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Effect of vibration damage on the storage quality of 'Elsanta' strawberry

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Abstract

Vibration tests were carried out on strawberry punnets at three frequency levels of 3, 4 and 5 Hz for 50 and 150 sec. 'Elsanta' strawberries were packed in 250 g polyethylene terephthalate (PET) punnets for the vibration test. Strawberry quality was determined immediately after vibration test on the initial day and after storage at 10°C (±1°C) and 70% RH (±5%RH) for 3 days. Strawberries in the punnets were evaluated for percentage of quality categories, severity bruise, electrical conductivity (EC), firmness as well as total soluble solids (TSS) and titratable acidity (TA). EC value and percentage of the dry bruise showed an increase with frequency level and time. The frequency at 5 Hz for 150 sec was the critical vibration for an increase of bruise and EC value and a reduction of severity score ($p<0.05$). No significant differences were observed among TSS and TA submitted to different frequency and time of the vibration test. The conductivity values were also highly associated with the severity of the bruises (r= -0.764) while there was no significant relationship between conductivity and firmness on the initial day. Results indicated that the electrical conductivity evaluation in the vibration test of strawberries can be used as a rapid evaluation method to assess strawberry bruises during the handling and transportation.

Keywords: bruise, firmness, vibration, strawberries.
Abbreviations: EC_electrical conductivity; PET_polyethylene terephthalate; *r*_ correlation coefficient; TSS_ total soluble solids; TA_ titratable acidity.

Introduction

Strawberries (*Fragaria* × *ananassa*) are the most important crop for the soft fruit industry in the UK and account for approximately 25% of total home production of UK fruit in value terms (Department for Environment Food and Rural Affairs, 2013). 'Elsanta' strawberry is the main cultivar used to supply the UK market for around 8 months (April to November) of the year (Fresh Produce Journal, 2012). The main causes of strawberry waste are mechanical damage when in the punnet, poor cool chain systems, mould, rot and different interpretations on specification by different suppliers (Terry et al., 2011). The most common form of mechanical injury on strawberries is compression damage, followed in importance by impact and vibration (abrasion) injuries (Smith et al., 2005). Most minimum requirements of strawberry standard define the appearance as undamaged by bruising and free from damage caused by pests or disease (Ministry of Agriculture, Fisheries and Food, 1996; Organisation for Economic Co-Operation and Development, 2005). The three factors that influence vibration testing on strawberries are frequency (Hz), exposure time (sec) and acceleration (g). Nakamura et al. (2007) found that in a vibration test of 'Tochiotome' strawberries it was a frequency of 7 Hz and acceleration of 1 g for 60 sec that caused a significant increase of bacterial growth at 25°C. Fischer et al. (1992) also reported the critical frequency at the range of 5 to 10 Hz at an acceleration of 0.6 g for 600 sec caused serious damage to 'Selva' strawberries. During strawberry transport, the frequencies of truck vibration of 3.35, 7 and 13.5 Hz with acceleration level of 0.02 to 0.19 g were found as the cause of strawberry damage under standard road conditions (Kojima et al, 1999).

Many attempts have been made to evaluate strawberry bruises but it is generally assessed by visual quality using a visual rating scale. The bruise severity of an individual strawberry is graded by the bruise diameter and percent of bruise area (Fischer et al., 1992). The number of strawberry bruises was assessed inside a package by severity scales from 5 (very good = no sign of bruise) to 1 (very severely damage = whole fruit bruised) (Pelletier et al., 2011). The calculation of bruise volume was assumed to be a cone shape ($1/3\Pi [w/2]^2D$)), where w = bruise width; D = bruise depth (Ferreira et al., 2008). These assessment methods require a great deal of time to have any accuracy as a large number of fruit must be accessed and a more rapid method is required. Electrical conductivity is a technique for the possible evaluation of postharvest strawberry damage. Jiang et al. (2001) found that the significant correlation between the conductivity and the percent pared fruit (r=0.938) or damage indexes of strawberries (r=0.917). The strawberry firmness directly affects the susceptibility to physical and mechanical injuries (Kader, 1999). However, very little is known about the correlation between vibration level and strawberry firmness. For example, Fischer et al. (1992) found that vibration level had no effect on strawberry firmness. There has been no study in the relationship between the electrical conductivity and the firmness of strawberry bruise. The objectives of the present research were firstly to examine vibration test in 'Elsanta' strawberries at 3, 4 and 5 Hz for periods of 50 and 150 sec and secondly to determine the strawberry damage and quality after the vibration test and after storage at 10°C for 3 days.

Table 1. Percentage of quality category and severity bruise score of 'Elsanta' strawberries at day 0 and 3 after vibration test at 3, 4 and 5 Hz for 50 and 150 sec.

Treatment	Undamaged (%)	Dry Bruise (%)	Wet Bruise (%)	Severity score
Day 0				
Control	100.00^{a}±0.00	0.00^{e}±0.00	0.00^{b}±0.00	5.0^{a}±0.04
3Hz-50 sec	84.56^{b}±0.85	11.24^{e}±2.91	4.20^{b}±3.00	4.8^{a}±0.03
3Hz-150 sec	61.90^{c}±8.86	38.10^{c}±3.95	0.00^{b}±0.00	4.8^{a}±0.05
4Hz-50 sec	87.24^{b}±7.21	9.56^{e}±3.15	3.20^{b}±1.96	4.8^{a}±0.04
4Hz-150 sec	38.86^{d}±11.24	56.40^{b}±5.63	4.74^{b}±3.11	4.7^{a}±0.06
5Hz-50 sec	72.38^{c}±9.11	24.62^{d}±2.65	3.00^{b}±1.85	4.7^{a}±0.04
5Hz-150 sec	15.28^{e}±10.95	71.06^{a}±5.82	13.65^{a}±4.32	4.2^{b}±0.13
Day 3				
Control	56.52^{a}±5.38	43.48^{d}±5.38	0.00±0.00	4.6^{a}±0.08
3Hz-50 sec	23.00^{c}±6.48	74.40^{bc}±4.99	1.66±1.66	4.1^{b}±0.07
3Hz-150 sec	38.44^{b}±4.93	61.56^{c}±4.93	0.00±0.00	4.3^{ab}±0.07
4Hz-50 sec	23.00^{c}±4.51	77.02^{abc}±4.53	0.00±0.00	4.1^{b}±0.05
4Hz-150 sec	14.28^{c}±4.03	82.64^{ab}±5.24	3.08±3.08	3.9^{b}±0.15
5Hz-50 sec	0.00^{d}±0.00	96.64^{a}±2.07	3.36±2.07	2.9^{c}±0.24
5Hz-150 sec	0.00^{d}±0.00	80.76^{abc}±11.79	19.24±10.45	3.2^{c}±0.17

Means in different letters in the same column in each day for DMRT test indicate significant differences at 5% level (mean±S.E., n=5).

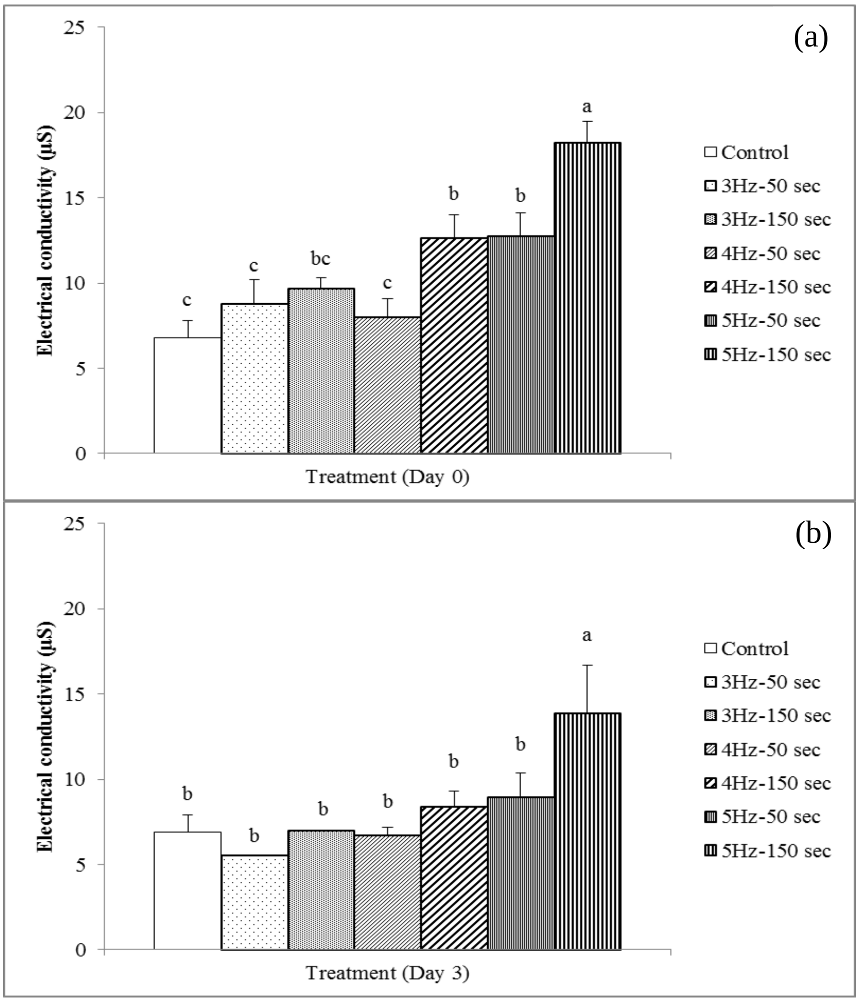

Fig 1. Electrical conductivity of 'Elsanta' strawberries after vibration test at day 0 (a) and day 3 (b). Different letters in treatments for DMRT test indicate significant differences at 5% level (mean±S.E., n=5).

Results and Discussion

The vibration damage by visual evaluation

On the first day of storage (day 0), the vibration tests (3 and 4 Hz at 50 sec) had the highest percentage of undamaged fruits (around 85%) among the treatments ($p<0.05$). At 5 Hz (1.1 g) for 150 sec, there was the greatest number of dry bruises (71%) and wet bruises (13%) ($p<0.05$) while control treatment had not any damage before the vibration test. The lowest severity bruise score by the visual assessment was also

Table 2. Puncture and compression values and fruit weight of 'Elsanta' strawberries at day 0 and 3 after vibration test at 3, 4 and 5 Hz for 50 and 150 sec.

Treatment	Puncture (kg)	Compression (kg)	Fruit weight (g)
Day 0			
Control	0.504±0.013	1.488±0.009	21.43±0.02
3Hz-50 sec	0.524±0.022	1.520±0.050	18.99±1.30
3Hz-150 sec	0.504±0.015	1.510±0.077	20.50±0.38
4Hz-50 sec	0.512±0.027	1.465±0.031	18.99±1.30
4Hz-150 sec	0.467±0.023	1.445±0.035	19.60±0.41
5Hz-50 sec	0.511±0.016	1.470±0.017	18.41±1.26
5Hz-150 sec	0.510±0.027	1.488±0.046	20.63±1.90
Day 3			
Control	0.627^{a}±0.018	1.955^{a}±0.051	19.51±0.45
3Hz-50 sec	0.552^{ab}±0.033	1.609^{b}±0.070	18.41±1.65
3Hz-150 sec	0.507^{bc}±0.087	1.557^{bc}±0.037	18.53±0.25
4Hz-50 sec	0.538^{bc}±0.040	1.541^{bc}±0.085	19.36±0.55
4Hz-150 sec	0.519^{bc}±0.019	1.391^{c}±0.052	19.03±0.17
5Hz-50 sec	0.551^{ab}±0.024	1.541^{bc}±0.040	18.91±0.93
5Hz-150 sec	0.454^{c}±0.033	1.496^{bc}±0.042	18.54±0.77

Means in different letters in the same column in each day for DMRT test indicate significant differences at 5% level (mean±S.E, n=5).

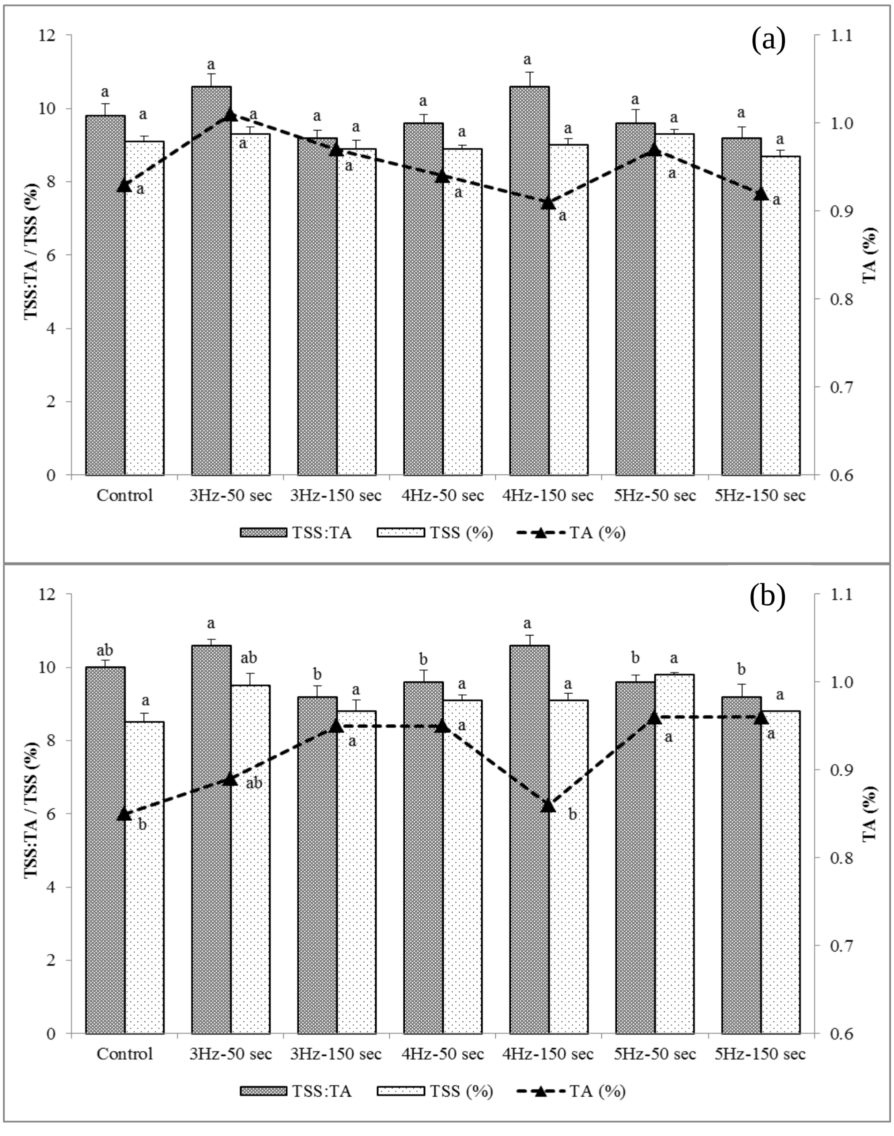

Fig 2. TSS:TA, TSS (%) and TA (%) of 'Elsanta' strawberries after vibration test at day 0 (a) and day 3 (b). Different letters in treatments for DMRT test indicate significant differences at 5% level (mean±S.E., n=5).

Table 3. The correlation coefficient (*r*) between EC value and firmness or severity score of bruise of 'Elsanta' strawberries at day 0 and day 3.

Properties	Severity score	EC
Day 0		
EC	-0.764**	1.000
Puncture	-0.071	-0.221
Compression	0.110	-0.082
Day 3		
EC	-0.571**	1.000
Puncture	-0.206	-0.478**
Compression	0.372*	-0.266

** Correlation is significant at 1% level (n=35).

found in the vibration frequency at 5 Hz (1.1 g for 150 sec) which related to the maximum percentage of bruise (Table 1). Our results are in agreement with Nakamura et al. (2008) report which showed a high correlation value between acceleration level and vibration damage in strawberries (*r*=0.8660). However, the similar vibration level was reported by Jiang et al. (2001). The vibration level at 5 Hz (1.6 g) for 40 sec was observed not to give damage following visual evaluation in 'Tayonoka' strawberries. In our study, the frequency at 5 Hz (1.1 g) of 150 sec was the critical frequency for the increases of the losses and a reduction of severity score in 'Elsanta' strawberries (Table 1). After storage condition (at 10^{O}C for 3 days), the vibration level at 5 Hz showed no undamaged fruits and that the severity score was significantly lower than at 3 and 4 Hz ($p<0.05$). The percentage range of dry bruise increased rapidly in the vibrated strawberries from 60 to 95% whereas control was found to have around 40% dry bruise (Table 1). In addition, our results showed no rot and mould were observed and agree with the Nakamura et al. (2007) result. The stimulated vibration level at 7 Hz (1 g) for 60 sec showed no increase of bacterial rot on strawberry fruits after storage at 10^{o}C for 4 days. However, the previous as well as our studies were based on the simulated vibration to strawberry damage. In the actual transport for strawberry shipment in Japan, Kojima et al. (1999) stated that the frequencies of vibration levels were 3.35, 7 and 13.5 Hz with acceleration levels (0.02 to 0.19 g) that caused strawberry damage. Therefore, our findings support previous studies that the range of vibration frequencies and accelerations to strawberry damage was approximately 3.35 to 13.5 Hz with 0.02 to 1.1 g, respectively.

Electrical conductivity

The electrical conductivity of 'Elsanta' strawberries was greater at 5 Hz (1.1 g) for 150 sec (18.2 µS) as compared to the control treatment, 3 Hz (0.4 g) and 4 Hz (0.8 g) ($p<0.05$). Undamaged strawberry fruits after harvesting had the lowest electrical conductivity level and there was little difference at the low vibration level of 3 Hz and 4 Hz for 50 sec (Fig 1). The highest frequency and time (5 Hz for 150 sec) also had the highest dry and wet bruises and the lowest severity score (Table 1). After storage condition for 3 days, the conductivity values decreased around 20 to 35% (Fig 1B). Jiang et al. (2001) reported that the conductivity of 'Toyonoka' strawberry greatly reduced after storage at 25^{o}C for 3 days. In our study, the highest vibration level (5 Hz for 150 sec) gave a significant ion leakage compared to other treatments after immediate test and storage (Fig 1). These observations agree with previous research that the simulated vibration test of 'Selva' strawberries at the 5 to 10 Hz (0.6 g) range for 1800 sec caused the maximum damage (Fischer et al., 1992).

In the comparison between 5 Hz (1.1 g) and 3 Hz (0.4 g) or 4 Hz (0.8 g) for 50 sec after storage, there was no a significant difference in EC value ($p>0.05$). Jiang et al. (2001) reported that at the vibration frequency of 5 Hz with a 3-dimensional vibrator at 1.4 g for 20 sec or 1.2 g for 40 sec there was no change in the EC value. Although the same acceleration level in this study could not be controlled for all frequency levels (3 to 5 Hz). Our acceleration condition in the range applied (0.4 to 1.1 g) is in agreement with previous studies (0.6 to 1.4 g) (Fischer et al., 1992; Jiang et al., 2001) The results of this study and previous research showed that the simulated vibration condition on the conductivity (undamaged fruits) is suggested in the range of frequency 5 to 10 Hz with acceleration (0.6 to 1.4 g) for over 40 sec.

Fruit firmness and fruit weight

Fruit firmness was measured by puncture and compression tests and was found to not show statistically significant differences after vibration condition ($p>0.05$). After cool storage for 3 days, control treatment had the highest puncture and compression values ($p<0.05$) (Table 2). Fischer et al. (1992) found in vibration test at 2-30 Hz (0.6 g) for 1800 sec that there was no effect on the firmness measurement with shear force test. The strawberry firmness also depends on fruit size and the small fruits were firmer than large ones (Døving and Måge, 2002). Our result showed that the fruit weight had no a significant difference on firmness with the range size (18.5 to 21.4 g per fruit) ($p>0.05$) (Table 2).

Total soluble solids (TSS), titratable acidity (TA) and TSS: TA ratio

The contents of TSS, TA and TSS:TA ratio in 'Elsanta' strawberries were around 9%, 0.93% and 9.5:1, respectively (Fig 2). TSS and TSS: TA ratio levels of our testing fruits were higher than the previous study (Strum et al., 2003). Our results also agreed with that reported from general strawberry cultivars. The minimum TSS and maximum TA levels for an acceptable flavour of strawberry were recommended at 7% and 0.8%, respectively (Kader, 1999). After the vibration test and storage, there were no the significant differences in TSS, TA and TSS;TA ratio. TSS content did not change statistically during storage condition ($p>0.05$) (Fig 2). Our results support Izumi et al. (1999) research into vibration of strawberries which had no effect on TSS and TA contents. In contrast, Kojima et al. (1999) observed that TSS content reduced around 5% after simulated vibration test and storage (5^{o}C) for 12 hours. While Chen et al. (2011) found that TA content in mulberry fruit, also a non-climacteric fruit, decreased during storage. Ornela-Paz et al. (2013) found that there was no significant correlation between firmness of 'Albion' strawberries and TSS content.

The correlation coefficient (r) between EC value and firmness or severity score of bruise

The EC value significantly correlated with severity score of bruises at day 0 and day 3 (r=-0.764 and r= -0.571) ($p<0.01$) whereas puncture and compression tests gave no correlation with severity score (Table 3). Interestingly, the EC value in the present study showed more accuracy than that firmness tests for damage evaluation.

Materials and Methods

Plant materials

'Elsanta' strawberry with A+ grade and crown diameter ≥ 15 mm was provided by RW Walpole Ltd, UK. Two hundred strawberry plants were grown in the greenhouse at Writtle College, Chelmsford. The strawberry cultivations were conducted from 10th February to 27th May in 2014. Only harvested marketable grade fruit was used (a uniform size and fruit weight from 18 to 21 g, full red colour with TSS > 8%). Strawberry fruits were packed in 250 g in polyethylene terephthalate (PET) vented punnets (105 x 170 x 60 mm). Packed fruits were transported to the postharvest laboratory within 2 hours of harvest. The punnet was cooled by room cooling within 4 hours to the pulp temperature of 7.0^{o}C ($\pm$1^{o}C). The cooled punnet was top sealed with commercial plastic film with 6 perforations of 8 mm diameter (Adare Advantage Ltd).

Vibration test

Vibration tests were carried out at three frequency levels at 3, 4, and 5 Hz for 50 and 150 sec by orbital shaker at amplitude 16 mm (Stuart SSL1, UK). Five punnets (replicates) were conducted in vibration test. The acceleration (g) level of the orbital shaker was measured by spectral vibration logger SVR101 (MadgeTech, USA). The frequency and acceleration levels of the vibration test were 3 Hz (0.4 g), 4 Hz (0.8 g), and 5 Hz (1.1 g). The acceleration level of this study was determined based on the previous studies presented by Fischer et al. (1992) and Jiang et al. (2001).

Quality determination

Strawberry quality was determined immediately after the vibration test (day 0) and after storage at 10$\pm$1^{o}C and relative humidity (RH) at 70% (±5%RH) for 3 days.

Assessment of percentage of quality category and severity bruise score

Percentage of each quality category was calculated from the number of fruits in each category of damage (undamaged, dry and wet bruises). The individual severity of bruises was scored and modified from undamaged level (score 5) to very severely damage level and mould formation (score 1) according to the rating scale, described by Fischer et al. (1992)

Measurement of electrical conductivity

Electrical conductivity (EC) was evaluated and adapted using the method of Jiang et al. (2001). Five fruits randomly selected from each punnet were immersed in a 500 ml of distilled water at 25^{o}C for 10 min. The sample temperature in distilled water was controlled using the water bath (Phillip Harris, UK). The immersed fruits were gently stirred for 5 sec before the determination of EC test was recorded with a handheld conductivity meter (CyberScan CON 110, Eutech Instruments, USA) and expressed as µS.

Fruit weight and firmness evaluation

Fruit firmness in each test (3 fruits in each punnet) was determined from the maximum peak of force (kg) using fruit texture analyser GS-20 (GüSS Manufacturing (Pty) Ltd, South Africa). The speed of measurement was at 10 mm/sec with a 8 mm cylinder probe (puncture test) and also a second test using a 42 mm compression platens (compression test) for 8.9 mm (a measured distance). The fruit weight of three fruits from each punnet was randomly measured with a digital balance (Mettler PE 600, Precisa Balances Limited, UK).

Measurements of total soluble solids (TSS), titratable acidity (TA) and TSS: TA ratio

Six strawberries in each punnet were cut into four identical portions which were randomly representative sampled for TSS (%), TA (%), and TSS:TA ratio. The strawberry juice was measured TSS with a digital pocket refractometer (PAL-1, Atago, Japan). Titratable acidity (TA) was measured by titration of strawberry juice with 0.1 M sodium hydroxide and expressed as citric acid (%w/w) (AOAC, 1990).

Statistical analysis

The experimental design was performed using a completely randomized design with 5 replications. Analyses of variance and correlation coefficient (r) were performed using SPSS version 16.0. Duncan's multiple range test (DMRT) were calculated at 5% level of significance ($p<0.05$). The correlation coefficient (r) between EC value and firmness or severity score of bruise was calculated by Pearson's correlation at 1% level of significance ($p<0.01$).

Conclusion

The vibration level at 5 Hz for 150 sec provided significantly the greater bruise and conductivity values as compared to 3 and 4 Hz. EC values of strawberry bruise decreased with an increasing storage at 10^{o}C for 3 days. Bruise symptom did not affect TSS, TA and TSS:TA ratio. The evaluation of electrical conductivity in 'Elsanta' strawberry bruises had a high negative correlation with the severity score of bruises at $P\leq0.01$ while there was no a correlation between severity score and firmness tests. The study suggests that EC could be applied and used to provide a rapid and accurate method to assess strawberry bruises during postharvest handling and transportation.

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References

AOAC (1990) Official methods of analysis of the Association of Official Analytical Chemists, 15th ed. Association of Official Analytical Chemists, Arlington, Virginia, pp: 1058-1059.

Chen Z, Zhu C, Han Z (2011) Effects of aqueous chlorine dioxide treatment on nutritional components and shelf-life of mulberry fruit (*Morus alba* L.). J Biosci Bioeng. 111: 675-681.

Department for Environment Food and Rural Affairs (2013) Basic horticultural statistics dataset. www.gov.uk/government/publications/basic-horticultural-statistics (Access 20 April 2015).

Døving A, Måge F (2002) Methods of testing strawberry fruit firmness. Acta Agr Scand. 51: 43-51.

Ferreira MD, Sargent SA, Brecht JK, Chandler CK (2008) Strawberry fruit resistance to simulated handling. Sci Agric. 65: 490-495.

Fischer D, Craig WL, Watada AE, Douglas W, Ashby BH (1992) Simulated in-transit vibration damage to packaged fresh market grapes and strawberries. Appl Eng Agric. 8: 363-366.

Fresh Produce Journal (2012) Refresh directory 2012: an essential resource for the fresh produce industry, London.

Izumi T, Toshihiro T, Hatsuko M, Massanobu T, Yan LJ, Takayuki K, Hideaki O (1999) Effect of vibration by simulated transportation on respiration rate and quality of strawberry fruits. Food Pres Sci. 25: 15-20.

Jiang Y, Shina T, Nakamura N, Nakahara A (2001) Electrical conductivity evaluation of postharvest strawberry damage. J Food Sci. 66: 1392-1395.

Kader AA (1999) Fruit maturity, ripening, and quality relationships. Acta Hort. 485: 203-208.

Kojima T, Liu JY, Fujita S, Inaba S, Tanaka M, Tatara I (1999) Analysis of vibration and its effects on strawberries during highway transport. Journal of SASJ. 29: 197-203.

Ministry of Agriculture, Fisheries, and Food (MAFF) (1996) Common standards of quality for strawberry. In: EC Quality standards for horticultural produce. MAFF Publications, London, pp: 9-1-9-4.

Nakamura N, Umehara H, Nei D, Okadome H, Ishikawa Y, Nakano K, Maezawa S, Shina T (2008) Effect of package conditions on the damage of strawberries. Journal of SASJ. 6: 1-8.

Nakamaru N, Inatsu Y, Kawamoto S, Okadome H, Nakano K, Maezawa S, Shiina T (2007) Effect of vibration on the bacterial growth on strawberry fruits. J Food Agric Environ. 5: 44-48.

Organisation for Economic Co-Operation and Development (OECD) (2005) International Standardisation of fruit and vegetables, Strawberries. http://www.oecd.org/tad/code/46597780.pdf (Access 27 April 2015).

Ornelas-Paz JDJ., Yahia EM, Ramírez-Bustamante N, Pérez-Martínez JD, Escalante-Minakata MDP, Ibarra-Junquera V, Acosta-Muñiz C, Guerrero-Prieto V, Ochoa-Reyes V (2013) Physical attributes and chemical composition of organic strawberry fruit (*Fragaria* x *ananassa* Duch, *Cv.* Albion) at six stages of ripening. Food Chem. 138: 372-381.

Pelletier W, Brecht JK, Nunes MCN, Émond JP (2011) Quality of strawberries shipped by truck from California to Florida as influenced by postharvest temperature management practices. Horttechnology. 21: 482-493.

Smith JP, Zagory D, Ramaswamy HS (2005) Packaging of fruits and vegetables. In: Barrett DM, Somogyi L, Ramaswamy H (ed) Processing fruits: Science and Technology, 2nd edn. CRC Press, Florida.

Sturm K, Koron D, Stampar F (2003) The composition of fruit of different strawberry varieties depending on maturity stage. Food Chem. 83: 417-422.

Terry LA, Mena C, Williams A, Whitehead P (2011) Fruit and vegetable resource maps: Mapping fruit and vegetable waste through the retail and wholesale supply chain. WRAP, RC008.