衝撃によるブドウの脱粒を防止するための包装方法の提案

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Proposal for an Efficient Packaging System for Preventing Shock-Induced Berry Drop in Grapes during Transportation and Handling

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In order to develop a packaging system for grape berries that would prevent them from falling owing to shocks caused during transportation and handling, we investigated the effects of the direction of the shock on the occurrence of berry drop. To verify this, we conducted a drop test by using a conventional corrugated fiberboard box employed for transporting grapes in Japan. The results of the drop test suggested that attenuation of the shock from the bottom of the box was necessary to prevent the grape berries from dropping. Our results also suggested that in order to reduce the occurrence of berry drop further, free spaces inside the box needed to be reduced. Based on these findings, we designed a packaging system that not only attenuates the shock from the bottom of the box, but also adapts to the different shapes of individual grapes. This was achieved by stacking several sheets of the cushioning material inside the corrugated fiberboard box. The results of the drop test obtained using the above-mentioned packaging system confirmed that this setup was effective in preventing the shock-induced dropping of grape berries. The study also revealed that it was indeed effective to attenuate the impact caused by the shocks, especially those emanating from the bottom and the side walls of the box during transportation and handling.

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Key words : *cushion packaging, drop test, shock direction, transportation*
緩衝包装，落下試験，衝撃方向，輸送

Grape berries sometimes drop off from the pedicel after the harvest. This phenomenon is called "berry drop". Berry drop causes a reduction in the commercial value of the grapes, which is why it is important to prevent it. Several studies have established physiological[1] and microbiological[2] factors responsible for berry drop in grapes after the harvest. Other studies have concluded that vibration is an important physical factor contributing to berry drop[3),4)].

Previously, we analyzed the effect of shock on soft fruits such as cherries[5)], strawberries[6)] and tree-ripened mangoes[7)] during transportation, and concluded that shock is a contributing factor towards fruit damage. Thus, in case of grapes too, it was suggested that shock may be an important factor causing berry drop during transportation and handling. However, till date very few studies have investigated the correlation between the impact of shock and the subsequent occurrence of berry drop.

Earlier studies attempting to analyze the impact of shock occurring during handling and transportation of packaged products showed that shock can not only be experienced in the vertical but also in the horizontal direction.[8),9)] By means of drop tests for packaged grapes, we investigated the effect of shock direction on berry drop.

Finally, we developed a packaging method to protect the grape bunches from suffering berry drop caused by shock. Takano *et al.*[4)] suggested that the rate of berry drop in grapes due to vibrations reduced, when the free space inside the packaging box was also reduced maximally. Therefore, we examined a cushioned layout that

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adapted itself according to the size and shape of the grape bunches.

Materials and Methods

1. Grape cultivar used for the drop test

All experiments were carried out with the grape cultivar 'Shine Muscat' (*Vitis labruscana* Bailey × *Vitis vinifera* L.). This cultivar has a strong flavor, large berry size, crisp flesh texture, high soluble solid content, low acidity, and berries with edible skin[10]. Owing to these factors, 'Shine Muscat' is getting increasingly popular in Japan as well as its neighboring regions. The grape clusters were harvested in the orchard of the Horticultural Experiment Station of Yamagata Integrated Agricultural Research Center (Sagae, Yamagata, Japan) on 9th October 2015. The number of berries per bunch and the average weight were calculated to be 43.9 ± 7.0 and 646.9 ± 88.0 g respectively.

The grapes were wrapped in paper bags, and placed in a chamber maintained at 0.5℃ temperature and 90% relative humidity for 12−53 days. After the completion of the storage period, they were enveloped in a 4-㎜ thick polyethylene (PE) foam net and transported from the above mentioned facility to the Food Research Institute, NARO (Tsukuba, Ibaraki, Japan) in a corrugated fiberboard box, containing a sheet of PE foam net (thickness, 5 ㎜) on the base of the box. The grapes were transferred to a chamber maintained at 10℃ temperature and 90% relative humidity for one day. Thereafter, the grapes were selected on the basis of uniformity in size, color, and absence of defects or mechanical damage. These were then subjected to the drop tests as detailed below.

2. Conditions for packaging and drop test

A sheet of foam net which was made from the same material as described above in sub-section 1 was laid inside a corrugated fiberboard box. The interior dimensions of the box were ~210 × 310 × 115 ㎜. Each bunch of grape was put in a paper bag and enveloped in the same foam net as described above in sub-section 1. Two such bunches were placed in the box (Fig. 1A). The empty spaces inside the box were filled with foam nets. The same foam net sheet that was used for lining the bottom, was also used to fill the free space at the top of the box. The opening of the box was then covered with corrugated fiberboard material same as that of the box itself. The total weight of

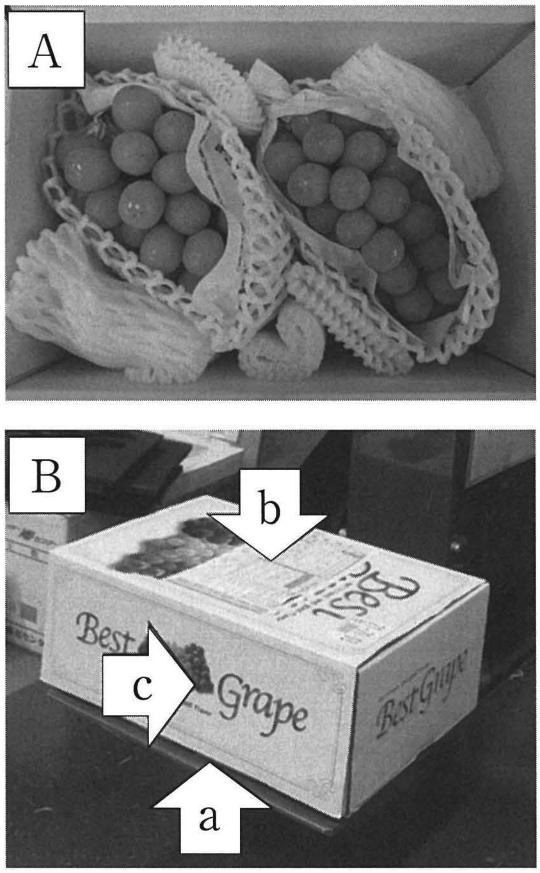

Fig. 1 Figure showing (A) Inner and (B) Outer view of the packaging system used for the drop test

Where the direction of delivering the shock is represented along the (a) bottom, (b) top, and (c) side walls of the box.

the box including the two grape bunches and the cushioning material was approximately 1.5 kg. This type of packaging represents the conventional system for transporting grapes in Japan. This was therefore, used as the control setup.

The box which contained two bunches of grapes was dropped once, perpendicularly on the dropping surface by a drop tester (DTS-50, Shinyei Testing Machinery Co. Ltd., Tsukuba, Japan). The drop height was set to 0.6 m according to JIS Z 0200[11], which is the Japanese test standard for freight packaging. The shock incurred due to the drop was delivered to the bottom, top, and side walls of the box (Fig. 1B). For assessing the shock incurred along the top and side walls, the box was placed upside down or sideways respectively, on a shock testing table. Tests were carried out in 3−4 replicates per drop condition.

3. Measurement of shock acceleration

A three-dimensional accelerometer (2366W, Showa

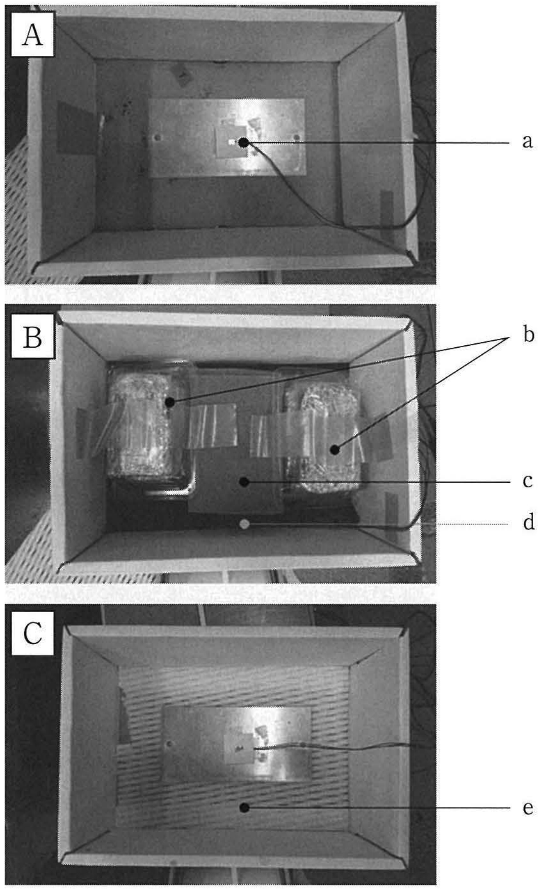

Fig. 2 Setup of the acceleration pick-up and the dummy sample to adjust the weight for the drop test

Figure showing (A) Acceleration pick-up attached on the inner side of the bottom of the box, (B) fixed clay blocks in the box, and (C) acceleration pick-up attached on the foam net sheet, where a-e represent (a) acceleration pick-up, (b) clay blocks, (c) two sheets of urethane foam to fix the clay blocks, sheet of (d) urethane foam, and (e) foam net.

Sokki Co. Ltd., k Tokyo, Japan; size, 8.0×7.0×5.5 mm; weight, 1.2 g), fixed on an aluminum plate with a plastic socket, was attached to the bottom surface of the box from the inside by using a double-sided tape (Fig. 2A). For performing the measurement, clay blocks (total weight, ~1.3 kg) were placed in the plastic trays, instead of the two bunches of grapes (Fig. 2B). The box was then dropped from a height of 0.6 m and the value of shock acceleration was measured. The experimental conditions for measuring the acceleration pickup were as follows: sampling rate, 10 μs; data, 8000 points; filter mode, automatic; trigger level, 2.8%; pre-trigger, 30%. These conditions were set using a shock measurement and analysis system (SMH-12, Shinyei Testing Machinery Co. Ltd.), connected to the accelerometer, along with the shock vibration analysis software (SMS-500 M, Shinyei Testing Machinery Co. Ltd.). The box did not drop completely perpendicular to the surface of impact, as the center of gravity of the box and its geometric center did not always coincide perfectly. Thus, the values of shock acceleration in the horizontal (right-left), horizontal (front-back), and vertical directions were calculated automatically by the software. Shock acceleration on the foam net was measured to evaluate its cushioning potential at the bottom of the box from the inside. In this case, the accelerometer was attached to the surface of the foam net (Fig. 2C). Each drop test was carried out eight times, so as to ensure a high degree of replicability.

4. Calculation of the rate of berry drop

The box was opened immediately after landing on being dropped. First, the number of berries that had detached from the pedicel (left berries, LB) was determined. Second, we counted the number of berries that were still attached to the pedicel (no left berries, NLB). Finally, we calculated the rate of berry drop (RBD) (%) by using the following formula:

$$RBD = [LB/(LB+NLB)] \times 100 \quad \cdots\cdots\cdots (1)$$

5. Design of alternative packaging to prevent berry drop

We prepared the cushioning sheets by using 10-mm thick urethane foam, having a density of approximately 0.027 g cm^{-3} and a pair of holes of different sizes. Four sheets, each bearing a pair of holes, were stacked on top of one another. Next, two bunches of grapes were wrapped in paper bags and placed inside the two holes, which were formed as a result of stacking the sheets (Fig. 3)[12]. The paper bags were identical to those described in sub-section 1. The sheets along with the grapes were packed in the box described in sub-section 1 and 2. We hypothesize, that this packaging system represents an improvement over the previous one. At the same time, the combination of sheets could be varied, according to the differences in the size and shape of the individual grape bunches. Additionally, instead of the foam net, a sheet of urethane foam, without holes and possessing the same physical properties as that of the sheet with the pair of holes, was laid out at the bottom of the corrugated fiberboard box. In order to evaluate the ability to attenuate shock, by the sheet of urethane

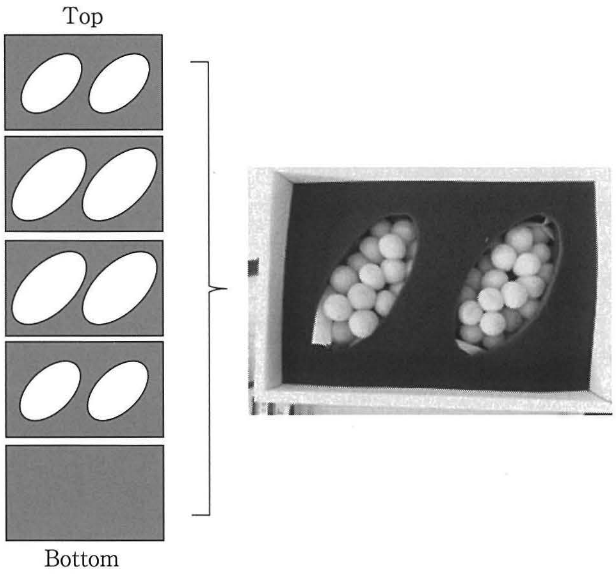

Fig. 3 Proposed improved packaging system for preventing grapes from berry drop[12]

Figure showing different combinations of the sheets with two holes, which can be used to adjust to the difference in the size and shape of the grape bunches.

foam lining the bottom of the box, we measured the shock acceleration on the surface of the sheet using the same method as described above in sub-section 3. The drop test conditions and the evaluation method for determining berry drop remained the same as described in sub-section **1**–**3**.

Results and Discussion

1. Attenuation of the drop shock caused by cushioning sheets placed at the bottom of the box

Without any cushioning sheets present, the value of shock acceleration near the bottom of the box was 4361 ms^{-2} (Fig. 4). In contrast, the magnitude of shock acceleration was attenuated upon using the foam net and urethane foam sheet (2144.8 ms^{-2} and 1353.4 ms^{-2}, respectively). Thus, it was evident that the sheet of urethane foam was more effective in attenuating the drop shock, followed by the foam net sheet.

2. Effect of the direction of the shock on the rate of berry drop

Bruised and / or crushed berries were not observed under any condition. Using equation (1), the rate of berry drop for the control setup, where the shock was delivered to the bottom, top, and side walls of box was 36%, 26%, and 10% respectively. The rate was highest when the shock

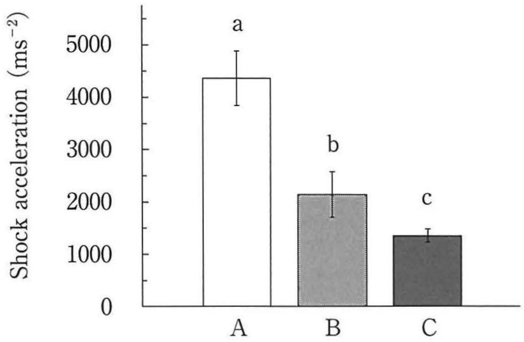

Fig. 4 Attenuation of the drop shock by cushioning sheets placed near the bottom of the box

Figure showing shock acceleration (A) without the cushioning sheet, (B) with the foam net sheet, and (C) with the urethane foam sheet; where a, b, and c represent significant differences according to Welch's *t*-test with Bonferroni correction (Family wise error rate, $\alpha = 0.05$; number of replicates, n = 8).

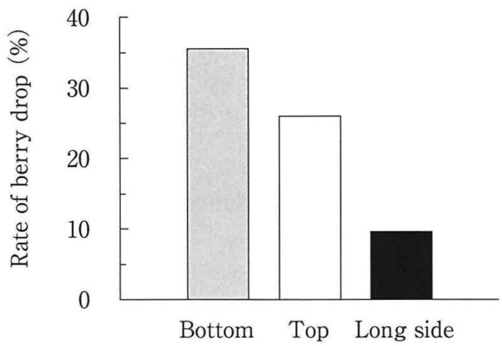

Fig. 5 Figure showing the rate of berry drop (%) varying according to the direction of the shock in conventional packaging (control setup)

Each value represents the mean of 3–4 replicates. Error bars have been omitted because each datum is shown as a percentage.

was delivered to the bottom of the box (Fig. 5). It was suggested that the reason for the differences in berry drop rates after changing the direction of the shock (bottom and top), was due to the difference in the direction of the opening of each foam net. The foam net could not offer adequate cushioning, when the shock was applied to the bottom of the packaging. The results indicated that attenuating the shock from the bottom of the packaging was necessary to prevent the grape bunches from suffering berry drop.

3. Evaluation of the performance of the proposed packaging

Bruised and / or crushed berries were not observed under any conditions, including the control

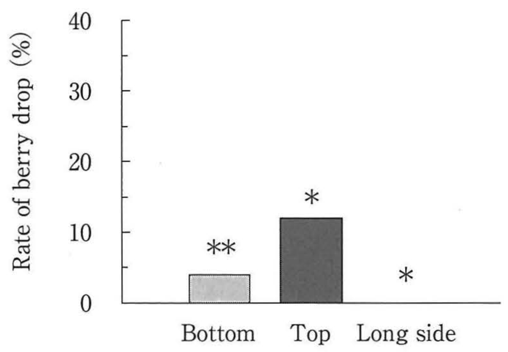

Fig. 6 Figure showing the rate of berry drop (%) varying according to the direction of the shock in improved packaging

Welch's *t*-test performed by comparing the values for the direction of the shock applied with that of the control set up, suggested significant differences between data at $p<0.01$ (indicated as '**' and $p<0.05$ (indicated as '**'). Each value represents the mean of 3－4 replicates.
Error bars have been omitted because each datum is shown as a percentage.

set up. Using equation (1), the rate of berry drop for the improved packaging, when the shock was applied to the bottom, top, and side walls of box was 4%, 12%, and 0% respectively. In each case, the rate of berry drop was lesser than that for the control setup (Fig. 6).

The result of the shock acceleration measurement (Fig. 4) showed that the sheet of urethane foam offered a higher attenuation of shock than the foam net sheet. Thus, it can be concluded that the suggested improved packaging is effective in attenuating the shock from the bottom as well as from the sides of the box. In this packaging design, the same foam net that was used in the control setup was used as a filling material for the empty space near the top of the box, resulting in lesser attenuation of the shock from the top, compared to that from the other two sides.

In this study, we assumed a single shock as the sole factor causing berry drop in grapes. However, it has been previously reported that repetitive shocks result in post-harvest damage of fruits.[7),13)] Considering the above results, our future work will focus on evaluating the ability of our proposed packaging system in preventing berry drop owing to repetitive shocks, under actual or simulated transportation and handling conditions.

Conclusion

The results of our drop tests suggested, that in order to prevent the grape bunches from suffering berry drop, attenuation of the shock delivered from the bottom of the packaging was necessary. Our results also suggested that the free space inside the packaging needs to be filled, so as to minimize berry drop. Moreover, cushioned packaging, which adapts itself to the differences in the shape of the individual grape bunches should be used. In the light of these findings, our proposed setup using stacked cushioning sheets is considered to be an effective packaging system against berry drop in grapes, caused by shocks during transportation and handling.

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衝撃によるブドウの脱粒を防止するための包装方法の提案

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ブドウの輸送時の衝撃に起因する脱粒を防止可能な包装方法を提案するために，日本のブドウ輸送において通常使用されている段ボール箱を用いた包装形態を対象として，落下方向の違いが衝撃による脱粒発生に及ぼす影響について調査した。落下試験の結果から，衝撃による脱粒を防止するためには，箱底方向からの衝撃に対する緩衝性能を高めておく必要があること，および箱内の隙間を極力減らすことが重要であることが示唆された。これらの結果に基づき，異なる大きさの貫通穴を開けたシート状の緩衝材を段ボール箱内に積層し，形成された穴内に果房を梱包することによる，個々の果房の形状に柔軟に対応可能な包装方法を提案した。落下試験の結果から，提案した包装方法がブドウの衝撃による脱粒に対する防止効果を有していることを実証した。また，この包装方法は，段ボール箱の底面および長側面からの衝撃に対して高い脱粒防止性能を有していた。

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