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Investigating bruise susceptibility of pomegranate cultivars during postharvest handling

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ABSTRACT

Bruising is the most common type of mechanical damage of horticultural produce which results mainly from excessive impact and compression forces due to improper postharvest handling. The presence of bruise contributes to downgrading and rejection of produce, thereby contributing to postharvest losses; it is therefore important to understand the mechanism of bruising and how to reduce it. This study investigated the susceptibility of three pomegranate (*Punica granatum* L) fruit cultivars (‘Acco’, ‘Herskawitz’ and ‘Wonderful’) to bruising by impacting a known mass of steel ball onto individual fruit. Impact threshold level required to cause bruising was investigated by subjecting fruit to damage at different drop heights (5, 10, 15, 20 and 25 cm) which corresponded to low impact energy levels. Bruise size (area and volume) and bruise susceptibility (bruise volume per unit of impact energy) at higher drop heights (20, 40 and 60 cm) were cultivar dependent in the order of ‘Wonderful’>‘Herskawitz’> ‘Acco’. Similarly, the drop height (cm) at which bruising was first observed and the associated bruising incidence (%) ranged from 5 cm and 34% for ‘Wonderful’, to 10 cm and 21% ‘Herskawitz’ and 15 cm and 27% for ‘Acco’. ‘Wonderful’ pomegranate fruit had the lowest equivalent drop height (3.13 cm) at which bruising occurred, which indicates its higher susceptibility to bruising compared with the other cultivars studied. The findings reported in this study provide science-based tools to assist in improving postharvest handling management of fresh pomegranate fruit to minimize the incidence of mechanical damage. In addition, the methodology can be applied to assess the bruise damage susceptibility of other types of fresh produce as part of overall management strategy to reduce the high incidence of postharvest losses of agricultural and horticultural commodities.

Keywords: bruise susceptibility, drop height, fresh produce, impact energy, mechanical damage, postharvest loss

RÉSUMÉ

La contusion (et les ecchymoses) est le type le plus fréquent de dommages mécaniques sur les produits horticoles, et résulte principalement d’un impact excessif et de forces de compression dues à une manipulation inappropriée post-récolte. La présence d’ecchymoses contribue à la dégradation et au rejet du produit, causant ainsi des pertes après récolte; il est donc important de comprendre le mécanisme de contusion et comment la réduire. Cette étude s’est intéressée à la susceptibilité de trois cultivars de grenade (*Punica granatum* L) (‘Acco’, ‘Herskawitz’ et ‘Wonderful’) à la contusion en exerçant une masse connue de boule d’acier sur chaque fruit. Le niveau de seuil d’impact requis pour causer des ecchymoses a été étudié en faisant subir aux fruits des dommages à différentes hauteurs de chute (5, 10, 15, 20 et 25 cm), qui correspondaient à des niveaux d’énergie à faible impact. La taille des ecchymoses (surface et volume) et la susceptibilité à la contusion (volume de contusions par unité d’énergie d’impact) à differentes hauteurs de chute plus élevées (20, 40 et 60 cm) ont varié avec le cultivar suivant cet ordre :‘Wonderful’> ‘Herskawitz’> ‘Acco’. De même, la hauteur de chute (cm) à laquelle les ecchymoses ont été observées pour la première fois de même que l’incidence d’ecchymose (%) variaient entre 5 cm et 34% pour ‘Wonderful’, 10 cm et 21% ‘Herskawitz’ et 15 cm et 27% pour ‘Acco’. Le cultivar ‘Wonderful’ avait la plus faible hauteur de chute (3,13 cm) à laquelle les ecchymoses apparaissent, ce qui indique sa susceptibilité aux ecchymoses plus grande que celle des autres cultivars étudiés. Les résultats de cette étude fournissent des outils scientifiques aidant à améliorer la gestion des fruits après récolte, afin de minimiser l'incidence des dommages mécaniques. En outre, la méthodologie peut être utilisée pour évaluer la susceptibilité aux dommages causés par les contusions d'autres fruits dans le cadre d'une stratégie de gestion globale, afin de réduire l'incidence élevée des pertes après récolte des produits agricoles et horticoles.

Mots-clés: susceptibilité aux bleus, hauteur de chute, produits frais, énergie d'impact, dommages mécaniques, perte post-récolte

INTRODUCTION

Postharvest and economic losses suffered by horticultural industry annually due to mechanical damages of fresh produce from harvest to postharvest handling are considerably huge (Montero *et al.*, 2009; Ahmadi *et al.,* 2010; Ghaffari *et al.,* 2015). Like any other fresh produce, pomegranate (*Punica granatum* L.) fruit is subjected to mechanical damage during postharvest handling due to the action of static and dynamic forces (Shafie *et al.,* 2015) which may occur due to fruit-to-fruit contact or contact between fruit and hard surfaces. Bruising is the most common type of mechanical damage which results from excessive impact and compression forces due to improper handling, poorly designed equipment or improper packaging (Ahmadi *et al.,* 2010; Tabatabaekoloor, 2013; Opara and Pathare, 2014). Bruise damage is a type of subcutaneous tissue failure without rupture of the skin where the discolouration of injured tissues indicates the damaged spot (Blahovec and Paprštein, 2005; Stropek and Gołacki, 2015).

Bruise susceptibility of fruit and vegetables is a measure for the response to external loading (Mohsenin, 1986). Impact test, which involves dropping the fruit on rigid surface is the most common test that has been used to study bruise damage of various types of produce such as apples *(Malus domestica*), citrus (*Citrus* sp.), peaches (*Prunus persica*) and strawberries (*Fragaria x ananassa*) (Opara, 2007; Montero *et al.,* 2009; Opara and Pathare, 2014; Stropek and Gołacki, 2015). However, given the fact that pomegranate fruit rind and internal structure are different from other types of fruit, the findings from previous research on pome, citrus and stone fruits cannot be extrapolated and applied to improve understanding on the potential of pomegranates to damage along the supply chain.

Bruising results from the action of excessive external force on fruit surface during impact or compression against a rigid body or fruit against fruit (Kitthawee *et al.,* 2011; Li and Thomas, 2014). Impacts may also occur as the result of sudden fall of fruit onto other fruits, parts of the tree, containers, parts of grading and treatment machinery and on any improperly cushioned surfaces (Idah *et al.,* 2007; Opara and Pathare, 2014). Bruise damage generally causes produce quality deterioration and subsequent economic losses due to decay and microbial spoilage, loss in fresh weight, change in epicarp colour and degradation of visual quality (Stropek and Gołacki, 2015). The extent of bruise damage in fruit may significantly detract consumer perceptions and consequently affecting the level of acceptability prior to purchase (Yurtlu and Erdogan, 2005; Montero *et al.,* 2009). Bruising also affects the produce physiological processes such as respiration and transpiration, causing loss of nutritional value and overall quality change of produce (Sablani *et al.,* 2006). Consequently, bruising is recognised as one of the most significant factors limiting the mechanisation and automation of harvesting, sorting and transport of many fruits and vegetables (Ahmadi, 2012; Opara and Pathare, 2014).

Considering the economic impacts of bruise damage to the farmers' economy and food security through high incidence of postharvest losses, a wide range of literatures on various aspects of bruising have previously been reported in several types of soft fruits and vegetables such as apples, peas, potatoes (Opara, 2007; Opara and Pathare, 2014). However, limited information is available on bruise damage susceptibility of pomegranate fruit cultivars during postharvest handling. This research investigated the bruise damage susceptibility of three commercially grown pomegranate fruit cultivars during postharvest handling. The study was twofold; to determine the impact threshold for the bruise damage to occur for each cultivar, and to determine bruise damage size and bruise susceptibility at higher impact levels above threshold.

RESEARCH APPROACH

Three pomegranate fruit (*Punica granatum* L.) cultivars ('Acco', 'Herskawitz' and 'Wonderful') were hand-picked at maturity stage from a commercial orchard in the Western Cape Province, South Africa. Only fruit without any physical defects such as such as cracking, sun burn and husk scald were chosen for the experiment. Prior to the experiment, fruit were pre-conditioned at 22 ± 5 ºC and 60 ± 5 % ± 5 relative humidity for 24 h in the Postharvest Technology Research Laboratory at Stellenbosch University. Fruit were weighed individually prior to testing using a Mettler weighing balance (± 0.01g). Impact bruising of whole fruit was performed by a drop test technique using the method reported by Opara *et al.* (2007). In this method, a ball impactor of known mass is dropped under free fall through a perforated tube from a range of preset heights (Figure 1). In order to ensure that fruit deformation at the support base was minimal, each fruit was placed on moistened sand in a plastic container to minimise the contact stress between fruit surface and the supporting sand (Jarimopas *et al.,* 2007). For each fruit across all experiments, the steel ball was dropped twice from the same height onto two opposite sides of the fruit, to allocate an impact at each of the two equidistant points on the cheek position of the pomegranate fruit. To avoid multiple impacts onto fruit, the steel ball was caught by hand after first rebound. Impact tests were followed by fruit incubation at ambient condition (19 – 22 ºC, 60 ± 5% relative humidity) for 48 h to allow bruise manifestation on damaged tissue. Prior to incubation, the bruised region of each fruit was marked using a marker after every impact in order to facilitate to the detection during measurement.

In the first experiment, we investigated the minimum impact energy (impact threshold) and equivalent drop height at fruit bruised occurred by dropping a stainless steel ball of known mass (260.45 g) on individual fruit at different drop heights (5, 10, 15, 20 and 25 cm). From this study, the percentage of bruised fruit which sustained visible and measurable bruise at each drop height was calculated using equation (1).

$$\%\ \text{bruised fruit} = \frac{\text{number of bruised fruit}}{\text{number of replications of the same treatment}} \times 100$$

(1)

The second set of experiments studied the bruise susceptibility of the three pomegranate fruit cultivars at higher impact levels by dropping the same steel ball from 25, 40 and 60 cm drop heights. For each cultivar, 10 fruit replicates was dropped individually twice from the same height, with one impact at each of the two equidistant points on the cheek position of the fruit (n=30 per cultivar).The impact energy (Ei, mJ) resulting from drop impact was calculated using equation (2).

$$E_i = m_b * g * h \qquad (2)$$

where m_b is the mass (g) of the steel ball, g is the gravitational constant (9.81 m s^{-2}), and h is the drop height of the ball (cm). The equivalent fruit drop height (H_{eq}) corresponding to each impact energy was determined using equation (3).

$$H_{eq} = Ei \,/\, (m_s * g) \qquad (3)$$

where, m_s is the average mass (g) of each fruit cultivar and g is the gravitational constant (9.81 m s^{-2}). Fruit were then sliced through the centre of the impact (marked) region (Figure 1) and the presence of bruise damage was identified by the presence of visible damaged tissue or arils which were clearly distinguishable from other unbruised parts of the same fruit. Measurement of bruise dimensions, w_1 and w_2 as major and minor width, respectively, and bruise depth (d) were all conducted using a digital calliper (Mitutoyo, ± 0.02 mm). Results of bruise damage size were expressed as bruise area (BA, m^2), bruise volume (BV, mm^3) and bruise susceptibility (BS, mm^{-3}/mJ) expressed as the ratio of bruise volume to the energy absorbed during impact using equations 4-6 (Opara and Pathare, 2014).

$$BA = \frac{\pi}{4} * w_1 w_2 \qquad (4)$$

$$BV = \frac{\pi}{8} * w^2 d \qquad (5)$$

$$BS = \frac{Bv}{Ei} \qquad (6)$$

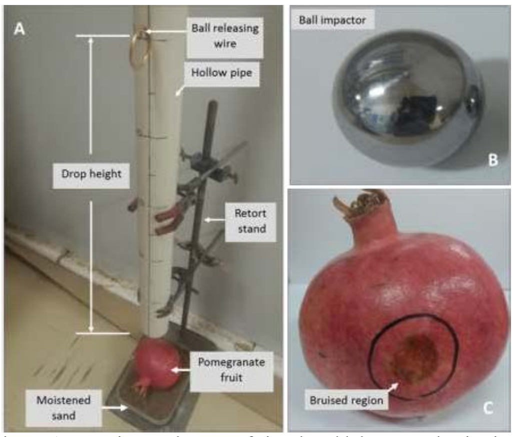

Figure 1 Experimental setup of simulated laboratory bruise impact test (A), stainless steel ball impactor (B), and bruised pomegranate fruit (C)

RESULTS AND DISCUSSION

Impact threshold for bruise damage. The percentage of bruised fruit at each of the selected minimal drop heights (5, 10, 15, 20 and 25 cm) is presented in Figure 2. Results showed that 34% of 'Wonderful' fruit were bruised by the low impact energy (127.75 mJ) generated at 5 cm drop height, whereas there was no bruise observed on 'Acco' and 'Herskawitz' at the same impact level. This results showed that the impact energy generated by the ball dropped at 5 cm was therefore below the bruise threshold of 'Acco' and 'Herskawitz' fruit. Furthermore, at 10 cm drop height, 63% of 'Wonderful' and 21% of 'Herskawitz' fruit were bruised, again, with no bruised fruit observed for 'Acco' fruit. Impact energy generated at 15 cm drop height resulted in 27, 44, and 100% of bruised 'Acco' 'Herskawitz' and 'Wonderful' fruit, respectively. At 20 cm drop height, the impact energy (511 mJ) was enough to cause bruise damage to the whole batch (100%) of 'Wonderful' fruit, while only 74 and 71% of 'Acco' and 'Herskawitz' fruit, respectively, were bruised. Finally, the highest impact energy (638.75 mJ) which corresponded with the 25 cm drop height resulted in 100% bruise in all fruit batches of the three pomegranate cultivars.

Equivalent drop height of the fruit. Using the known average mass of each fruit cultivar used in this study, it was possible to determine the drop height of fruit that is equivalent to the impact energy value calculated using ball drop test as described earlier in section 2. The equivalent drop height (H_{eq}) of fruit could be the most useful parameter in practical applications since 'fruit drop' (or 'fruit fall') represents typical impacts that occur during harvesting and postharvest handling operations. Therefore, this parameter could provide a useful guideline to farmers and fruit handlers in understanding the levels of impacts that can potentially cause bruise damage at various stages of the postharvest handling chain.

Results in Table 1 showed that the equivalent drop height of the three fruit cultivars differed in the order of 'Acco' > 'Herskawitz' > 'Wonderful', corresponding with increasing susceptibility to physical damage. The pomegranate cultivar with the lowest impact threshold ('Wonderful') had the lowest equivalent fruit drop height (3.13 cm). This value was slightly lower than the minimum drop height (5 cm) used in drop test study using the ball impactor as described in section 2. Similarly, both 'Herskawitz' and 'Acco' fruit cultivar had lower equivalent drop heights than the minimum impact ball drop height which caused bruise damage (Table 1). The higher equivalent fruit drop height for 'Herskawitz' (8.7 cm) and 'Acco' (13.14 cm) showed the slight resistance of these cultivars to bruising as compared to 'Wonderful' fruit. The lower equivalent fruit drop height required to cause bruise damage as well as the higher bruise susceptibility of 'Wonderful' pomegranate would be associated with cultivar differences in morphology and cuticular structures (Opara and Pathare, 2014). Practically, the lower equivalent drop height of 'Wonderful' fruit indicates that it is the most susceptible to bruise damage, and therefore needs to

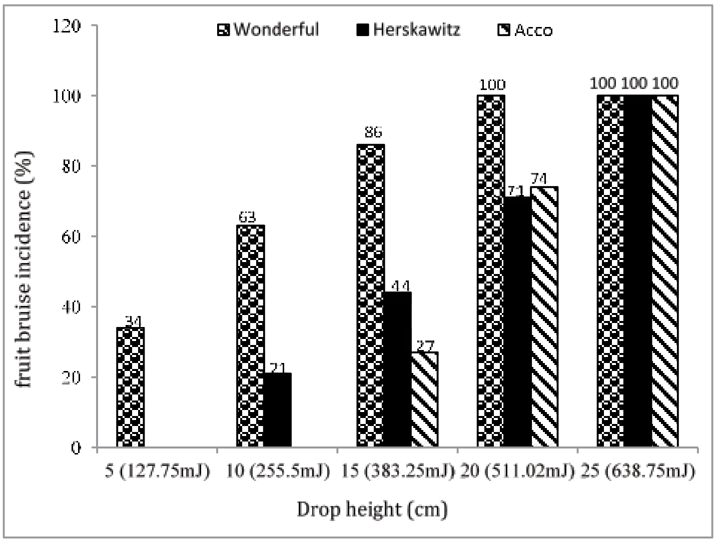

Figure 1 Percentage of bruised fruit affected by bruise damage at different drop heights for each pomegranate cultivar. Numbers in bracket represent the equivalent impact energy applied on fruit.

be handled with extra care during harvest and postharvest operations. However, careful handling of other investigated pomegranate fruit cultivars that will minimize impacts during handling is highly recommended to reduce bruise damage.

Bruise damage size and bruise susceptibility at higher impact levels. Impact energy generated by dropping the steel ball on pomegranate fruit increased linearly with increasing drop height. Likewise, fruit impact energy significantly affected both bruise size and bruise susceptibility of the three pomegranate fruit cultivars studied (Table 2). The results showed that 'Wonderful' fruit was characterized by the highest bruise size (area and bruise) and bruise susceptibility in the order of 'Wonderful'> 'Herskawitz' > 'Acco'. For 'Wonderful', bruise susceptibility (BS) was highest (4.53 mm^3/mJ) in fruit impacted at 60 cm drop height, whereas no significant difference was found between 25 and 40 cm drop heights. However, there was no significant difference ($p < 0.05$) in bruise susceptibility of 'Herskawitz' fruit at 40 cm (2.17 mm^3/mJ) and 60 cm (2.10 mm^3/mJ) drop heights. Overall, these results are in agreement with previous studies in apples (Ozturk *et al.,* 2010), tomatoes (Buccheri and Cantwell, 2014) and banana (Bugaud *et al.,* 2014), where variation in bruise damage among cultivars of the same fruit have also been reported.

Literature evidence shows that differences in susceptibility to bruising of fruit cultivars subjected to the same impact loading condition has been associated with their differences in mechanical properties (Van Linden *et al.,* 2006; Ghaffari *et al.,* 2015). The natural variability that is common in biological materials (even within the same batch) could be another important source of differences in susceptibility to bruising as previously described by Van Linden *et al.* (2006). Overall, this comparative study has provided new evidence on the bruise damage susceptibility of three important commercial pomegranate cultivars to assist in better postharvest handling practices to reduce fruit losses due to mechanical damage. The research methodology, especially in determining the minimum equivalent fruit drop height at which damage may occur, is applicable to other types of fruit and other fresh agricultural and horticultural produce.

Table 1 Estimated individual fruit drop height required to cause bruise damage during impact

Cultivar	Fruit mean size (g)	Impact threshold (mJ) for bruise damage	Equivalent drop height (cm)
Wonderful	415.96 ± 14.66	≤ 127.75	3.13
Herskawitz	298.69 ± 14.07	≤ 255.50	8.72
Acco	350.90 ± 4.68	≤ 383.25	11.13

Table 2 Bruise size and bruise susceptibility of selected pomegranate fruit cultivars at high impact energy levels

Parameters	Drop height (cm)	Impact energy Ei (mJ)	Bruise susceptibility (mJ)		
			Wonderful	Herskawitz	Acco
Bruise volume (mm^3)	25	638.75^{C}	2283.22 ± 79.54^{aC}	1191.55 ± 45.42^{bC}	397.68 ± 17.38^{cC}
	40	1022.01^{B}	3868.14 ± 41.04^{aB}	2221.46 ± 45.42^{bB}	1523.41 ± 95.35^{cB}
	60	1533.01^{A}	6946.63 ± 87.53^{aA}	3220.99 ± 46.89^{bA}	3362.33 ± 87.61^{bA}
Bruise area (mm^2)	25	638.75^{C}	225.97 ± 7.28^{aC}	151.93 ± 14.46^{bC}	115.03 ± 3.19^{bC}
	40	1022.01^{B}	334.69 ± 7.52^{aB}	222.47 ± 14.46^{bB}	194.85 ± 10.28^{bB}
	60	1533.01^{A}	577.77 ± 40.43^{aA}	344.71 ± 13.98^{bA}	232.37 ± 0.86^{cA}
Bruise susceptibility (mm3/mJ)	25	638.75^{C}	3.57 ± 0.12^{aB}	1.87 ± 0.07^{bB}	0.62 ± 0.03^{cC}
	40	1022.01^{B}	3.78 ± 0.04^{aA}	2.17 ± 0.07^{bB}	1.49 ± 0.09^{cC}
	60	1533.01^{A}	4.53 ± 0.06^{aA}	2.10 ± 0.03^{bA}	2.19 ± 0.06^{bA}

All data are presented as mean ± SE. According to Duncan's multiple range test, all means of bruise susceptibility in the same row followed by different lower case superscript letter are significantly different ($p < 0.05$). Similarly, mean values in the same column for each parameter followed by different upper case superscript letter are significantly different ($p < 0.05$).

CONCLUSION

Bruise damage size and bruise susceptibility were cultivar dependent. 'Wonderful' pomegranate was found to be more susceptible to bruise damage followed by 'Herskawitz'. Secondly, increase in drop height (or impact energy) increased the potential for bruise damage to occur on fruit. Finally, equivalent fruit drop height for bruise damage to occur was found to be lowest for 'Wonderful' (3.13 cm) and highest for 'Acco' (11.13 cm).

To reduce bruise damage incidence, impacts should be minimised during fruit harvesting and postharvest. 'Wonderful' pomegranate fruit requires additional care during handling due to its critically lower bruise threshold.

Future research is warranted to investigate the effects of postharvest handling and storage conditions such as temperature, humidity and controlled atmosphere on the susceptibility of pomegranate fruit to bruising.

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DECLARATION OF NO CONFLICT OF INTEREST

We the authors of this paper hereby declare that there are no competing interests in this publication.

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