Orchard management strategies to reduce bruises on apples in India: a review

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Abstract

India is the fifth-largest apple producer in the world with more than 2 MT per year. Mechanical damage such as bruises of apples (*Malus domestica* Borkh.), which can result in considerable wastage and decline in quality, is a major problem of the apple industry. On-site investigations of apple orchard management strategies to reduce bruises in Northern India were conducted by the first author in collaboration with the University of Bonn. The apple industry including the farmers is in a continuous process of reducing losses caused by mechanical damage. Apple bruises can develop along the whole value chain. Orchard management offers countermeasures to reduce bruise susceptibility of the apples. At harvest, bruises can be caused by impact and compression forces due to unsuitable practices. This review explains the formation and development of bruises, followed by the causes of mechanical damage and orchard management measures to reduce or avoid bruises, with particular regard to India. The orchard management measures include crop load management, fruit water status and nutrient composition, maturity stage, harvest time later in the day, gentle harvest methods, packing into soft, padded bins and careful transport of the apple bins out of the orchard.

Keywords Apple (*Malus domestica* Borkh.) · Bruise · Food waste · Fruit quality · Mechanical damage

Introduction

Apple production and demand in India

As part of work at the University of Bonn to reduce food waste, particularly in apple production systems (Blanke 2015), the cultivation in Northern India was investigated. Annual apple production in India exceeds 2 MT, i.e. twice the apple yield in Germany, making it the fifth-largest apple producer worldwide (FAO 2019). For the Indian apple growing states Jammu & Kashmir, Himachal Pradesh and Uttarakhand, apple production is of significant economic importance and contributes to a healthy diet. The growth in economy as well as population in India led to a continuous rise in demand for apples (De Pablo Valenciano et al. 2018). The market potential for apples in India ranks as the

largest in the world and exceeds inland production by far (Arora 2018).

The demand for high quality apples is increasing, especially in upper income segments of the population, who are willing to pay a high price; this demand exceeds domestic supply (Golombek and Blanke 2020). The import of foreign high quality apples with a good reputation, amounts to only 8–14% (since 2014) of the Indian apple consumption of 2–3 MT/year (Golombek and Blanke 2020). Apples with slight damages are accepted by lower income groups because of the lower fruit price. To meet the demand for high quality fruit and thereby increase the income of Indian apple farmers and stakeholders of the supply chain, a further rise in fruit quality is desirable, which also allows storage and profitable supply long after harvest season. The objective of this review is to explain the causes of bruise formation and to present opportunities to reduce or avoid bruises, with particular regard to India.

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Causes of bruising

Impact of mechanical damage and infection risks

By their nature, apples are vulnerable to mechanical damage especially during harvest and post-harvest management. Significant losses may occur by mechanical damage resulting spoilage, so that any reduction of only few percent would result in a larger amount of better fruit in the market and improve the economic gain along the whole value chain.

Mechanical damages can be bruises, cuts, puncture, split and abrasion (Opara and Pathare 2014); bruises result in damaged epidermal and hypodermal tissue without rupture of the skin (Fig. 1), comprising living and dead cells (Mitsuhashi-Gonzalez et al. 2010; Opara and Pathare 2014). Indian consumers judge fruit quality predominantly on size and appearance; minor visible damages result in price and quality downgrading and reduce the financial returns. Additionally, mechanical damages may induce physiological disorders, which can lead to off-flavour, loss of nutritional value, decay and spoilage (Opara and Pathare 2014). Even minor injuries can enable bacterial and fungal infection, which may shorten the shelf-life of the apples (Van Zeebroeck et al. 2007). Predominantly gray mold (*Botrytis cinerea*) and blue mold

(*Penicillium* spp.), but also other microorganisms, enter the apple fruit mainly through bruises. These infections play a major role in the wastage of apples (Kumari et al. 2018) and may spread throughout the packing box, making mechanically damaged fruit a potential source of infection throughout the value chain. Therefore, mechanically damaged apples are not suitable for storage and transport over long distances.

Forces causing bruises and minimum drop height

Excessive impact, compression, and/or vibration forces can cause bruises (Fig. 1). *Impact forces* result from dropping an apple onto a solid surface or against each other (Opara and Pathare 2014; Opara and Fadiji 2018; Schefler et al. 2018). The minimum dropping height, which causes bruising, depends on the elasticity of the surface material, on which the apple drops (concrete, wood, cardboard or polyethylene foam) (Table 1). For wood and concrete as target material, the minimal dropping height of apples, which caused bruises was only 1–1.3 cm (or converted into Newton meter: 0.02 N m), for cardboard 3–4 cm (0.06 N m) and for polyethylene foam 8–9 cm (0.14–0.15 N m). The minimal drop height of an apple against another apple to avoid bruising should be less than 3 cm for apples of the NZ cultivar ‘Jazz’ according to Fu et al. (2020). *These data show that the minimal dropping height, which causes bruising, is very low.* With a larger drop height onto surfaces of different materials (concrete, wood, cardboard, concrete, polyethylene foam), the bruise volume within the fruit increases (Jung and Watkins 2009; Kormanicki et al. 2017; Stopa et al. 2018; Stropiek and Gołacki 2013).

Apples are exposed to *compression forces* (a) by the fingers of the picker in the orchard, (b) when the size of the apples exceeds the pocket size of the tray, (c) excessive fruit stacking (Fig. 2), (d) collapse of the cardboard boxes, or (e) an operator forcing cartons into a tight spot (Fadiji et al. 2017; Opara and Fadiji 2018). *Vibration forces* during motorised transportation (Opara and Pathare 2014) may cause bruises.

Fig. 1 Bruises on a ‘Granny Smith’ apple

Table 1 Minimal dropping height of apples onto different materials which causes bruises

Material	Height (cm)	Energy (Nm)	References (in the order of the indicates heights)
Concrete	1–1.3	0.02	Stopa et al. 2018; Stropiek and Gołacki 2013
Wood	1	0.02	Stopa et al. 2018; Kormanicki et al. 2017
Cardboard	3–4	0.06	Stopa et al. 2018; Kormanicki et al. 2017
Polyethylene foam	8–9	0.15–0.14	Stopa et al. 2018; Kormanicki et al. 2017
Apple	< 3	< 0.05	Fu et al. 2020

Fig. 2 Compression of apples against each other or the hard plastic with the largest compression force at the bottom of the pannier

Role of physico-textural characteristics for bruise susceptibility

The bruise susceptibility of apples depends on their mechanical properties, which include peel and flesh firmness, water content ('turgor'), elasticity, fruit shape and size (Hussein et al. 2018; Stopa et al. 2018; Stropiek and Gołacki 2015). During the ripening process of the apple, the degradation of cell wall components, including pectin, hemicellulose, and cellulose leads to less firm fruit (Ortiz et al. 2011; Win et al. 2019), which is promoted by ethylene and synthesis of cell wall degrading enzymes (Ireland et al. 2014), so that ethylene inhibitors such as 1-MCP would be suitable to reduce bruises. Decreasing firmness of apples makes them more susceptible to bruises (García et al. 1995; Hussein et al. 2018, 2019; Opara 2007), which can be explained by cell wall properties and a loss in cell-to-cell adhesion, rounder cells and larger intercellular spaces (Iwanami et al. 2005; Johnston et al. 2002).

The water content (exactly: turgidity) of the apple fruits directly affects their bruise susceptibility. A slight dehydration results in lower stiffness, thereby reducing the risk/susceptibility to bruising (Iwanami et al. 2008; García et al. 1995). Baritelle and Hyde (2001) measured that a mass loss of 2–3% due to slight dehydration reduced the bruise susceptibility by doubling the bruise threshold, i.e. the minimum force causing bruises.

Delay in bruise visibility

Bruises on apples do not become instantly visible (Fig. 1) until several hours after the impact (Zhang and Li 2018). The damaged tissues may soften, become brownish or dry (Zhang and Li 2018). As a consequence of the delay between impact and bruise visibility, bruises may become visible at a later stage of

Table 2 Orchard management measures which reduce bruise susceptibility (for references see text)

Crop load	● Optimum crop load (avoid too high crop load, especially under well-watered conditions)
Water	● Deficit irrigation
Nutrients	● Sufficient calcium supply ● K/Ca fruit ratio below 25–30 ● Depending on the location, avoidance of nitrogen oversupply

the value chain. Bruises are more visible on green (e.g. Granny Smith; Fig. 1) or yellow (e.g. Golden Delicious) apples, as the red (e.g. in Red Delicious, Gala) fruit colour often masks bruises (Ferrari et al. 2015).

Orchard management—tips for farmers and farm managers

Effect of crop load on the apple tree and water availability on bruise susceptibility

The *crop load* on the tree influences fruit firmness and can be manipulated by bloom thinning and pruning to achieve the optimum fruit load for fruit firmness (Table 2). Excessive crop load can reduce both the firmness and size of the apples (Musacchi and Serra 2018). The interaction of crop load and water availability in their effect on bruise susceptibility or firmness had been investigated. Opara (2007) found a higher bruise susceptibility and lower fruit size when the crop load of 'Gala' was increased under well-watered conditions. Under water deficit, increasing crop load of 'Gala' had no effect on bruise susceptibility, but decreased fruit size. Opara (2007) reported that *water deficit* decreased bruise susceptibility and fruit size only under high crop load. In contrast to Opara (2007), Mpelasoka et al. (2001) could not detect an interaction of water availability with crop load regarding fruit firmness; deficit irrigation during early or late fruit developmental stages of the cultivar 'Braeburn' increased fruit firmness associated with a smaller fruit size at harvest independent of crop load. Similarly, apple cultivars 'Fuji' and 'Gala' responded to deficit irrigation with firmer and smaller fruit (Fallahi et al. 2018; Opara et al. 1997). Overall, crop load management (CLM) by bloom thinning or pruning integrates fruit size, colour, firmness and other fruit quality parameters, and can enable an acceptable yield without alternate bearing.

Role of plant nutrition such as calcium, potassium and nitrogen for bruise development

Calcium stabilizes cell walls by cross-linking adjacent pectins (Hocking et al. 2016), ensures fruit firmness and helps

to reduce physiological disorders like bitter pit and lenticel breakdown. Hence, pre-harvest foliar calcium sprays such as calcium chloride and/or calcium nitrate promoted firmness of ‘Red Delicious’ (Ranjbar et al. 2020) and ‘Idared’ (Murtic et al. 2019) and of average size apples of ‘Golden Delicious’ (Siddiqui and Bangerth 1995) at harvest. The fruit size has an effect on the calcium content. As fruit size increases, its calcium concentration is diluted (with more risk of bitter pit) in susceptible apples (Kalcsits et al. 2017; Neilsen and Neilsen 2003).

Potassium and calcium are competitors during nutrient uptake from the soil solution into the roots. Hence, an increase of potassium (K) in the soil solution can decrease the calcium (Ca) uptake into the roots and finally into the fruits. Further, the relation between potassium and calcium in the apple fruit is of importance for the firmness, bruise susceptibility and the development of physiological disorders. Therefore, a negative correlation between the K/Ca ratio of the apple and the firmness in ‘Golden Delicious’ as well as the bruise resistance in the cv. ‘Aroma’ was observed (Dilmaghani et al. 2005; Tahir et al. 2007). Depending on the growing region, K/Ca ratios of the fruit below 25:1 up to 30:1 have been recommended for calcareous soils in Iran for a favourable firmness and storage potential and to prevent physiological disorders (Dilmaghani et al. 2005).

In the majority of soils of the Indian apple growing regions of Himachal Pradesh and Kashmir the content of the available calcium is sufficient and the content of the available potassium medium to high (Block fertility map of HP of the Himachal Pradesh Agricultural University; Soil maps of the Department of Agriculture Kashmir 2015); there are only few areas in the Indian apple regions with low available calcium or potassium in the soil.

Oversupply of nitrogen can retard fruit maturation and lead to softer fruit with more bruise susceptibility

(Musacchi and Serra 2018; Neilsen and Neilsen 2003; Tahir et al. 2007). Tahir et al. (2007) showed that an increase in nitrogen to moderate or excess levels increased fruit weight, fruit N and K content, while decreasing Ca content and therefore increased the bruise susceptibility at harvest.

Harvest management—tips for farmers and farm managers

Optimum harvest date (OHD) (Maturity stage)—an important factor influencing bruise susceptibility

OHD is determined by the marketing intention, where long-term storage requires an early harvest but immediate consumption needs late picking. The Streif index is a common testing tool to determine the optimum picking date (OHD) for apples and includes fruit firmness. The range of the Streif index (immediate consumption—long-term storage) is e.g. for Gala 0.13–0.3, Fuji 0.04–0.08, and Golden Delicious 0.05–0.10. Progressive apple growers and traders can easily and quickly measure apple firmness with an affordable, hand-held penetrometer. During maturation, apple firmness declines and other quality parameters such as sugar and organic acid contents and skin colour improve (Ganai et al. 2018; García et al. 1995; Musacchi and Serra 2018). An important factor influencing the bruise susceptibility of apples is the maturity stage at harvest (Table 3). With decreasing firmness, apples become often more susceptible to bruises (Hussein et al. 2018; García et al. 1995).

Table 3 Harvest management measures which reduce bruise susceptibility or impact and compression forces (for references see text)

Optimum harvest date (OHD)	● Early harvest for long term storage and late picking for immediate consumption
Fruit turgor at harvest	● Harvest time during the day: not early morning or after rain
	● If necessary: slight dehydration in the shade after picking
Harvest procedure	● Gentle plucking (whole hand grip and bending movement to concentrate the force on the pedicel)
	● Apples should be placed gently into bags or padded baskets
	● Harvest bag should not bump against the tree
	● Bags or baskets should be emptied slowly and gently into bins
	● Crates should be padded
	● Stacking height: not too high, as e.g. when using a pannier
Transport of the bins out of the orchard	
By porters	● Shaking and swinging should be avoided; crates should be set down with care
	● Apples should be covered to avoid exposure to the sun
With vehicles	● Slow and careful driving on uneven ground
	● Good vehicle suspension

Harvest time during the day—a decline in water content reduces the bruise susceptibility

Because the water content of the fruit decreases during the day, apples harvested later in the day are less susceptible to bruising than those harvested in the morning (Abbott et al. 2010), particularly after severe overnight rainfall. Overnight water refill, dew in the morning as well as fog and rain raise the water content of the fruit and therefore increase bruise susceptibility and depends on the extent to which the region is influenced by the monsoon during the harvest. There are apple growing areas in the South slopes of the Himalayas which are exposed to the monsoon at fruit maturation near harvest, as for instance the district Shimla. Other apple growing areas lie in the rain shadow of the Himalayas, like in the regions Kinnaur and Lahaul and Spiti, with dry climate and glacial water supply. Again in other regions apples are harvested when the monsoon has ceased, like in Shopian. The harvest of wet, fairly turgescient apples increases their bruise susceptibility significantly. Delaying harvest until the late morning, when moisture/humidity and risk of bruises have decreased, might get the farmers a fair reputation of good quality fruit with fewer bruises.

Harvest method—a major key to reduce bruises

The harvest procedure is a crucial stage to reduce bruises. Apple picking can cause compression damage to the fruit, when pickers grasp the fruit too tight (Li and Thomas 2014). Pickers need to be trained to pick the apples gently by use of a whole hand grip and an upward bending movement to detach the fruit with the stalk (Knee and Miller 2002) and pick the apples with their stalk. They should not hold more than one apple in the hand at a time and should not wear jewellery on the fingers. In India, apples are picked usually into bags or padded baskets (Fig. 3a). Padding of the baskets decreases the risk of bruises. To prevent bruising, the fruit

should not be dropped, but to lay them gently into bags and baskets. If the harvest is performed by climbing in the trees with a harvest bag, care should be taken not to bump the harvest bag against the tree.

The fruit bags or baskets should be emptied slowly and gently into bins like plastic crates or panniers (Figs. 2 and 3b). Dumping the apples into the bins, as it can often be observed, should be avoided to prevent the formation of bruises. The training of the picker and, if possible, supervision, is beneficial. The plastic crates should be padded to avoid bruises during filling and the transport out of the orchard (Fig. 3b), often they are not. The pannier, a traditional/universal bin for the transport of agricultural products on the back of a person, allows a stacking height, which often leads to bruising of the apples by compression and vibration during transport (Fig. 2). Bruise damage increases gradually from the upper layers to the bottom layers.

In the case the freshly harvested apples are too turgescient, their bruise susceptibility can be reduced by transporting the apple bins out of the orchards only after the apples have dehydrated slightly in the shade (Baritelle and Hyde 2001; Bollen 2005). Then the bins should be transported without much time delay into a cool room for better storability.

Transport of the apple boxes out of the orchard—a potential source for bruises

The long-winded transport of the filled plastic boxes on rough terrain out of the orchard can be another potential source for bruises. In hilly orchards, as it is often the case in the apple growing regions of India, apple boxes are carried out of the orchard on the back of porters (Fig. 4). To avoid exposure to the sun and unnecessary warming, the apple boxes should be covered before and during transport (Nissen et al. 2018). Shaking and swinging of the boxes should be avoided if possible, because it might cause a sequence of collisions leading to bruises (Van Zeebroeck et al. 2007). The boxes should be

(a) Padded basket

(b) Padded plastic crate to protect fruit from bruises

Fig. 3 a Padded basket b Padded plastic crate to protect fruit from bruises

Fig. 4 Transport of apple boxes out of the orchard by a porter

set down with care to minimize further compression damage of the fruit, which can be overcome by training the porters (Fig. 4).

Apples fallen to the ground are collected separately and packed with other poor quality apples into sacks in India. These sacks are collected by transporters of processing industries for the production of e.g. juice, squash, jelly, jams, cider and vinegar. They should be stored in the shade to avoid unnecessary warming of the fruit and expansion of the bruises, and separately from apples of higher quality, because a part of these apples might be infested by pathogens.

Conclusion and future prospects

In this review, options to reduce bruises on apples are described along all orchard processes with particular regard to the situation in India. Impact, compression and/or vibration forces cause mechanical damages. Fruit firmness plays an important role in bruise susceptibility. Orchard management can reduce the bruise susceptibility by increasing the fruit firmness with the measures: obtaining an optimal crop load and K/Ca fruit ratio without nitrogen oversupply. Proper harvest management can diminish bruise susceptibility by choosing the optimum harvest date (OHD) according to final destination, possibly a later harvest time during the day when fruit dehydration started and by appropriate harvest methods. Gentle picking, preventing bumps of the harvest bag against the tree, placing apples gently into padded harvest devices and moderate stacking height are measures (Fig. 4) to reduce impact and compression damages. During transport of the apple boxes out of the orchard, shaking, swinging, and rough handling should be avoided (Fig. 5).

In the future, further education of all persons involved in orchard management measures important for the development

Fig. 5 Schematic overview over measures to reduce bruises in apple

of bruises would be of benefit. The Horticulture Departments of Indian universities and governments and the ‘Horticulture Mission for North East and Himalayan States’ are already offering measures like training, information, recommendations, online-tools, and technology transfer to improve the apple cultivation.

Because there are also many factors causing apple bruises along the Indian apple value chain from the transport out of the farm until reaching the consumer, these factors will be reviewed in a further article. A decline of mechanical damage would meet the increasing demand for more high quality apples and improve the income of Indian apple farmers and stakeholders along the whole supply chain. A quality which also allows storage and profitable supply long after harvest season is desirable and would also allow a better competition with foreign apples.

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