KOREAN JOURNAL OF PACKAGING SCIENCE & TECHNOLOGY
Vol. 23, No. 2 97~101 (2017)
https://doi.org/10.20909/kopast.2017.23.2.97

Ethylene Production of Packaged Apples under Vibration Stress in Simulated Transportation Environment

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Abstract Fruits are subjected to a variety of vibration stress during the transportation from a production area to markets. Vibration inputs are transmitted from the transporting vehicle through the packaged fruit. And the steady state vibration input may cause serious internal damage of fruit. Product quality of fruits declines by various factors while they are stored right after harvesting and among the substance in charge of post ripening action, ethylene (C_2H_4) biosynthesis increases fruits' respiration process after harvesting and decreases storage expectancy. Ethylene production of apples rapidly increases while storage duration becomes longer. This tendency is much clearer for the apples with vibration stress at input acceleration level. When there was no vibration stress, change in ethylene production level of apples are not very large during storage. Ethylene production rates inside the gas collecting container increased significantly ($p \leq 0.05$) after 24 hours storage, particularly for apples with vibration stress (0.7 μl/kg·hr (1st stack), 0.78 μl/kg·hr (2nd stack), 0.96 μl/kg·hr (3rd stack)); whereas less ethylene was produced in control apples (0.18 μl/kg·hr) during storage. Also ethylene production rates of apples according to the stack position were significantly different ($p \leq 0.05$). The vibration stress clearly accelerated the degradation of apple quality during storage, resulting in increased ethylene production.

Keywords Ethylene, Vibration stress, Transportation, Packaging, Apple

Introduction

Distribution environment of Korea is taking a sudden turn because of the opening of distribution and agricultural market. Purchasing pattern of consumers became luxurious and diverse, so consumer demand for quality and safety of agricultural product is getting higher than before. Particularly, agricultural products are not uniform and they are interchangeable. They have large volume compared to the price, and original characteristics are continuously changing in the process of distribution. So it is difficult to handle agricultural products in logistics manner.

Unlike industrial products, packaging of agricultural product has special characteristics. First, functionality is the most important thing considered for agricultural products because they are still living organisms after the harvesting and packaging. In case of the industrial products like electronics, they have mutual relationship between product design and packaging design. But agricultural products should be properly packaged under the original condition. Therefore, packaging of agricultural products is very complicated, but it often has been treated easily because of the low value added. But as agricultural product market becomes one big world market, packaging of agricultural product becomes an important competing factor as well as the quality.

Product quality of fruits declines by various factors while they are stored right after harvesting, and sold to consumers after lots of steps including sorting, packaging, and processing. These factors are mold and other bacteria, rats and pests, inappropriate temperature and humidity, damages from poor handling and chemical process of fruits themselves. Particularly after the harvesting, post ripening process due to physiological process of fruits leads to mollification of products, resulting in weakened storage capability. Among the substance in charge of post ripening action, ethylene (C_2H_4) biosynthesis increases respiration process of fruits after harvesting and decreases storage expectancy (Jung and Choi, 1999).

Lots of researches in Korea have been done to find out factors affecting ethylene production during storing process by Lim et al. (2009), Park et al. (2009), Seo et al. (2005), and so on. However, there is no such research project about quality change by ethylene production occurred by vibration stress on the way of transportation. Also, preexisting research papers (Turczyn et al. (1986), Slaughter et al. (1993), Barchi et al.

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(2000), Berardinelli et al. (2005)) mostly deal with physical damage of fruits by vibration during distributional process, not the research about physiological quality.

Domestically, trucks are the most generally used transportation method for fruits. They are distributed under normal temperature, and these environmental conditions in the process of transportation process significantly affect the quality of fruits. If transporting fruits do not go over a severe environmental change, the major factor of damage during the transportation would be a vibration stress. While this mechanical stress goes up, physical damage like bruise or scratch is occurred. Fruits with vibration stress produce more ethylene, promoting aging process and decrease in quality (Barchi et al., 2000).

To measure the effect of vibration shock response on the internal change in quality by ethylene production of packaged apples under simulated transportation environment, vibration tests were performed in the lab.

Materials and Methods

Apples of the 'Fuji' cultivar were used in this experiment, and they were harvested in Guh-chang, Kyungnam, in October 2015. Then they were sorted and packaged in local packaging center and stored in low temperature of 5±1°C at relative humidity of 85±5% for two days until the experiment. Selected apples were similar in weight (0.34 ± 0.015 kg) and number in a cluster and were free of blemishes and other defects. Also, packaging box is double wall corrugated fiberboard with BE flute that is generally applied to small packaging of fruits in Korea. The box is mostly opened for upside, folded type of 0435 regulated by KS T 1006. Particularly, corrugating medium was hardened flute paper that attached two pieces of S^{120} kraft papers with 120 g/m^2 basis weight and 9.0 kg$_f$ ring crush, and the surface linerboard of outside is coated for all side to prevent water penetration. Fuji apples in 5-kg packages were used and there were 12 apples in each box in the experiment.

The experiment equipment was vibration tester (EDS 150, EDS, Austin, TX, USA) to generate vibration to packaged apples and gas chromatography (GC-14A, Shimadzu, Kyoto, Japan) to measure and analyze physiological characteristics of apples. Fig. 1 is an outline showing the overall constituent of vibration tester, and Fig. 2 shows vibration experiment.

Vibration test system is constituted with electronic shaker producing vibration, control device controlling vibration from shaker, amplifier amplifying control signal generating from control device to electronic shaker, accelerometer controlling shaker and measuring vibration characteristics. We measure and analyze ethylene production rate using gas chromatography (2 m active alumina SUS column, FID) to compare and examine physiological characteristics of apples exposed and non-exposed (control group) by vibration.

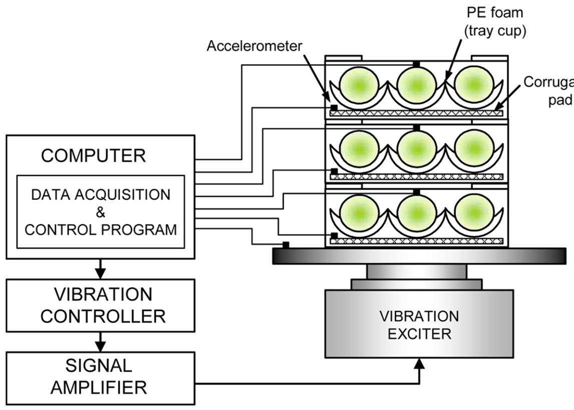

Fig. 1. Schematic diagram of the vibration test apparatus for packaged apples.

Fig. 2. Vibration test for the apples in the packaged freight.

Vibration experiment was used by random vibration according to PSD profile of highways that is domestic distributional route of measured fruits. The method of random vibration was set in special way so that initial input value could increase step by step from the value at least 6 dB lower than the whole level. The vibration of whole experiment was continued for 60 minutes considering measured transportation time. In the case of experiment of random vibration, the range of experiment frequency was 5~250 Hz, and amplitude of spectrum was set to 0.3669 G-rms same as the case of actually measured highway. Fig. 3 shows Kyung-bu highway PSD profile from Daejeon to Seoul in Korea measured by Kim et al. (2008) to simulate transportation environment.

Packaged apples are stacked in 3 tiers on vibration table like Fig. 3, and accelerometers were attached to the bottom of every box for each tier to measure vibration level by the num-

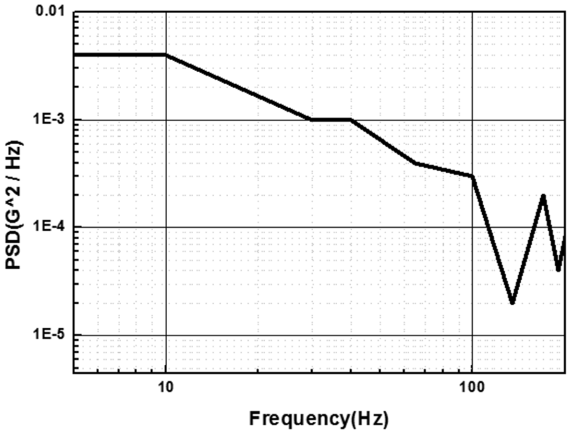

Fig. 3. PSD curve of the tested expressway from Deajeon to Seoul (Kim et al., 2008).

ber of stack tiers. All experiments were repeated three times with different samples. Also, we classified apples exposed and not exposed to vibration by the number of stack tier, and collected ten apples from each packaging box. Then we put two apples in the gas collecting jars and stored for 120 minutes in 20°C, relative humidity of 80±5% using chamber of constant temperature and humidity. Using 1-ml syringe, we collected 4 gases for each jar to measure ethylene production level by utilizing gas chromatography equipment as shown in Fig. 4. Three replications were used to determine ethylene productions. And these experiments were also done for the control group.

A completely random design was used with the four apple groups, and experimental data were analyzed using SPSS for Windows, Release 9.0.0 (SPSS Inc., Chicago, IL, USA). Analysis of variance was performed to compare changes in ethylene production among the four groups. Duncan's test was used to compare means and establish the significance of differences at the 5% significance level.

Results and Discussion

1. Vibration properties of the packaged apples

In case of applying random vibration by PSD profile of vibration signal measured from highway with stacking the packaging box for apples by 3 tiers, vibration response characteristics of packaged apples is shown on Fig. 5. Fig. 6 represent PSD response characteristics for each stack tier. Acceleration and PSD applied to packaged apples increase as number of stack tiers increases. When there are many tiers, physical damage of apples is estimated to be bigger in upper tier. According to the result of PSD response characteristics of domestic highway, rage of frequency of fruit transportation route was less than 30 Hz. Because resonance frequency occurs in frequency distributed range of transportation route, there is a bigger chance of damage by vibration during transportation (Kim et al., 2010).

Therefore, one way to prevent internal damage of fruits during transportation is shock absorbing packaging so that resonance frequency of apples in packaged freight does not occur in resonance frequency region of transportation route and fruits themselves.

2. Ethylene production of the packaged apples

As in Fig. 7, ethylene production rate of apples rapidly increases while storage duration becomes longer. This tendency is much clearer for the apples with vibration stress at more input acceleration level. When there was no vibration stress, change in ethylene production level of apples are not very large during storage, but bigger vibration acceleration results in rapidly increased ethylene production during storage.

Ethylene production rates inside the gas collecting container increased significantly ($p \leq 0.05$) after 24 hours storage, particularly for apples with vibration stress (0.7 μl/kg·hr (1st stack), 0.78 μl/kg·hr (2nd stack), 0.96 μl/kg·hr (3rd stack)); whereas less ethylene was produced in control apples (0.18 μl/

Fig. 4. Container (jar) for the ethylene gas collection of apples.

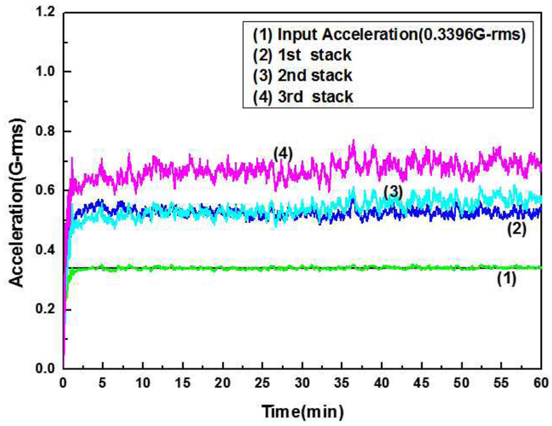

Fig. 5. Acceleration levels of the apple in packaged freight according to the number of stack by the random vibration test.

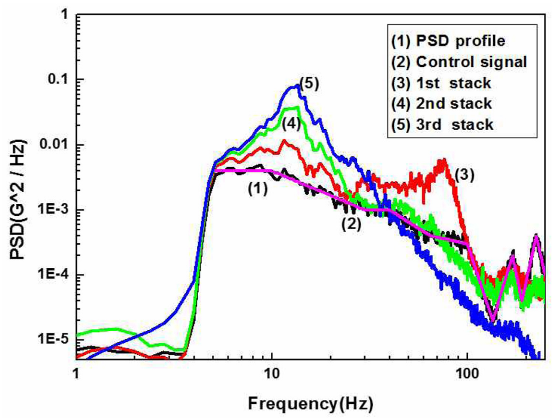

Fig. 6. PSD curves of the apple in packaged freight according to the number of stack by the random vibration test.

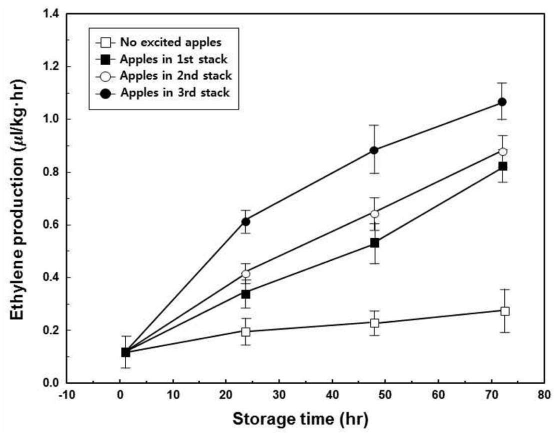

Fig. 7. Ethylene production of the apple by vibration stress according to the storage time.

kg·hr) during storage. Also ethylene production rates of apples according to the stack position were significantly different ($p \leq 0.05$). Ethylene production increased and accumulated inside the gas collection container throughout storage, Hence, ethylene production increased owing to continued ripening after harvest. Ethylene accelerates fruit ripening, and these results showed that vibration stress during transportation clearly accelerated the degradation of apple quality.

The result means that aging process of fruits transported on the severely uneven road (vibration with big input acceleration during transportation) is much faster than other fruits. When fruits are stacked and distributed, fruits on the upper tiers have bigger vibration stress, resulting in quicker internal quality change.

Conclusions

We performed the vibration experiment about packaged apples using PSD profiles of domestic highway to measure ethylene production from packaged apples in simulated transportation environment. Acceleration and PSD of packaged apples measured increase as number of stack tiers increases. When there are many tiers, physical damage of apples is estimated to be bigger in upper tier. When there was no vibration stress, change in ethylene production level of apples are not very large (0.18 μl/kg·hr) during storage, but bigger vibration acceleration results in rapidly increased ethylene production (0.7 μl/kg·hr (1st stack), 0.78 μl/kg·hr (2nd stack), 0.96 μl/kg·hr (3rd stack)) during storage. Aging process of fruits transported on the severely uneven is much faster than other fruits. When fruits are stacked and distributed, fruits on the upper tiers have bigger vibration stress, resulting in quicker internal quality change. Further studies are needed to develop proper packaging methods to minimize the degradation of fruit quality by vibration stress during transport.

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투고: 2016.12.30 / 심사완료: 2017.06.22 / 게재확정: 2017.07.24