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Harvest and Postharvest Factors Affecting Bruise Damage of Fresh Fruits

Zaharan Hussein[a], *Olaniyi A. Fawole*[b], *and Umezuruike Linus Opara*[a,b,*]

[a] *Postharvest Technology Research Laboratory, South African Research Chair in Postharvest Technology, Department of Food Science, Faculty of AgriSciences, Stellenbosch University, Stellenbosch 7602, South Africa*

[b] *Postharvest Technology Research Laboratory, South African Research Chair in Postharvest Technology, Department of Horticultural Science, Faculty of AgriSciences, Stellenbosch University, Stellenbosch 7602, South Africa*

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A B S T R A C T

Fresh fruits are susceptible to bruising, a common type of mechanical damage during harvest and at all stages of postharvest handling. In quest of developing and adoption of strategies to reduce bruise damage, it is of utmost importance to understand major factors influencing bruise susceptibility of fresh produce at these stages. This review presents a critical discussion of factors affecting bruising during harvest and postharvest handling of fresh fruits. Excessive compression forces during harvesting by handpicking or machines, and a series of impacts during harvesting, transport and packhouse operations can cause severe bruise damage. The review has further revealed that bruising is dependent on a number of other factors such as produce maturity, ripening, harvest time (during the day or season) and time lapse after harvest. The susceptibility to bruising is partly dependent on how these factors alter the produce physiological and biochemical properties, and the environmental conditions such as temperature, humidity and several other postharvest treatments. Hence, the successful applications of harvesting techniques by use of trained personnel and proper harvesting equipment are essential to reduce both the incidence and severity of bruising. Furthermore, the careful selection of postharvest handling temperature and other treatments can increase resistance of fresh produce to bruise damage.

Keywords: bruise damage; harvest; postharvest; fruit quality

1. Introduction

Fruits are remarkable source of micronutrients, fibres, vitamins, phytochemicals and antioxidants (Rico et al., 2007; Hussein et al., 2015). The consumption of fruits is therefore highly recommended as a healthy diet due to its association with such numerous nutritional and health benefits, including fighting against sedentary lifestyle and degenerative diseases. This has led to a high demand for healthy, fresh-like and ready-to-eat fruits (Ramos et al., 2013).

The increase in demand for fresh fruits has sparked the need for large-scale mechanisation in both harvesting and postharvest handling operations (Li and Thomas, 2014; Stropek and Gołacki, 2015). Consequently, both harvesting and postharvest activities such as produce handling, sorting, grading, packing, and transportation require extensive mechanical operations. The actions of static and dynamic forces resulting from the handling operations predispose the fruits to mechanical damage (Opara, 2007; Montero et al., 2009). Mechanical damage is the plastic deformation, superficial rupture and/or destruction of plant tissue

* Corresponding author. Tel.: +86 27 218089242
E-mail address: opara@sun.ac.za

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(Montero et al., 2009), and comprises of bruising, crushing, or rupture (Polat et al., 2012).

Bruising is the most common type of mechanical damage which can occur during harvesting, handling and transport (Ahmadi et al., 2010; Tabatabaekoloor, 2013). Bruise damage results from the action of excessive external force on fruit surface during the impact against a rigid body, or fruit against other fruit (Li and Thomas, 2014; Stropek and Gołacki, 2015). The physical evidence of bruising is a result of cell breakage (Schoorl and Holt, 1983), which results from stress and distortion of individual cells (Ruiz-Altisent and Moreda, 2011). The breakage of cell membranes leads to the release of cytoplasmic enzymes into the intercellular spaces and react with vacuolar contents (Mitsuhashi-Gonzalez et al., 2010).

The impacts of bruising on produce quality and its economic importance in the horticultural industry are well known and documented. Majority of research efforts has focused on evaluation of bruise damage susceptibilities in relation to the fruit physical, mechanical and engineering properties (Kitthawee et al., 2011; Shafie et al., 2015). In addition, adequate attention has been given to various aspects of fruit bruising including the effects of physical properties of fresh produce on bruise susceptibility, the effect of impact or compression energy on bruise susceptibility, bruise occurrence and severity (Boydas et al., 2014). Major research interests have been fruits with soft rind, including pome fruit such as apples (Stropek and Golacki, 2013) and pears (Komarnicki et al., 2016) and stone fruits such as nectarine (Polat et al., 2012), cherries (Blahovec, 1999) and peaches (Tabatabaekoloor, 2013). Others include, tomatoes (Buccheri and Cantwell, 2014) and kiwifruit (Ahmadi, 2012).

2. Impact of bruising on fruit quality: causes and mechanism of deterioration

Bruise damage could hasten the quality deterioration of fruit while detracting from the cosmetic appearance and salability (Brosnan and Sun, 2004). Bruise damage on fruits is not always immediately visible after its occurrence until a later stage in the handling chain (Shewfelt, 1986). However, the symptoms of internal bruising can develop into more severe external blemishes over time, the changes that are usually accompanied by a number of serious quality deteriorations (Lee, 2005). Bruise damage on freshly harvested produce significantly affects such physiological processes as respiration and moisture loss through injured skin (Kumar et al., 2016). Additionally, changes in metabolic processes such as ethylene production, relative electrical conductivity, respiration, and transpiration usually lead to a mass loss, senescence and spoilage as well as loss of nutritional value (Li et al., 2011).

Bruise damage of fresh fruit may also accelerate other biological processes such as microbial spoilage (Prusky, 2011; Eissa et al., 2013). Fruit bruising heightens the risk of microbial contamination, hence providing potential causes for fruit quality losses and lower shelf life (Prusky, 2011). Postharvest rots and decay are more prevalent in bruised or mechanically damaged fruits than in non-damaged produce. Accordingly, decay pathogens can easily enter through dead or wounded tissues and contaminate the rest of the fruit, resulting in significant losses (Pholpho et al., 2011). Hence, fruit bruising contributes to downgrading and fruit rejection thereby contributing to postharvest losses (Shafie et al., 2017).

3. Fruit journey from the orchard to the supermarket

Postharvest operations follow a complex route from the fruit tree to the supermarket (Lewis et al., 2008; Eissa et al., 2013), and comprises of various stages and processes, including harvesting, packing, sorting, storage and transport (Fig. 1). These handling operations and processes predispose fruits into varying levels of loading conditions that cause various forms of mechanical damage including bruising (Ahmadi, 2012; Eissa et al., 2013).

The magnitude of bruise damage on fresh produce and subsequent postharvest losses is dependent on a number of factors relating to harvest, postharvest handling, and environmental storage conditions. Therefore, alteration to these factors could potentially modulate biological and/or physiological makeup of produce and subsequent changes to its susceptibility to bruise damage. There is lack of information and knowledge on harvest and postharvest factors that could significantly influence bruise damage susceptibility of fresh fruits. The review by Opara and Pathare (2014) focused on recent technological developments in bruise measurement, detection, and analysis of bruise damage in fresh horticultural produce. While the review by Li and Thomas (2014) focused on the quantitative evaluation of bruise damage to fresh fruits, sources and mechanisms of fruit damage during handling as well as quantitative assessments to characterise surface and internal mechanical damage. This review paper presents an extensive information on the harvest and postharvest factors that affect the bruise damage susceptibility of various fresh fruits.

4. Factors influencing bruise damage of fresh fruits

4.1. *Harvest factors*

4.1.1. *Harvest methods*

The cost of fruit harvesting can range between 20% and 40% of the total on-farm variable production costs and is largely contributed by manual labour (He et al., 2017). In addition to the increasing labour costs and uncertainty in manual labour availability, the fruit bruising during harvest adds to the equation an important factor to put into consideration when deciding on which harvest method to be employed (Hu et al., 2017). Fruit harvesting is the crucial stage where fruits are more prone to bruise damage (Toivonen et al., 2007). Bruising in most fruits starts in the field, and is by high chance induced by compression and impact stress during harvest, field packing and subsequent handling operations (Ferreira et al., 2009). Furthermore, the substantial amount of bruising at harvest also results from dumping of fruit from picking bags and overfilling of the bins in the orchard (Kupferman, 2006). A report by Kupferman (2006) suggested that apple bruising could reach as high as 35% during harvesting and transport alone. Similarly, a technical report by FAO (2003) showed that dozens of fruits with little damage inflicted during harvest are wasted due to decay or losses of fresh quality, causing up to 51% losses from harvest to consumption. Hence, the trained workers, adequate harvesting facilities and techniques coupled with gentle fruit handling procedures dur-

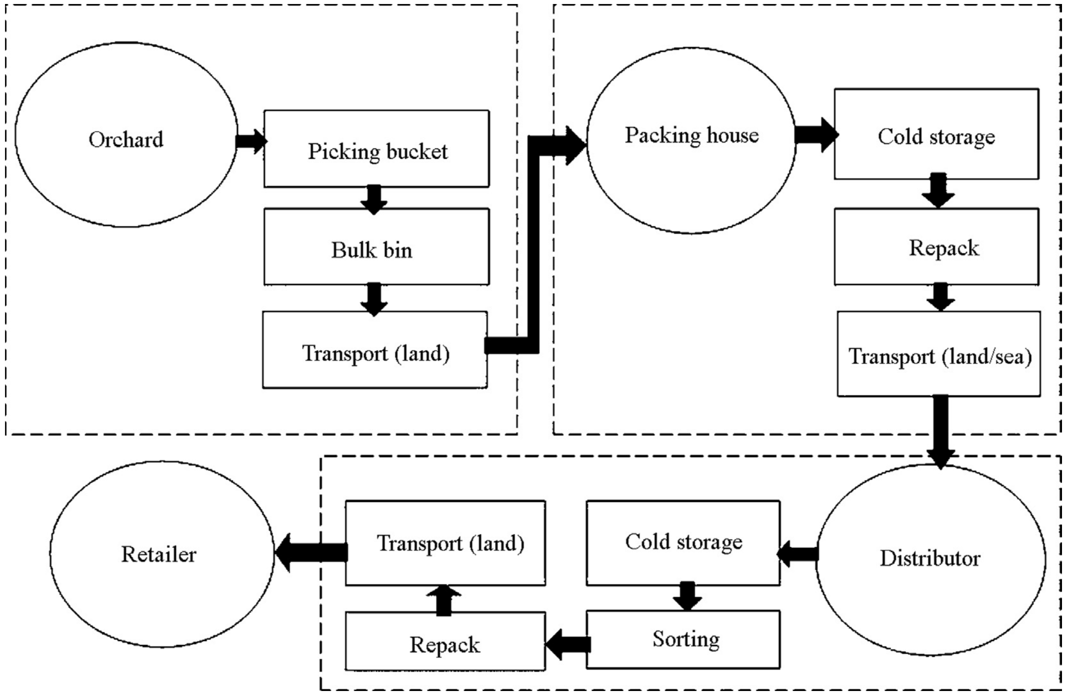

Fig. 1 Postharvest journey of fresh fruit from the orchard to retail stores

ing manual harvesting and hauling could be essential to reduce bruise incidence.

Manual fruit harvesting operations are traditionally carried out by hand using thumb and fingers, secateurs or clippers (Dhatt and Mahajan, 2007). Grapes, strawberries, apples, cherries, prunes, peaches and blueberries have soft outer skins that are highly prone to mechanical damage (Stow et al., 2004; Aliasgarian et al., 2013: Xu et al., 2015). Therefore, the desired destination of fruit harvest could be one of the important deciding factors on which harvest method should be employed. Fruits that are destined for processing could suitably be harvested by any means, since bruise damages might not significantly affect the quality of final processed products and often the produce is processed quicker (Aliasgarian et al., 2013; Xu et al., 2015; Hu et al., 2017). However, this may not be true for all fruits; for instance, bruising in olives has a high potential to reduce the quality of the final processed products (Morales-Sillero et al., 2014). For fruits destined for fresh market, harvesting practices should cause as little bruise damage as possible and hence manual harvesting is preferred over mechanical machines (Aliasgarian et al., 2013).

Harvesting by hand picking can cause compression damage when grasp forces surrounding the fruit exceed a threshold for tissue failure (Li and Thomas, 2014). This highlights the need for adopting proper means of picking to minimise bruising of fruit. Li et al. (2016a) showed that hand-picked apples did not show detectable bruising damage in comparison to robotic picked apples. On the other hand, Yu et al. (2014) reported the bruising incidence of handpicked blueberries was close to 2% just after fruit harvest. In the results reported by Brown et al. (1996), it was also shown that 23% of the handpicked Northern highbush blueberries sustained some internal bruise damage just after a week in storage.

Mechanical harvesting methods are employed to speed up harvest and field handling operations (Thompson, 2003). However, mechanised harvesting techniques contribute much to the additional wounding to fruit. Mass harvest using shake-and-catch systems can potentially cause bruising during fruit catching and collecting operations and while falling through the tree to the uncushioned surface (Fu et al., 2017). Robotic fruit harvesting is one of the mechanical harvesting technique that has the potential to reduce the labour cost for manual harvesting (Sarig, 2012; Li et al., 2016a). Automated fruit picking machines are designed to use a system that emulates the human picker (Sarig, 2012; Li et al., 2016a). However, studies have shown that excessive grasping force during robotic picking can potentially induce bruise damage on fruit (van Zeebroeck et al., 2006; Mika et al., 2015). Bruise damage during robotic picking could also be linked to the impact level caused by grasping force, and the picking pattern (van Zeebroeck et al., 2006). Li et al. (2016a) found that use of a three-finger gripper of robotic fruit picking machine resulted in higher percentages of picking-induced fruit bruising due to higher grasping pressure required to detach apples from the tree.

There are other reported mechanical harvesting techniques used for commercial harvest of fruits. Mika et al. (2015) found that mechanical harvesting using straddle fruit harvester resulted in overall higher percentage of bruise damaged plum and prune than handpicked fruit, although the quantity of mechanically damaged fruit varied among cultivars. Similarly, Brown et al. (1996) showed that 32% of harvested blueberries were bruised during the harvesting process using commercial mechanical harvester. The incidence and severity of fruit bruising during mechanical harvest could also depend on other factors that are directly linked to the harvesting method, such as the type of fruit and cultivars. For instance, handpicked ‘Manzanilla de Sevilla’ olives had 50% bruise incidence and just 9% for ‘Manzanilla Cacerena’ olives; most of which were classified as slight damage for both cultivars. On contrary, there was 100% of bruise incidence for mechanically harvested ‘Manzanilla de Sevilla’ and 91% for ‘Manzanilla Cacerena’ olives when harvested with the straddle mechanical harvester, with the severe and slight bruise damage for the former and the later, respectively. Table 1 summaries some studies reported various harvest methods and the influence of each fruit bruising during harvest.

4.1.2. *Harvest time during the day*

Time of harvest during the day affects the susceptibility of fresh fruit to bruising. Overall, harvesting during the hotter part of the day results in faster senescence, shrivelling and wilting of fruits, which could in part contribute into bruise damage susceptibility at harvest (Garcia et al., 1995; Abbott et al., 2009). Banks and Joseph (1991) revealed that bananas harvested in the early morning had a higher threshold for compression bruising than those harvested later in the day. These findings concurred with an earlier survey by Banks (1990), that turgor of fruit on banana plants in the field declines from early morning to midday, as indicated by the decrease in latex released from developing fruit tips following flower removal at the later time of day.

Abbott et al. (2009) examined the effect of harvest time on bruise susceptibility of ‘Cripps Pink’ and ‘Granny Smith’ apples. Among the three studied harvest times (morning, midday and the late afternoon), fruits harvested later in the day were less susceptible to bruising than those harvested in the morning hours. This is in agreement with several other studies that have shown the influence of tissue’s cell turgor on susceptibility to bruising of apples (Garcia et al., 1995; Opara, 2007). Furthermore, Abbott et al. (2009) concluded that regardless of fruit cultivars, fruits are more likely to suffer larger bruise damage during morning hours than in the late afternoon if fruits of the same species are subjected to the same impact energy. Hence fruit harvested later during daytime would be less prone to bruise damage as the result of reduced turgor, elevated temperatures and a combination of these effects.

4.1.3. *Seasonal variation at harvest*

Researchers have obtained conflicting results on the influence of harvest time during the season (late or early harvest) on bruise damage susceptibility of fresh fruits. Several studies have found that fruits harvested at the end of the commercial harvest period are more susceptible to bruising than those harvested at the beginning of the season (Garcia et al., 1995; Gunes et al., 2002; Opara, 2007). Garcia et al. (1995) reported that early-picked ‘Golden Delicious’ and ‘Golden Supreme’ apples and pears were less susceptible to bruising than those harvested at a later stage of development. These results were similar to the effect of harvest dates on the bruise occurrence in three apple cultivars ‘Aroma’, ‘Cox’s Orange Pippin’ and ‘Ingrid Marie’ reported by Ericsson and Tahir (1996). The bruise susceptibility measured as bruise weight percentage (BWP) increased by delayed harvest in ‘Aroma’ and ‘Ingrid Marie’. The less sensitivity to bruising in late harvested fruit could be attributed to higher pulp firmness as opposed to less mature fruits, as previously reported by Garcia et al. (1995).

Similarly, Bollen et al. (2001) reported that late harvested ‘Braeburn’ and ‘Granny Smith’ apple fruits from the first season were more susceptible to damage than early harvested ones. ‘Braeburn’ and ‘Granny Smith’ apples harvest on season 1 absorbed less impact energy than those harvested during season 2. However, during the same period (seasons 1 and 2), the authors could not find any significant difference in bruise susceptibility between early and late harvested ‘Royal Gala’ and ‘Granny Smith’ apples. Consistently with that, Gunes et al. (2002) reported higher

Table 1 Influence of harvest methods on bruising of various fresh fruit

Cultivar	Cultivar name	Harvest method	Major conclusion	Reference
Blueberry	King	Commercial mechanical harvester	78% of mechanically harvested blueberries had severe bruise damage	Brown et al. (1996)
		Hand picking	23% of hand-harvested blueberries had detectable bruise damage	
Apple	Jazz, Pacific Rose, Pink Lady	Shake-and-catch harvesting system	~8% of all three cultivars were bruised	He et al. (2017)
	Pink Lady	Robotic picking using three-finger gripper	46.7% and 60% of bruised apples picked using 14.47, 15.87 N mean grasping force, and 0.28 and 0.29 MPa mean grasping pressure, respectively	Li et al. (2016a)
		Hand picking	Average grasping force (5.05 N) and grasping pressure (0.24 MPa) exerted on fruit by grasping fingers did not cause any detectable bruise damage	
Table olive	Hojiblanca, Manzanilla	Manual picking	Manual picking of ‘Hojiblanca’ and ‘Manzanilla’ resulted in 17.5% and 50.8%, respectively, of severe bruise-damage	Zipori et al. (2014)
		Trunk shaking harvester	Harvesting by mechanical trunk shaker caused 61.9% and 77% of bruise damage in ‘Hojiblanca’ and ‘Manzanilla’, respectively	
	Manzanilla de Sevilla, Manzanilla Cacerenaz	Grape straddle harvester	‘Manzanilla de Sevilla’ had 100% bruise incidence and 91% bruise incidence for ‘Manzanilla Cacerena’	Morales-Sillero et al. (2014)
Prune	Sweet Prune	Straddle mechanical harvester	< 10% of the prunes mechanically harvested had signs of bruising	Mika et al. (2015)
		Hand picking	~50% of bruise damage for ‘Manzanilla de Sevilla’ and 9% for ‘Manzanilla Cacerena’	
Plum	Cacanska Lepotica, Jojo, Valjevka	Straddle mechanical harvester	~18% of the plums showed some bruise damage	Mika et al. (2015)

losses of cranberry fruit in the later harvest lot than early harvest fruit lot, 'Pilgrim' and 'Stevens'. It was presumed that the later harvested cranberry fruits were riper and hence more prone to bruising compared to early harvested berries. In buttress of the earlier statement, Studman (1997) highlighted that the ripening process is associated with a loss in cell wall strength. In that regard, the cells of riper fruit stand less to withstand external loading that subsequently increases the bruise damage susceptibility (Studman, 1997; van Linden et al., 2006). Bruise damage in 'Jonagold' apples increased from late to early harvest as reported by van Zeebroeck et al. (2006). According to the authors, early harvested apples were more susceptible to bruise damage during transport in comparison to late or optimal harvested apples.

Eckhoff et al. (2009) investigated the influence of harvest time on the susceptibility of apples to bruise damage measured as pressure sores. The influence of harvest time was significant, such that the subsequent (late) harvesting leads to an increased expression of pressure points. The later the harvest took place, the stronger was the expression of the pressure points. This effect was attributed to the influence of fruit ripening on the bruising sensitivity, which has been reported in apples (Bollen, 2005; Tahir, 2006; Opara, 2007). However, these results do not approve for premature harvest since too early crop harvest promotes postharvest losses and leads to substantial quality losses too.

Similarly, Opara (2007) reported that bruise susceptibility of mature apple fruit 'Gala' picked on three harvest dates, early, mid (11 days later), and late harvest (21 days later) differed significantly. The bruise volume increased between early and mid-season fruit, followed by a decrease in late harvested fruit. Similarly, the increase in bruise diameter followed the same trend as observed in bruise volume but no statistical difference was observed among the harvest dates. Furthermore, bruise susceptibility increased between early and mid-season harvested fruit while that of late season harvest was declined. Overall, the observed differences in bruise damage susceptibility in 'Gala' apples between harvest dates were attributed to the differences in fruit's physico-textural attributes at harvest. Data revealed that early harvested apple fruits were firmer and had higher skin strength by 23.6% and 21.4%, respectively, in comparison to late harvested fruit (Opara, 2007).

4.1.4. *Time after harvest*

The understanding of the effects of time lapse after harvest on bruising susceptibility is crucial for the right time for fruit packaging and storage. The prolonged time between harvest and transportation leaves the produce with field heat for a longer time, which subsequently leads to faster senescence and loss of turgidity (Bollen, 2005). Martinez-Romero et al. (2004) identified that the number of days elapsed between harvest and onset of the observed mechanical damages could be an effective factor impacting the fruit bruising. Furthermore, an increase in the time elapsed after harvest is attributed to the decline in fruit turgidity of young tissue, which consequently improves their resistance to bruising damage. 'Braeburn' apples damaged 24 h after harvest were less susceptible to bruising than those damaged within 10 min of harvest (Bollen, 2005). It has been suggested that increased water loss from fruit after harvest results in a loss of turgor, which can potentially reduce the susceptibility of fresh fruit to bruising (Bollen, 2005).

4.1.5. *Maturity and ripening at harvest*

Maturity stage is one of the most important factors influencing bruise damage susceptibility for many fruits (Martínez-Romero et al., 2004; Lee, 2005). Previous studies have revealed that mature fruits are more susceptible to bruise damage than immature fruit (van Zeebroeck et al., 2007a; Canete et al., 2015). Kader (1983) reviewed that fruit maturity is an important parameter with a huge effect for fruit removal from the plant during picking. Furthermore, maturity at harvest stage potentially influences susceptibility of fruits to water loss and mechanical damage (van Linden et al., 2006; Canete et al., 2015).

Fruit firmness has been useful as a criterion for sorting the fruit into different levels of maturity and for separating overripe and damaged fruits from good ones (Wang et al., 2006). Garcia et al. (1995) established a good relationship between fruit firmness, turgor, ripening process and bruise susceptibility through modelling. Proposed models suggested that susceptibility to bruising is affected by fruit turgidity and changes in firmness occurring during ripening. Working with apples, Garcia et al. (1995) observed the decrease in bruise damage with declining fruit turgor, while the opposite was true for the fruit firmness. This leads to the conclusion that, the effect of harvest date on bruise damage of fresh apples depends on change in turgor and firmness that primarily dominates the ripening process. In concurrent with this, Baritelle and Hyde (2001) revealed that adjusting turgor by a slight reduction in hydration (equivalent to 2−3% mass loss) of apple could reduce enough fruit turgor to double the bruise threshold. Hertog et al. (2004) later found that the cell turgor also contributes to producing firmness besides the structural cell wall components.

Bugaud et al. (2014) indicated that during ripening of banana, the peel electrolyte leakage, and to a lesser extent peel hardness were the main parameters closely related to the differences in bruise damage susceptibility. The peel electrolyte leakage reflects membrane permeability (Saltveit, 2002), such that as ripening progresses, banana peel tissues lose their cohesion due to solubilisation of the cell wall (Kojima et al., 1994) and thus losing membrane integrity. Consequently, stress due to impact damage overcomes the cell wall strength, causing the breakdown. According to Bugaud et al. (2014), the membrane permeability of 'Grande Naine' and 'Flhorban925' bananas that showed higher resistance to bruising was below 27% irrespective of the ripening stage while the most bruise-prone 'French Corne' bananas exhibited the highest membrane permeability during ripening.

The effects of fruit ripening on bruise damage susceptibility have been reported in apple (Bollen, 2005), tomato (van Zeebroeck et al., 2007b) and loquat (Canete et al., 2015). The degree of fruit ripening affected the incidence of bruising in loquat fruit. Ripe loquat fruits are highly susceptible to bruise damage in comparison to unripe fruit, whereas less mature fruits have lower bruise incidence. Similarly, higher bruise damage was observed with advanced ripeness of tomato (van Linden and de Baerdemaeker, 2005). The mechanism of bruising is a combination of physical injury and the subsequent breakdown of the cell wall components by the action of cell wall-related proteins. Furthermore, van Linden et al. (2006) described the fruit texture and the fruit susceptibility to bruising as two parameters that change throughout the development and ripening process. Overall, maturation and ripening stages and their respective relative influence on bruise susceptibility of fruit need to be fully comprehended prior to harvest. For instance, some fruits such as peach and loquat may fail to ripen properly or may ripe abnormally if harvested too soon (Canete et al., 2015). Consequently, this may affect the fruit marketability due to impaired physicochemical quality attributes.

4.2. Postharvest factors

4.2.1. Effects of pre-cooling

Pre-cooling after harvest could potentially affect the way in which fruits respond to impact or compression. Ferreira et al. (2009) indicated that both the cooling effect and cooling method could lead to varying responses to both compression and impact damage of fruit. For instance, 'Sweet Charlie' strawberries forced-air cooled to 1 °C had larger bruise volume than those held at 20 °C both subjected to the same drop impact. In comparison, hydrocooled fruit had larger damage at 20 °C than those held at 1 °C. Further results revealed that berries that were forced-air cooled to 1 °C, had larger bruise volume compared to berries hydrocooled to 20 °C. These findings suggest that immediate cooling after harvest could be a potential approach to improve fruit resistance to bruise damage. Toivonen et al. (2007) suggested rapid air-cooling after harvest could also be useful to ensure complete recovery from harvest-induced bruises of non-severely damaged apples.

The effect of pre-cooling using forced-air on the fruit firmness and bruise damage of plums was studied by Martinez-Romero et al. (2003). The study revealed that fruit firmness was 39.4% higher in pre-cooled bruise damaged fruit in comparison to fruit damaged before the pre-cooling process. It is conceivable that improved fruit firmness influenced the mechanical strength of plums, as shown by reduced bruise damage and prolonged fruit shelf life in pre-cooled damaged fruit. These results strengthen the need for pre-cooling of fruit immediately after harvest to reduce the incidence of bruising and improve postharvest storage and shelf life. Tahir (2006) reported a positive relationship between the decrease in bruise susceptibility of apple and pre-cooling treatment. Pre-cooling with air reduced the bruise area of 'Aroma' apples by 25% and 'Ingrid Marie' by 15% in comparison to untreated fruit, with no significant effect observed in 'Cox's Orange Pippin' apples. The effect of pre-cooling with air on decreasing bruise damage susceptibility relies in part on creating a vapour gradient between the interstitial air spaces in the fruit cortex and the atmosphere around the fruit that enhance increased water loss from the fruit (Klein, 1987). Subsequently, water loss from fruit tissue causes the decrease in turgidity, resulting in improved resistance to bruising (Tahir, 2006).

4.2.2. Effects of temperature

Temperature is one of the major post-climacteric factors that influence bruising of fruits (de Martino et al., 2002; van Zeebroeck et al., 2006). The temperature of the fruit flesh affects tissue flexibility, hence equally affecting susceptibility to bruising (Bajema et al., 1998; Hertog et al., 2004). Lee (2005) stated that temperature influences the tissue resistance to bruising by affecting cell hydration that leads to increased turgor. Subsequently, an increase in fruit turgor potentially increases both the stiffness and elastic modulus of the tissue. An increase in the cell internal pressure tends to reduce the additional force needed for breakage of preloaded tissue (Bajema et al., 1998), which means the increase in tissue susceptibility damage. There is another suggestion that low temperature affects a lag in metabolic activity and a change in fruit texture, and the final effect of temperature on bruise susceptibility could depend on the balance between the aforementioned processes (van Linden et al., 2006). For instance, work on tomatoes revealed that cold temperature reduces the susceptibility to bruising (Chun and Huber, 1998). The authors attributed this to the rate of fresh fruit softening that decreases with storage temperature, and vice versa. Additionally, temperature does influence the polygalacturonase activity, an enzyme that is responsible for increased bruise damage susceptibility in higher concentrations (Chiesa et al., 1998).

Based on the above various means in which temperature influences the bruise damage susceptibility in fruit, frequently researchers have reported conflicting results. Some works have established the dependency of fruit susceptibility to bruise damage on fruit temperature and temperature of handling environment (Bollen, 2005). Stow et al. (2004) noted that at the same impact level, 'Colney' sweet cherries at 0 °C had higher impact bruise damage than those maintained at 5 °C. Bugaud et al. (2014) found that reduction in storage temperature from 18 °C during ripening to 13 °C reduced susceptibility to impact bruising in bananas. The drop in temperature delayed maturity of bananas by two days, which was indicated by the rate of ripening, the pulp firmness, and soluble solids.

The effect of pulp temperature on susceptibility to bruising of three strawberry cultivars was reported by Ferreira et al. (2009). Their findings highlighted the incidence and severity of bruising as temperature dependent. During compression test, the bruise size of berries decreased with a declining temperature of the fruit pulp, with the highest values of bruise volume significantly higher at 30 °C compared to that of cold pulp (1 °C). Similarly, the bruise size due to drop impact of strawberry fruit increased with increase in drop height and decreasing temperature of the fruit pulp. These observations are in agreement with earlier findings in bananas, pears and some stone fruits that have different responses to injuries when subjected to different types of forces at low temperatures (Banks and Joseph, 1991). Sweet cherries handled at a temperature < 10 °C had a higher internal and external bruise damage whereas less damaged cherries were noticed when handled at a temperature >10 °C (Crisosto et al., 1993). Overall, the understanding of the fruit response on compression or impact loading at different temperatures could be used to minimise the incidence and severity of fruit bruising during harvest and postharvest handling.

There are a few reports that the temperature of the fruit pulp/flesh or of storage environment does not affect bruise damage susceptibility. Jung and Watkins (2009) reported that the bruise size in damaged 'Empire', 'Fuji' and 'Golden Delicious' apples was not affected by fruit temperature at the time of bruising. Similar results were confirmed in New Zealand apples, that fruit temperature at the time of impact has no significant influence on the bruise damage susceptibility (Klein, 1987; Bollen, 2005). Bollen (2005) could not find any significant difference in bruising between 'Braeburn' apples dropped at 8 °C and those at 26 °C.

4.2.3. *Effects of humidity*

Limited data are available on the effects of storage humidity on bruise damage of fresh fruit. However, a few earlier works have revealed that humidity during storage potentially affects the bruising. Garcia et al. (1995) reported that there was a difference in bruising susceptibility between dry and humid air stored apples, both for 'Golden Supreme' and 'Golden Delicious' cultivars. On contrary, Akkaravessapong et al. (1992) observed that neither of low, medium or high storage humidity had significant effect on bruise susceptibility of bananas during subsequent storage and ripening. However, the authors observed the difference in colour of bruised areas of bananas at low or medium humidity and those stored in high humidity. Banks and Joseph (1991) examined the effects of time and humidity level on the compression bruise threshold and weight loss of bananas. The results showed the drop in compression bruising threshold with time after harvest at low humidity treatment (75% RH). These results were similar for bananas held at higher humidity (92% RH), where the bruise threshold declined within 48 h of harvest. The summary of the effects of temperature and humidity on bruise damage susceptibility of various fruits is presented in Table 2.

4.2.4. *Effects of storage duration*

Generally, stored fruits are less susceptible to bruising than freshly harvested fruit (Klein, 1987; Pang, 1993; Garcia et al., 1995). Klein (1987) studied the effects of harvest date and length of time in the storage of New Zealand 'Gala' and 'Granny Smith' apples. The results showed an increase in bruising with the lateness of harvest and decreased over storage time. Similarly, Pang (1993) working with apple 'Jonathan' and 'Delicious' reported an increase in bruise size with advancing preharvest maturity while decreasing with an increase in storage time. Vursavus and Ozguven (2003) stated that immediately after harvest, peaches exhibited superior strength properties measured as bio-rupture forces, modulus of elasticity and shear stress before rapid softening observed after 14 days of storage.

Freshly harvested 'Golden Delicious' and 'Golden Supreme' apples were more susceptible to bruising compared to after storage (Garcia et al., 1995). Similar results were reported for 'Blanquilla' and 'Conference' cultivars of pear fruit. Susceptibility to bruising has been attributed to changes in fruit turgidity during storage (Klein, 1987; Garcia et al., 1995). In view of that, Garcia et al. (1995) stated that at a given impact energy, turgid fruits have lower deformation than flaccid fruits. Similarly, long storage duration of fruit could potentially increase the resistance to mechanical impact. The susceptibility of pears and apples to impact bruising decreased with increasing duration of cold storage. The authors attributed this propensity to an increase in fruit skin resistance and changing texture over storage duration, which could subsequently decrease the energy absorbed during impact.

A few reports have revealed that storage duration can increase the sensitivity of fruit to bruising. Lippert and Blanke (2004)

Table 2 Effects of fruit temperature at the time of bruising, storage temperature after bruising and humidity on bruise susceptibility of fresh fruits

Factor	Fruit	Main finding	Reference
Temperature	Sweet cherry	Lower fruit temperature (2.5–3.8 °C) increased sensitivity of cherries to bruising than higher temperature (7–10 °C) Temperature of 7–10 °C for packing line operations was recommended to avoid bruise damage	Zoffoli and Rodriguez (2014)
		Fruits handled between 0 °C and 10 °C had higher bruise damage (> 50% increase for internal and 30%–40% for external damage) Handling at a temperature above 10 °C resulted in 5%–40% of fruit with damage	Crisosto et al. (1993)
		Increase in drop impact on fruit by 0.01 J resulted in 6.3% and 5.7% increase in bruise size maintained at 0 °C and 5 °C, respectively	Stow et al. (2004)
	Apple	'Jonagold' handled at 1 °C were more damaged by vibrational transportation than apples at 20 °C. The effect of temperature on apple bruising was more noticeable at high acceleration amplitudes	van Zeebroeck et al. (2007c)
		No difference in bruise susceptibility observed between 'Braeburn' fruit held at 8 °C and 26 °C during impact At minimal impact energy levels (0–0.1 J), fruit temperature was not a major factor affecting bruise susceptibility	Bollen (2005)
	Banana	Temperature drop from 18 °C to 13 °C reduced bruise susceptibility (higher impact energy in low temperature and lower in high temperature handled fruit)	Bugaud et al. (2014)
	Apricot	Impact of 'San Castrese' at low temperature (4 °C) inhibited the bruise symptoms	de Martino et al. (2002)
	Strawberry	Decrease in fruit pulp temperature from at 30 °C to 1 °C decreased bruise volume for cultivar 'Chandler', 'Oso Grande' and 'Sweet Charlie' For impact tests, change in drop height (from 20 to 38 cm) had more severe impact to bruising than change in pulp temperature (1–24 °C), with variation among cultivars	Ferreira et al. (2009)
Humidity	Apple	'Golden Supreme' and 'Golden Delicious' stored in low humidity (35%–49%) had 0.04% and 0.07% fewer bruise susceptibility values, respectively, compared to high humidity (100%)	Garcia et al. (1995)
	Banana	Low (~50%), medium (~70%) and high (~90%) humidity did not affect bruising of 'Williams' during subsequent storage and ripening	Akkaravessapong et al. (1992)
		Low humidity (75%) reduced bruising threshold due to compression within 48 h of harvest while at higher humidity (92%) the decline was delayed for about 24 h	Banks and Joseph (1991)

observed that longer cold storage (2 °C) of mechanically harvested European plums induced fruit softening and bruising. Gołacki et al. (2009) observed higher values of bruise resistance coefficient (BRC) for fresh apples dropped within the studied range of damaging heights and less for 4-week-stored apples. Fresh apples suffer less interior damages under the identical impact conditions compared to stored apples; hence apples after storage exhibited lower bruise resistance than the fresh ones. Shafie et al. (2015) showed that storage time of pomegranate fruit impacted at cheek position at a high impact energy (1390 mJ) increased slightly the bruise size by ~5% after 120 days of storage. A similar trend of increase in bruise volume was also observed for fruit impacted at calyx position using the same impact energy level. The changes in bruising of pomegranate fruit was attributed to physiological and structural changes during cold storage, usually loss of cell-wall integrity, leading to an increase in soluble pectin and a decrease in fruit firmness (Mirdehghan et al., 2006). Overall, the influence of storage duration on fruit bruising could rely on the storage conditions such as temperature, humidity as well as the atmosphere surrounding the stored fruit.

4.2.5. *Effects of controlled atmosphere storage*

Application of controlled atmosphere storage (CAS), in combination with appropriate temperature control, has been a common practice for maintaining quality and extending shelf life of fresh produce (Hussein et al., 2015). The effectiveness of CAS in maintaining fruit quality could be achieved through the regulation of humidity, in addition to air (oxygen and carbon) concentrations. Hence, changes in other attributes such as physico-mechanical properties of fruit during storage in CAS could also rely on the aforementioned conditions. Prange et al. (2000) studied the effect of low-humidity CAS (4.5% $CO_2 + 2.5\% \ O_2$) on compression bruising of apple cv. McIntosh. The authors observed the decrease in visible bruising on both green and red side of the 'McIntosh' apples when compressed with a force of 90 N.

Tahir et al. (2009) investigated the effect of postharvest heating on bruise susceptibility of apples after storage in normal atmospheric air- or controlled atmosphere (CAS). It was revealed that both heat treatment (at 40 °C and 80% RH for 24 h) and CAS (2.0 kPa O_2 + 2.0 kPa CO_2 and 90% RH), significantly decreased the bruise damage of apples. Earlier research has established that heat treatment results in the cushioning effect that decreases the impact pressure by melting skin wax and induces structural changes of the fruit (Roy et al., 1994). Additionally, according to Tahir et al. (2009), the combination of heat treatment and CAS improve the fruit firmness compared to those in control, non-heated or normal air storage.

Eckhoff et al. (2009) studied the effect of storage methods on bruising of 'Braeburn' and 'Jonagold' apples. Their finding showed that at lower temperature (2 °C), neither of the storage conditions, controlled atmosphere (CAS) or ultra-low oxygen (ULO) storage had influence on bruise sensitivity of apples. The resistance to bruising was ascribed to the positive influence of the CAS/ULO storage in reducing the degradation of the fruit pulp strength (Eckhoff et al., 2009). These results contrasted those of normal atmosphere storage, which showed reduced fruit sensitivity to bruising (Eckhoff et al., 2009). The later was attributed to increased water loss during storage due to lower humidity in normal atmosphere storage (Kupferman, 2006). However, Tahir (2006) reported the contrasting finding that ULO stored apples had the improved resistance to bruising in comparison to normal atmosphere stored fruit. According to van der Sluis et al. (2003), the ULO storage results in delayed softening of fruit (Johnston et al., 2003) and also to a decrease in phenolic acid concentration.

Application of rapid CAS (21% $O_2 + 30\% \ CO_2$) reduced the cranberry fruit losses due to bruise damage, physiological or fungal breakdown (Gunes et al., 2002). The authors observed fewer incidences of bruising in CAS stored cranberries after 2 months storage, in comparison to the high level of bruise incidences in normal atmospheric air. On the other hand, super-atmospheric O_2 in combination with high CO_2 levels resulted in greater losses of cranberries. Firmer fruits are more resistant to bruise damage under normal harvesting and handling conditions (Canete et al., 2015; Li et al., 2016b).

4.2.6. *Effects of chemical treatment*

Application of exogenous polyamines such as putrescine and spermidine play important physiological functions including delaying fruit senescence, improving firmness and bruise resistance while prolonging fruit storage (Martínez-Romero et al., 2000). Martínez-Romero et al. (2000) reported the deformation (bruising) caused by 50 N compression was significantly lower in putrescine-treated andcalcium-treated lemon fruit than in untreated fruit with no differences between putrescine and calcium treated fruit. After 21 days of storage, the relatively lower decline in initial firmness was observed in putrescine- and calcium-treated lemon fruit in comparison to untreated fruit. Higher firmness in putrescine treated lemon was contributed by an additional effect of exogenous putrescine in the inhibition of enzymes involved in softening of peel (Kramer et al., 1989).

Martínez-Romero et al. (2002) reported the 1 $mmol \cdot L^{-1}$ putrescine treated apricots showed less susceptibility to compression damage compared to untreated ones. They attributed the reduced fruit sensitivity to higher firmness and lower tissue disruption. The effective function of putrescine in increasing fruit resistance to bruising is related to its capacity to bind the pectic substances at the cell wall and its inhibition effect of enzyme activity that stops degradation of pectic acids (Kramer et al., 1989). In agreement with apricots, Martínez-Romero et al. (2000) reported the treatment of peaches with 1 $mmol \cdot L^{-1}$ putrescine or 100 $mg \cdot L^{-1}$ gibberellic acid was effective in modifying the fruit susceptibility to mechanical damage. Putrescine and GA_3 treated peaches compressed by 25 N had lower bruise volume and percentage of fruit deformation than untreated fruit.

Li et al. (2016b) demonstrated that treatment with 10 $mg \cdot L^{-1}$ of 1-Methylcyclopropene (1-MCP) prior to impact damage reduced the bruise susceptibility of 'Yali' pears. The lower bruise volume was attributed to improved firmness of 1-MCP treated pears. The role of 1-MCP in improving fruit firmness has also been reported in different cultivars of plum (Menniti et al., 2004) and pears (Li et al., 2016b). Treatment with 1-MCP improves fruit texture, one among other essential rheological parameters that contribute to bruise damage susceptibility (Ahmadi, 2012; Canete et al., 2015). Similarly, application of 1-MCP after harvest of European plums cv. Hauszwetsche improved the fruit quality by retarding bruising in 2–3 weeks of cold storage (Lippert and Blanke, 2004). Manually harvested plums without 1-MCP treatment had lower bruise incidence in the first 4 weeks after harvest.

Jung and Watkins (2009) reported that treatment with 1-MCP reduced slightly the bruising effect of apple cv. Empire and Golden Delicious. No changes in bruise volume of 1-MCP treated 'Fuji' apples was observed while bruise depth of 1-MCP treated 'Golden Delicious' apples was lower than that of untreated fruit. In conclusion, authors attributed the lack of changes in bruise volume and bruise depth of cold (0.5 °C) 1-MCP-treated apples to the possible effect of temperature on the response of 1-MCP.

In conclusion, the benefits of timely use of 1-MCP in reducing incidences and severity of bruise damage and application on the tree prior to harvest are presented. The present information highlights that postharvest treatment using chemicals with a potential to modify the fruit texture without compromising the sensory quality of fruit could reduce fruit susceptibility to bruising. The summary of chemical treatments and response to bruise damage susceptibility of various fruits is presented in Table 3.

4.2.7. *Effects of packaging*

Type of packaging and arrangement of produce inside the package could influence the bruising for fresh produce. In the course of loading, offloading or during handling, packages containing fresh produce are at times thrown from certain heights, an attempt that could result in impact bruising (Jarimopas et al., 2007). Impact bruise damage of produce could also result from vibrational movement during transportation in trucks (Fadiji et al., 2016a, 2016b). Bruise damage of fruit inside the package is due to the energy transformation as some of the kinetic energy absorbed by produce leads to bruising (Jarimopas et al., 2007; Zarifneshat et al., 2010).

Aliasgarian et al. (2013) reported that bruise damage of berries did not differ between top and middle layers within the boxes, whereas those in the bottom layers differed significantly from the two other layers. Kumar et al. (2016) reported similar findings with litchi fruit packaging, where they assessed losses during long distance transportation. Corrugated fibreboard box (CFB) packaging was more effective in reducing both mechanical (bruised and compressed) and pathological (fruit decay) losses, as opposed to conventional wooden boxes. Similarly, Lu et al. (2010) showed that the percentage of damaged apples was less in the double-wall corrugated fibreboard box than that in the single-wall corrugated fibreboard box. This was explained by the ability of double-wall corrugated fibreboard box to absorb more impact energy, and hence less energy left for the apple resulting in fewer bruises.

Fadiji et al. (2016a) evaluated the susceptibility of apple cv. Golden Delicious in two commercial ventilated corrugated paperboard (VCP) packages, MK4 and MK6. In vibration frequencies tested, the bruise damage susceptibility was the highest for MK6, measured as bruise area and the lowest bruise area in MK4. The MK6 package transmitted more vibration and hence more damage to the fruit packed inside due to the lower length-to-height ratio (1.45), in comparison to its counterpart ratio of 1.86.

Another research assessed the impact bruise damage of 'Golden Delicious' apples inside the two types of ventilated corrugated paperboard package designs, Bushel MK4 and Econo (Fadiji et al., 2016b). Irrespective of drop height, fruit placed in the MK4 package in layers (with plastic trays) experienced less bruising than bulk packed fruit in Econo package (inside polyethylene plastic bags without trays). They estimated a 50% higher bruise incidence and 66% higher bruise susceptibility in bulk packaged fruit than those in the layered package. They found that lower bruise damage corresponds to the effectiveness of trays inside the package to absorb more of the exerted impact energy than the energy transferred to the fruit. These findings highlight that both the package design and fruit arrangement within the package potentially influence the bruise damage.

Evaluation of protective performance of various shipping packages (corrugated fibre boxes, reusable plastic crates, and foam nets) based on the measurement of bruise damage inflicted to packed mangoes during simulated shipping test was reported by Chonhenchob and Singh (2003). The results indicated that the percentage of bruise damage during shipping was reduced with the use of foam net cushions of individual fruit in comparison to crates and box-packed bare fruit. Mangoes in a ten fruit-per-layer and five fruit-per-layer configurations crates showed less bruising as compared to nestable reusable and straight-walled plastic containers. Reduction in bruise damage was 50% higher in the crate-packed mangoes in comparison to the latter containers.

Application of various packaging materials to wrap individual fruit is being used for reducing both the incidence and bruise damage severity. It has been suggested that good interior packaging should be characterised by practical ability to treat fruit as

Table 3 Fruit bruising as affected by exogenous chemical treatment

Fruit	Postharvest treatment	Main finding	Reference
Lemon	1 $mmol \cdot L^{-1}$ putrescine	Compression bruising in putrescine-treated lemon was lower (5.18%) than calcium-treated (5.27%) and control lemons (5.63%)	Martínez-Romero et al. (2000)
Apricot	1 $mmol \cdot L^{-1}$ putrescine	Fruit treated with 1 $mmol \cdot L^{-1}$ of putrescine had a lower bruise area and bruise volume (90 mm^2 and 240 mm^3) than untreated apricots (160 mm^2 and 510 mm^3), respectively	Martínez-Romero et al. (2002)
Peach	1 $mmol \cdot L^{-1}$ putrescine or 100 $mg \cdot L^{-1}$ gibberellic acid (GA_3)	Treated peaches had lower bruise volume in putrescine (229.90 mm^3) and GA_3 (299.23 mm^3) in comparison to non-treated fruits (378.36 mm^3)	Martínez-Romero et al. (2000)
Pear cv. Yali	10 $mg \cdot L^{-1}$ 1-MCP	Treatment with 1-MCP prior to impact bruising reduced the bruise susceptibility of pears. 1-MCP treated fruits were 14.3% firmer than non-treated fruits	Li et al. (2016b)
Plum	0.5 $\mu L \cdot L^{-1}$ 1-MCP	Treatment with 1-MCP before the mechanical harvest of plums increased bruising incidence, while the mechanical harvest after the 1-MCP treatment did not	Lippert and Blanke (2004)
Apple	1 $\mu L \cdot L^{-1}$ 1-MCP	Bruise volume reduced by 7% and 7.6% in 1-MCP treated 'Empire' and 'Golden Delicious' apples, respectively, in comparison to 'Fuji' and untreated apples	Jung and Watkins (2009)

separate units, avoids fruit-to-fruit contact, and above all capable of absorbing the impact energy (Jarimopas et al., 2007). Jarimopas et al. (2007) showed that irrespective of the cushioning materials, small values of bruise volume were measured in cushioned apples of lower lines in the package, in comparison to bruise volume for bare or uncushioned fruit. Jarimopas et al. (2002) studied the suitability of paper as the internal lining surface of plastic and bamboo fruit containers for protecting fresh fruit from bamboo cuts and moisture loss during transport and found it as a poor cushioning material against impact damage. Elsewhere, wrapping of apples with dry banana string made-netting provided suitable cushioning against impact energy (Jarimopas et al., 2004).

Chonhenchob and Singh (2003) evaluated the efficiency of two cushioning systems, the plastic foam nets, and paper-wrap materials in terms of physical protection among other quality parameters of papaya fruit packed in shipping containers by performing actual shipment and vibration tests. Results showed that papayas both wrapped with foam nets and paper-based materials had the lowest percentage of bruise damage in comparison to uncushioned fruit. Hence, to maintain the quality of papayas throughout the handling and distribution system, a single or double layer placement of papayas inside packages coupled with cushioning is recommended.

Another research examined the parameters essential for apple packaging processes by exposing them to random excitation and evaluated effect of individual apple cushioning on vibrational bruise damage (Eissa et al., 2013). Foam-net and paper-wrap efficaciously reduced bruise volume per fruit compared to bruise incidence in uncushioned apples. Further results singled out the foam-net cushioning materials as more effective in reducing bruise damage than paper-wrap materials or uncushioned apples.

Overall, the strategies to reducing bruise damage of packed fresh fruit could revolve around designing of new packaging systems. Hence, the use of fruit handling materials with improved cushioning features to reduce the susceptibility of fruits to bruising is paramount. Other factors such as appropriate stalking, avoiding overfilling in the package and proper handling of packages could also contribute to the same.

4.2.8. *Static versus dynamic loading – impacts on fruit bruising*

As stated earlier, fruit bruising is induced by either dynamic (impact or vibration) or static (compression) stress during harvest, transport, field packing, and subsequent handling operations. Hence, the mechanical energy applied to or absorbed by produce is a major deciding factor on bruise damage (Opara, 2007; Zarifneshat et al., 2010). Dynamic loading is likely to occur during harvesting as fruit dropping into the picking buckets, during sorting and packing or vibration movements, mainly occurring during transportation (Li and Thomas, 2014; Komarnicki et al., 2016). Likewise, after harvest produces are occasionally subjected to static loading conditions in the field, during transportation or storage, especially when poorly designed bins are overfilled and stalked (Thompson, 2003; Lewis et al., 2008; Li and Thomas, 2014; Komarnicki et al., 2016).

Banks et al. (1991) suggested that the effects of tissue injuries due to compressive and impacting injuries might differ significantly. Mechanical damage caused by impact and compression has been related to the conformation of the fruit cell wall (Ferreira et al., 2008). Dynamic loading leads to the failure of the intercellular bonds or actual cleavage of the cells, whereas compression under constant loading affects the viscoelastic cell wall, causing cell bursting under high stress. As shown in Table 4, under normal harvesting and postharvest handling practices, fruits are more exposed to dynamic loading than static (Kupferman, 2006).

With respect to bruise severity, studies have reported conflicting results between compression and impact bruising. Holt and Schoorl (1976) suggested that more energy is dissipated in the breaking of microfibrils of the stressed tissues during impact stress, and hence resultant bruise severity is less than that under compressive loading. Ferreira et al. (2008) simulated conditions encountered during commercial handling of strawberry fruits subjecting individual fruit to impact or compression forces to determine the sensitivity to bruising. Strawberry fruit subjected to impact had lower bruise volume than compressed fruit.

Table 4 Potential loading situations influencing bruise damage of fruit

Destination/ inception point	Process stage	Type of loading
Orchard	Harvest into:	
	– buckets	Dynamic
	– field-boxes, or	Dynamic
	– pallet boxes	Dynamic
	Transportation to packing-house	Dynamic/static
Packing house	Dumping, dry or into water	Dynamic/static
	Sorting	Dynamic
	Grading	Dynamic
	Repack	Dynamic
	Transportation to:	
	– wholesale markets	Dynamic
	– chain store distributors	
	– retail markets	
	– shelf storage	
Distributor	Sorting (conveyors etc.)	Dynamic
Retailer	Putting on display	Dynamic/static

4.2.9. *Effects of impact surface*

The size and shape of the bruise influenced the impact surface among others (Kupferman, 2006; Xu et al., 2015). Materials for cushioning are being used to provide effective energy absorption and dissipation (Armstrong et al., 1995; Ortiz et al., 2011). Kupferman (2006) revealed that picking into cushioned buckets could reduce bruising at harvest compared to a soft-sided bag or uncushioned bucket.

Impact surfaces differ in their ability to absorb the energy generated during fruit impact (Jarimopas et al., 2007; Ortiz et al., 2011). Ortiz et al. (2011) investigated the shock absorbing capacity of different impact surfaces (concrete floor, elevated canvases and concrete floor covered with shock absorber canvases) during simulated mechanical harvesting of Mandarins, orange and lemon. The authors revealed that bruising of citrus fruit during harvest depends on the impact surface, among other factors.

Fu et al. (2017) studied the impact bruising of 'Jazz' apples by comparing three types of cushioning materials (polyurethane foams, 1, 2 and 3) with firmness ratings of 2.1, 4.8, and 9.7 to 11 kPa, to cover an aluminium plate impact surface. Use of cushioning forms 2 and 3 provided sufficient cushioning for apples due to the relatively higher non-bruising level of impact (160 and 160 N) tolerated by fruit at impact. Chen et al. (2018) determined the effect of load conditions on mechanical damage of citrus and the protection performance of different materials for citrus. Their evaluation revealed that corrugated paper had the best performance in reducing compression damage. With respect to drop impact experiment, the expanded polystyrene had the lowest damage degree, while high-density polyethylene had the best effect on reducing damage.

5. Outlook

This literature has reviewed a number of factors influencing the incidence and severity of bruising in fruits at harvest and all along the postharvest handling chain. Incidences of bruise damage of various fresh produce during mechanical harvest have been widely reported.

It has further been established that, among other postharvest factors, the temperature is the major post-climacteric factor influencing the susceptibility of bruising. Consistent contrasting results reported on the temperature effect on bruise susceptibility. Appropriate temperature control could be an attempt to reduce incidences and severity of bruise damage. Furthermore, the review has also shown the use of postharvest treatments alone or in combination with other storage methods in minimising the sensitivity of fresh produce. A number of chemical treatments have been proved effective in improving the resistance of fruits to bruising.

Given the increasing demand of fresh produce in the global market and expanding use of mechanised techniques in both harvesting and postharvest handling operations, future research direction must target towards the exploration of how bruising is influenced by these emerging techniques at each stage and specific produce. Study of postharvest treatments and their influence on bruise damage susceptibility is also paramount. This could provide a science based-tool to help in adjusting operating conditions including changing the design of harvesting machine and plant architecture to reduce bruising.

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