NOTE〜〜〜〜〜〜〜〜〜〜〜〜〜〜〜〜〜〜〜〜〜〜〜〜〜〜〜〜〜〜〜〜〜〜

Alleviation of Strawberry Bruising due to Vibration Using 1-Layer Packaging with Cushioning

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To alleviate strawberry bruising caused by transport vibration, the effect of different cushioning materials placed between the box and the tray for strawberries was investigated using the standard 1-layer packaging. The vertical, but not the horizontal, vibration of this packaging was amplified and transmitted to the fruit, suggesting that decreasing vertical vibration transmission to the fruit is an effective method for alleviation of bruising. Among the cushioning materials, rubber sponge (RS) could decrease vertical vibration and bruising compared with no cushioning, while corrugated fiberboard (CF) and urethane foam (UF) increased them. Thus, placing a cushioning material like RS between the box and tray appears to alleviate some strawberry bruising caused by vibration during transport.

Keywords: cushioning material; packaging; strawberry; transmissibility of acceleration; transport; vibration

1. Introduction

Strawberry (*Fragaria* × *ananassa* Duch.) is a flavorful, fragrant fruit with a large quantity of ascorbic acid[1] and other organic compounds[2,3] which are part of a balanced diet, making it one of the most popular fruits worldwide. Its stable supply is therefore an important concern.

Stresses like vibration which afflict fresh produce during transport have been alleviated by improvements in transport factors including the quality of trucks[4] and roads[5]. Despite these improvements, transport vibration remains a major cause of strawberry bruising[6,7]. Bruising is known to accelerate changes in the chemical components of strawberry[8], and increased propagation of disease-causing bacteria has been reported in bruised strawberries due to vibration[9]. Thus, alleviation of fruit bruising from vibration needs to addressed.

Cushioning materials placed in packaging for strawberries has been considered effective for reducing bruising. In Japan, the standard 1-layer packaging used for strawberries (Fig. 1) includes an approximately 3 mm-thick sheet of foamed urethane which is usually placed on the bottom of the tray to provide cushioning (Fig. 2a). However, bruising from vibration has still been reported using this

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packaging system[6,7]. Thus, the layout and/or characteristics of urethane might not be adequate for reduction of strawberry bruising, while increasing the thickness of urethane foam (UF) is limited to the capacity of the packaging. Therefore, to reduce bruising during transport other layouts and/or materials for cushioning need to be considered; however, an appropriate cushioning material for strawberry packaging has yet to be determined.

To clarify the characteristics of cushioning materials suitable for reducing strawberry bruising from vibration, this study examined the effects of different cushioning materials placed between the box and tray in a 1-layer packaging system on strawberry bruising. As actual transport generates both vertical and horizontal vibration[10,11], the relationship between vibration in both directions and bruising were also investigated.

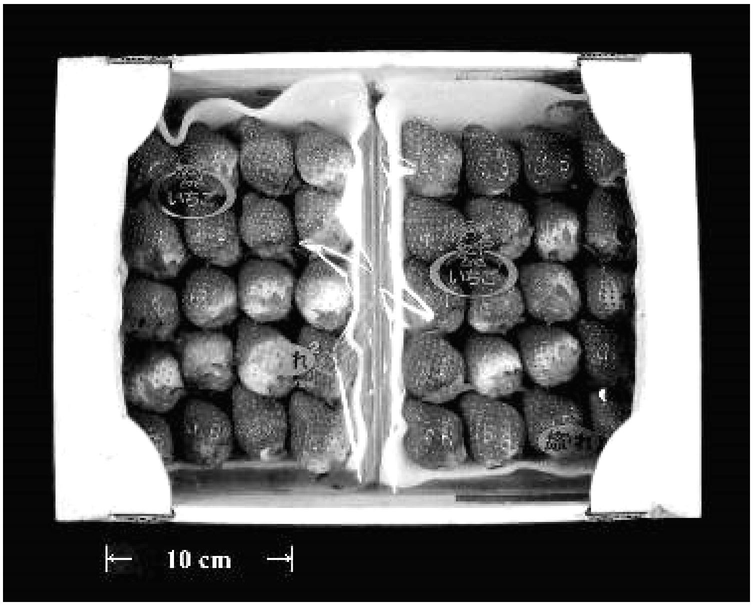


Fig. 1　Standard 1-layer packaging for strawberries

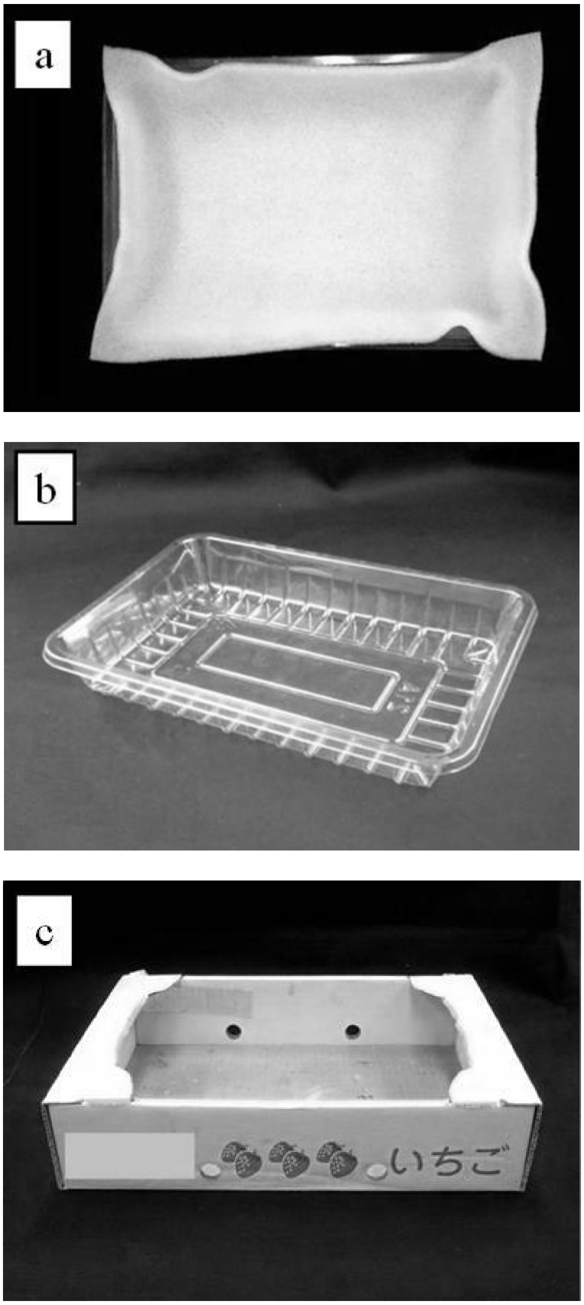


Fig. 2　Components of standard 1-layer strawberry packaging. a: Sheet of urethane foam inside the tray; b: polyethylene terephthalate resin tray; and c: folding box made of double-faced corrugated fiberboard

2. Materials and Methods

2.1 Materials

In this study, the strawberry cultivar tested ‘Tochiotome’ was produced in Ibaraki Prefecture, Japan. This fruit had an average vertical diameter of 44 mm and horizontal diameter of 30 mm, and weighed approx. 13.0 g. The degree of coloring was 75-100% of the whole fruit. Strawberries were selected for uniformity of size and freedom from defects and mechanical damage. Selected fruit were stored at 5˚C for 24 h before the experiment.

The components of the 1-layer packaging system are shown in Fig. 2. The trays (Fig. 2b) inside the box were made of polyethylene terephthalate (PET) resin and had internal dimensions of 12.9 × 19.3 cm at the top and 11.4 × 17.3 cm at the bottom, with a 2.8-cm height. The folding box (Fig. 2c; No. 0435, JIS Z1507) was composed of 3-mm thick double-faced corrugated fiberboard (CF) (No. 1003, JIS Z0104), with internal dimensions of 29.5 × 21.0 × 5.8 cm. Each tray contained 20 strawberries and 2 trays were packed in each box. Other conditions followed the standard practices for the 1-layer packaging system.

CF, UF, and rubber sponge (RS) were tested as cushioning materials between the box and the trays. All cushioning materials had dimensions of 29.2 × 20.7 × 1.0 cm. CF was made by affixing 2 pieces of 5-mm thick corrugated fiberboard each with a flute of 34±2/30 cm (A-flute, JIS Z1516). The density of UF and RS was 1.5×10^{-2} and 8.7×10^{-2} g/cm^3, respectively, and their compression stress at 25% distortion was 1.9 and 26.9 kPa, respectively. As a control, the effect of no cushioning material was also investigated.

2.2 Experimental Conditions

2.2.1 Estimation of transmissibility of acceleration

(1) Vibration conditions

Vibration was measured in the vertical and horizontal directions using a vibration tester (VTVH-5, Saginomiya). The peak acceleration on the bed of a large truck traveling on the highway has been estimated to be around 4.0-6.0 m/s^2 [12-14], while the vibration frequency generated on conventional trucks has been reported to on average less than 30 Hz[11,13,15]. Thus, acceleration and frequency in this study were set to 6.0 m/s^2 and 2-35 Hz, respectively.

(2) Measurement conditions

A laser displacement meter (LK-500, Keyence) was used to estimate the transmissibility of vertical acceleration. For converting displacement data to acceleration data and other conditions, the method of Nakamura et al. was used[5,7]. This method could not be used for estimating the horizontal acceleration because the walls of the box and trays obstructed the laser beam of the meter. Therefore, two accelerometers (2366W, Showa Sokki) connected to an analysis device (SMS-12, Yoshida Seiki) were used to measure the transmissibility of the horizontal acceleration. One accelerometer was inserted into a fruit and the other was attached to the platform by a piece of double-sided tape. The transmissibility of acceleration at each frequency (1-Hz intervals) was measured by comparing the acceleration between the platform and the fruit. The sampling interval and time were 200 μs and 8 s, respectively. Each test was replicated 3 times.

2.2.2 Damage estimation

(1) Vibration sweep test

The output acceleration was set to 6.0 m/s^2 and the scanned frequency range was 2-35 Hz. One scanning period was 3 min, and this period was repeated 20 successive times (total time, 1 h).

(2) Appearance index

The degree of bruising was estimated by a modified version of Tatara's method[13]. That is, each fruit was scored based on the area of bruising relative to the total surface area (6-point scaling instead of the original 5-point scaling was used): 5, bruise-free; 4, <5%; 3, 5–10%; 2, 10–30%; 1, 30–50%; and 0, >50% bruising (In the original version, each fruit was scored based on the area with the most bruised surface: 5, bruise-free; 4, <5%; 3, 5–10%; 2, 10–30%; and 1, >30% bruising). The average score for each experiment was assessed according to an 'appearance index' (AI). According to the AI, the score of commercially available strawberries in markets ranged from 2.0 to 3.0. To confirm the extent of the bruised area, vibrated fruit were stored at 15˚C for 24 h and then examined. Other conditions were the same as that previous study.

3. Results

3.1 Estimation of transmissibility of acceleration

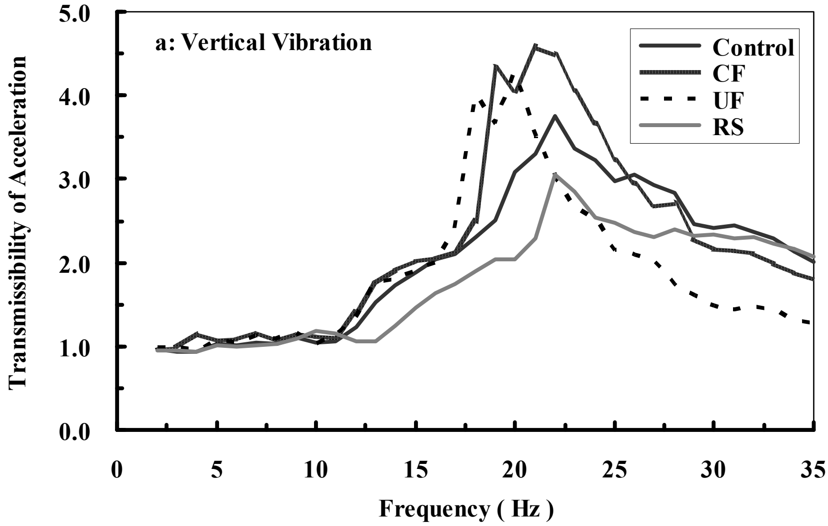
3.1.1 Vertical vibration

Few differences in vertical vibration were observed at 2-11 Hz among cushioning conditions, and each transmissibility of acceleration was around 1.0 (Fig. 3a). The control vibration level tended to increase from 12 Hz reaching a peak level of 3.8 at 22 Hz. Above the peak frequency, the level tended to decrease. For CF, the vibration level within 10-25 Hz tended to be higher than that of the control, and its peak level was 4.6 at 21 Hz; similar to the control, the level began to decrease above 26 Hz. For UF, the vibration level within 16-21 Hz was also higher than that of the control, peaking at 20 Hz with 4.3; this value also decreased above 22 Hz. For RS, the vibration level (3.1) peaked at 22 Hz, but was lower than that of the control over a wide frequency range (12-33 Hz).

3.1.2 Horizontal vibration

Transmissibility of acceleration at each frequency was around 1.0 with no obvious peaks in the control (Fig. 3b); a similar tendency was observed for CF. In contrast, UF and RS had peak vibration levels of 2.1 at 17 Hz and 1.7 at 23 Hz, respectively. For UF, this level was higher than that of the control within

13-21 Hz, while for RS, it was higher within 21-25 Hz and above 30 Hz. Vibration levels were low for all cushioning conditions within 3-12 Hz. Such levels were also observed within other frequency ranges, such as 27-34 Hz for CF and 22-34 Hz for UF.



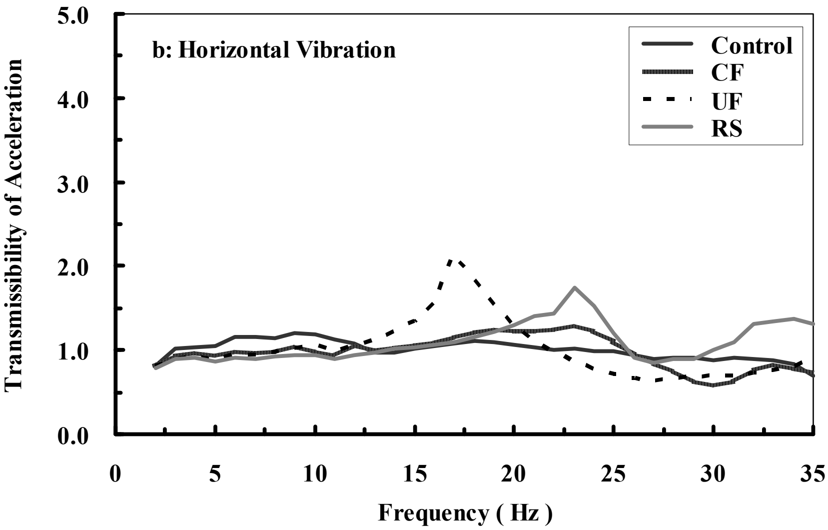


Fig.3 Transmissibility of acceleration at each frequency. Control: no cushioning material between the box and tray, CF: corrugated fiberboard, UF: urethane foam, and RS: rubber sponge. Data represents the average values of three experiments.

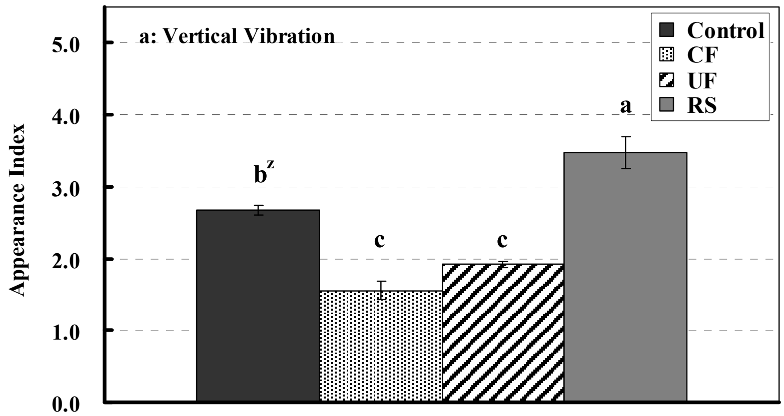
3.2 Damage estimation

3.2.1 Vertical vibration

In the case of vertical vibration, the AI for CF (1.6) and UF (1.9) was significantly lower than that for the control (2.7) (Fig. 4a). In contrast, the AI for RS was 3.5, which was significantly higher than that of the control.

3.2.2 Horizontal vibration

In the case of horizontal vibration, the AI for CF (3.8) and RS (3.7) were similar to that for the control (3.7) (Fig. 4b). However, the AI for UF was 1.6, which was significantly lower than the other scores.



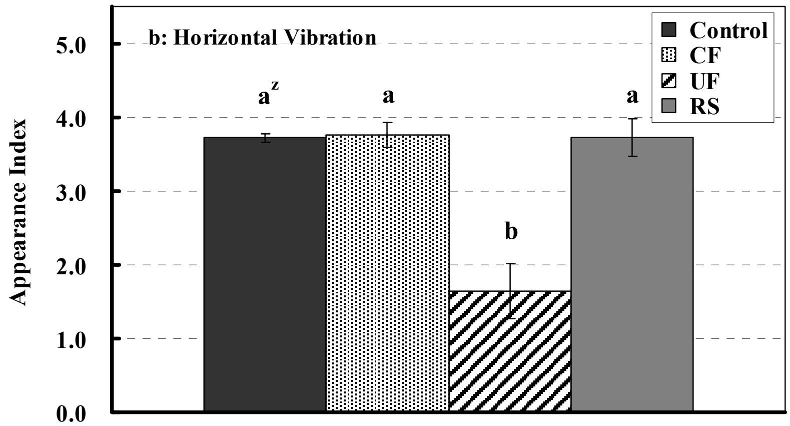


Fig.4　Effect of vibration on the appearance of strawberries. Control: no cushioning material between the box and tray, CF: corrugated fiber–board, UF: urethane foam, and RS: rubber sponge sheet. zValues with different letters differ significantly by Tukey's test (P=0.05, n=3).

4. Discussion

Without cushioning, vertical vibration of strawberries was amplified, which induced bruising. A remarkable increase in vibration was particularly seen around 20 Hz, which has been reported to reflect resonance in strawberry[5,7] that is known to cause bruising[5]. Thus, the standard 1-layer packaging could not prevent bruising induced by amplified vibration in this frequency region, which is well known to occur during actual transport; i.e., Singh et al.[16] reported the characteristic vibration of truck tires around 20 Hz. Therefore, one approach to alleviate strawberry bruising during transport would be to reduce vertical vibration around 20 Hz.

Using CF and UF as cushioning in strawberry packaging increased the transmission of vertical vibration around 20 Hz, compared to using no cushioning. Based on an appearance test of strawberries placed in boxes with both of these cushioning materials, the level of bruising was relative to that without cushioning, suggesting that such materials promoted resonance making them inappropriate for the reduction of bruising. In contrast, RS decreased the transmission of vertical vibration over a wide frequency range including around 20 Hz as well as decreased the level of bruising. Therefore in this study, RS appears to be the most appropriate cushioning material for reducing vertical vibration and thereby preventing strawberry bruising.

Tokunaga and Hirata[17] observed almost no amplification of horizontal vibration in their vibration response test of goods packaged in CF boxes. A similar tendency was also observed in this study in which little amplification of horizontal vibration was found for all cushioning conditions, compared to that of vertical vibration. However, severe bruising was observed for UF, which had the largest transmissibility of acceleration (2.1), followed by RS (1.7). As vibrational acceleration for both materials increased to 12.6 and 10.2 m/s^2, respectively, the threshold for the level of bruising caused by horizontal vibration appears to occur between these values. Although the peak frequencies in both treatments were different (UF: 17 Hz, RS: 23 Hz), such difference did not seem to influence greatly on the bruising according to the past study; Nakamura et al.[7] reported that the fruit bruising was affected greatly by the transmissibility of acceleration rather than frequency in their vibration test for strawberry. Considering that strawberries packaged with RS were only slightly bruised even at vertical vibration of 18.6 m/s^2 (Fig. 3a), fruit bruising seemed to be more easily affected by horizontal than vertical vibration, as reported previously by Nakamura et al.[5] However, an increase in transmissibility of acceleration in the horizontal direction was not observed for even standard 1-layer packaging without cushioning, and less bruising was caused by horizontal vibration than by vertical vibration for standard 1-layer packaging. Moreover, the vibration level on the beds of large transport trucks has been reported to be on average less than 10.0 m/s^2 [12,13]. Taken together, measures for reducing horizontal vibration might not be as important as those for reducing vertical vibration in this packaging system.

5. Conclusion

In the 1-layer packaging system for strawberries, cushioning with characteristics similar to rubber sponge placed between the box and the tray may reduce the transmission of vertical vibration and alleviate bruising during transport. Based on these results, more effective cushioning materials are being investigated.

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底面緩衝材による1段トレー包装されたイチゴの振動による損傷の軽減

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振動によるイチゴの損傷防止に適した緩衝材に関する基礎研究として、1段包装における底面緩衝材の違いが振動伝達および損傷発生に及ぼす影響を調査した。この包装形態において、上下振動は増大され果実に伝達したが、水平振動の増大はみられなかったことから、上下振動の伝達を軽減することが損傷軽減に有効であると考えられた。底面緩衝材として段ボール板または発泡ウレタンを用いた場合、上下振動および果実の損傷は、そこに緩衝材が無い場合よりも増加した。一方、ゴムスポンジを用いた場合、それらは軽減された。従って、この素材に類似した物性を持つ緩衝材が果実の損傷防止に適していると考えられ、現在これらの知見を元に最適な素材の探索を進めている。

キーワード：　緩衝材、包装、イチゴ、加速度伝達率、輸送、振動