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Review

Quantitative evaluation of mechanical damage to fresh fruits

Zhiguo Li[a,*] and Colin Thomas[b]

[a]School of Mechanical and Power Engineering, Henan Polytechnic University, 454003 Jiaozuo, China (Tel.: +86 391 3983223; e-mail: lizhiguo0821@163.com)

[b]School of Chemical Engineering, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK

Fresh fruits are very susceptible to mechanical damage during harvesting, packaging and transport, which can result in a substantial reduction in quality. Ideally, such damage would be minimized through improved understanding of the mechanisms. If damage occurs, economic losses might be minimized by grading affected fruits, based on the severity of damage, into those that need more than minimal further processing and those that do not. In either case, an objective and quantitative evaluation of the degree of mechanical damage is required. However, this is still far from being realized and remains an important challenge of past and proposed research in food safety.

This review concerns the quantitative evaluation of mechanical damage to fresh fruits. Firstly, the sources of damage to fresh fruits during mechanical handling are summarized. The mechanisms are described in detail. Existing quantitative assessments characterizing surface and internal mechanical damage and its prediction are then reviewed. Finally, future research directions are discussed. The main challenge in evaluating mechanical damage to fresh fruit objectively is to develop a method to assess accurately the extent of internal damage to fruits caused by excessive external forces.

* Corresponding author.

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Introduction

Fruits play an important role in providing essential vitamins, minerals, and dietary fiber to the world, and nowadays have become an important component of many human diets. The Food Agricultural Organization of the United Nations (FAO) has predicted that the world population will top eight billion by the year 2030. Furthermore, perceptions of health benefits have increased the popularity of minimally processed fruits whilst there has also been an ongoing trend to eat out and to consume ready-to-eat foods (Alzamora, Tapia, & Lopez-Malo, 2000). The demand for fresh and processed fruits and vegetables should therefore increase dramatically. To satisfy this demand, large-scale planting and mechanical handling (e.g. harvesting, packaging and transport) of fruits is necessary but fleshy fruits are very susceptible to mechanical damage (Li, Yang, *et al.*, 2013). Mechanical damage to fruits is mainly inflicted during field harvesting operations but also occurs in grading and packing lines, during transport, and in handling at the end of the supply chain for example during produce display and selection by retailers and consumers (Margarita, 1996). The quality of these crops can be substantially reduced by poor care and handling, especially if they are not consumed immediately, which is a serious food safety and economic issue.

Food security and agricultural efficiency require that urgent action is taken to minimize such losses. The potential mitigation schemes include (i) minimizing the incidence of damage by investigating the effects of the application of external forces during harvesting, packaging and transport and therefore to recommend improved handling methods to growers and others in the supply chain; and (ii) assessing the surface and internal damage of post-harvest fruits nondestructively and then sorting them into different damage grades for immediate or optional handling (i.e. not storable or storable). However, both (i) and (ii) require an objective and quantitative evaluation of the surface and internal mechanical damage to fruits. Surface damage of fruits is easily observed and may be determined objectively but internal damage is difficult to assess and measure. Unfortunately, internal damage usually leads to subsequent accelerated rot of a whole fruit (Van Linden, De Ketelaere, Desmet, & Baerdemaeker, 2006). Many fruits with apparently little damage during harvesting are subsequent discarded and losses in the harvest–consumption system might be as high as 51% (FAO, 2003). The objective of this paper is to review the literature in this field and to discuss future research directions.

Sources of mechanical damage

Improper physical handling during harvesting, grading, packaging and transport can result in structural, tissue and cell damage to fruits caused by impact, compression, abrasion, puncturing, testing, or several actions combined. Structural failure may increase susceptibility to decay and growth of microorganisms.

Impact damage

Impact damage occurs when an item hits a surface with sufficient force to rupture or even separate cells. The external sign is a bruise or crack. Common impact damage usually happens in free drops of fruits from trees to ground during harvesting and in dynamic impacts between single fruits and between them and packaging or containers. The latter results from vibrations (e.g. vibration of transporting vehicles, fruit containers subjected to transport vibration, conveyor belts with grading system vibration). Impact damage is the most severe mechanical damage mechanism in fruit handling (Van Zeebroeck *et al*., 2007a).

Free drop tests have shown that impact on metal surfaces inflicts the greatest damage to tomato fruits compared to five other potential packaging materials, whilst damage is least with foam (Idah & Yisa, 2007). Weeds, mulch and shock absorbing canvases covering the ground have been shown to reduce impact damage to fresh citrus fruits during mechanical harvesting (Ortiz, Blasco, Balasch, & Torregrosa, 2011). The percentage of damaged apples in single-wall and double-wall corrugated boxes increased with drop height during transport and handling and damage to apples in the lower layer of both boxes was notably higher than in the upper layer (Lu, Ishikawa, Kitazawa, & Satake, 2010). Bruise prediction models from impact tests show that factors such as impact energy, cultivar, impact location, ripeness, storage temperature and curvature radius at the location of impact have a significant effect on the bruise susceptibility of tomato fruits (Van Zeebroeck *et al*., 2007a) whilst the duration of impact plays a critical role. The bruising potential of low and medium energy impacts is largely controlled by the fruit texture whilst the effects of high and very high energy impacts depend mainly on fruit ripeness and the impact location (Van Linden, Scheerlinck, Desmet, & De Baerdemaeker, 2006). Simulations of impact damage to fruit during the passage of a truck over a speed bump showed that higher truck loads led to less bruising and that apples in bulk bins behind the rear axle suffered more damage than those in bins in front of the rear axle (Van Zeebroeck *et al*., 2008). Impact damage is alleviated by the harvesting of fruits at the half ripe stage when the fruit stiffness is higher than that of ripe fruits. This is because the extent (volume) of impact damage to fruit is inverse proportional to stiffness (Abedi & Ahmadi, 2013; Armstrong, Stone, & Brusewitz, 1997; Zarifneshat *et al*., 2010). Clearly, impacts during mechanical handling should be avoided as much as possible.

Compression damage

Compression also causes bruising and cracking. Compression damage occurs primarily during or after packing as a result of forcing too much product into too small a container. While fruits such as melon should be packed firmly enough to avoid chafing, they should not be stuffed in so tightly that their curved surfaces become flat. Compression damage also occurs during mechanical harvesting if grasp forces exceed a threshold for tissue failure. Compression tests have shown that the extent of compression, the curvature of the finger surfaces and internal structural characteristics affect mechanical damage to tomato fruits (Li, 2013; Li, Li, & Liu, 2010; Li, Li, & Yang, 2013; Li, Li, Yang, & Liu, 2013). Locular gel tissues were damaged before mesocarp and exocarp tissues.

Advancing fruit ripeness or increased vibration levels increase the susceptibility of packaged fruit to damage by compression loading. The factors (ripeness and vibration) are inter-related and together determine the intensity of compression damage inflicted on packaged fruits. Because of this, half-ripe tomatoes fruits should be preferred for road transportation in packaging containers (Babarinsa & Ige, 2012).

Strawberry fruits subjected to impact showed bruise volumes lower than compressed fruits, indicating the possibility of their being handled and graded in a packing line (Ferreira, Sargent, Brecht, & Chandler, 2008). The cultivar of the fruit may be important. For example, ‘Sweet Charlie’ strawberries showed bruise volumes about 40% higher than the others cultivars when subjected to compression. Aliasgarian, Ghassemzadeh, Moghaddam, and Ghaffari (2013) reported that the operations related to picking, packing and delivery to the market, fruit position in the box and box position on the truck, had significant effects on the extent of the mechanical damage to strawberry fruits.

The pattern of fruit bruising caused by slow compression is quite different from that caused by impact. Chen, Ruiz, Lu, and Kader (1987) reported that the cross section of a pear compression bruise resembled a parabola, similar to that in apples and peaches, but the cross section of an impact bruise often had long spikes extending radially from the impact area into the body of fruit. The irregular pattern of impact bruises makes it more difficult to quantify damage than with compression damage.

Abrasion

Abrasion occurs during movement of one body against another leading to the removal of surface layers. This may occur (i) during harvest when roots or tubers are dug up; (ii) when fruits are conveyed at excessive speed; and/or (iii) when the fruit surface is rubbed away by friction against dirt or sand or container surfaces during packing. Abrasion requires enough energy to be absorbed to remove