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Pre-harvest fruit bagging: a useful approach for plant protection and improved post-harvest fruit quality – a review

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SUMMARY
Several good agricultural practices (GAP) are becoming popular throughout the World for the production of high quality fruit with less dependence on man-made chemicals. Among such practices, pre-harvest fruit bagging has emerged as an effective method. Bagging is a physical protection method which not only improves the visual quality of fruit by promoting skin colouration and reducing blemishes, but can also change the micro-environment for fruit development, which can have several beneficial effects on internal fruit quality. Pre-harvest bagging of fruit can also reduce the incidence of disease, insect pest and/or mechanical damage, sunburn of the skin, fruit cracking, agrochemical residues on the fruit, and bird damage. Due to its many beneficial effects, fruit bagging has become an integral part of peach, apple, pear, grape, and loquat cultivation in Japan, Australia, China and the USA. Moreover, countries such as Mexico, Chile, and Argentina do not import apples unless they are bagged. Several studies have been conducted to identify the desirable effects of pre-harvest fruit bagging on skin colour development and quality, but contradictory results have been reported. These may be due to differences in the type of bag used, the stage of fruit development when bagged, the duration of fruit exposure to natural light following bag removal, and/or fruit- and cultivar-specific responses. Bagging is laborious and its cost:benefit ratio must be investigated in order to promote adoption of the method in much of the World. The aim of this review is to improve our understanding of the beneficial effects of bagging in different fruit by collecting otherwise scattered information so that more growers could consider using this method on a commercial scale.

During their growth and development, fruit undergo several physical and chemical changes and are susceptible to insect pest infestations, bird attack, various pathogens, and mechanical damage, all of which can reduce their commercial value and thereby cause significant yield and economic losses. To prevent the losses caused by biotic and abiotic factors, several good agricultural practices (GAP) are becoming popular throughout the World (Sharma, 2009). Furthermore, the development of alternative techniques to improve the appearance and quality of fruit and to reduce disease and insect infestations is becoming increasingly important as consumer anxiety over the use of man-made agro-chemicals and environmental awareness increases. Thus, more emphasis is being placed on reducing the use of pesticides to ensure worker safety, consumer health, and environmental protection (Sharma *et al.*, 2009).

Among several such alternatives, pre-harvest fruit bagging has emerged as an effective approach in different parts of the World. In this technique, individual fruit or fruit bunches are bagged on the tree for a specific period. Bagging is a physical protection technique, commonly applied to many fruit, which not only improves their visual quality by promoting peel colouration and reducing the incidence of fruit cracking and russeting, but can also change the micro-environment for fruit development (Fan and Mattheis, 1998), which can have multiple effects on internal fruit quality. Bagging has been used extensively in several fruit crops to improve skin colour and to reduce the incidence of disease, insect pests, mechanical damage, sunburn of the skin, agrochemical residues on the fruit, and bird damage (Bentley and Viveros, 1992; Kitagawa *et al.*, 1992; Hofman *et al.*, 1997; Joyce *et al.*, 1997; Tyas *et al.*, 1998; Amarante *et al.*, 2002a; Xu *et al.*, 2010). Pre-harvest bagging of fruit is practiced in Japan, Australia, and China during peach, apple, pear, grape, and loquat cultivation in order to optimise fruit quality by reducing physiological and pathological disorders and to improve fruit colouration to increase market value (Joyce *et al.*, 1997) leading to an improved appearance (Amarante *et al.*, 2002b). Some countries such as Mexico, Chile, Argentina do not import apples unless they are bagged.

There have been contradictory reports on the effects of pre-harvest fruit bagging on fruit size, maturity, skin colour, flesh mineral content, and fruit quality, all of which may be due to differences in the type of bag used, the stage of fruit development when bagged, the duration of exposure to natural light following bag removal and/or fruit- and cultivar-specific responses (Hofman *et al.*, 1997; Fan and Mattheis, 1998). Extensive research has been conducted on the effects of fruit bagging in different parts of the World, but the results have not been compiled. We have therefore attempted to compile all the scattered information on fruit bagging to assist researchers and extension personnel working in this area.

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EFFECTS OF BAGGING ON FRUIT

Physiological factors influenced by fruit bagging

Fruit size and weight

After fruit set, fruit grow slowly and increase in size to maturity. Covering fruit with a bag at a particular developmental stage may influence their growth and size. Reports on the effects of fruit bagging on fruit size and weight have been contradictory, and may be due to differences in the type of bag used, fruit age at bagging, fruit and cultivar responses, prevailing climatic conditions, and/or the storage conditions of fruit after harvest (Tyas *et al.*, 1998; Zhen *et al.*, 2000; Wang *et al.*, 2002; He *et al.*, 2003; Huang *et al.*, 2007; Chen *et al.*, 2012; Zhou *et al.*, 2012). Fruit bagging can increase, reduce, or have no effect on fruit weight and size.

Increases in fruit size and weight: Positive effects of bagging on fruit growth, size, and weight have been reported by Stover and Simmonds (1987), Xu *et al.* (2008), Watanawan *et al.* (2008), Yang *et al.* (2009), Harhash and Al-Obeed (2010), Chonhenchob *et al.* (2011), and Zhou *et al.* (2012). For example, Xu *et al.* (2008) reported that bagging with plastic bags increased fruit weight in carambola when applied 10 d after full bloom. Watanawan *et al.* (2008) reported that bagging 'Nam Dok Mai #4' mango fruit with two-layer paper bags (black inside with brown, or brown and waxed, or white outside), newspaper, or golden paper bags and non-bagged fruit for 52 d increased fruit weight. Yang *et al.* (2009) reported that bagging promoted longan fruit development, resulting in larger-sized fruit. Similarly, Harhash and Al-Obeed (2010) reported that bunch bagging in 'Succary' and 'Khalas' date palm cultivars using blue bags increased finger and bunch weights significantly. Chonhenchob *et al.* (2011) studied the effects of pre-harvest bagging with different wavelength-selective bags on 'Nam Dok Mai #4' mango in Taiwan and reported that bagging increased fruit weight, size, and sphericity over un-bagged fruit. Individual fruit size in 'Xiangtian' olive was improved by Shengda™ bags in China (Zhou *et al.*, 2012).

Reductions in fruit size and weight: Pre-harvest fruit bagging has been reported to reduce fruit size and weight in some fruit. For instance, Xu *et al.* (2010) attempted to bag 'Baiyu' and 'Ninghaibai' loquat and reported that bagging decreased the weight of fruit. Similarly, Hudima and Stamper (2011b) reported that bagging 'Conference' pears reduced the fruit weight to such an extent that the fruit were not marketable. Bagging has also been reported to reduce fruit size and weight in pomegranate (Hussein *et al.*, 1994) and in apple (Arakawa *et al.*, 1994).

No effect on fruit size or weight: Some studies have reported that bagging neither increased nor decreased fruit size or weight. For example, Rodrigues *et al.* (2001) reported that polyethylene covers had no effect on banana bunch or total fruit weights. Amarante *et al.* (2002a) reported that pre-harvest bagging of 'Doyenne du Comice' pear fruit with micro-perforated polyethylene bags, 30 d after full-bloom (DAFB), did not affect fruit size or weight. Muchui *et al.* (2010) reported that bunch bagging in banana had no significant effect on grade, finger length, or bunch weight. Similarly, Hudima and Stamper (2011a) reported that bagging 'Concorde' pear (*Pyrus communis* L.) fruit with triple-layer paper bags had no adverse effects on fruit size or weight.

Fruit maturity

Bagging can influence fruit maturity, yet contradictory results have been reported. For instance, Johns and Scott (1989) and reported that bagging advanced fruit maturity in banana. In their book, Stover and Simmonds (1987) described the use of polyethylene bags to enhance fruit maturity in banana. Similarly, Rodrigues *et al.* (2001) reported that the time of harvest in banana plants with covered bunches was 12 d earlier in the second crop. Debnath and Mitra (2008) reported that the harvest period in litchi could be staggered over 30 d because cellophane paper (CP) bags (a biodegradable polymer) advanced commercial maturity by 12 d, while brown paper or biodegradable newspaper bags delayed maturity by approx. 10 d. Kim *et al.* (2008b) reported that fruit maturity in 'Janghowon Hwangdo' peach bagged with white paper occurred 6 d earlier compared to fruit covered with newspaper bags or un-bagged fruit. Wang *et al.* (2010b) reported that pre-harvest fruit bagging in 'Wanmi', a late-ripening peach cultivar, accelerated fruit maturity by approx. 10 d. In contrast, Ju (1998) reported that bagging did not affect fruit maturity in 'Delicious' apple.

Fruit ripening

Pre-harvest bagging influences the ripening of fruit. Awad (2007) reported that bunch bagging in 'Helali' date palm, a late-season cultivar, enhanced the rate of fruit ripening significantly. Signes *et al.* (2007) reported that pre-harvest bagging delayed ripening in 'Perla', a black table-grape. Harhash and Al-Obeed (2010) observed that bunch bagging with black, white, blue, or yellow plastic bags accelerated ripening in 'Succary' and 'Khalas' date palm cultivars, and that blue-coloured bags were superior in accelerating the fruit ripening process. Kassem *et al.* (2011) reported that spathe-bagging with transparent or blue polyethylene bags at the time of pollination caused significantly earlier fruit ripening in 'Zaghloul' date compared to no bagging (control).

Fruit appearance

During culture, harvesting, packing, and transportation, fruit are prone to physical defects and damage. As a result, they become less attractive to consumers. Fruit that are free from blemishes, abrasions or injuries, attract consumers. Bagging has been widely used to improve the commercial value of fruit (Han *et al.*, 1999). For example, as early as 1956, Berill (1956) reported covering of banana bunches with plastic or hessian to protect the fruit from blemishes. Amarante *et al.* (2002b) reported that pre-harvest bagging of 'Doyenne du Comice' pear increased the percentage of fruit that were accepted for export primarily by reducing bird damage and skin blemishes. Katagiri *et al.* (2003) reported that fruit blemishing in 'Fuyu' persimmon was reduced by a bagging treatment, which resulted in increased marketability. Similarly, Faoro and Marcia (2004) reported that fruit bagging in 'Housui' pear resulted in a better fruit appearance as the fruit were more uniform in size, with a smooth and shiny skin. Jia *et al.* (2005) reported that 'Hakuho' peach covered with orange bags appeared bright red, which accounted for their high visual quality.

In the Philippines, the mango industry suffers from problems of fruit defects such as scab, misshapen fruit, distinct veins, undersized fruit, wind scar, mottling, sooty mould, and sap burn. Bayogan *et al.* (2006) reported that bagging the fruit helped to reduce these problems significantly, which improved the acceptability of the mango fruit for export. Huang *et al.* (2007) reported that bagging 'Cuiguan' pear fruit could increase the proportion of fruit without (or with few) russet and made the skin brighter. Lin *et al.* (2008) reported that bagged 'Cuiguan' and 'Hosui' pear fruit were brighter and more attractive, with less russet and visible dots than non-bagged fruit, which increased their market value. Furthermore, due to bagging, there were increases in the percentages of Extra Class and Class I fruit, and a reduction in the number of defective (blemished, sun-burned or cracked) fruit. Similarly, bagged litchi fruit were free from blemishes due to a low incidence of sun-burn and fruit-cracking, with added luster on the skin, and so were more appealing to consumers (Debnath and Mitra, 2008). Sarker *et al.* (2009) reported that the physical quality (i.e., the incidence of black spots) of bagged mango fruit was better than un-bagged healthy fruit, which increased their market appeal. Xu *et al.* (2010) tried bagging 'Baiyu' and 'Ninghaibai' loquat fruit with different materials and reported that bagging improved the appearance of fruit. In banana, Muchui *et al.* (2010) reported that bagged fruit had no blemishes and were more attractive to consumers at a glance, while un-bagged fruit had black spots and blemishes. After a fruit bagging experiment using the mango cv. Apple, Mathooko *et al.* (2011) reported that bagged fruit had a smoother texture and a spotless, light-green skin colour. Hence bagged fruit were rated superior in terms of their general appearance and overall consumer acceptance, which led to improved exports and better prices for mango fruit farmers.

Fruit colour development

Fruit colour is the fundamental feature that attracts consumers. An attractive colour improves the physical appearance of the fruit, which helps to get better prices in domestic and export markets. Several studies have indicated that pre-harvest fruit bagging can promote or inhibit fruit colour development.

Colour promotion: Bagging improves the colour of fruit by increasing their anthocyanin content. For example, in litchi, semi-transparent-CP bags resulted in excellent skin colouration in fruit (Tyas *et al.*, 1998, Chen and Li, 1999, Hu *et al.*, 2001). In earlier studies, fruit bagging had been reported to inhibit colour development in apple (Proctor and Lougheed, 1976); however, it has now been established that fruit bagging is an effective way to improve fruit colour in apple (Ritenour *et al.*, 1997; Ju, 1998). It is believed that bagging increases the light sensitivity of fruit and stimulates anthocyanin synthesis when the fruit are re-exposed to light after bag removal (Ju *et al.*, 1995a, b; Ju, 1998).

The ground colour of the skin of un-bagged pear fruit was darker-green compared to the brighter-green of bagged pears. Amarante *et al.* (2002a) reported that pre-harvest bagging of pear fruit improved their skin colour, with a more attractive light-green colour, without reducing the blush on the exposed side of the skin. Similarly, red Chinese sand pears (*P. pyrifolia* Nakai) that had been bagged until harvest had a yellow tinge with a higher lightness value ($L^* = 72.6$) and a higher hue angle (h^o = 96.2) than control fruit (Huang *et al.*, 2009). Signes *et al.* (2007) reported that pre-harvest bagging with cellulose bags increased the uniformity of colour development, even in the black grape variety 'Perla'. Watanawan *et al.* (2008) reported that bagging mango fruit with two-layer paper bags advanced their skin colour development from green to yellow. Bagging with black paper could help in the degreening of 'Harumanis' mango. It was found that one-layer of black paper was sufficient to degreen the fruit (Ding and Syakirah, 2010). However, in 'Keitt' mango, white paper bagging increased the percentage of yellow skin area compared to un-bagged fruit (Hofman *et al.*, 1997). Zhou *et al.* (2012) investigated the effect of bagging with different materials on 'Xiangtian' olive and reported that the attractive golden-yellow colour of the fruit was obtained using Shengda™ double-layer bags in particular. Recently, Wang *et al.* (2013) and Liu *et al.* (2013) reported that bagging induced a red colour in green-type ('Granny Smith') and yellow-coloured ('Golden Delicious') apples, respectively. In 'Granny Smith', most anthocyanins (cyanidin 3-*O*-galactoside and cyanidin 3-*O*-arabinosides) were synthesised within 7 d of bag removal. Similarly, bagging improved the peel colour in sweet orange cultivars; but, in bagged fruit of 'Tacorro', the anthocyanin content was ≤ 42.7-fold higher than that in un-bagged fruit (Xie *et al.*, 2013).

Colour inhibition: The fundamental effect of fruit bagging is to inhibit colour development, rather than to promote it (Proctor, and Lougheed, 1976). The effect depends on the stage of fruit development at which it is bagged, the bagging date, the kind of bag used, the date of bag removal, and the climatic conditions of the area (Ju *et al.*, 1995a, b; Ju, 1998; Amarante *et al.*, 2002a). For example, Ju (1998) reported that bagging inhibited the accumulation of anthocyanins in the skin of 'Delicious' apple fruit. However, when fruit were covered with three-layered bags and exposed to light, they started to accumulate anthocyanins rapidly, with a maximum after 3 d of light exposure. Kwan et al. (2000) reported that bagging 'Yuzu' citrus (*Citrus junos* L.) fruit before early-September with recycled Japanese phone-book paper (PBP) resulted in less colouration. Murray *et al.* (2005) reported that bagged plum fruit had a greener ground colour, and a poorer red colour than un-bagged fruit. Wei *et al.* (2006) reported that the content of anthocyanins was notably lower in bagged 'Red Fuji' apples than in un-bagged control fruit; however, 5 d after bag removal, the anthocyanin content surpassed that in the controls. Takada *et al.* (2006) found that there was no significant difference in the rate of reddish-pulp development in 'Takei Hakuho' peach between un-bagged fruit and those in white and orange double bags, but fruit covered with orange and black double bags showed a lower rate of reddish-pulp development at harvest.

Furthermore, Lin *et al.* (2008) reported that bagged fruit of 'Cuiguan' and 'Hosui' pear were brighter than non-bagged fruit. Xia *et al.* (2009) reported that the anthocyanin contents of bagged 'Jiang Su Red Fuji' apple fruit were notably lower than in the controls during fruit development, but increased more rapidly after the bags were removed, surpassing the anthocyanin contents of the controls. Hudima and Stampar (2011a) reported that the appearance of bagged 'Concorde' pear fruit was less attractive, their colour was a muddy-yellow, and their extent of russeting was much higher compared to un-bagged fruit.

Biotic factors influenced by fruit bagging

Pest control

Pre-harvest fruit bagging is a good technique to maintain a physical separation between the environment and the produce. One of the most significant effects of fruit bagging has been protection from the damage caused by insect pests (Table I). Several studies have indicated that bagging reduced the incidence of fruit fly in guava (Pereira, 1990; Morera-Montoya *et al.*, 2010), mango (Buganic *et al.*, 1997; Hofman *et al.*, 1997; Sarker *et al.*, 2009), codling moth in apple (Bentley and Viveros, 1992), woolly aphid in apple (Teixeira *et al.*, 2011a,b), fruit borer in litchi (Debnath and Mitra, 2008), San Jose scale in apple (Sharma *et al.*, 2013), and fruit borer in pomegranate (Bagle, 2011; Table I). Thus, it appears that pre-harvest fruit bagging can be a useful approach to reduce the losses caused by insects, the control of which otherwise requires the application of several insecticides.

Disease control

Fruit bagging also prevents pathogens from reaching the developing fruit, which protects them from several diseases that can cause major losses. Bagging can protect some fruit from several pathogens, yet in other fruit it may not have any effect (Kitagawa *et al.*, 1992; Amarante *et al.*, 2002a; Senghor *et al.*, 2007; Chonhenchob *et al.*, 2011; Table II). Fruit bagging has been reported to reduce the incidence of anthracnose and stem-end rot in mango (Buganic *et al.*,1997; Hofman *et al.*, 1997; Senghor *et al.*, 2007; Chonhenchob *et al.*, 2011), sooty blotch and fly speck in apple (Sharma *et al.*, 2013), and anthracnose and fruit rot in guava and loquat, respectively (Martins *et al.*, 2007; Ko *et al.*, 2010; Table II). In contrast, Fan and Mattheis (1998) reported that bagging during fruit development increased superficial scald and eliminated "stain" during cold storage. Similarly, bagging increased the incidence of brown spot in apple (Wang *et al.*, 2011). Thus, fruit bagging can be a beneficial practice for producing higher quality fruit, without or with less use of chemicals to control diseases.

Bird damage

In fruit such as banana, mango, apple, and date, birds are major pests at the fruit-ripening stage and cause considerable losses. Several approaches such as beating drums, stretching reflecting ribbons in the field etc, are adopted to control birds, but they soon become

TABLE I

Influence of pre-harvest fruit bagging on insect infestation

Fruit crop/cultivar	Bagging date/time	Bagging material	Insect-pest controlled	Reference(s)
Apple 'Imperial Gala'	40 d after flowering	Transparent micro-perforated plastic or non-textured fabric bags	Fruit fly (*Anastrepha fraterculus*) Oriental fruit moth (*Grapholita molesta*) Apple leaf roller (*Bonagotasa lubricola*) Woolly apple aphid (*Eriosoma lanigerum*)	Teixeira *et al.* (2011a)
Apple 'Fuzi Suprema'	40 d after flowering	Transparent micro-perforated plastic or non-textured fabric bags	Fruit-fly (*Anastrepha fraterculus*) Oriental fruit moth (*Grapholita molesta*) Apple leaf roller (*Bonagotasa lubricola*)	Teixeira *et al.* (2011b)
Apple 'Granny Smith'	At golf-ball fruit size	Brown paper bags	Reduction in fruit infested by codling moth	Bentley and Viveros (1992)
Apple 'Royal Delicious'	30 d before harvesting	Spun bounded light-yellow coloured bags	Reduction in San Jose Scale incidence	Sharma *et al.* (2013)
Guava	6-9 week before harvesting	Biodegradable films (BF30, BF50, BF70) from cassava starch and poly (butylene adipate-co-terephthalate) (PBAT) by extrusion	Fruit fly (*Anastrepha* spp.) and the guava weevil (*Conotrachelus psidii*)	Bilck *et al.* (2011)
	175 d of fruit set	Waxed paper, nylon fabric, Taiwan bag and telephone book paper	Fruit fly	Morera-Montoya *et al.* (2010)
Pomegranate 'Mridula', 'Ganesh', 'Jyoti', 'Ruby', 'Jalore Seedless'	60-70 d before harvesting	Parchment bags	Nearly 90% reduction in the incidence of anar butterfly, *Deudorix* (*Virachola*) *Isocrates*)	Bagle (2011)
Mango 'Langra' and 'Khirshapat'	30 d before harvesting	Bagging materials (black polybag, transparent polybag, brown paper bag)	100% Control of fruit fly	Sarker *et al.* (2009)
Mango 'Carabao'	60 d before harvest	Brown paper bags	Complete reduction in fruit fly incidence	Buganic *et al.* (1997)
Litchi	Bagging after 1 week of fruit set	Cellophane paper bags, brown and newspaper bags (biodegradable)	Reduced incidence of stalk-end borer (*Conopomorpha cramerella*)	Debnath and Mitra (2008)
	Bagging after 1 week of fruit set	Cellophane paper bags, brown and newspaper bags (biodegradable)	Reduced incidence of stone borer (*Platypepla* sp. and *Conogethes* sp.)	Debnath and Mitra (2008)

TABLE II
Effect of pre-harvest fruit bagging on the incidence of disease in fruit

Fruit crop/cultivar	Bagging date/time	Bagging material	Disease incidence	Reference(s)
Apple 'Fuji Suprema'	40 d after flowering	Transparent micro-perforated plastic or non-textured fabric bags	No effect on apple scab, bitter rot, and mouldy core	Teixeira *et al.* (2011a,b)
Apple 'Royal Delicious'	30 d before harvesting	Spun bounded light-yellow coloured bags	Reduction in fly speck and sooty blotch	Sharma *et al.* (2013)
Apple	Fruit development	Plastic bags	Increased incidence of superficial scald	Fan and Mattheis (1998)
Mango 'Nam Dok Mai #4'	45 DAFB	Plastic bags with wavelength-selective characteristics	Reduction in the incidence of most of post-harvest diseases	Chonhenchob *et al.* (2011)
Mango 'Keitt'	100 d before harvest	White paper bags	Incidence and severity of anthracnose and stem-end rot was reduced	Hofman *et al.* (1997)
Mango 'Carabao'	60 d before harvest	Brown paper bags	Significant reduction in anthracnose and stem-end rot	Buganic *et al.* (1997)
Mango	During fruit development	White bags	Control of *Colletotrichum gloeosporioides*	Senghor *et al.* (2007)
Guava	One month before harvesting	Paper bags	Reduction in black spot (*Guignardia psidii*) and anthracnose (*Colletotrichum* spp.)	Martins *et al.* (2007)
Loquat	During fruit development	Plastic bags	Reduction in fruit rot (*Alternaria* sp.)	Ko *et al.* (2010)
Pear 'Huangguan'	During fruit development	Three-layered bags	Increase in the incidence of browning spot	Wang *et al.* (2011)

acclimatised to these practices (Sharma, 2009). In our opinion, fruit bagging may be the best practice to produce sound, bird-damage-free fruit, if used at the right time of fruit development. Fruit bagging has helped to reduce bird damage in various fruit (Kitagawa *et al.*, 1992; Hofman *et al.*, 1997; Joyce *et al.*, 1997; Amarante *et al.*, 2002a; Harhash and Al-Obeed, 2010).

Physiological and biochemical factors influenced by bagging

Physiological disorders

Physiological disorders are anomalies in the fruit which are not caused by insect damage or pathogen invasion, but are the result of a deficiency or an excess of a nutrient, low or high temperatures, or high or low rates of ethylene production or respiration (Sharma, 2009). Several such disorders have been reported which affect fruit yield and quality and several approaches have been adopted for their management. Studies have revealed that fruit bagging may be used to reduce the incidence of some disorders in fruit (Table III). Hence, fruit bagging has been used extensively in some countries to reduce the problems of sun-burn and fruit cracking (Kitagawa *et al.*, 1992). It also reduced the incidence of black stain (BS) on the skin of 'Shinsyu' persimmon fruit (Fumuro and Gamo, 2001), sun-burn in apple (Bentley and Viveros, 1992) and pear (Amarante *et al.*, 2002b), fruit drop in longan (Yang *et al.*, 2009) and carambola (Xu *et al.*, 2008), stone cells in pear (Lin *et al.*, 2008), fruit splitting in nectarine (Ding *et al.*, 2003), fruit spot in citrus (Kwan *et al.*, 2000), russeting in apple (Teixeira *et al.*, 2011b) and pear (Amarante *et al.*, 2002a), fruit cracking in pomegranate (Abdel-Rhman, 2010), lenticel discolouration in mango (Mathooko *et al.*, 2011), and bitter pit, cork pit, and brown core in apple (Sharma *et al.*, 2013; Table III). However, in contrast, fruit bagging increased the incidence of water core in Japanese pear (Han *et al.*, 1999) and russeting in apple (Teixeira *et al.*, 2011a).

Fruit nutrient concentrations

Fruit contain several nutrients which contribute to their quality. Since fruit bagging is usually done in the orchard during the fruit development stage, it may influence the nutrient composition of fruit. For instance, Dong *et al.* (2007) reported that apple fruit covered with paper bags had the lowest concentration of calcium (Ca), but other bags increased this. Kim *et al.* (2008a) reported that bagging fruit in Ca-coated paper 4 – 5 weeks after full-bloom increased the Ca concentration in the skin of 'Gamhong' apple in Korea. The concentrations of N and P in pear fruit were not significantly affected by bagging, but the concentrations of K, Ca, Mg decreased by 9.6%, 38.9% and 6.7%, respectively (Lin, 2008). Similarly, Wang *et al.* (2010a) found that the Ca concentrations in bagged apple fruit were higher than in un-bagged fruit. Accordingly, the incidence of bitter pit in bagged fruit was lower than in un-bagged fruit (Sharma *et al.*, 2013). In contrast, bagging of 'Keitt' mango with white paper bags for up to 56 d reduced Ca concentrations, but prolonged bagging (82 – 131 d) did not have such an effect (Hofman *et al.*, 1997). Similarly, Beasley *et al.* (1999) found no significant differences in either skin or flesh Ca concentrations between bagged (plastic or paper) and un-bagged fruit. Amarante *et al.* (2002a) reported that pre-harvest bagging of 'Doyenne du Comice' pear fruit with micro-perforated polyethylene bags, 30 DAFB, did not affect flesh concentrations of N, P, K, Ca, or Mg. Similarly, Wang *et al.* (2011) reported no significant effect of bagging on Ca concentrations in the skin of 'Huangguan' pear fruit. Bagged 'Fuji Suprema' apple fruit had higher Ca concentrations, which decreased the incidence of bitter pit during storage (Teixeira *et al.*, 2011b).

Eating quality of fruit

The ultimate aim of the grower is to produce fruit of high quality. Consumers also want to have fruit of high quality. The eating quality of fruit includes attributes such

TABLE III
Influence of pre-harvest fruit bagging on the occurrence of physiological disorders in fruit

Fruit crop/cultivar	Bagging date/time	Bagging material	Disorder	Reference(s)
Apple	40 d after flowering	Transparent micro-perforated plastic or non-textured fabric bags	Increase in russeting	Teixeira *et al.* (2011a)
Apple 'Fuji Suprema'	40 d after flowering	Transparent micro-perforated plastic or non-textured fabric bags	Reduction in bitter pit incidence	Teixeira *et al.* (2011a)
Apple 'Fuji Suprema'	40 d after flowering	Transparent micro-perforated plastic or non-textured fabric bags	Reduction in russeting	Teixeira *et al.* (2011b)
Apple 'Gamhong'	4-5 weeks after full bloom	Ca-coated paper bags	Reduction in bitter pit	Kim *et al.* (2008a)
Apple 'Royal Delicious'	One month before harvesting	Spun-bound light-yellow coloured bags	Reduction in the incidence of bitter pit, cork pit and brown core	Sharma *et al.* (2013)
Apple 'Granny Smith'	At golf-ball fruit size	Brown paper bags	Reduction in sun-burn	Bentley and Viveros (1992)
Carambola	10-17 d after full bloom	Plastic bags	Reduction in fruit drop	Xu *et al.* (2008)
Date palm 'Zaghloul'	At pollination time	Transparent and blue polyethylene bags	Reduction in tip cracked fruit	Kassem *et al.* (2011)
Lonagn 'Chuliang'	34 d after anthesis	White adhesive-bonded fabric bag (WAFB) and black adhesive-bonded fabric bag (BAFB)	Reduction in fruit drop	Yang *et al.* (2009)
Mango 'Apple'	40-50 d before harvesting	White bags	Reduction in lenticel discolouration	Mathooko *et al.* (2011)
Nectarine	Fruit development	Plastic bags	Reduction in fruit splitting	Ding *et al.* (2003)
Pear 'Doyenne du Comice'	30 d after full bloom	Micro-perforated polyethylene bags	Reduction in russeting	Amarante *et al.* (2002a)
Pear 'Conference'	Fruit development	Plastic bags	Reduction in sun-burn	Amarante *et al.* (2002b)
Pear 'Cuiguan'	35 DAFB or 20 DAFB	Paper bags (once or twice)	Reduction in stone cells	Lin *et al.* (2012)
Pear 'Cuiguan' and 'Housi'	28 DAFB	Haoguo™ bags (a two-layer paper bag), Jiatian™ bags (a one-layer paper bag) or common bags (a two-layer paper bag)	Reduction in stone cells	Lin *et al.* (2008)
Persimmon 'Shinsyu'	50-35 d before harvest	Paper bags	No black stain	Fumuro and Gamo (2001)
Yuzu (*Citrus junos* L.)	Bagging before early September	Recycled Japanese phone-book paper (PBP), grey-coloured paper bags (BP) or black polyester (PET) bags	Significant reduction in fruit spot injury	Kwan *et al.* (2000)

as total soluble solids content (TSSC) and titratable acidity (TA). Studies have indicated that fruit bagging also influences the eating quality of fruit (Table IV). For example, Bentley and Viveros (1992) reported that sweetness in 'Granny Smith' apple fruit was improved by bagging in brown paper bags at the golf-ball size of fruit development. Similarly, improvements in TSSC have been reported in loquat (Liu *et al.*, 2004; Ni *et al.*, 2010; Xu *et al.*, 2010), 'Red Globe' grape (Zhou and Guo, 2005), peach (Kim *et al.*, 2008b), guava (Singh *et al.*, 2007), pear (Lin *et al.*, 2012), mango (Watanawan *et al.*, 2008), litchi (Debnath and Mitra, 2008), and apple (Sharma *et al.*, 2013).

In contrast, bagging has been reported to reduce TSSC and/or TA values in apple fruit (Chen *et al.*, 2012), plum (Murray *et al.*, 2005), pear (Lin *et al.*, 2008; Hudima and Stamper, 2011b), and mandarin (Hiratsuka *et al.*, 2012; Table IV). However, fruit bagging did not alter TSSC or TA values in 'Yali' pear (Xin *et al.*, 2003), Nashi pear (Faoro and Marcia, 2004), peach (Jia *et al.*, 2005), apple (Xia *et al.*, 2009), longan (Yang *et al.*, 2009), or banana (Muchui *et al.*, 2010; Table IV). Bagging can also affect the vitamin contents of some fruit (Table IV).

Enzyme activities

Several biochemical changes occur in developing fruit, and several enzymes play crucial roles in such changes. Fruit bagging also plays a vital role in such biochemical changes by influencing the activities of key enzymes. For instance, Ju *et al.* (1995b) found that fruit bagging significantly inhibited both phenylalanine ammonia lyase (PAL) activity and anthocyanin synthesis. Although, PAL catalyses the production of precursors for anthocyanin synthesis, under conditions of sufficient precursors, changes in anthocyanin concentration can occur independently of changes in PAL activity. Wang *et al.* (2000) reported that the maximum PAL activity was not the only factor regulating anthocyanin accumulation in bagged mature and ripe apple fruit. Similarly, Hu *et al.* (2001) reported that bagging 'Feizixiao' litchi fruit enhanced colour development, which was associated with the metabolism of phenolics and flavonoids, and the activities of PAL and polyphenol oxidase (PPO). Zhou and Guo (2005) reported that fruit bagging in 'Red Globe' grape increased acid invertase activities, which were responsible for the higher accumulation of sugars in the bagged fruit. Ni *et al.* (2010) found that the activities of acid invertase (AI) and neutral invertase (NI) in bagged loquat fruit were lower than in non-bagged fruit, and that the activities of sucrose synthase (SS) and sucrose-phosphate synthase (SPS) in bagged fruit were higher than in non-bagged fruit. The activities of sorbitol dehydrogenase (SDH) and sorbitol oxidase (SOX) in bagged fruit were lower than in non-bagged fruit, suggesting that bagging increased the products of photosynthesis largely by enhancing the activities of SS and SPS.

Wang *et al.* (2010a) reported that the activities of superoxide dismutase (SOD), peroxidase (POX), catalase (CAT), and ascorbate peroxidase (APX) in bagged apple fruit were higher than in un-bagged fruit. Chen *et al.* (2012) reported that PAL activities in different cultivars of apple tended to rise, then decline after bag removal from treated fruit, while it decreased slowly in control fruit. On day-2 after bag removal, the PAL activity in bagged fruit exceeded that in control fruit and reached a maximum on day-6 after bag removal. Hiratsuka *et al.* (2012) reported that the peak of phosphoenolpyruvate carboxylase (PEPC) activity in mandarin fruit was 90% of control values after fruit bagging. Thus, just before colour development, mandarin fruit actively assimilate CO_2 via photosynthesis and PEPC activity. However, these activities were inhibited by bagging, resulting in lower sugar concentrations at harvest. Thus, it can be concluded that fruit bagging may either enhance or inhibit the activities of key enzymes involved in skin colour synthesis or fruit quality improvement.

Phenolic compound concentrations and anti-oxidant activities

Phenolic compounds are secondary metabolites which act as anti-oxidants and protect plants (and us) from several diseases. Fruit bagging can also influence the concentrations of phenolic compounds and anti-oxidant activities in fruit. For example, Ju *et al.* (1995b) reported that the concentrations of simple phenolic compounds increased with bagging up to 60 d, then declined in ‘Delicious’ apple fruit. Xu *et al.* (2010) reported that total phenolics and flavonoid concentrations and total anti-oxidant activity in loquat fruit decreased following bagging treatments. Bagged ‘Concorde’ pear fruit resulted in significantly lower concentrations of phenolic compounds in the skin, while there were no significant difference in the pulp (Hudima and Stampar, 2011a; Hudima *et al.*, 2012). However, Wang *et al.* (2010b) reported that bagging did not affect chlorogenic acid and catechol concentrations in fruit skin or flesh in ‘Wanmi’ peach. In contrast, Hudima and Stamper (2011b) reported that bagging ‘Conference’ pears increased the concentrations of some phenolic compounds such as epicatechin and caffeic acid, in the skin, and these were highest in bagged fruit. Chen *et al.* (2012) reported that fruit bagging decreased most phenolic compound concentrations in both the skin and the flesh of three apple cultivars (‘Golden Delicious’, ‘Red Delicious’, and ‘Royal Gala’). Similarly, Xie *et al.* (2013) reported reductions in phenolic compound concentrations and anti-oxidant activities in three orange cultivars following fruit bagging.

Aroma volatiles

Many fruit are selected by consumers for their pleasing aroma and flavour. Several volatile organic compounds (VOCs) contribute to the development of a characteristic flavour or aroma. Since bagging intercepts light, it may indirectly influence the synthesis of VOCs that contribute to flavour.

TABLE IV
Influence of pre-harvest fruit bagging on the eating quality of different fruit

Fruit	Quality attribute(s) affected	Reference(s)
Apple	Improvement in fruit sweetness	Bentley and Viveros (1992)
	Slight reduction in total soluble sugar (TSS) content	Chen *et al.* (2012)
	Reduction in β-carotene contents in skin and flesh	Jia *et al.* (2011)
	Improvement in total soluble solids and ascorbic acid contents	Sharma *et al.* (2013)
	No effects on the content of soluble sugars, reducing sugar and titratable acidity (TA)	Xia *et al.* (2009)
Banana	No adverse effect on total soluble solids, TA, and fruit firmness	Muchui *et al.* (2010)
Guava	Increase in soluble solids concentration	Singh *et al.* (2007)
Grape	Increase in soluble sugars	Zhou and Guo (2005)
Litchi	Significant improvement in TSS:TA ratio	Debnath and Mitra (2008)
Longan	No significant effect on sugar content	Yang *et al.* (2009)
Loquat	Increase in soluble solids and decline in acidity	Liu *et al.* (2004)
	Content of sucrose, glucose and soluble solids increased, while the content of fructose, sorbitol and titratable acidity decreased	Ni *et al.* (2010)
	Improvement in total sugar content	Xu *et al.* (2010)
Mandarin	Reduction in sugar and organic acid content	Hiratsuka *et al.* (2012)
Mango	Significant effects on total soluble solids, TA, TSS:TA ratio, vitamin C	Watanawan *et al.* (2008)
Nashi pear	No effect of total soluble solids	Faoro and Marcia (2004)
Orange	Increase in flesh lycopene and β-carotene contents	Wang *et al.* (2006)
Peach	No effect of total soluble solids and titratable acidity	Jia *et al.* (2005)
	Improvement in soluble solids concentration	Kim *et al.* (2008b)
Pear	Reduction in soluble solids and increase in TA	Lin *et al.* (2008)
	Negative impact on sucrose and sorbitol content	Hudima and Stamper (2011b)
	Double increase in soluble solids	Lin *et al.* (2012)
	Reduction in the content of sugars and acids	Xin and Zhang (2003)
Plum	Reduction in soluble solids concentration	Murray *et al.* (2005)

Studies on the effects of pre-harvest bagging on VOCs have primarily concentrated on peach. For instance, Jia *et al.* (2005) reported that bagging 'Hakuho' peach fruit with orange paper bags did not affect total VOC production by whole fruit, but significant differences were observed in the concentrations of aroma VOCs between the skin and the flesh, which increased fruit flavour significantly. Zhang and Jia (2005) reported increases in the synthesis of VOCs in 'Hujingmilu' peach. In 2006, Li and co-workers supported the findings of Zhang and Jia (2005), and concluded that high quality 'Hujingmilu' peach fruit could be produced when bagged with a single layer of orange paper with 27% light transmittance. Such single-layer bagged fruit showed the highest concentration of γ-decalactone, the main characteristic aroma of peach, and total lactones at the firm-ripe and full-ripe stages. In contrast, Wang *et al.* (2010b) reported that bagging did not affect the concentrations of keracyanin or quercetin-3-rutinoside in 'Wanmi' peach fruit flesh during fruit development. However, keracyanin and quercetin-3-rutinoside concentrations were significantly reduced in bagged fruit skin before ripening, compared to non-bagged fruit skin. Considering the large changes in VOCs, they recommended that 'Wanmi' peaches should be harvested between 126 – 147 DAFB, approx. 1 month before full-maturity. In 'Hanfu' apple, the total concentrations of aroma VOCs in fruit bagged in double-layer paper or reflective film bags were 40.03% and 20.33% lower than in un-bagged fruit (Li *et al.*, 2011). While bagging increased the total content of esters, it decreased the total content of alcohols and aldehydes (Li *et al.*, 2011).

Fruit firmness

Fruit firmness is an important indicator for harvesting fruit at appropriate stage of maturity. It also determines the post-harvest life of a particular fruit. Fruit bagging can influence fruit firmness at harvest. For example, Bentley and Viveros (1992) reported that fruit firmness in 'Granny Smith' apple was improved by using brown paper bags, when bagging was done at the golf-ball size of fruit development. Murray *et al.* (2005) subjected the Japanese plum cultivars 'Laetitia' and 'Songold' to different levels of shading by bagging entire scaffold branches with shade netting, and reported that bagged plums were firmer than un-bagged plums. Similarly, Sharma *et al.* (2013) reported that bagged 'Royal Delicious' apple fruit were firmer at harvest than un-bagged fruit, and that bagged fruit retained higher firmness values during storage. In contrast, Singh *et al.* (2007) reported that bagging of 'Allahabad Safeda' guava fruit produced soft textured fruit. Similarly, Teixeira *et al.* (2011a) reported a reduction in fruit firmness in apple after bagging. Some studies have also concluded that bagging did not influence fruit firmness. For example, Hofman *et al.* (1997) reported that mango fruit firmness was not affected by white paper bags. Faoro and Marcia (2004) studied the effects of bagging on fruit firmness and reported that bagging did not affect fruit firmness in 'Nashi' pear.

Pesticide residues

Several pesticides (insecticides and fungicides) are used to protect fruit trees from biotic stresses. Some of the residues of these pesticides may be harmful to humans, hence non-chemical approaches in the form of Good Agricultural Practices (GAP) are gaining in popularity throughout the World. Fruit bagging, which provides a physical barrier between the applied chemical and the produce, may be a useful approach to reduce pesticide residues on fruit (Kitagawa *et al.*, 1992; Liu *et al.*, 2003; Chen *et al.*, 2006; Lin *et al.*, 2008; 2009). However, few studies have been conducted in this area. For example, Wang *et al.* (2003) found that bagging had no effect on the taste of *Litchi chinensis* fruit, but reduced fenpropathrin and trichlorphon residues on the fruit. Liu *et al.* (2003) reported a reduction in pesticide residues on 'Red Fuji' apple fruit. Similarly, Chen *et al.* (2006) reported that non-bagged apple fruit had higher concentrations of heavy metals (Pb, Cd, and Cr) and pesticide residues than bagged apples, and that single-layer bagged apples had higher concentrations than double-layer bagged fruit. It was therefore concluded that apple-bagging was an effective measure to improve sanitation and safety. Debnath and Mitra (2008) reported that those litchi fruit that developed inside bags were free from agrochemical residues. Furthermore, Lin *et al.* (2008) reported that residues of chlorpyrifos, carbendazim, and cyhalothrin were greatly reduced by bagging 'Cuiguan' and 'Hosui' pear fruit. Similarly, Lin *et al.* (2009) reported that cyhalothrin and carbendazim residues were much lower on bagged 'Cuiguan' pear fruit and recommended that double-bagging was more effective at producing high-quality pear fruit.

AGRONOMIC FACTORS IN FRUIT BAGGING

Date of bagging

For fruit bagging, individual fruit (e.g., apple, mango, guava), panicles (e.g., litchi), or fruit bunches (e.g., grape, banana) are covered by polyethylene, newspaper, or some other type of bag during development. Several experiments have been conducted on different fruit to study the effect of the date of bagging on the appearance, colour, insect damage, diseases and other disorders of fruit (Ju, 1998; Li *et al.*, 2005). The date of bagging had a profound influence on fruit colour in 'Yuzu' citrus fruit (Kwan *et al.*, 2000). Bagging before early-September with recycled Japanese phone-book paper (PBP) resulted in less colouration than in un-bagged fruit; whereas, bagging on 20 September or later resulted in a similar colouration to non-bagged fruit. Hu *et al.* (2001) reported that bagging 'Feizixiao' litchi fruit should be done from 15 DAFB until harvest for better skin colouration.

Black stain (BS) is a major problem in 'Shinsyu' persimmon (*Diospyros kaki* L.) fruit. To reduce the incidence of BS, Fumuro and Gamo (2001) covered all the fruit on each tree with paper bags on 17 September (the start of colouration), and reported that bagging significantly decreased the occurrence of BS and increased the ratio of BS-free fruit by 4- to 7-fold over non-bagged fruit. They suggested that 'Shinsyu' persimmon fruit should be bagged 50 – 35 d before harvest to prevent BS.

To increase the marketability of 'Fuyu' persimmon fruit by improving their appearance, Katagiri *et al.* (2003) bagged fruit with white paper bags from 6 August – 3 December, 6 August – 23 October, 18 September – 3

December, or 18 September – 3 December and reported that bagging from early-August or mid-September until early-December markedly reduced blemishing compared to un-bagged control fruit. Early removal of the bags in late-October caused an increase in blemishing at harvest time. Faoro and Marcia (2004) studied the effect of bagging on two bagging dates (34 or 83 DAFB) and reported that the use of small, transparent paraffin-paper bags 34 DAFB, or the use of large brown craft-paper bags, or the use of small transparent paraffin-paper bags at 34 d, followed by the use of a large double-bags at 83 DAFB, resulted in a better fruit appearance (i.e., more uniform, shiny and smooth skin, with small lenticels).

In carambola, Xu *et al.* (2008) studied the effects of bagging date and reported that the best quality fruit could be obtained if bagging was carried out 10 DAFB. Wang *et al.* (2010b) reported that if bagging of 'Wanmi' peach was done early during endocarp hardening, the total concentrations of VOCs in bagged fruit were significantly lower than in non-bagged fruit. Mathooko *et al.* (2011) reported that bagging mango fruit 70 DAFB promoted skin colour development, reduced blemishes, and produced high-quality fruit, leading to improved exports and better prices for mango fruit farmers. Lin *et al.* (2012) reported that bagging 'Cuiguan' pear once using large paper bags 35 DAFB, or twice using small paper bags 20 DAFB, followed by large paper bags 45 DAFB produced more top-grade fruit than bagging once. In contrast, Beasley *et al.* (1999) reported that neither bagging date, nor bagging material made any significant difference to skin or flesh Ca concentrations between bagged (plastic or paper) and un-bagged 'Kensington' mango fruit.

Bagging material

The kind of bag and its material may have a significant influence on the fruit. The type of bag recommended for one fruit may not work well for another fruit (Hong *et al.*, 1999). Several studies have been conducted on this aspect and have produced contradictory results (Table V). For example, cellophane or fabric bags were recommended for colour improvement in litchi (Hu *et al.*, 2001), orange and black bags for better skin colour in peach (Takada *et al.*, 2006), black or blue polyethylene bags for date (Awad, 2007), paper bags for apple (Dong *et al.*, 2007), transparent polypropylene micro-perforated bags for peach (Coelho *et al.*, 2008), Haoguo^{TM} bags to improve fruit quality of 'Cuiguan' and 'Hosui' pear (Lin *et al.*, 2008), white-coated bags for 'Janghowon Hwangdo' peach (Kim *et al.*, 2008b), brown paper bags to reduce the incidence of fruit fly in mango (Sarker *et al.*, 2009), nylon bags to reduce fruit fly in guava (Morera-Montoya, 2010), brown and/or black paper bags for colour improvement in mango (Ding and Syakirah, 2010), and spun-bound light-yellow fabric bags for colour and quality improvement in apple (Sharma *et al.*, 2013; Table V).

Date of bag removal

It is not only the date of bagging or the kind of bag which influences fruit colour, fruit size, and/or the quality of fruit, but the date of bag removal also plays a vital role. For instance, initial bagging studies in apple reported a strong inhibition of skin colour development, primarily because bagging intercepts light, which is required for anthocyanin synthesis (Saure, 1990). However, later experiments revealed that the date of bag removal had a greater influence on colour development in apple (Ju, 1998). In general, if bags are removed from fruit on the date of harvest, it is likely that the fruit will display poor colour development; however, if the bags are removed 3 – 7 d before the date of harvest, the fruit are likely to develop a more attractive colour than un-bagged fruit (Ju, 1998). Thus, it appears that re-exposure of fruit to sunlight after bag removal promotes anthocyanin synthesis. For example, Fan and Mattheis (1998) reported that enclosing 'Fuji' apple fruit in paper bags 60 DAFB delayed and reduced red colour development, but the skin colour changed significantly within the first 4 d after the bags were removed. Ju (1998) reported that re-exposing bagged apples to sunlight for 3 d increased the maximum concentration of anthocyanins. Hu *et al.* (2001) reported that cellophane or fabric bags should be kept on 'Feizixiao' litchi fruit until harvest, for better colouration. Huang *et al.* (2009) reported that, in order to obtain red Chinese sand pear fruit with an attractive appearance and good flesh qualities, the bags should be removed at least 10 d before harvest. Qu *et al.* (2012) reported that anthocyanin concentrations in 'Fuji' apple fruit were noticeably lower than in control fruit at bag removal, but increased rapidly following bag removal. Anthocyanin concentrations exceeded control values 6 d after bag removal and were approximately twice the control values 8 d after bag removal.

FUTURE STRATEGIES AND CONCLUSIONS

Pre-harvest fruit bagging is labour-intensive and cost is a major factor in determining its adoption on a commercial scale. Similarly, there are differences in opinion among researchers regarding the type of bag, the date of bagging, and the date of bag removal to use for various fruit. Some researchers have recommended the use of plastic bags, but considering environmental issues, the development of (and recommendations for) biodegradable bags is required. Some authors have shown profitable results using paper bags, but the use of such bags in areas of heavy rainfall may not be feasible. Despite these issues, fruit bagging has become an integral part of the commercial culture of apple, pear, peach, and loquat in countries such as Japan, China, and the USA. Yet, its benefits remain to be promoted in other countries, and cost-benefit analyses should be performed to support its adoption elsewhere.

We conclude that pre-harvest fruit bagging is a simple, grower-friendly technology which is safe to use and has several beneficial effects on the physical appearance and quality of fruit. Furthermore, it is the safest approach to protect fruit from insect pests, diseases, and other disorders. This approach is an integral part of fruit production in some parts of the World. It is a laborious process, and needs the development of biodegradable bags which decompose after use. Moreover, we need to standardise specifications for the type of bag to be used, the date of bagging, and the date of bag removal for growers to benefit from this technology.

TABLE V
Effect of different types of bags on skin colour, insect pests, disorders, and quality in different fruit

Fruit	Bagging material used	Best recommendation	Positive influence(s)	Reference(s)
Apple	Blue, light-yellow, red and green coloured spun-bound single layered bags	Light-yellow coloured bags	Improvement in colour, firmness and reduction in storage disorders	Sharma *et al.* (2013)
	Different types of bags	Paper bags	Better absorption of calcium in fruit	Dong *et al.* (2007)
Banana	Different types of bags	Plastic bags	Increase in fruit size and enhancement in fruit maturity	Stover and Simmonds (1987)
Carambola	Plastic bag, self-made newspaper bag and non-woven cloth bag	Plastic bags	Increase in fruit size, higher soluble solids content	Xu *et al.* (2008)
Date palm	Black or blue polyethylene bags, white 'agrlsafe' (polypropylene fleece), and paper bags	Black and blue bags	Increased rate of ripening	Awad (2007)
	Black, white, blue or yellow coloured plastic bags	Blue coloured plastic bags	Acceleration fruit ripening process	Harhash and Al-Obeed (2010)
Guava	Waxed paper, nylon fabric, Taiwan bag and telephone book paper	Nylon bags	Highest protection against the fruit fly	Morera-Montoya *et al.* (2010)
Litchi	Cellophane paper, adhesive-bonded fabric, newspaper and craft paper	Cellophane or fabric bags	Better colouration in fruit	Hu *et al.* (2001)
Loquat	One-layered white paper bags (OWPB) and two-layered paper bags with a black inner layer and a grey outer layer (TGDPB)	One-layered white paper bags (OWPB)	Promotion in appearance	Xu *et al.* (2010)
	Eleven kinds of paper bags	Shengda™ paper bags	Improvement in the appearance of fruit by reducing rate of strain, fruit rust, splitting fruit and anthracnose	Liu *et al.* (2004)
Mango	Black polybag, transparent polybag, brown paper bag	Brown paper bags	Reduction in the incidence of fruit fly, maintained higher total soluble sugars (TSS) and better physical quality of fruits	Sarker *et al.* (2009)
	Bags made from old newspaper, brown and black paper	Brown and/or black paper	Improvement in skin colour	Ding and Syakirah (2010)
	The wavelength-selective bags (no pigment, yellow, red, blue/violet, blue) and kraft paper bags with black paper liner	Value-Mailer Ltd plastic bags	Improvement in fruit weight and skin glossiness	Chonhenchob *et al.* (2011)
	Two-layer paper (black inside with brown, brown and waxed and white outside), newspaper and golden paper bags	Two-layered paper (brown outside and black inside)	Improvement in fruit weight and skin appearance	Watanawan *et al.* (2008)
Nashi pears	Small transparent paraffin paper bags, large craft paper bags of brown colour	Small transparent papaffin paper bags	Development of uniform colour, shine and smooth skin colour with small lenticels in fruit	Faoro and Marcia (2004)
Peach	White, orange and black bags	White or orange bags	Better colouration in pulp	Takada *et al.* (2006)
	14 Different types of bags	Transparent polypropylene micro-perforated bags	Better colour of fruit	Coelho *et al.* (2008)
	Coated white paper, white paper, coated yellow paper, yellow paper and newspaper	White coated bag	Improvement in the appearance and accumulation of higher amount of anthocyanins	Kim *et al.* (2008b)
Pear	'Haoguo' bags, Jiatian bags and common bags	Haoguo™ bags	More attractive surface, higher soluble solids content and lower acid content in fruit	Lin *et al.* (2008)

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