongju Korean melon was higher than that in other directions. However, in the attachment (fork carrier), the level was similar in the vertical direction and the longitudinal direction, and the maximum vibration magnitude generated was more than 10G. The vertical overall G_{rms} of forklift truck's main-body for the entire frequency band was also about

2.7~3.2 times higher than that in other directions. However, in the attachment, it is judged that the stiffness of the forklift truck's fork and mast is greatly affected by the handling weight in the order of lateral directions, vertical directions, and longitudinal directions.

3. The maximum vibration magnitude measured in the two transport routes of Seongju ~ Seoul and Seongju ~ Jeju was about 3G, which occurred in the vertical direction. In these transport routes, the average vibration intensity (overall G_{rms} for 1~250 Hz) in the vertical direction was about 2.5~3.1 times greater than that in the lateral direction and about 3.7~4.5 times greater than that in the the longitudinal direction, respectively, and the difference between directions was more pronounced in the low-frequency band of 10 Hz or less. In the land transport section by truck, the response of leaf-spring suspension in the frequency band of 2~3 Hz showed high vibration energy, and the lateral vibration energy in the frequency band of 10~30 Hz was large. On the other hand, the vibration level in the sea transport section by the ferry was significantly smaller than that of land transport, so it was negligible. Based on the field-data of the transport environment during domestic distribution of Seongju Korean melon measured through this study, it is believed that it is possible to develop a lab-based simulation protocol for appropriate packaging design.

4. The laboratory-based simulation protocol developed for the distribution environment of Seongju Korean melon in this study is considered to be applicable to the appropriate packaging design of major fruits such as apples, pears, and peaches because the two transport routes and applied vehicles set up for this study are not different from the general transport environment of domestic fruits.

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