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Effect of vibration stress on quality of packaged grapes during transportation

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ABSTRACT

This study was conducted to determine vibration characteristics of packaged grapes during truck transportation and mechanical injury by such vibration stress. Vibration impact generated during a major freight distribution route of packaged grapes in Korea was measured in terms of the power spectral density (PSD). By using the PSD profile measured at the rear side of truck, a simulated transportation experiment was carried out to investigate how vibration stress influenced quality deterioration in grapes. The quality degradation of grapes under vibration stress and grapes without vibration stress was determined by measuring quality index indicators such as weight loss, soluble solids content (SSC), and ethylene production. Both grape groups were stored at refrigeration condition (1–2 °C, 65–75% RH) for 30 consecutive days. As compared to the control grape group, the decrement of weight loss and SSC in grape group suffered from vibration was 6% and 1.3° Brix, respectively; while ethylene production was increased by 7 nL/g.hr. The results clearly showed that vibration stress could result in the degradation and rapid ripening of packaged grapes.

1. Introduction

Change in distribution environment has been occurred in Korea due to the openness of distribution channels and agricultural markets. The pattern of consumer purchases has become diversification and consumers' requirements for the quality and safety of agricultural products are higher than ever. In general, agricultural commodities are more difficult to properly manage than industrial commodities in terms of logistics because agricultural commodities are highly sensitive to vibration stress during transportation. The other factors that affect the quality of agricultural commodities during transportation can be transportation route, transportation vehicle, driver, temperature, and humidity.

The quality of fruits and vegetables can be degraded by physical and biological damage from vibration stress during transportation. The power spectral density (PSD) was frequently employed to measure and analyze vibration impact during truck (or trailer) transportation of agricultural products. PSD can be defined as the density of gravitational acceleration (G) generated at various frequency ranges. A typical PSD function (G^2/Hz) also describes the strength of the vibration energy depending upon a function of the frequency (Singh et al., 2007). PSD can be often approximated with a simple function, using only a few parameters and PSD approximation can be employed for a concise account for road roughness level and vehicle dynamics (Andren, 2005). In addition, PSD approximation can be varied depending upon load roughness parameter and the wavelength of frequency generated by vibration. By using PSD profile measured on the floor of truck during transportation of agricultural products, it is technically feasible to determine the frequency range of dominant vibration impact. PSD profile could be employed to simulate transportation vibration environment of agricultural products in laboratory scale. Simulated vibration experiments were conducted to evaluate the effect of stress caused by vibration impact during transportation on the change in respiration and quality of packaged agricultural products. A number of researchers investigated damage caused by transportation vibration to fruits and vegetables with laboratory scale shaker (Vergano et al., 1991; Singh and Singh, 1992; Slaughter et al., 1993; Vursavuş and Özgüven, 2004; Berardinelli et al., 2005).

Grape is the common name of the genus *Vitis* in the plant family *Vitaceae*. *Vitis* species are woody climbing vines that produce clusters of berries. There are about 60 *Vitis* species found mostly in temperate regions in the northern hemisphere. Grapes species and cultivars can be classified into four main groups as food usage: table grapes, wine grapes, sweet juice grapes, and raisin grapes. Harvest time of table grape is mostly determined by color and size of berries. Individual clusters are judged for maturity by pickers, and clipped from vines with minimal handling. Packaging and shipping are immediately done after harvest or a short period of cold storage.

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Table grape is a nonclimacteric fruit and can be easily damaged in postharvest handling, storage, and marketing (Valero et al., 2006). In order to maintain postharvest quality of table grape, Crisosto et al. (1994, 2001) studied water loss and stem browning of table grape during harvest operations and postharvest handling. Lichter et al. (2002) examined the effect of applying a postharvest ethanol dip on the decay of table grapes. Since table grape is mostly consumed in fresh state, it is essential to retain postharvest quality during transportation. Ethylene (C_2H_4), which is plant hormone, has an impact on nearly every development stage in plant growth and is intimately related with the ripening of fruits which significantly affects the quality of fruits (Arshad and Frankenberger, 2002). Ethylene can accelerate ripening and septicity of fruits and vegetables, and can be produced during storage and transportation, consequently degrading quality of fruits and vegetables. Therefore, ethylene production of grapes during postharvest handling should be monitored and controlled for expanding their shelf life.

The majority of studies about damage by vibration stress to in-transit fruit have focused on mechanical injuries such as bruising, skin discoloration, firmness, and weight loss by shattering. To our best knowledge, the effect of vibration stress on inner quality degradation (such as ethylene production and decrease in soluble solids content) of fruits was not clearly investigated during the cold storage of transported fruits. When mechanical stress on the grape increases during transportation, the more scratches on grape skin can be caused. This can lead to provoke the production of ethylene, finally resulting in acceleration of aging and quality degradation.

In Korea, the harvested grapes are generally transported and distributed by truck under atmospheric temperature, which heavily influences on the quality and marketability of grapes. If other external variables are not put into consideration, the main factor causing the degradation of grape quality would be impact force caused by vibration. Therefore, weight loss, soluble solids content (SSC), and ethylene production of packaged grape were considered as quality index indicators in this study. This study was aimed to measure the vibration level (PSD) of domestic transportation routes of grape and to evaluate the effect of vibration stress on quality of packaged grapes using the simulated transportation environment.

2. Materials and methods

2.1. Sample and corrugated fiberboard box preparation

Campbell Early, Kyoho, and Muscat Bailey A (MBA) grapes, which were grown and harvested on Yeongcheon in North Gyeongsang province, Korea, were used for this study. Grape samples were collected and packaged in the local packaging center right after harvest. A special attention has been paid in selecting samples so that the grape clusters were of uniform weight and berry numbers as much as possible. Campbell Early and Kyoho grapes were employed for measurement of truck transportation vibration and MBA grapes were used for simulation of transportation vibration under an electro-magnetic shaker.

The corrugated fiberboard boxes used in this study were the modified folder-type boxes (Code No. 0435) regulated by KS A 1003, which had open-top configuration. KS A 1003 is a type of packaging box regulated by Korea industrial standard (KS) and the dimension of this box can be adjusted depending on load capacity (Fig. 1). The boxes were made of double-wall corrugated fiberboards with combination of B and E flutes, typically used for packaging fruits in small units in Korea. Flute is a single ridge in the arched layered fluting medium on the corrugated roll. The fluting medium was reinforced by a lamination of two S^{120} kraft papers with basis weight of 120 g/m^2. The exterior of the outside liner board was coated for waterproofing and the coating material was sodium-alginate (Na-alginate) film.

2.2. Measurement of PSD profile

Grape transportation route for measuring the PSD profile was 311.9 km long from Yeongcheon (the largest grape producing area) to Garak Market in Seoul (the biggest wholesale market of agricultural and marine products), which is a major freight distribution route of packaged grapes in Korea. This route consists of short local and national roads and long highway.

Campbell Early and Kyoho grapes were packaged in corrugated fiberboard boxes for maximum load of 5 kg and 2 kg, respectively. Total 1500 boxes (1000 of 5 kg box and 500 of 2 kg box) were loaded on the truck. Grape boxes of total 6 tons were loaded onto a 4.5 ton truck with air cushion suspensions and were basically stacked in 20 rows on the floor of the truck. The truck was structurally modified to allow 7.5 ton capacity at maximum. The grape freight was covered with a canvas shelter over the top and then tightly fixed by ropes not to wobble.

Fig. 2 shows the schematic diagram of data acquisition system to record vibration impact affecting in-transit grape freight during truck transportation. In order to measure real-time vibration of grape freight, four accelerometers (8774A50, Kistler, NY, USA) were installed at different locations on the floor of truck (front, middle, and rear). All data points of vibration signal were collected and recorded by a data acquisition unit (SoMat eDAQ, SoMat, Urbana, IL, USA). Experiments to measure characteristics of the vibration for truck transportation were performed in duplicate.

2.3. Simulation of transportation vibration

The packaged MBA grapes in the corrugated fiberboard boxes for each 5 kg were stored at 5 ± 1 °C and 85 ± 5% RH condition for 2 days in the facility where temperature and humidity were controlled. The grapes were then divided into two groups: one group afflicted with vibration stress (vibrated group) and the control group without vibration. Prior to the vibration experiment, 5 grape boxes were kept at room temperature for 1 h in order to the grapes to the experimental condition.

As shown in Fig. 3, a vibrating system (EDS 150, EDS, Austin, TX, USA) for simulation of transportation vibration of packaged MBA grapes were composed of an electro-magnetic shaker for generating vibration based on measured PSD profile, a controller for adjusting the vibration of the shaker, an amplifier for the output signal from the controller, and an accelerometer installed on the plate of the shaker to measure vibration characteristic exerting on packaged MBA grapes. A column of 5 MBA grape boxes was stacked on the plate of the shaker and fixed by transparent tape to prevent motion of the boxes during vibration experiment.

The simulation of transportation vibration were carried out based on random input in accordance with measured PSD profiles during truck transportation of packaged Campbell Early and Kyoho grapes from Yeongcheon to Garak Market. Although transportation environment factors such as temperature and humidity have influence on quality of agricultural products, the effect of vibration stress on quality of the packaged grapes was only considered and estimated in this simulation.

The condition of random vibration was set starting from at least 6 dB lower than the overall level and then gradually increasing by levels. The vibration experiment was lasted for 342 min corresponding to the actual transportation time of the packaged Campbell Early and Kyoho grapes from Yeongcheon to Garak Market. The range of the applied frequencies for vibration experiment was between 1 Hz and 200 Hz. Vibration experiments were conducted in triplicate.

2.4. Ethylene production and soluble solids content (SSC) measurement

After each vibration experiment, a bunch of MBA grape samples was randomly picked up from each of the 5 vibrated boxes (vibrated group)