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The changes of physical properties in 'Elsanta' strawberries from the winter and summer cultivations after vibration tests

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Abstract

Strawberries (*Fragari*a x *ananassa* Duchesne) cv. 'Elsanta' were grown in the greenhouse during the winter and summer seasons of 2014 and 2015. A vibration test of strawberry fruits from these cultivations was carried out at the two frequency levels of 3 Hz and 5 Hz for 150 sec plus a control of no vibration to simulate transport. The physical properties (fruit weight, puncture, compression, electrical conductivity (EC), and respiration rate) and bruise incidence of fruits were determined after the vibration test (day 0) and after storage at 10^{o}C (±1^{o}C) and 70% RH (±5% RH) for 3 days (day 3). A higher average temperature (21 as opposed 25^{o}C) during strawberry growth and development of the summer crop gave a shorter period for harvesting, with a smaller fruit and a softer fruit as compared to a lower average temperature in the winter cultivation (8 to 21^{o}C). The fruit from the summer cultivation when vibrated at a frequency of 5 Hz were observed to have significantly higher for wet bruise (50% of total fruits), electrical conductivity (EC) and respiration rate (63.78 mgCO_2/kg.hr), as well as lower firmness values (puncture and compression tests) than other treatments ($p \leq 0.05$). The lower vibration level at 3 Hz of the winter strawberries did not affect the percentage of bruise and both firmness values ($p > 0.05$), whilst the EC method could noticeably distinguish the bruise incidence, particularly for a frequency of 5 Hz ($p \leq 0.05$). The EC method gave a highly significant correlation with wet bruise (r = 0.854) and severity score (r = -0.499) when compared with either firmness tests (puncture and compression) or respiration rate ($p \leq 0.01$). The EC technique is suggested for use as a bruise indicator of strawberries and an application for a bruise assessment for a whole strawberry punnet during postharvest handling operation and transport.

Keywords: bruise, firmness, electrical conductivity, vibration, strawberries.
Abbreviations: EC_electrical conductivity; PET_polyethylene terephthalate; *r*_ correlation coefficient; RR_respiration rate.

Introduction

Strawberries are susceptible to damage from impact and compression, but also vibration (Smith et al., 2004; Ferreira et al., 2008). In trial work, simulated vibration conditions of strawberries mostly focus on frequency, acceleration, and exposure time. For example, Jiang et al. (2001) studied the simulated vibration test of 'Toyonoka' strawberries, which were exposed to a frequency of 5 Hz with an acceleration of 1.6 *g* for 40 sec. In a simulated vibration test, Lu et al. (2008) suggested the shock and vibration values should be analysed separately by removing the shock value. In the vibration level monitored from actual transport, all frequencies were in the range of 3.35, 7 and 13.5 Hz with an acceleration range of 0.02 to 0.18 *g*, and this caused a strawberry bruise but was lower than the simulated condition (Kojima et al., 1999). In addition, the preharvest environmental conditions also affect the quality attributes and susceptibility to damage of strawberries after harvesting. A higher temperature affected the fruit size (smaller fruit) in 'Nyoho' and 'Toyonka' strawberries (Ledesma et al., 2008) as much as also producing less fruit firmness and a short fruiting period (Pyrotis et al., 2012; Palencia et al., 2013). Up to now, however, there is no published study on the effect of different seasons on the strawberry quality.

The important quality attributes of strawberries should be free from defect, juice leakage, spongy, bitterness and fermentation flavour (Mitcham 1996; Ṕeneau et al., 2007). Also, the appearance (firmness) was one of the most critical of strawberry quality characteristics (Mitcham, 1996; Shin et al., 2008). Bruise damage is normally found with mechanical damage of fresh produce and occurs in all steps of postharvest handling, but especially in packinghouse operations, transport and storage (Opara and Pathre, 2014). Commercially, the determination of fruit bruise is analysed in terms of percentage bruise area rather than bruise volume (Pang et al., 1992). In the case of the visual score of an individual strawberry fruit, the most acceptable score is recommended to have damage of less than 25% of surface bruise or damage (Shin et al., 2008; Fischer et al., 1992). Several studies thus far have linked fruit bruise damage with physical attributes such as fruit firmness (Fischer et al., 1992; Tatara et al., 1999), respiration rate (Massey et al., 1982) and electrical conductivity (Jiang et al., 2001; Bugard et al., 2014; Chaiwong and Bishop, 2015). An increase of electrolyte leakage has been used as a good indication of cell membrane integrity from mechanical damage, fruit ripening and chilling injury symptoms, which are associated with quality of fresh produce (Saltveit, 2002; Ahmed et al., 2010; Deng et al., 2005; Jiang et al., 2001; Milczarek et al., 2009; Zhou et al., 2007).

'Elsanta' strawberry is the most popular cultivar supplying the UK market due to the fruit firmness and good shelf-life (Terry, 2012; RW Walpole, 2014). No literature has been found on the differences in quality between winter and summer cultivations. Additionally, there has been little analysis of physical attributes as a rapid method to indicate strawberry bruise and to apply this to commercial practice during postharvest handling and transport. Thus, the two primary aims of this study were firstly to study the vibration test in 'Elasata' strawberries from the winter and summer cultivations at the two frequency levels (3 and 5 Hz) for 150 sec and to developing a non-destructive method as a bruise indicator, this study was secondly to analyse the correlation between physical attributes and bruise damage of 'Elsanta'stawberries.

Results and discussion

Bruise incidence and severity score

There has been a wide range of simulated vibration for strawberry tests, such as a frequency of 5-10 Hz (0.6-1.6 *g*) for 40-3600 sec (Fischer et al., 1992; Jiang et al., 2001; Nakamura et al., 2007; Nakamura et al., 2008). In the current study, the vibrated 'Elsanta' strawberries at 3 Hz (0.4 *g*) and 5 Hz (1.1 *g*) were only investigated for the exposure time of vibration for 150 sec, for both winter and summer cultivations. The results showed that the strawberry fruits from the summer cultivation were observed to have a significant reduction of undamaged fruits with an increase of wet bruise, particularly at a frequency of 5 Hz (1.1 *g*) for 150 sec ($p \leq 0.05$). The lowest percentage of undamaged fruits was found at a frequency of 5 Hz for both seasons (20%), while fruits from the summer cultivation at a frequency of 5 Hz (5 Hz-summer) gave the highest wet bruise (50%) ($p \leq 0.05$) (Fig 1a). These results are in agreement with Fischer et al. (1992), who found that the frequency of 5-10 Hz (0.6 *g*) for 600 sec gave the highest damage of 'Selva' strawberries.

In the current study, after storage at 10^{o}C for 3 days, the percentage of dry bruise increased to over 40% of total fruits, even where there was no vibration treatment (Fig 1b). Also, the vibrated punnets at 5 Hz for 150 sec from the summer cultivation gave the lowest severity score, followed by that frequency from the winter season ($p \leq 0.05$) (Fig 1a). However, there was no significant difference in severity score at a lower vibration level (0 and 3 Hz) ($p > 0.05$) (Fig 1a, b). In terms of vibration damage from actual transport of strawberries, the range of vibration frequencies was 3.5 to 13.5 Hz with a lower acceleration level (0.02-0.18 *g*) than the simulated vibration (Kojima et al., 1999). It is possible, therefore, that 'Elsanta' strawberries may have 30-80% bruising of total fruits after handling and actual transport within a day when exposed to vibration conditions at a frequency of 3 to 5 Hz (0.4 to 1.1 *g*). Also, the critically simulated vibration of 'Elsanta' strawberries from both cultivations was a frequency of 5 Hz for 150 sec and there was a significant increase of vibration damage from the late production (the summer season).

Fruit firmness (puncture and compression tests) and fruit weight

The spring and summer cultivations of 'Elsanta' strawberries is commonly carried out and supplies for the British strawberry market. In this study, the duration of their growth and development in the winter cultivation was longer than in the summer cultivation by approximately a month (36 days) (data not shown). The harvesting period for 'Elsanta strawberry fruits from the winter cultivation was in May, whereas the summer cultivation produced the mature strawberry fruits in August. As shown in Table 1, a wider range of average temperature was experienced in the greenhouse during the winter cultivation in 2014 and 2015 (8 to 21^{o}C) was lower than that of the summer cultivation in 2014 (21 to 25^{o}C). Growing temperature had a strong negative correlation with strawberry firmness (r = -0.87) (Pyrotis et al., 2012). Also, the effect of a higher temperature caused smaller fruit and a shorter fruit period (Singh et al., 2007). In this study, a higher temperature during the summer season produced considerably softer and smaller strawberries than those fruits of the winter season ($p \leq 0.05$) (Fig 2a, b and Table 2). The strawberries under a higher temperature (summer season) also gave lower firmness values by puncture and compression tests, particularly at a frequency of 5 Hz ($p \leq 0.05$). Conversely, there was not a significant difference in these firmness values between 3 and 5 Hz from the winter cultivation ($p > 0.05$) (Fig 2a, b). The fruit size of 'Elsanta' strawberry in the winter cultivation was larger than in the summer cultivation by 8 g per fruit ($p \leq 0.05$) (Table 2). These results of lower firmness levels related to an increase in the percentage of bruise and a reduction of the severity score in the summer cultivation (Fig 1). For the summer cultivation of 'Elsanta' strawberries, therefore, a higher temperature during strawberry growth and development produced significantly softer and smaller fruit and a higher bruise incidence as well as a shorter period of cultivation.

Electrical conductivity of vibrated strawberries

Electrical conductivity (EC) method is suggested for the evaluation of vibrated and pared fruits (Chaiwong and Bishop, 2015; Fischer et al., 1992). In the previous study by Chaiwong and Bishop 2015, the EC method showed a better evaluation of bruised 'Elsanta'strawberries from the winter cultivation rather than fruit firmness test. In the current study, the EC method could differentiate the strawberry bruise from lower to higher frequency (3 to 5 Hz), particularly at the frequency of 5 Hz ($p \leq 0.05$) (Fig 3c). The undamaged fruits from the summer cultivation (< 20 µS) had a higher EC value than those fruits from the summer cultivation (10 µS) ($p \leq 0.05$). The EC value of undamaged fruits from the summer cultivation was similar to that of the bruised strawberries from the 5 Hz frequency treatment of the winter cultivation ($p > 0.05$). The maximum EC level of undamaged fruits (50 µS) was observed at the highest frequency of 5 Hz from the summer cultivation ($p \leq 0.05$).

The conductivity level gradually decreased after storage at 10^{o}C for 3 days due to the possibility of wound healing of the

Table 1. Temperatures (°C) inside greenhouse at Writtle College during the winter cultivation in 2014 and 2015 and the summer cultivation in 2014.

Year	Temperature (°C)						
	The 1st winter cultivation				*The summer cultivation*		
2014	February	March	April	May	June	July	August
Mean	11.00	14.28	17.95	20.93	23.09	24.89	21.28
Max	38.61	45.02	48.14	53.02	46.01	50.92	44.15
Min	1.39	-1.09	1.61	1.86	11.78	10.31	7.96
2015	*The 2nd winter cultivation*						
Mean	8.70	11.83	15.64	17.70			
Max	27.60	40.45	42.94	39.05			
Min	-1.44	-1.45	1.52	-1.48			

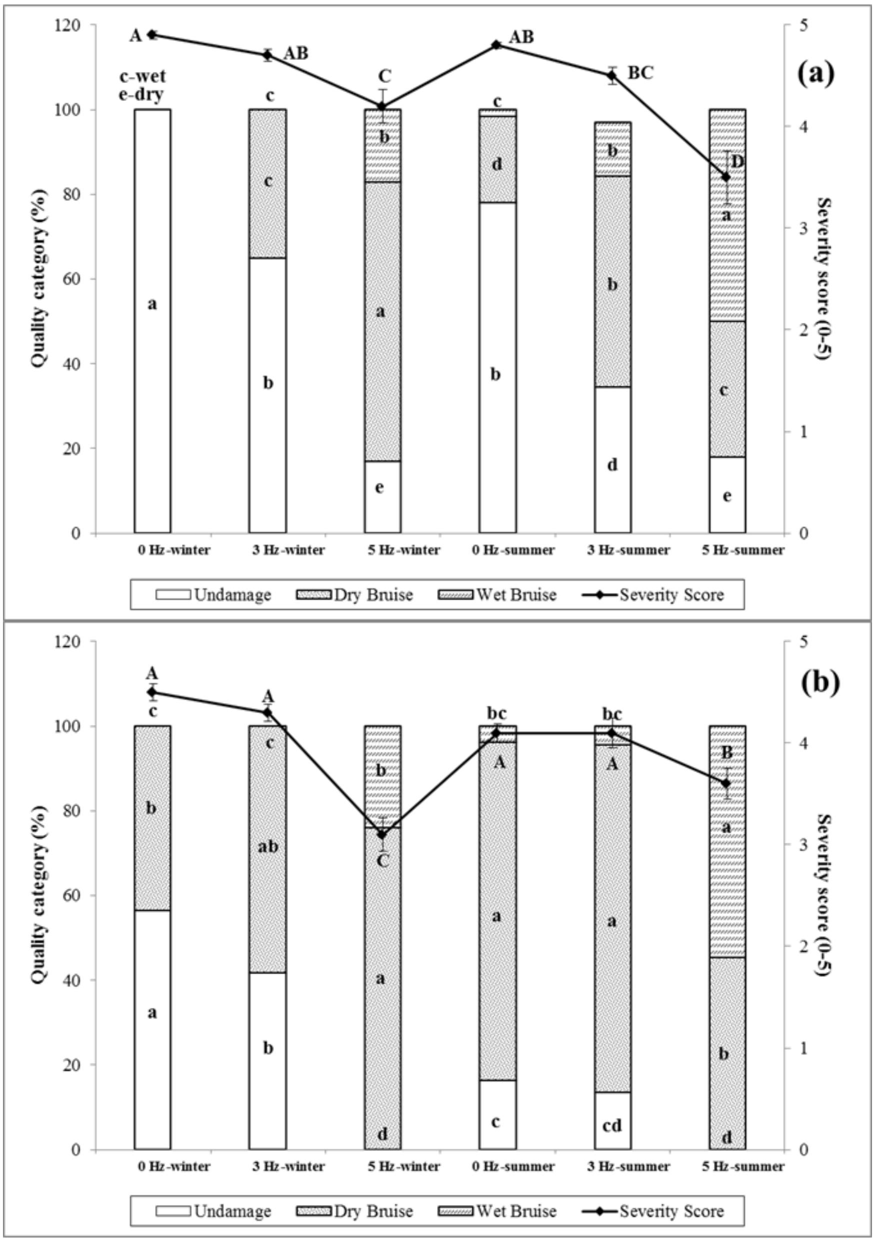

Fig 1. Distribution quality categories and severity score (%) of 'Elsanta' strawberries from the summer and winter cultivations after vibration test at 3 and 5 Hz for 150 sec on day 0 (a) and after storage on day 3 (b). Different letters in the different frequency levels in each parameter for DMRT test indicate significant differences at p≤0.05. Values are the mean ±S.E. from 5 replicates (winter) and 3 (summer) replicates.

Table 2. The fruit weight of 'Elsanta' strawberries produced from the winter and summer cultivations in 2014 after vibration test at 3 and 5 Hz for 150 sec on day 0 and after storage on day 3.

Treatment	Day 0	Day 3
0 Hz-winter	21.43[a]±0.20	19.51[a]±0.20
3 Hz-winter	20.34[a]±0.25	18.48[a]±0.20
5 Hz-winter	20.73[a]±0.20	18.18[a]±0.20
0 Hz-summer	13.75[b]±1.20	13.52[b]±0.20
3 Hz-summer	10.18[c]±0.31	10.81[c]±0.20
5 Hz-summer	10.60[c]±0.31	10.86[c]±0.20

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 winter cultivation, n = 3 summer cultivation).

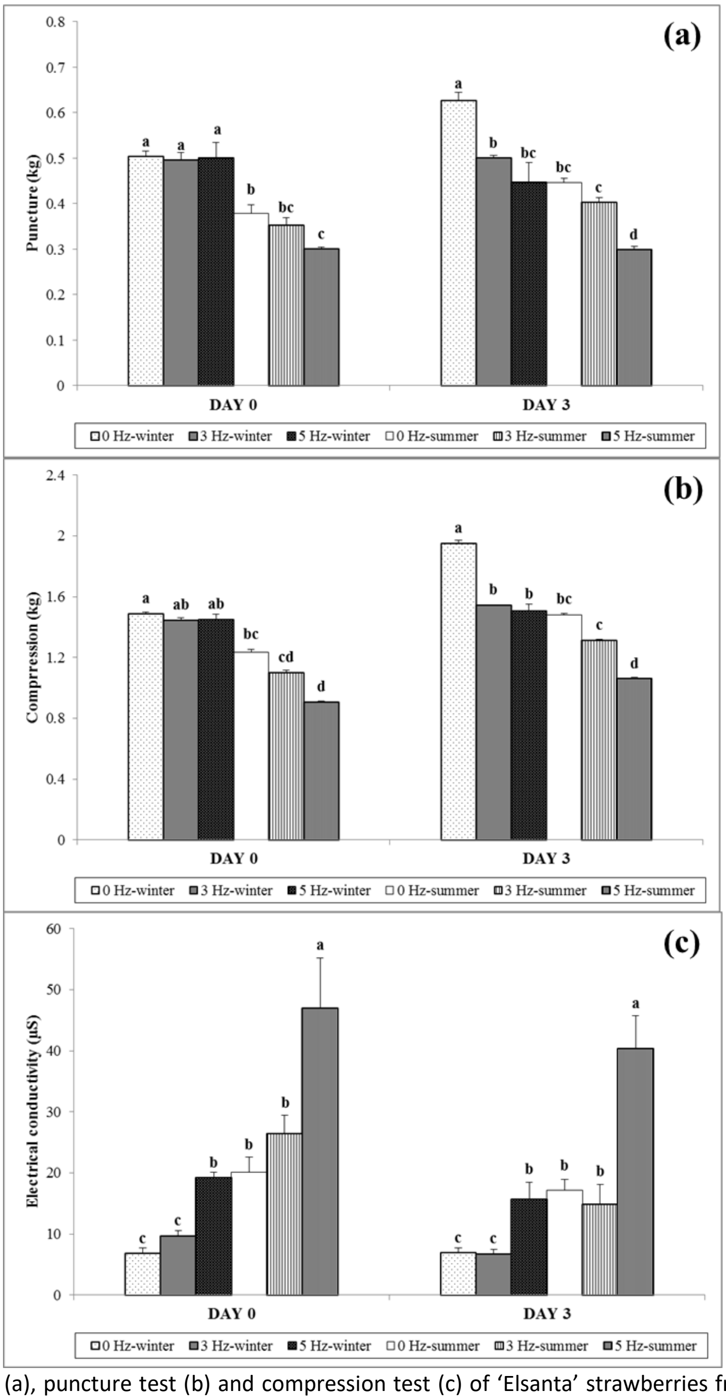

Fig 2. Electrical conductivity (a), puncture test (b) and compression test (c) of 'Elsanta' strawberries from the summer and winter cultivations after vibration test at 3 and 5 Hz for 150 sec on day 0 (a) and after storage at day 3 (b). Different letters in the different frequency levels for DMRT test indicate significant differences at p≤0.05. Values are the mean ±S.E. from 5 replicates (winter) and 3 (summer) replicates.

Table 3. The correlation coefficient (*r*) between EC value and firmness or fruit bruise of 'Elsanta' strawberries (day 0 and day 3) from the winter and summer cultivations after vibration test.

Properties	EC	Puncture	Compression	RR	Dry bruise	Wet bruise	Severity score	Fruit weight
EC	1.000							
Puncture	-0.758**	1.000						
Compression	-0.721**	0.875**	1.000					
RR	0.797**	-0.712**	-0.754**	1.000				
Dry bruise	-0.058	0.051	0.117	-0.043	1.000			
Wet bruise	0.854**	-0.629**	-0.585**	0.614**	-0.083	1.000		
Severity score	-0.499**	0.340	0.244	-0.309	-0.519**	-0.668**	1.000	
Fruit weight	-0.697**	0.741**	0.667**	-0.650**	-0.171	-0.466**	0.332	1.000

** Pearson's correlation is significant at 1% level in the winter and cultivations (n=48).

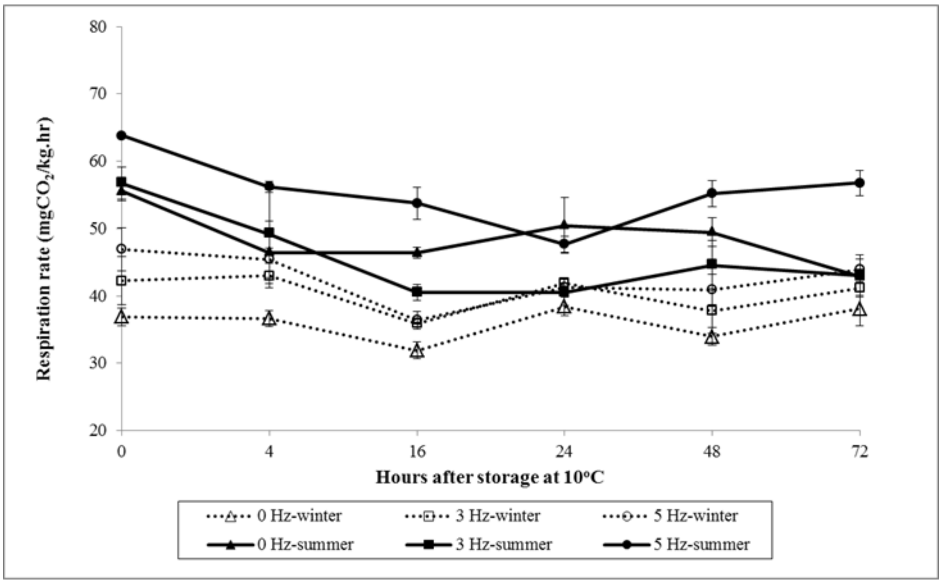

Fig 3. Respiration rate of 'Elsanta' strawberries from the summer and winter cultivations after vibration test at 3 and 5 Hz for 150 sec and then storage at 10^{o}C for between 0-72 hours. Values are the mean ±S.E. from 5 replicates (winter) and 3 (summer) replicates.

fruit (Fig 3c), which agreed with Chaiwong and Bishop (2015) and Jiang et al. (2001). Also, the number fruits with dry braise notably increased under the lowest vibration level at a frequency of 3 Hz (Fig 1b).

Respiration rate of 'Elsanta' strawberries

The respiration rate of strawberries at 10^{o}C have a typical range of respiration rate of 50-100 $mgCO_2$/kg.hr (Mitcham, 2014). In this study, the measured respiration rates of undamaged strawberries for the winter and summer cultivations were 37 and 56 $mgCO_2$/kg.hr respectively after an immediate test. As expected, a stronger vibration level produced a higher respiration rate of bruised 'Elsanta' strawberriesand this gradually reduced after the test within the first hour. The highest respiration rate was at a frequency of 5 Hz from the summer season (63.78 $mgCO_2$/kg.hr) (Fig 4). An increase of the respiration rate related to increased bruise damage, firmness and the EC values (Figs 1 and 2). Tatara et al. (1999) reported that the respiration rate of bruised strawberries from a vibration test increased by 17% at 15^{o}C as compared to undamaged fruits. Also, Fischer et al. (1992) found that there was an unclear pattern of respiration rate in vibrated 'Selva' strawberries. However, the changes of respiration rate in 'Elsanta'strawberries matched the pattern of respiration rate reported for olives in either unbruised or bruised fruits at 25^{o}C (Segovia-Bravo et al., 2011). Nevertheless, there have been few published research studies on the respiration rate of bruised strawberries. Further studies should be done to investigate the respiration rate of bruised strawberries at different temperatures.

Assessment of bruise damage

There has been very little discussion about the physical properties to evaluate bruised berries with differentiated bruise incidence and severity levels, particularly strawberries bruised from vibration damage. In this vibration study, the correlation between physical properties and bruise damage was analysed for all six treatments and storage conditions. As shown in Table 3, the EC method gave a significantly higher correlation with wet bruise (r = 0.855) than puncture test (r = -0.629), respiration rate of a static system (r = 0.622), and compression test (r = -0.585) ($p \le 0.01$). Also, the EC method had greater correlation with severity score when compared with the other three methods ($p \le 0.01$). These results agreed with the previous report by Chaiwong and Bishop (2015). The EC method still had a significant negative correlation with 'Elsanta' strawberry bruise (r = -0.764) and was not significantly associated with EC method and firmness test after vibration test on the first day. In this study, in terms of firmness test, puncture and compression tests there was a significant relationship with fruit size (weight) (Table 3). However, there was not a consistent relationship between fruit size and firmness of strawberry fruits as well as variations in the method of testing, probe size and fruit cultivar (Døving and Måge, 2002). Tatara et al. (1999) found that the vibration of strawberries caused a reduction of firmness by puncture test. In contrast, Fischer et al. (1992) reported that maximum damage from vibration test at 5 to 10 Hz (0.6 *g*) for 600 sec did not relate to strawberry firmness. Evaluation by the respiration rate of CO_2 was used as an indicator of bruise damage in small fruits such as sweet cherries, blueberries and cranberries (Burton and Schulte-Pason, 1987; Massey et al., 1982). In the current study, the respiration rate of strawberries showed a good indication for a bruise assessment as well as the firmness tests (Table 3). For a commercial practice for strawberry handling and operation, the firmness tests cannot be carried out on each individual punnet (only an individual fruit test) and also may give inconsistent results due to the variation of fruit size and pulp temperature. In addition, the respiration rate in each punnet requires a long period of measurement for the CO_2 accumulation (minimum of 7200 sec). Therefore, the EC value is recommended to be used as an indicator of bruised strawberries and applied to be a rapid technique of non-destructive method. It has potential to be used to evaluate the assessment of bruising of a whole strawberry punnet and other soft fruits during handling and transport.

Materials and methods

Plant materials

The 'Elsanta' strawberry plant was supplied by RW Walpole Ltd, UK, with a crown size of over 15 mm and A+grade. Two hundred strawberry plants in each season were grown in the greenhouse at Writtle College, Chelmsford. The winter and summer cultivations were carried out during February to May and June to August in 2014, respectively. For the respiration rate trial of strawberry punnet, the strawberries were produced the winter production in 2015 in the same period of months in 2014. The temperature inside the greenhouse during fruit cultivation was recorded every 20 minutes by temperature logger (Tinytak Talk2, Gemini Data Loggers Ltd., UK) and reported for each month in terms of average, maximum and minimum temperatures.

The fruit maturity was selected from a fruit weight of 10 g (summer) and 20 g (winter) and a full red colour with total soluble solids over 8%. The pack size of 'Elsanta' fruits was 250 g and packed in polyethylene terephthalate (PET) vented punnets (105 x 170 x 60 mm) with a piece of bubble sheet (75 mm x 152 mm) as for supermarket presentation. After harvesting and packing within 2 hours, the strawberry punnet was cooled by room cooling as opposed to forced air cooling until the pulp temperature dropped to 7.0^{o}C ($\pm$1^{o}C) which was a maximum of 4 hours. The PET punnet was top sealed with plastic film with an six 8 mm diameter perforations (Adare Advantage Ltd).

Vibration test

The strawberry punnets from the winter and summer cultivations were placed on the platform of an orbital shaker at a fixed amplitude of 16 mm (Stuart SSL1, UK). There were ten punnets (five punnets in each row) on a platform in a single layer. The five (winter cultivation) and three (summer cultivation) punnets (replicates) were exposed to vibration tests at 3 Hz (0.4 *g*) and 5 Hz (1.1 *g*) for 150 sec. The control punnet in each cultivation had no vibration test. The acceleration and exposure time of strawberry test was controlled and reported in the previous research study by Chaiwong and Bishop (2015).

Quality determination and storage condition

Strawberry quality from the winter and summer cultivation in 2014 was evaluated immediately after the vibration test (day 0) and after a cool storage at 10$\pm$1^{o}C and relative humidity (RH) at 70% (±5% RH) for 3 days (day 3).

Evaluation of percentage of quality category and severity bruise score

The fruit in each punnet was evaluated by visual assessment and categorized for undamaged, dry and wet bruises. The number of fruits in each category was calculated to be percentage of quality category. The individual fruit in each punnet was also scored from undamaged level (score 5) to very severely damaged level and mould symptom (score 1) using an adapted rating score of Fischer et al. (1992). The acceptable score of strawberry quality was limited over a severity score of 3 level, which was less than 30% bruise of fruit surface.

Firmness evaluation and fruit weight

Fruit firmness was evaluated by puncture and compression methods for a random three fruits in each punnet and each method. Each fruit was measured on the external shoulder using fruit texture analyser GS-20 (GüSS Manufacturing (Pty) Ltd, South Africa) and expressed in maximum peak of force (kg). The testing condition was at 10 mm/sec of a measurement speed and an 8.9 mm of a measured distance. Two sizes of probe were used: a 8 mm cylinder probe for the puncture test and a 42 mm compression platens for the compression test. Again, an individual fruit was randomly weighed for three fruits in each punnet with a digital balance (Mettler PE 600, Precisa Balances Limited, UK).

Electrical conductivity measurement

Electrical conductivity (EC) of bruise strawberry was adapted using the technique of Jiang et al. (2001). After day 0 and storage condition (day 3), five fruits (winter cultivation) and eight fruits (summer cultivation) in each punnet were immersed in a 500 ml of distilled water in a 600 ml beaker. The temperature of the sample beaker was controlled at 25^{o}C for 10 min by water bath (Phillip Harris, UK). The immersed fruits were gently stirred for 5 sec and measured by handheld conductivity meter (CyberScan CON 110, Eutech Instruments, USA) and expressed as µS.

Respiration rate measurement

Strawberry fruits from the winter cultivation in 2015 and the summer cultivation in 2014 were determined respiration rate (RR) by a static system. The strawberry punnet (250 g) was placed in a closed plastic food container (3,800 ml). The gas accumulation was collected for two hours after vibration test and low temperature storage. Gas sampling was measured at 0, 4, 16, 24 (day 0), 48 (day 2), 72 (day 3). CO_2 gas determination of strawberry punnet was measured using a combo gas analyzer (David Bishop Instruments Ltd, UK). The respiration rate was calculated and reported in $mgCO_2$/kg.hr.

Statistical analysis

The design of this experiment was conducted using a completely randomized design for 6 treatments with 5 replicates (winter cultivation) and 3 replicates (summer cultivation). Statistical analysis was carried out using SPSS version 16.0 by Duncan's multiple range test (DMRT). Physical properties and bruise score of strawberries were analysed variance at 5% level of significance ($p \leq 0.05$). The correlation coefficient (*r*) between physical properties (EC, firmness, RR and fruit weight) and bruise incidence or level was calculated by Pearson's correlation at the 1 % level of significance ($p \leq 0.01$).

Conclusion

Growing 'Elsanta' strawberry plants under a higher temperature produced a significant reduction of fruit firmness after vibration test and storage ($p \leq 0.05$). Vibration test at a frequency of 5 Hz for 150 sec provided the lowest firmness and EC values as well as the highest respiration rate, particularly for fruits from the summer cultivation. The EC method had a significant relationship with wet bruise and bruise score as compared to firmness tests by puncture and compression tests, and respiration rate method ($p \leq 0.01$). The EC technique is recommended to be used as a bruise indicator of strawberries for the bruise assessment of either a whole punnet or other soft fruits during postharvest operation, transport and distribution.

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