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Cultivar and fruit size influence bruise susceptibility and some physical properties of apple fruit

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ABSTRACT- For most fruit types, including apples, bruising is the most common type of postharvest mechanical injury. Bruise susceptibility was investigated in 3 commercial cultivars ('Jazz^{TM}', 'Granny Smith' and 'Fuji') and among a range of 4 different fruit sizes (commercial counts of 135, 120, 100, and 88) in each cultivar. Bruising was carried out by dropping a uniform round steel ball (110g) from a height of 30 cm through a vertical hollow PVC pipe onto the apples. Fruit physical properties and bruise assessments were evaluated. The results showed that 'Jazz^{TM}' and'Granny Smith' apples had the lowest and highest bruise susceptibility, respectively, indicating that 'Granny Smith' apple would be more likely to be bruised during harvest and post-harvest handling. Results also showed that smaller fruits were less susceptible to bruising. There was a positive significant correlation between fruit bruising and fruit volume; but, there were significant negative correlations between fruit bruising and fruit density, fruit firmness and fruit dry mater. These findings will be very useful to reduce the incidence of fruit damage of studied apple cultivars, which is of interest to both growers and operators of postharvest handling and marketing facilities.

INTRODUCTION

Bruising has been defined as damage to plant tissue by external forces causing physical change in texture and/or eventual chemical alterations of color, flavor, and texture (Mohsenin, 1986). The bruising is initiated by the breakage of cell membranes, allowing cytoplasmic enzymes to act on sequestered substrates (Ragni and Berardinelli, 2001). The resultant browning is caused by the enzyme action on phenolic substrates. This is not restricted to visual aspects, but higher risk of bacterial and fungal contamination, leading to a lower shelf-life, also results from this damage (Schulte et al., 1992).

Apple fruit bruising is a major quality problem, which occurs mainly due to excessive impact and compression forces during harvesting and postharvest handling operations (Ericsson and Tahir, 1996). Dynamic forces during fruit transport and handling cause by far the most bruise damage because these forces are higher in incidence and magnitude than static forces (Mohsenin, 1986). To reduce the incidence of fruit damage, knowledge of fruit sensitivity to bruising is of interest to both growers and operators of postharvest handling and marketing facilities (Ericsson and Tahir, 1996).

A considerable amount of research has been done on apple impact damage, meanwhile, bruise damage is still a major problem in the fruit sector (Van Zeebroeck et al., 2006). Although bruising had been investigated for more than 45 years, most of the past researches have focused on pre- and post-harvest factors related to bruising, or developing the detection methods for packing industry, and there is no research on the genetic-related aspects of resistance or differences of cultivar susceptibility to bruising (Pang et al., 1996). Bruising varies among varieties, and the amount of bruising which occurs at a constant value of impact energy is variable (Ericsson and Tahir, 1996; Pasini et al., 2004; Bollen, 2005; Kupferman, 2006).

In some cultivars, bruising may result in down-grading of up to 50% of the total crop picked (Mohsenin, 1986; Studman et al., 1997). Even for the same cultivar, industry experience indicates that fruit appears to be more susceptible to bruising under some cultivation practices, harvest and post-harvest handling conditions (Garcia et al., 1995). If a particular shipment of fruit is known in advance to be highly susceptible to bruising, then damage can be reduced by adjusting the flow rate through the grading machinery and by increasing the level of care at all stages of handling. However, this is costly in terms of time and labour, and it is essential that any adjustments be made as soon as possible. It is, therefore, important to be able to assess bruise susceptibility of a new line of fruit rapidly (Pang et al., 1996). Also, bruising may be intensified by some other factors such as texture, water content, fruit shape, temperature, size and a series of fruit interior factors such as firmness, modulus of elasticity, strength of cell walls, internal structure and cell shape (Studman et al., 1997; Scheerlinck et al., 2006; Jafari and Nassiri, 2013).

Breeding bruise resistant cultivars offers a better and more permanent solution to the problem. Therefore, understanding the bruising behaviour of different cultivars is important. According to comparisons of commercial cultivars, there is a genetic component to explain the susceptibility to bruising (Schulte et al., 1992; Pang et al., 1996; Ragni and Berardinelli, 2001; Pasini et al., 2004; Bollen, 2005). The differences between cultivars can be explained by dissimilar mechanical properties of the cultivars due to differences in fruit structure and mechanical properties like cell wall strength, cell wall elasticity, intracellular bonding, etc., all of which could be controlled genetically.

Bruise damage can occur in any stage of fruit long journey, from orchard to consumer; specially in sorting, grading, and transportation to market that commonly took place after storage. As the effect of fruit size on bruise susceptibility is not clearly known and also there is little information on differences of bruising properties in apple cultivars, in this study, we sought to determine variation in bruise susceptibility of different fruit sizes in three commercial cultivars and also to evaluate some fruit characteristics that might explain this variation.

MATERIALS AND METHODS

Fruit Materials

Commercial apple cultivars 'Fuji', 'Granny Smith', and 'Jazz™' were harvested at their respective commercial harvest times (using starch test method) in the Hawke's Bay region of New Zealand, and after grading, fruits were put in cool-store at 0.5 ˚C. Grading was done using a grading machine based on internationally accepted commercial counts. In this method of grading, a commercial count represents number of fruits of special size that could be packed in a standard fruit box (supposed to contain 18-20 kg of fruits). The commercial fruit counts used for grading in this experiment were as fallow; count 135 (average fruit size =137 ± 7 g), count 120 (average fruit size = 155 ± 10 g), count 100 (average fruit size = 180 ± 15 g), count 88 (average fruit size = 210 ± 15 g).

Fruit Evaluation

After 4 months from harvest date, fruits were transferred to 20˚C for 24 h, and 15 fruit of 4 common commercial size counts [135 (137 ± 7 g), 120 (155 ± 10 g), 100 (180 ± 15 g), 88 (210 ± 15 g)] per replicate (3 replicates), per cultivar (total of 180 fruits per cultivar) were randomly selected and numbered for bruise measurement. Prior to bruise testing, individual fruit was weighed using a digital balance with accuracy up to 0.001 g and then fruit volume was measured (by floating on water, using a container of water set up on a platform digital balance) to calculate whole fruit density. Fruit density was calculated using this formula; D = M/V; where D = Fruit density (g/cm^3), M = Fruit weight (g) and V = Fruit volume (cm^3). Bruising was carried out by dropping a uniform round steel ball (110 g) from a height of 30 cm through a vertical hollow PVC pipe onto the apple (Opara, 2007). The opposite sides of the pipe were perforated along the pipe length to minimize air resistance, which permit a free fall of the steel ball during impact testing. During testing, fruit was placed on double layer paperboard to ensure that bruising occurs only on the impacted surface. Each fruit was tested twice on opposite sides along the equatorial axis and the data were averaged to give one reading per fruit. Under these impact conditions, it was assumed that virtually all of the energy of the ball was absorbed on the first impact (Banks and Joseph, 1991). Bruised fruits were put in paper bags and held in the laboratory at room temperature (22 ˚C; 45% RH) for about 20- 24 h prior to the evaluation. Bruise sizes were measured using a slice of tissue obtained by vertically cutting the fruit at a perpendicular axis through the centre of bruise down to the fruit core. Bruise diameter (*d*) and depth (*h*) were measured using a digital calliper (± 0.01 mm). Bruise volume (mm^3) was calculated (Eq. 1), assuming a spherical shape below and above the contact plane, using thickness method (Mohsenin, 1986):

Eq. 1. $$BV = \frac{\pi h}{24}(3d^2 + 4h^2) \qquad (1)$$

where *h* is the bruise depth at the centre (mm) and *d* the bruise diameter (mm).

General bruise susceptibility (mm^{3}J^{-1}) is defined as the ratio of bruise volume (Eq. 2) to the impact energy (Eq. 3), IE (J):

$$GBS = \frac{BV}{IE} \qquad (2)$$

$$IE = m_i g h_D \qquad (3)$$

where m_i is the mass of the impacting object (kg), *g* the acceleration due to gravity (ms^{-2}), and h_D is the drop height (m).

In an attempt to reduce the possible future effects of fruit mass on measured bruise susceptibility, specific bruise susceptibility (SBS, mm^{3}J^{-1}kg^{-1}) that has already been defined by Opara (2007) was calculated by Equation 4:

$$SBS = \frac{GBS}{m_F} \qquad (4)$$

where m_F is the mass of fresh fruit (kg).

After bruise measurements, fruit firmness was measured in both sides of bruised fruits (opposite side of bruising) using table penetrometers (Model FG5005, Luton, Taiwan). For fruit dry matter, from each fruit, two longitudinal wedges of 15-25 g, one from each side (including skin but excluding seeds and woody core tissue) were removed. After measuring fresh weight, fruit pieces were put in small Petri dish and then were put in dehydrators rack (20 sample per rack, and maximum 6 rack + two empty on the top and bottom per dehydrators). Samples were dried for 24 hours at 65 ˚C and then dry weight was measured using digital balance with accuracy up to 0.001 g.

Statistical Analysis

Data were subjected to analysis of variance (ANOVA). Sources of variation were cultivar and count, and the interaction of cultivar × count. Mean comparisons were performed using the LSD test (Cody et al., 1991) to examine if differences between cultivar and count were significant at $P < 0.05$. As the interaction between cultivar and count were not significant at $P < 0.05$ for almost all of measured fruit attributes, then the means were presented only for main effects. Correlation analyses between measured parameters were carried out using the correlation program in MINITAB 16. Correlations were obtained by Pearson's correlation coefficient (r) in bivariate linear correlations. Principal component analysis (PCA), an unsupervised pattern recognition technique, was used in order to observe trends in the data indicating relationships between samples and/or between variables (Massart et al., 1997; Brereton, 2003). All analyses were performed with SAS software package v. 9.1 (SAS Institute, 1985).

RESULTS AND DISCUSSION

Fruit Physical Properties

'Granny Smith' and 'Jazz™' apples showed the highest (206.83 cm^3) and lowest (187.48 cm^3) fruit volume, respectively and 'Fuji' was ranked as intermediate (199.73). When comparing the different counts, the value of fruit volume was increased from count 135 (smaller fruit size) to 88 (bigger fruit size).

The highest and lowest fruit density was recorded in 'Jazz™' and 'Granny smith' (0.91 and 0.82 g/cm^{-3}, respectively) and 'Fuji' had intermediate fruit density (0.85 g/cm^{-3}) (Table 1). When comparing different counts, the value of this parameter was decreased from count 135 to 88.

The trends of fruit firmness were similar to that of fruit density; 'Jazz™' had the highest value (7.43 kg/cm^2), 'Granny Smith' and 'Fuji' (with no significant difference) were placed in the second position (Table 1). When comparing different counts, values of this trait were significantly different between counts (except for counts 100 and 88) and the trend was decreasing from count 135 to 88.

The highest fruit dry matter was measured in 'Jazz™' (16.90 %), the lowest was recorded in 'Granny Smith' (13.55 %) and 'Fuji' was intermediate (15.92 %). When comparing different counts, the value of this trait did not have a clear trend (Table 1).

Bruise Assessment

Results showed that parameters related to the size of bruises (including diameter, depth and volume) were affected by both cultivar and fruit size (Table 2). There were significant differences between cultivars, with 'Jazz™' having the lowest (15.51 mm, 7.14 mm and 876.8 mm^3 for bruise diameter, depth and volume, respectively), and 'Granny smith' having the greatest (18.83 mm, 9.17 mm and 1697.01 mm^3 for bruise diameter, depth and volume, respectively) bruise size. The value of bruise volume for 'Fuji' was close to that of 'Granny Smith' but with bigger bruise diameter and smaller bruise depth compared to 'Granny Smith'. When comparing different commercial counts, the three trends mentioned above about bruise size related parameters were increasing from count 135 to 88.

Results also showed that Bruise susceptibility parameters (including GBS and SBS) were also affected by both cultivar and fruit size (Table 2); 'Granny smith' was the most bruise susceptible cultivar (GBS = 5.24 mm^3J^{-1} and SBS = 31.18 SBS, $mm^3J^{-1}kg^{-1}$), closely followed by 'Fuji' (there was no significant difference in SBS between 'Granny smith' and 'Fuji') whereas 'Jazz™' remained significantly less susceptible than 'Fuji' and 'Granny smith' (GBS = 2.71 $mm^3J^{-1}$and SBS =16.02 SBS, $mm^3J^{-1}kg^{-1}$). Comparing different commercial counts, the trend of GBS was increasing from count 135 to 88, but for SBS, as the effect of fruit mass was eliminated in the calculation of this parameter, not surprisingly, the trend was decreasing from count 135 to 88.

Table 1. Effect of fruit size and cultivar on physical properties of apple fruit.

	Fruit Weight (g)	Fruit Volume (cm^3)	Fruit Density (g/cm^3)	Firmness (Kg/cm^2)	Dry Matter (%)
Cultivar					
'Jazz™'	171.27a	187.48c	0.91a	7.43a	16.90a
'Granny Smith'	170.1a	206.83a	0.82c	4.64b	13.55c
'Fuji'	169.83a	199.73b	0.85b	4.67b	15.92b
LSD $_{P=0.05}$	1.66	3.38	0.003	0.09	00.75
Commercial Count					
135 (137 ± 7 g)	137.6d	158.18d	0.87a	5.82a	15.74a
120 (155 ± 10 g)	154.5c	179.25c	0.86b	5.64b	14.85b
100 (180 ± 15 g)	178.58b	208.27b	0.85c	5.47c	15.49ab
88 (210 ± 15 g)	210.96a	246.34a	0.85c	5.38c	15.75a
LSD $_{P=0.05}$	1.91	3.9	0.004	0.1	00.86

Means followed by different letters are significantly different at $P \leq 0.05$.

Table 2. Effect of fruit size and cultivar on bruise assessment of apple fruits.

	Bruise size			Bruise susceptibility (BS)	
	Diameter (mm)	Depth (mm)	Volume (mm^3)	General BS (mm^3J^{-1})	Specific BS (SBS, $mm^3J^{-1}kg^{-1}$)
Cultivar					
‘Jazz™’	15.51c	7.14c	876.8c	2.71c	16.02b
‘Granny Smith’	18.83b	9.17a	1697.01a	5.24a	31.18a
‘Fuji’	19.47a	8.65b	1640.69b	5.07b	30.40a
LSD $_{P=0.05}$	00.38	0.14	50.67	0.15	01.2
Commercial Count					
135 (137 ± 7 g)	17.49c	7.97c	1266.75d	3.91d	28.49a
120 (155 ± 10 g)	17.67bc	8.30b	1368.80c	4.23c	27.38a
100 (180 ± 15 g)	17.96b	8.43ba	1432.23b	4.42b	24.85b
88 (210 ± 15 g)	18.64a	8.57a	1551.66a	4.79a	22.75c
LSD $_{P=0.05}$	00.44	0.16	0058.5	0.18	01.39

Means followed by different letters are significantly different at $p \leq 0.05$.

Correlation Between Parameters

Correlation coefficients between fruit physical properties and bruise related parameters are presented in Table 3. Fruit weight was highly correlated (R = 0.96) only with fruit volume. Fruit volume had significant but relatively low positive correlations with bruise diameter, depth and volume as well as general bruise susceptibility (R = 0.42, R= 0.44, R = 0.47 and R = 0.47, respectively) and also negative correlations with fruit density and firmness (R = -0.35 and R = -0.33, respectively). Fruit density and firmness also were highly and positively correlated with each other and both of them with the same trend had very high negative correlations with all of bruise related parameters (Bruise diameter, depth and volume, GBS and SBS), but high positive correlations with dry matter. All bruise related parameters were also correlated highly and positively with each other.

Principal Component Analysis

Results obtained from bruise analysis of apples (GBS, SBS, bruise diameter, bruise depth and bruise volume) and fruit physical parameters (fruit density, fruit weight, firmness, dry matter, fruit volume), were submitted to PCA, then two main PCs were used to generate the bi-plot diagram (Fig. 1).

Considering the bi-plot (Fig. 1), SBS and GBS present a similar trend, which is opposite to those of fruit density, dry matter and firmness pattern. Moreover, this analysis has also revealed the relationship between bruising parameters and other variables quite similar to the results obtained from correlation analysis. Accumulated bruising depth, diameter, and volume presented a direct relationship with GBS and in a lesser extent with SBS and fruit volume. On the other hand, accumulated dry matter presented an inverse relationship with the contents of the SBS and the same trends were seen for firmness and fruit density and bruise size related parameters and GBS of apples.

Table 3. Correlation coefficients between fruit physical properties and Bruise related parameters

N= 36	Fruit Weight	Fruit Volume	Fruit Density	Bruise Diameter	Bruise Depth	Bruise Volume	General Bruise Susceptibility	Specific Bruise Susceptibility	Fruit Dry mater
Fruit Volume	0.96***								
Fruit Density	NS	-0.35*							
Bruise Diameter	NS	0.42**	-0.87***						
Bruise Depth	NS	0.44**	-0.97***	0.86***					
Bruise Volume	NS	0.47**	-0.95***	0.95***	0.95***				
General Bruise Susceptibility	NS	0.47**	-0.95***	0.95***	0.95***	0.99***			
Specific Bruise Susceptibility	NS	NS	-0.86***	0.81***	0.80***	0.82***	0.82***		
Fruit Dry mater	NS	NS	0.70***	-0.41**	-0.71***	-0.55***	-0.55***	-0.57***	
Firmness	NS	-0.33*	0.95***	-0.94***	-0.94***	-0.97***	-0.97***	-0.88***	0.57***

NS: not significant, * Significant to 0.05P level, ** Significant to 0.01 P level, *** Significant to 0.001 P level

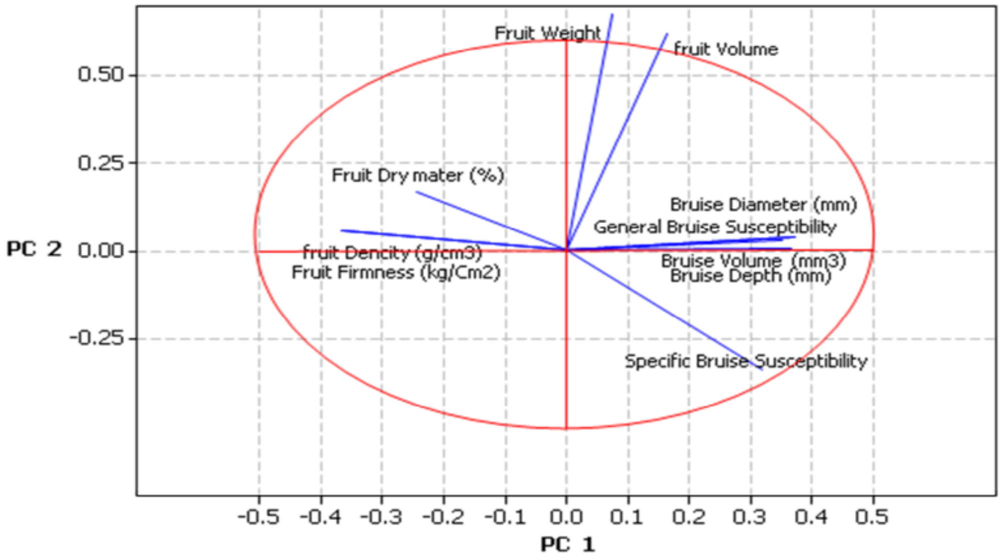

Fig. 1. Biplot of the two main principal components of different measured parameters in apple

Fruit Physical Properties

According to the results (Table 1), as it was expected, there was no significant difference in fruit weight among cultivars because fruits were graded based on weight prior to evaluation and the same sizes were chosen for all cultivars in each commercial count. Considering fruit physical properties, 'Jazz^{TM}' was ranked as a superior cultivar, having lower fruit volume but higher fruit density, firmness and dry matter. From this point of view, 'Granny smith' was placed in the lowest position and 'Fuji' was intermediate, but located closer to 'Granny smith' than 'Jazz^{TM}'. 'Jazz^{TM}' is a trademarked brand of the 'Scifresh' apple cultivar which was developed in New Zealand (Malone, 2005). This promising cultivar is resulted from cross between 'Braburn' × 'Royal Gala' and was launched commercially in April 2004. This cultivar is very famous for its best texture (especially crunch, density and firmness) and flavor (Malone, 2005). Outstanding quality characteristics of this cultivar have been proved by results of this study. Comparing different fruit counts from the physical property point of view, not surprisingly, smaller fruit had higher density and higher firmness than larger fruit but the trend for dry matter was not clear.

Bruise Assessment

According to the results, almost all bruise-related parameters (Table 2) are affected by cultivar and fruit size. Based on these assessments, 'Jazz^{TM}' is the least susceptible and 'Granny smith' is the most susceptible cultivar. When comparing their SBS (eliminating the effect of fruit mass), there were no significant differences between 'Granny Smith' and 'Fuji'. The value of bruise volume for 'Fuji' is also very close to that of 'Granny Smith'. There is no report on bruise susceptibility of 'Jazz^{TM}' apple but superiority of its parent ('Gala' and study has been proved previously by Pasini et al. (2004) 'Braeburn') compared to other two cultivars used in this who demonstrated that 'Gala' apples are less susceptible to mechanical impact than 'Fuji' apples, and Pang et al. (1996) who found that 'Braeburn' apples are less susceptible to bruising than 'Granny Smith' apples. Since 'Granny smith' has a uniform green color, bruises would be visible relatively easily, indicating that it needs special cares during harvest and postharvest handling whereas in 'Fuji', they would be harder to see (Pang et al., 1996). Ragni and Berardinelli (2001) also reported the 'Granny smith' among the susceptible cultivars to bruising.

Bruise susceptibility is cultivar dependent and the differences between cultivars can be explained by dissimilar physical and mechanical properties of the cultivars due to differences in fruit internal factors like cell wall strength, cell wall elasticity, intracellular bonding, etc. (Schulte et al., 1992). The effect of cultivar on the incidence of bruising can be multiple because (1) the apple shape contributes to bruise sensitivity by either enhancing or reducing the pressure during impact due to surface irregularities, radius of curvature, resistance to rolling, etc. (2) differences in fruit structure determine the exposure of sensitive tissue to impacts and (3) the composition of cell walls also affects the fruit's response to physical injury. All these factors mutually distinguish various cultivars (De Ketelaere et al., 2006).

For all cultivars, bruise susceptibility was affected by fruit size and all bruise parameters (except SBS) increased with increased fruit size, thereby showing a direct relationship between bruise parameters and fruit size. Larger fruit is more prone to bruise in handling operations because they have a higher kinetic energy thus they impact energy when dropped. Larger fruits are generally composed of larger cells with less cell wall material and cell-to-cell contacts, which results in reduced tissue strength (Harker et al., 1997). Also, the strength field inside the fruit depends on the fruit geometry (Johnson and Johnson, 1987), described in the easiest form by the fruit maximal diameter and the so-called fruit index as a ratio of the fruit axial length to the FMD. A similar effect of the fruit mass with respect to bruise susceptibility was reported by Van Zeebroeck et al. (2006).

Correlations and Principal Component Analysis

Principal components analysis is a multivariate statistical technique for exploration and simplifying complex data sets. This method has the ability to transform a number of possibly correlated variables into a smaller number of variables called principal components. Each principal component is a linear combination of the original variables; so, it is often possible to ascribe the meaning to what the components represent (Everitt and Dunn, 1992). Bruise parameters had a very high and negative correlation with fruit firmness and fruit density and a relatively high negative correlation with fruit dry matter (Table 3). In other words, firmer fruit was shown to be less susceptible to bruising. Considering PCA, also opposite tendencies were observed between bruise parameters and fruit characteristics such as firmness, density and dry matter which were in accordance with the results obtained from correlation analysis. Fruit volume influences the bruise of apples, and as it was expected according to the results of PCA and correlation, apples with higher fruit volume suffered a significantly higher bruise damage compared to those of lower fruit volume. It is worth emphasizing that the correlation between firmness and bruise susceptibility has been reported in apple (Garcia et al., 1995; Van Zeebroeck et al., 2006), pear (Garcia et al., 1995) and banana (Banks and Joseph, 1991). It is also known that the characteristics of different cultivars are responsible for severity of bruise damage (Schulte et al., 1992). Ragni and Berardinelli (2001) also used statistical models to determine the correlations among the parameters describing the alterations, the impacts, the mechanical responses and the characteristics of apple fruits. They concluded that in the study on the mechanical behavior of apple fruit responding to shocks, the fruit properties, particularly the geometry of the impact zone, the fruit firmness and the dry refract metric residue should be considered.

CONCLUSIONS

This experiment enabled the ranking of apple cultivars studied according to their bruise susceptibility. 'Granny smith' was ranked as the most bruise susceptible cultivar, indicating that it needs special care during harvest and postharvest handling. Newly commercialized 'Jazz^{TM}' cultivar with outstanding quality characteristics was ranked as the least susceptible cultivar, which showed that it has good potentials for postharvest handling. Larger fruits were more prone to bruising than smaller ones and this fact should be considered in treating them in harvest and postharvest handling to reduce the mechanical damages and economical lost. Correlation and PCA analysis showed that bruise susceptibility is highly correlated with some of fruit characteristics such as firmness, density, dry matter, so that these fruit features could be used as an indirect indicator for bruising behaviours of apple cultivars. The ball drop test indicates a significant difference between cultivars as well as commercial counts (fruit size), showing that it is a reliable indicator of bruising levels; however, the results of laboratory tests do not always agree with experience of the growers and commercial operators.

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اثررقم واندازه میوه بر حساسیت به کوفتگی و برخی خواص فیزیکی میوه سیب

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چکیده- برای اغلب میوه ها، ازجمله سیب،کوفتگی متداول‌ترین آسیب مکانیکی پس ازبرداشت است. حساسیت به کوفتگی ناشی از آسیب‌های مکانیکی درسه رقم تجاری (شامل 'جاز'، 'گرانی اسمیت' و 'فوجی') و در هر رقم در چهار درجه تجاری میوه (شامل ۱۳۵، ۱۲۰، ۱۰۰ و ۸۸) اندازه‌گیری شد. برای ایجاد کوفتگی یک گلوله فلزی با وزن مشخص (۱۱۰ گرم) از ارتفاع مشخصی (۳۰ سانتی‌متر) و از درون یک لوله پی وی سی بر روی میوه ها رها شد برخی خواص فیزیکی میوه و همچنین شاخص‌های مربوط به کوفتگی اندازه گیری شد. نتایج نشان داد که رقم جاز کمترین و رقم گرانی اسمیت بیشترین حساسیت را در برابر کوفتگی داشتند که می تواند بیانگر این مسئله باشد که رقم گرانی اسمیت در فرایند نقل و انتقال تجاری آسیب بیشتری خواهد دید. ارزیابی اندازه میوه نشان داد که میوه‌های کوچکتر در برابر کوفتگی حساسیت کمتری داشتند. بررسی ارتباط بین خواص فیزیکی میوه و میزان کوفتگی نیز نشان داد که به طور کلی حجم میوه همبستگی مثبت بالا و چگالی، سفتی و وزن خشک میوه نیز همبستگی منفی بالایی با حجم کوفتگی داشتند. نتایج این پژوهش می تواند در کاهش میزان صدمات مکانیکی وارده به میوه سیب بسیار مفید واقع شود که مورد توجه هر دو تولید کنندگان میوه و شرکت های فعال در بخش نگهداری و بازاررسانی میوه می باشد.