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Quality Change of Packaged Pears for Export due to Vibration Stress during Transportation

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⟨Abstract⟩

The characteristics of vibrational stress (shock and vibration) during transport and the possibility of damage to the packaged pears were investigated. And this study was conducted to analyze how environmental conditions during transportation affect quality factors such as oxygen (O_2) and carbon dioxide (CO_2) concentrations, weight loss rate, ethylene production, soluble solids content (SSC), and firmness (bioyield strength) of packaged pears for exporting. Pears with or without vibration stress were stored for 30 days at low temperatures (5 ± 0.8℃, 80 ± 5% relative humidity). Statistically significant difference ($p \leq 0.05$) between pears with and without vibrational stress for oxygen concentration (O_2; 11.8 ± 1.5% and 16.1 ± 2.1%; initial 20.9 ± 1.4%), carbon dioxide (CO_2; 25.8 ± 3.2% and 19.1 ± 02.9%, initial 1.1 ± 0.2%) and ethylene (72.3 ± 5.2 μLL-1 and 65.1 ± 4.8 μLL-1, initial 18.3 ± 2.5 μLL-1) in the headspace of the gas collection container after 30 days storage. Significant differences also for pears with and without vibrational stress in relation to soluble solids content (16.2 ± 1.2% and 17.1 ± 1.4%, initial 13.8 ± 0.8% and 14.1 ± 0.9%, respectively), weight loss (6.4 ± 0.7 g day^{-1} and 5.0 ± 0.6 g day^{-1}), firmness (38.23 ± 7.2 kPa and 70.92 ± 13.2 kPa; initial 249.87 ± 14.8 kPa and 254.29 ± 10.7 kPa) after 30days storage. Vibration stress accelerated pear quality deterioration during storage, resulting in increased weight loss, soluble solids content, headspace CO_2 and ethylene production, and reduced hardness and headspace O_2.

Keywords : Shock and Vibration, Transportation, Quality change, Pear, packaging

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1. Introduction

When transporting products from one location to another, we use packaging materials and technologies to protect them from the various hazards present within the distribution environment. Some of those hazards are climatic (temperature, humidity, atmospheric pressure) and some are dynamic (shock, vibration, compressive forces). Shock and vibration dynamics possess energy that has the potential to cause both physical and cosmetic damage to packaged products.

Because agricultural products can be easily damaged, they require special packaging. Fruit quality declines during storage after harvesting, and to reach consumers, fruit products must go through numerous steps, including sorting, packaging, and processing. Damage of fruit could occur from mold and bacteria, rats, and other pests, inappropriate temperature and humidity, poor handling, and chemical processes within the fruit. Particularly after harvesting, the physiological post-ripening process leads to fruit softening, diminishing storage life [17]. Environmental conditions may cause the quality change of fruits during transportation after harvesting. To prevent the damage of quality change of fruits for distribution, the characteristics of fruits by the environmental conditions.

Pear, one of the representative summer fruits in Korea, has a 4.7% increase in consumption per capita each year, and its price is relatively stable compared to other fruits such as apples and peaches. However, the firmness of pear is not as great as that of apples and is very sensitive to the physical environments such as shock and vibration during transportation from the production area to the wholesale market [8].

Most of the previously published research papers are experimental studies on the factors that change the fruit quality of temperature and humidity. Fruits harvested in summer are sensitive to temperature changes and can slow the rate of quality change by controlling the temperature and humidity during storage. However, the physical environment that packaged fruit receives in the process of delivery to the wholesale market from the production regions to the consumer causes changes in the respiration characteristics of the fruit, and the quality changes more rapidly as the respiration rate increases. During transportation, the quality of fruits and vegetables can be degraded due to physical and biological damage caused by vibration. Damage to produce due to transport vibration has also been demonstrated for tomato [25, 32], potato [11, 36], peach [8, 37], apple [17, 18, 28, 34, 38], pear [5, 22, 29], loquat [4], and grape [19].

Ethylene can be produced during storage and transportation, and its presence can accelerate ripening and septicity, resulting in degrading fruit quality [6, 9, 12, 15, 18]. Ethylene production has been studied in atmospheric controlled apples [15], apples treated with hot water [30], apples, and peaches treated with 1-methylcyclopropene

[7], and grapes stored in refrigerated space under various relative humidity conditions [13]. To minimize the effects of ethylene, storage at low O_2 levels with moderate to high CO_2 levels generally extends the shelf life of freshly cut products [35]. Several different techniques are used, such as controlled atmosphere (CA) and modified atmosphere (MA) methods, to maintain the quality of the fruit. These techniques can be used to reduce the oxygen concentration and increase the carbon dioxide concentration during distribution to provide atmospheric conditions and to slow down the metabolic processes in fruits during storage [15]. Cold storage is also used to keep the fruits at low temperatures within the range that minimizes low-temperature damage [20]. The packaging is also very important for preserving the freshness of the fruit, and appropriate packaging can maintain fruit freshness during distribution at low or normal temperature until the product reaches the consumer [9]. However, optimal storage conditions depend on the metabolic properties of each product [20]. In South Korea, most of the pears harvested are transported and distributed by truck, which affects the quality and marketability of pears. Pear quality is highly affected by shock and vibration stress caused by the transportation environment. To better understand this issue, we measured the effects of shock and vibration on the internal quality of packaged pears for exporting in domestic transportation environments.

2. Materials and Methods

2.1 Fruit and corrugated fiberboard box materials

Pears of the *Niitaka* (Shingo) cultivar (harvested in Cheonan, South Korea in September 2020) were sorted and packaged at a local packaging center and then stored for 2 days at 3 ± 1℃ and 85 ± 5% relative humidity environment before the experiment. Selected pears were similar in weight (0.42 ± 0.015 kg) and number in clusters and were free of blemishes and other defects. The corrugated fiberboard boxes were a variation of the folder-type box (Code No. 0435) specified in KS T 1006 [23], and has a configuration with an open-top as shown in **Figure 1**. The boxes were made of double-wall corrugated fiberboard with single ridge B and E flutes in the arched fluting medium of corrugated rolls, commonly used in small unit packaging of fruits in South Korea. The corrugated medium board is reinforced by laminating two S^{120} kraft papers with a 120g/m^2 basis weight and 9.0 kg_f ring crush. The outside of the outer liner board is

(a) Folder-type open box (b) Tray cup pad (EPE)

Fig. 1 Folder-type open box and tray cup pad for packaging of pears

coated for waterproofing. The box cushioning materials was tray cup pad of polyethylene foam, as shown in **Figure 1**. *Niitaka* (Shingo) pears in 5 kg packages were used, and there were 12 pears in a box with a dimension of 470 mm x 315 mm x 110 mm in the experiment.

2.2 Transportation test

All transportation time was about 350 min, in accordance with the round-trip transportation time between the production regions (Cheonan) and the wholesale market (Garak Market in Seoul) in South Korea. Cheonan has the largest pear production regions in Korea, and Garak Market is Korea's largest wholesale market of agricultural and marine products. The shipping trucks with a leaf-spring suspension and 5-ton payload capacity were used in this study, which is commonly applied to transport palletized unit-loads in Korea. The route consisted of a mixture of 157.0 km of highway, and 80.6 km of national roads and all routes were asphalt-surfaced roads. The travel speed of the truck during the transportation test was 60~100 km/h on highways and 40~80 km/h on national roads. A data recorder (SAVER 3X90, Lansmont Corporation, Monterey, California, USA) with built-in triaxial acceleration sensors was used to record the shock and vibration signals in a traveling truck. The instrument was held securely by double-faced adhesive tape at the center position at the rear end of the load platform of the truck,

Fig. 2 Transportation truck of packaged pears and installation of data recorder

where the vibration level is relatively large [27, 33] as shown in **Figure 2**.

Before starting the measurement, the data recorder was configured with the following settings: an event trigger threshold of 0.5G, a sampling rate of 1,000Hz, a record time of 2s, and a signal pre-trigger of 50% for signal-triggered data, and a sampling rate of 1,000Hz and record time of 2s for timing-triggered data [26].

Corrugated fiberboard boxes for pears were stacked in 18 tiers on one pallet, and 8 boxes were stacked for each stage, as shown in **Figure 2**. In this experiment, they were then divided into 4 groups with imposed shock and vibration stress (1st group with 1~6 stages, 2nd group with 7~12 stages, and 3rd group with 13~18 stages) and 4th control group that was not subjected to shock and vibration stress. The control group pears were stored in an environment similar to temperature (23.2±2.1℃) and humidity (79.5±6.8%) during transportation.

2.3 Headspace gas analysis

After the transport test, 3 pears (913.1±

Fig. 3 Containers for the headspace gas collection of pears

95.3g) were placed in each gas collection container filled with air (20.9±1.4% O2, 1.1±0.2% CO_2) as shown in **Figure 3**, and 30 sample containers were made for each group. O_2 and CO_2 concentrations were measured using an O_2/CO_2 analyzer (MultiRAE IR, RAE systems Co., San Jose, CA, USA). The needle was plunged into the gas collection container, and the pump was electronically timed to retrieve the sample required for analysis. Three replicates were performed for each group of 5 container samples to determine the O_2 and CO_2 concentrations inside the container. Three collections (using a 1-ml syringe) were taken from each container to measure ethylene concentrations using a gas chromatograph (GC-14A, Shimadzu, Kyoto, Japan) equipped with an activated alumina column and a flame ionization detector. Five gas collection containers were randomly selected for each group for gas analysis every 6 days during the 30-day storage period.

2.4 Quality evaluations

Soluble solids content (SSC) was measured every 6 days using a portable digital refractometer (PAL-16S, ATAGO Co., Kobe, Japan). All pears were weighed and weight loss was measured every 6 days. In general, the price of agricultural products is determined by net weight, so the loss of weight during distribution leads to the economic loss of farmers. Therefore, the low temperature management of agricultural products is intended to prevent quality degradation and weight reduction of them **[16]**. Triplicate measurements were expressed as the percentage loss of weight of pear taken at the start of the experiment. Also, the weight-loss rates of pears were estimated using the equation (1) (ASHRAE Handbook-Fundamental **[3]**).

$$\dot{m} = k_t (P_{ss} - P_{va}) \quad (1)$$

where $\dot{m}$ is the weight loss rate of fruits (ng/kg・s), k_t is transpiration coefficient (ng/kg・s・Pa), P_{ss} is saturated vapor pressure (Pa), and P_{va} is vapor pressure (Pa).

To measure the firmness (bioyield strength) change of pear, a 5 mm/min loading rate **[2]** was applied to pears and a compression test performed with a cylindrical compression jig (10 mm diameter following ASABE S368.3 **[2]** using a universal compression machine (SY-005, Sunyoung Systec Co., Daejeon, Korea). Fruit firmness is closely related to storability. Compression tests were performed on two opposite surfaces for each sample [16]. Bioyield strength was measured every 6 days for changes in firmness. Three replications were used for each gas collection container to evaluate the quality of the 30-day storage period, and these experiments were performed for all groups.

2.5 Statistical analysis

All experimental data were analyzed using SPSS for Windows, Release 9.0.0 (SPSS Inc., Chicago, IL, USA). An analysis of variance was performed to compare the quality changes in all four groups. Tukey's test was used to compare the means and establish the significance of the differences at the 5% significance level.

3. Results and Discussion

3.1 Vibration stress

Figure 4 shows the vibration level measured on a truck transporting packaged pears from the production area to the wholesale market. The average vibration level measured in the transportation route was 0.224 G_{rms}, which is similar to the results presented in previous studies [14, 26] related to the vibration level

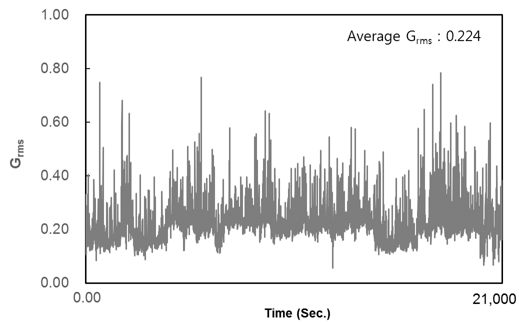

Fig. 4 Vibration stress (G_{rms}) generated by truck during transportation from the production area to the wholesale market

measurement of the transportation trucks. The packaged pears receive mainly vertical vibration impact of the average acceleration measured during transportation, which causes internal quality change and bruising in the pears.

3.2 Headspace gases

The headspace O_2 content decreased significantly ($p \leq 0.05$) over time up to day 30 in the control group (0.14% day^{-1}, up to 16.1%) and vibration stress group (0.29% day^{-1}, up to 11.8%) compared to the initial value (20.9±1.4%) without reaching the equilibrium concentration during storage (**Figure 6**). And there was no significant difference in headspace O_2 between groups 1, 2 and 3 at the loading stage of the packaged pears. Low O_2 and high CO_2 concentrations slow down respiration and delay ethylene production [21] and low O_2 promotes anaerobic metabolites [39]. Slow changes in the composition of the headspace O_2 can be caused by the low respiration rate

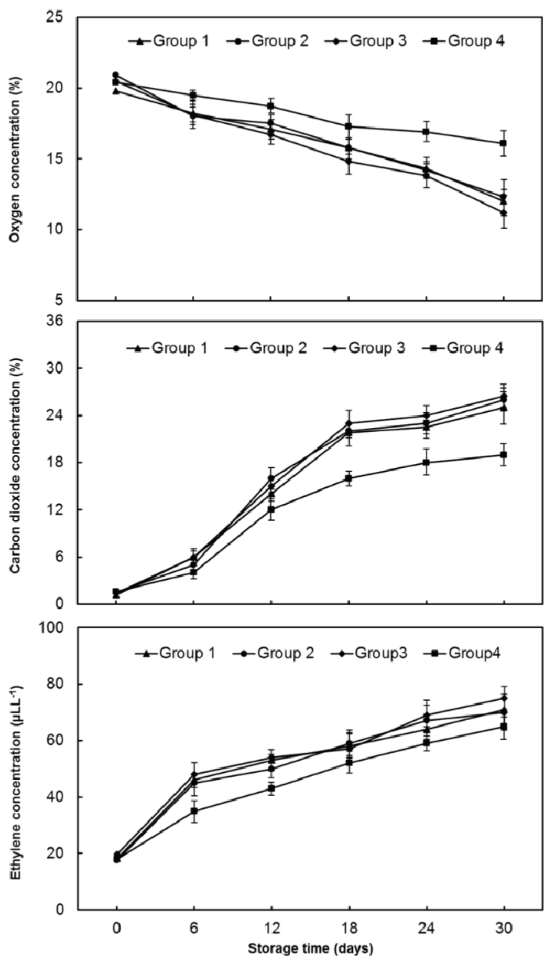

Fig. 5 Evolution of the headspace oxygen (O_2), carbon dioxide (CO_2) and ethylene concentration in four group pears stored at 5°C: Control pears (Group 4) not received vibration stress and vibrated pears (Group 1, 2 and 3) received vibration stress under transportation environment. The values are mean of five determinations ± standard deviation

of pears at low storage temperatures (5℃).

In contrast, CO_2 levels increased significantly during storage ($p \leq 0.05$) in the control group (0.58% day^{-1}, up to 19.1%) and vibration stress group (0.82% day^{-1}, up to 25.8%) compared to the initial value (1.1±0.2%) (**Figure 5**). These results suggest that the two gases may be inversely correlated during storage. And there was no significant difference in headspace O_2 between groups 1, 2 and 3 at the loading stage of the packaged pears.

The concentrations of ethylene inside the gas collecting container increased significantly ($p \leq 0.05$) 6 days before storage, especially for pears with vibrational stress. On the other hand, less ethylene was produced in the control pears during storage (**Figure 5**). Ethylene concentrations were significantly different ($p \leq 0.05$) between the control group (1.57 μLL^{-1} day^{-1}, max. 65.1 μLL^{-1}) and the vibration stress group (1.78 μLL^{-1} day^{-1}, max. 72.3 μLL^{-1}) without reaching equilibrium concentrations throughout storage. And there was no significant difference depending on the stack location. Thus, ethylene production increased and accumulated inside the gas collection container throughout storage, but it did not exceed 75 μLL^{-1} during storage. Hence, ethylene production increased owing to continued ripening after harvest. Ethylene promotes fruit ripening, and these results show that vibrational stress during transport accelerates the degradation of pears.

3.3 Changes in quality parameters

3.3.1 Soluble solids content (SSC)

SSC of pears with or without vibration stress increased 2.9% and 2.3%, respectively, by 30 days, increasing significantly with storage time in all samples (**Figure 6**). SSC increases during storage owing to amylase-mediated conversion of starch to sugar [1]. SSC increased more rapidly in pears with vibration stress compared to control pears, suggesting a more rapid ripening of stressed pears under these conditions. Generally, High temperature causes a rapid change in SSC, presumably because of higher enzyme activity and more rapid conversion of starch to sugar. A slow SSC change indicates an extension of shelf life [10]. Currently, the grade of fruits is determined by their SSC, exterior shape, damage status, and size in Korea, and SSC quality is the most important thing for ordinary consumers to consider when purchasing fruits. Therefore, farmers are spending a lot of money on buying equipment for quality measurement of the SSC [18].

3.3.2 Firmness

The force-deformation curve of pears measured by compression tests, with the bio-yield strength (the value of dividing the bioyield point (N) derived from the force-deformation curve by the area of contact with a cylindrical compression jig) indicating a firmness factor. As expected, the firmness of pears in the four groups decreased significantly ($p \le 0.05$) during storage, with 6.94 kPa day^{-1} (vibration stress) or 6.16 kPa day^{-1} (control) firmness loss after 30 days (**Figure 6**). In general, the soft texture of fruit and vegetables is a consequence of many factors such as the loss in cell turgor pressure and vascular air and the degradation of cell wall constituents and polysaccharides [24]. Texture degradation has been closely correlated to ripening. During ripening, there is rapid enzyme synthesis and subsequent SSC release, which would explain the greater softening in ripe fruit. Firmness varies for different ripening conditions in fresh-cut pears [31]. There were no significant differences between the two pear groups in fruit firmness after the initial 6

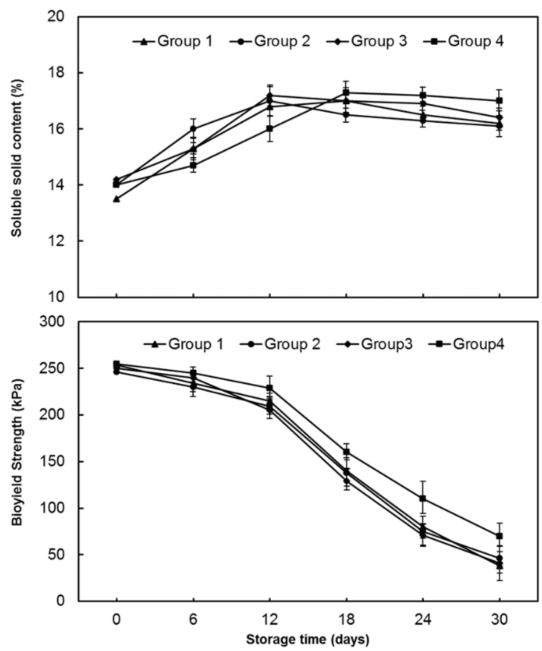

Fig. 6 Soluble solids content (%) and Bio-yield strength (kPa) of firmness factor in four group pears stored at 5°C: Control pears (Group 4) not received vibration stress and vibrated pears (Group 1, 2 and 3) received vibration stress under transportation environment. The values are mean of five determinations ± standard deviation

days of storage, but there were significant differences (p≤0.05) after 12 days. These results indicate that no vibration stress could significantly delay ripening, reduce weight loss, and retain firmness of fresh pears during storage and transport, thus effectively extending shelf life. Also, the bioyield strength (firmness, hardness) of the fruits is deeply related to storage. The larger the bioyield strength, the longer the period of storage is available in same storage conditions, and the less damage is caused by shock and vibration in transit **[19]**.

3.3.3 Weight loss

Generally, weight loss during storage was expected owing to fruit transpiration. Low-temperature storage at 5℃ reduced weight loss of pears compared to room temperature storage. Weight loss during the 30 days differed significantly ($p \leq 0.05$) between the vibration stress (5.95 g day^{-1}) and control (4.21 g day^{-1}) groups (**Figure 7**). And there was no significant difference by stack position. These results suggest that pears stressed by external vibration may have higher respiration and, therefore may experience more weight loss during storage. Also, the weight loss rate was 0.192 g/kg・hr following Equation (1). The transpiration coefficient of the pears was 572 ng/kg・s・Pa (ASHRAE Handbook-Fundamental **[3]**), and the saturated vapor pressure of 1.705 kPa and vapor pressure of 1,370 kPa at 15℃ and RH 80% were estimated under a standard atmospheric pressure of 101325 Pa by using a Psychrometric chart. The weight loss rate of pears during storage for 30 days was largely compared to the weight loss rate calculated by the model formula.

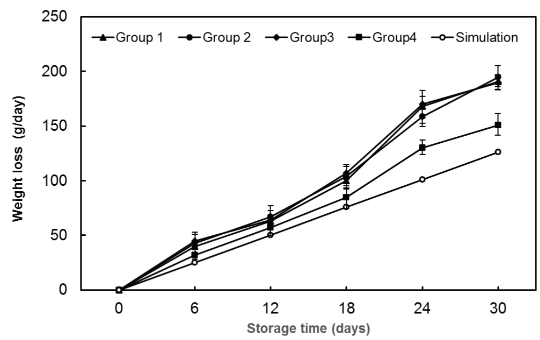

Fig. 7 Weight loss (g/day) in four group pears stored at 5°C: Control pears (Group 1) not received vibration stress and vibrated pears (Group 1, 2 and 3) received vibration stress under transportation environment and weight loss by simulation was calculated using equation (1). The values are mean of five determinations ± standard deviation

4. Conclusions

In this study, the effect of vibration stress on the quality of packaged pears during transportation from the production area to the wholesale market was investigated. There were no significant differences between groups according to the stack tiers. Also, the significant differences were also measured for pears with and without vibration stress for soluble solids content, weight loss, and firmness after 30 days of storage. Vibration stress during transportation accelerated the degradation of pear, resulting in increased weight loss, SSC, headspace CO_2, and ethylene production, and decreased firmness and headspace O_2. The marketability of fruits is highly related to freshness and there were many studies on methods to slow down the quality change of fruits during storage, and through this study, internal and external damages of fruits were caused by shock and vibration during transportation and it could be seen that transportation conditions of fruits are also an important factor in quality change. Until now, the cushioning packaging of fruits has been aimed at minimizing the impact force of the packaged fruits during transportation. It is necessary to minimize the vibrational stress that fruits receive during transportation. And further studies are needed to develop proper cushion packaging methods to minimize the degradation of fruit quality by vibration stress during transportation.

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