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Susceptibility to impact damage of apples inside ventilated corrugated paperboard packages: Effects of package design

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A B S T R A C T

The incidence of fruit postharvest losses and waste due to mechanical damage during handling is a major problem in the fresh produce industry. Ventilated corrugated paperboard (VCP) packages used extensively in the fruit industry are designed to minimize handling damage and to facilitate airflow around the produce to maintain the cold chain. During handling and transportation, both the package and contents experience a range of force loading conditions, including impact, compression and vibration which may result in bruise damage. The objectives of this study were to investigate the impact bruise damage susceptibility of apples packed inside two ventilated carton designs (one with fruit on tray layers and the other with fruit in retail polyethylene plastic bags). The spatial variation of bruise damage inside the packages and the incidence of physical damage of the packages were also investigated. Results showed that both the incidence and susceptibility to bruise damage of the apples were affected by package design and drop heights; with more than 50% higher incidence and 66% higher bruise susceptibility occurring on fruit packed in the bulk package design than on those packed in the layered package design. Irrespective of package design, both bruising incidence and susceptibility were highest at the bottom of the package, which increased significantly by about 50% when the package drop height increased from 30 cm to 50 cm.

1. Introduction

Packaging fresh fruit and vegetables is an important step in the long and complicated journey from the grower to consumer. Bags, crates, hampers, baskets, cartons, bulk bins, and palletized containers are common forms of packaging used when handling, transporting, and marketing fresh produce. However, despite the availability and use of different packaging formats and designs in fruit handling, the occurrence of bruise damage is still a frequent quality problem (Lu et al., 2010a,b; Opara and Pathare, 2014).

Consumer perception of fresh produce quality is influenced by the appearance, shape and textural characteristics, and these in turn influence purchasing decisions. Consumers desire high quality produce that is free from bruise, cuts, punctures, physiological disorders and pathogens (Matzinger and Tong, 1993; Timm et al., 1996). The presence of bruising and other types of physical damage reduce the aesthetic appeal of fresh produce. Previous studies have shown that bruising due to excessive compression, impact and vibration forces is the most common type of postharvest mechanical injury (Brown et al., 1993; Maness et al., 1992; Knee and Miller, 2002; Jarimopas et al., 2007; Opara, 2007; Lewis et al., 2008; Opara and Pathare, 2014). In addition to the loss of appearance quality, bruised fruit is also susceptible to high risk of fungal and bacterial contamination and excessive moisture loss, as high as 400 times more than that of intact fruit (Wilson et al., 1995). Several researchers have studied fruit bruising due to impact (Holt and Schoorl, 1977; Schoorl and Holt, 1980; Peleg, 1981, 1985; Jarimopas et al., 1984; Chen and Yazdani, 1991; Pang et al., 1992; Bajema and Hyde, 1998; Ragni and Berardinelli, 2001).

Peleg (1985) describes good interior packaging as that which treats individual fruits as separate units, avoids fruit-to-fruit contact, and absorbs the impact energy. Holt and Schoorl (1984) compared three different types of packaging for their protection

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Fig. 1. Packaging designs used: (a) MK4 box; (b) tray arrangement in MK4 box; (c) Econo box; (d) fruit packed in plastic bags arranged in bulk inside Econo box.

afforded to apples against damage due to impact. The authors found that wooden boxes afforded the least protection, followed by returnable crates and tray packs. In another study of apples in bulk bins during semi-trailer transport, Timm et al. (1996) found that fruit in plastic bins had less abrasion damage in comparison to those packed in hardwood and plywood bins. In contrast, Acıcan et al. (2007) studied the mechanical forces exerted on apples in wooden crates during transport from harvest to market under free fall, horizontal impact and vibration forces and found that the mechanical forces acting on the apples at the bottom of the crate was greater than those at the upper layer and that there was a significant difference between the damage at the lowest and the uppermost layers.

Ventilated paperboard carton is the most common type of packaging used for handling fresh fruit (Pathare et al., 2012). A wide range of ventilated package designs are used for handling produce in the fresh fruit industry (Berry et al., 2015); however, in the two main types of ventilated packaging designs, produce may be packed on tray layers or placed inside plastic bags each containing up to ten pieces of fruit. Both types of package design and multi-scale packing are used extensively in long distance (export) and local fresh fruit supply chains. Previous studies have reported the significant influence of package design on cooling performance of ventilated package designs used for handling fresh fruit, including energy efficiency (Defraeye et al., 2014, 2013; Delele et al., 2013a,b; Zou et al., 2006a,b). Although there is a vast

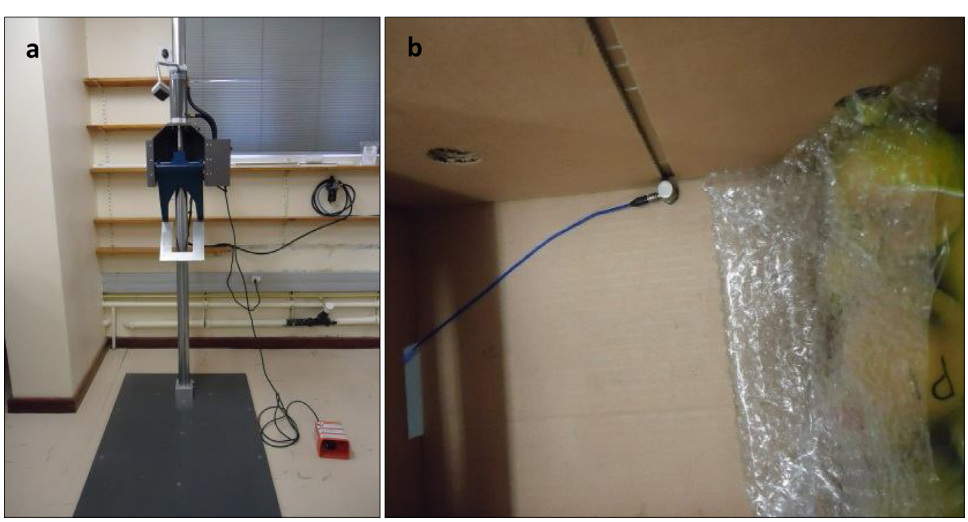


Fig. 2. Drop testing equipment used (a) Lansmont model PDT-56 drop tester (b) PCB model 353B15 accelerometer.

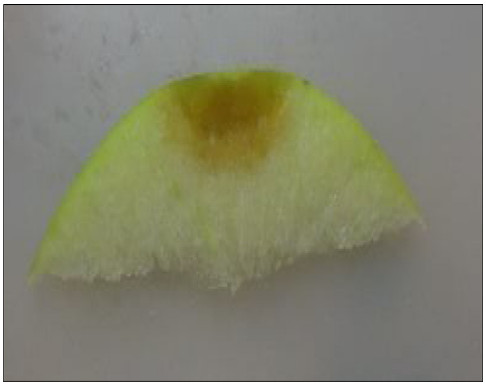


Fig. 3. Apple section prepared for bruise size measurement.

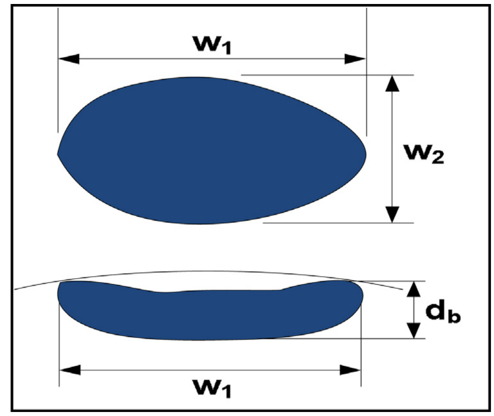


Fig. 4. Elliptical bruise thickness method for bruise volume determination.

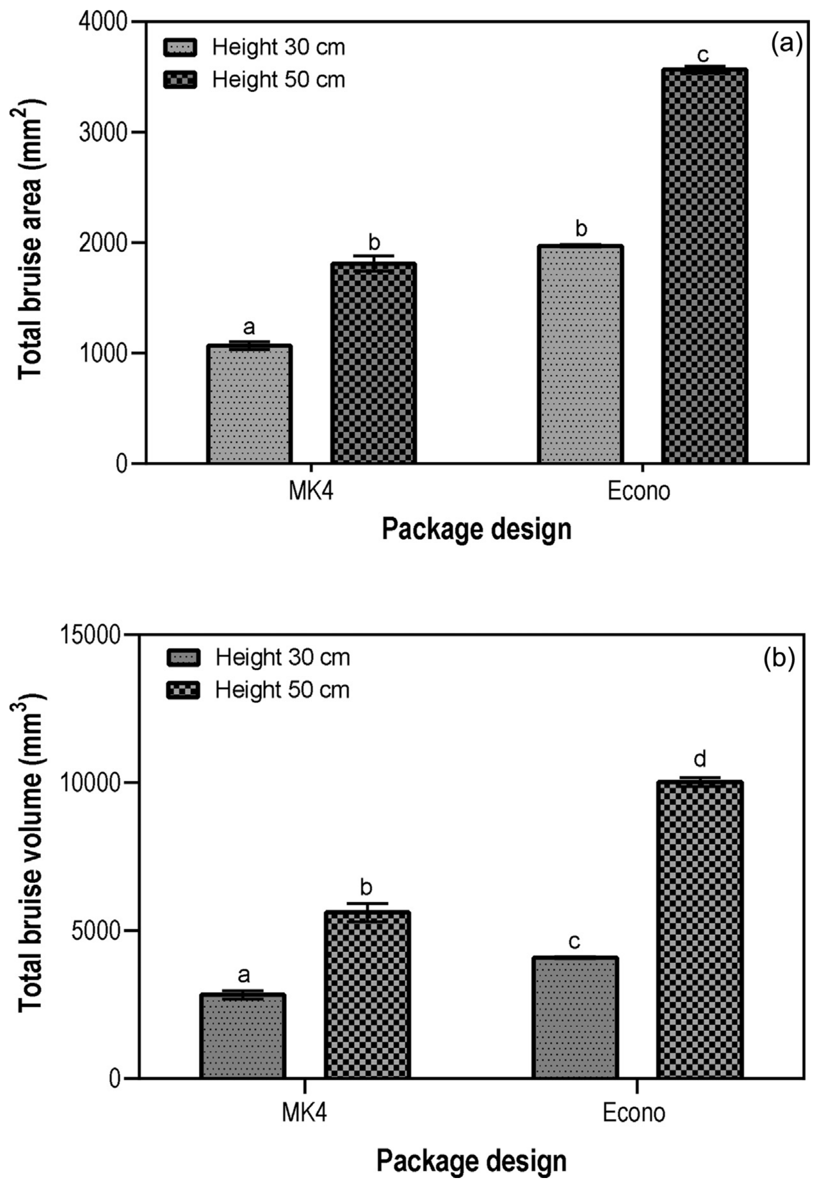
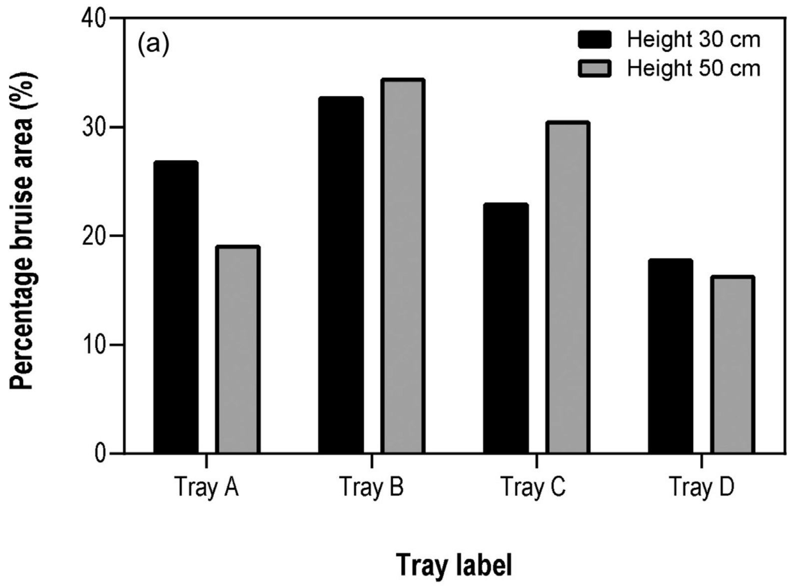


Fig. 5. Bruise area (a) and volume (b) of apples packed inside MK4 package (fruit on trays) and Econo package (fruit placed inside polyethylene plastic bags).



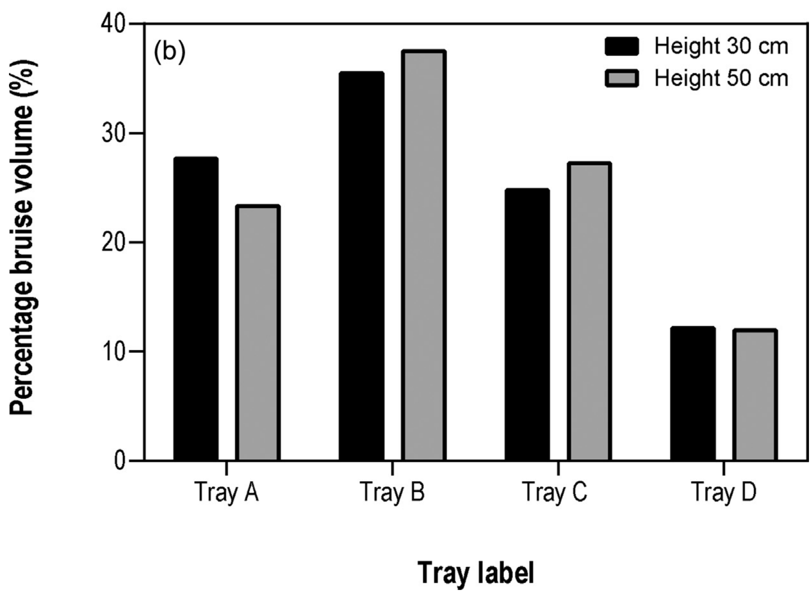


Fig. 6. Distribution of total fruit bruising inside the MK4 package with apples on trays.

amount of published information about preharvest and postharvest factors contributing to fruit bruising, including methods for measuring and analysing bruise damage (Opara and Pathare, 2014; Opara, 2007; Van Zeebroeck et al., 2007a,b), little is known about differences in bruise susceptibility of fruit packed inside different ventilated packaging designs. The objective of this research was to investigate the susceptibility of apples to impact bruise damage inside ventilated corrugated paperboard packages, including the spatial variability and severity of bruise incidence inside the package.

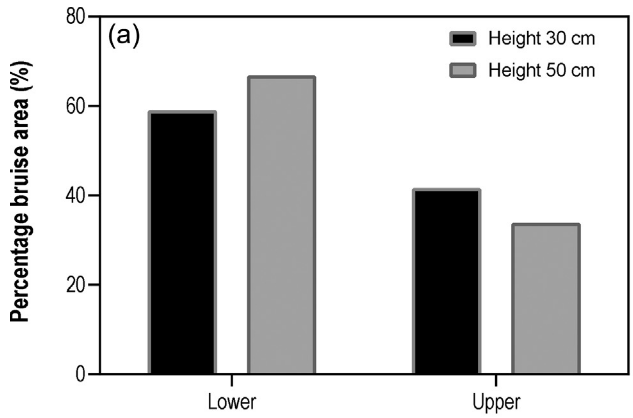
2. Materials and methods

2.1. Fruit supply

'Golden Delicious' apples (packed in two different carton designs) were purchased during commercial harvest from a packhouse in Grabouw, Western Cape, South Africa (34°48′14″S, 19°02′50″E). Fruit of uniform size and maturity based on the background colour, firmness and free from physical defects were used for the experiments. The mean diameter and mass of the apples were 65 ± 2.0 mm and 148.7 ± 7.0 g, respectively. The packed apples in both tray and bulk packaging design were stored at the same environmental condition (30 °C, 90% relative humidity) for two days prior to drop test.

2.2. Packaging materials

Two types of ventilated paperboard package designs (Bushel MK4 and Econo packages) used for handling apples were studied (Fig. 1). The MK4 package design consists of inner and outer boxes separated by pulp trays, while the Econo pack has an open top. The MK4 package dimensions (length × width × height) were 495 mm × 326 mm × 266 mm externally and 488 mm × 319 mm



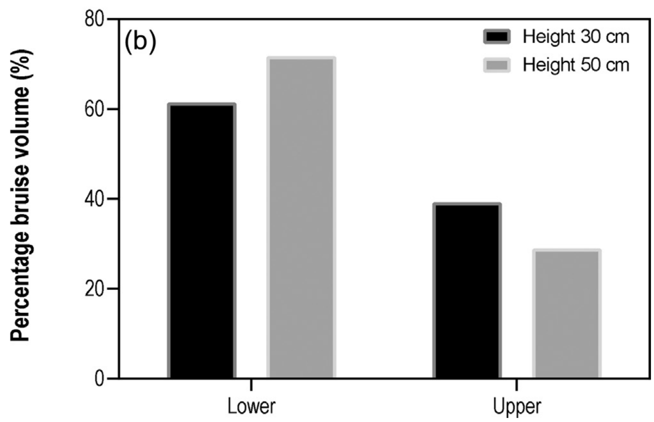


Fig. 7. Distribution of total fruit bruising inside the Econo package with apples placed in bulk inside polyethylene plastic bags.

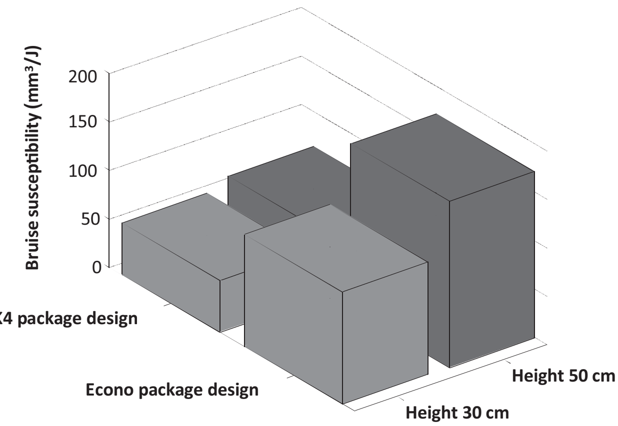


Fig. 8. Bruise susceptibility of apples inside the packages at different heights.

× 266 mm internally. The Econo package dimensions were 460 mm × 292 mm × 238 mm. Fruit were placed in the ventilated paperboard package in layers (with trays) for MK4 package and in bulk (without trays) for the Econo package. The final mass was 18 kg and 12 kg for the MK4 and the Econo package designs respectively. For the packaging arrangement with trays, apples were placed into the package in four layers of 30 fruits per tray and the trays were labelled A to D, starting with the bottom tray. The apples were placed carefully with the flower stalk axis horizontal and in the same direction in the moulded pockets of the trays. Apples in the Econo type of package were arranged in bulk, in polyethylene plastic bags. These were arranged in two layers with each layer containing four packs and each pack contained eight apples in total. The lower packs were numbered 1–4 while the upper packs were numbered 5–8. The apples were numbered so as to aid in the bruise position analysis.

2.3. Drop test

The Lansmont Model PDT-56 Drop tester (Lansmont Corporation, Monterey CA, USA) was used (Fig. 2a). Impact bruises were produced by dropping the ventilated corrugated paperboard packages five times from a specific dropping height onto a steel surface. The PCB 353B15 accelerometer (PCB Piezotronics, Inc., Depew, New York, USA) was used to measure the shock response (Fig. 2b). The packages with fruit arranged in layers and in bulk were dropped from the specific height. In this study, the packages were dropped from two drop heights, 30 cm and 50 cm. The test was done in duplicate for the two packaging methods at the different heights.

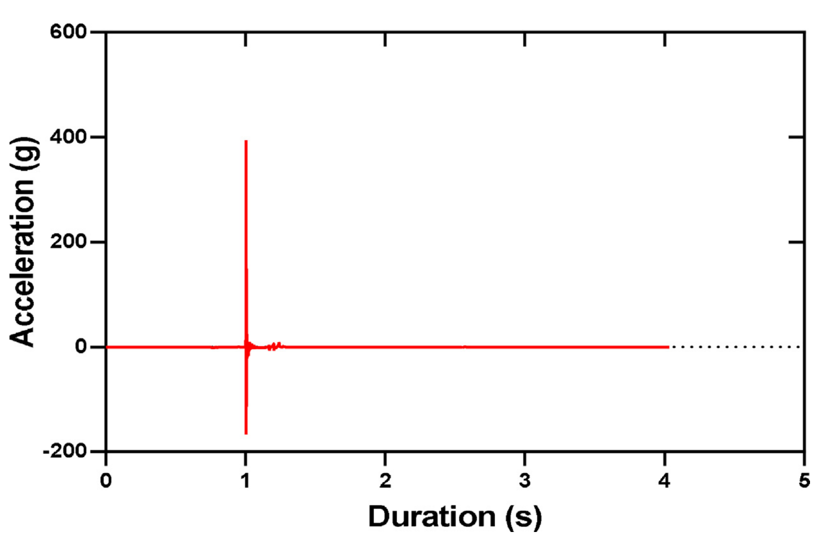


Fig. 9. Typical acceleration-duration curve during impact response.

Table 1
Equivalent impact energy (J) on the packages.

Package design	Height 30 cm	Height 50 cm
MK4[a]	52.97	88.29
Econo[b]	35.32	58.86

[a] Apple fruit placed on trays.
[b] Apple fruits placed inside polyethylene plastic bags.

2.4. Bruise damage measurement and analysis

For full development of bruises and for the bruises to become more apparent, the apples were left at room temperature for 24 h after being dropped. Bruise dimensions (major and minor width, and depth) were measured using digital callipers (±0.01 mm). Bruise depth was measured by cutting perpendicularly along the major axis of the fruit. Bruise area (BA) and bruise volume (BV) were quantified by assuming an elliptical bruise shape (Bollen et al., 1999; Lu et al., 2010a,b; Opara and Pathare, 2014):

$$BA = \frac{\pi}{4} w_1 w_2 \quad (1)$$

where w_1 and w_2 are the bruise width along the major and minor axes (mm).

$$BV = \pi \frac{d_b}{24}\left(3w_1w_2 + 4d_b^2\right) \quad (2)$$

where d_b is the depth of the bruise (mm). Fig. 3 shows a typical cut section through bruised tissue while Fig. 4 shows the bruise dimensions. The bruise susceptibility BS ($mm^3 J^{-1}$) was calculated as the ratio of bruise volume BV (mm^3) to the impact energy IE (J) (Opara, 2007; Opara and Pathare, 2014).

$$BS = \frac{BV}{IE} \quad (3)$$

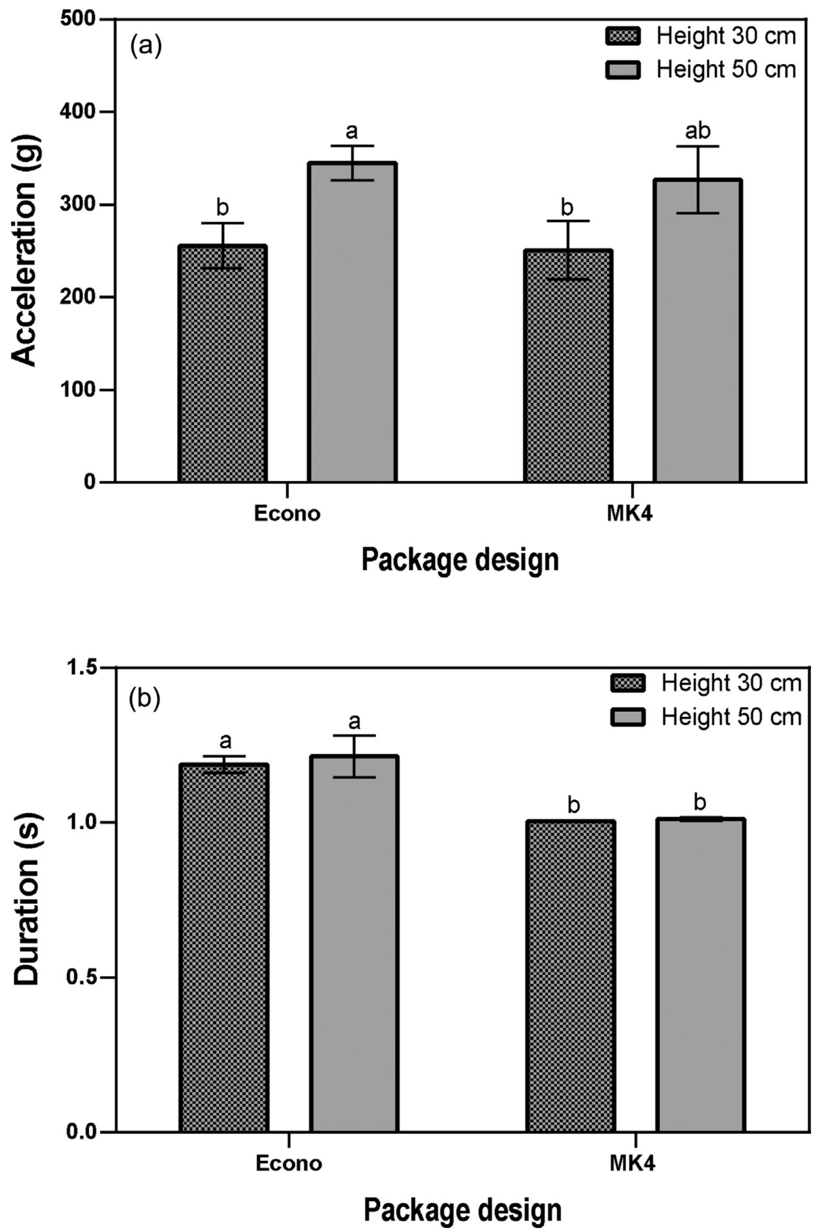


Fig. 10. Maximum acceleration and duration of the impact response.

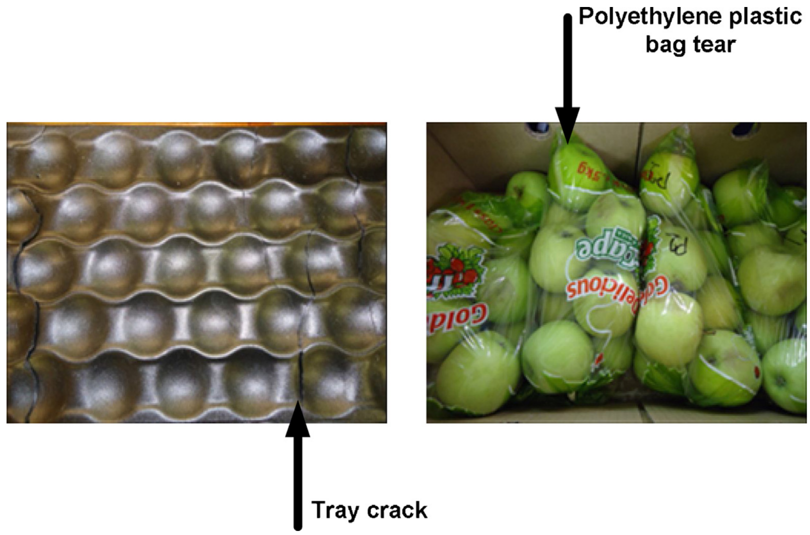


Fig. 11. Cracked tray and torn polyethylene plastic bag after impact test.

$$\mathrm{IE} = m_i g h_d \quad (4)$$

where m_i is the mass of the falling object (kg), g is the acceleration due to gravity (m/s^2) and h_d is the drop height (m).

2.5. Package damage assessment

After each drop test, a subjective pass/fail determination was made on the package. A box passed if it had no major gaps or tears, retained all products and could still be manually handled. Conversely, a box was deemed to have failed if it had major holes or gaps, the contents spilled out or was exposed, or if the box could no longer be manually handled.

2.6. Statistical analysis

The experimental data were treated with one-way analysis of variance (ANOVA) at 95% confidence level and with the differences at $p < 0.05$ considered statistically significant. The statistical tests were performed using Statistica (v. 11.0, Statsoft, USA). Graphical representations were made using GraphicPad Prism 6 software (GraphicPad Software, Inc. San Diego, USA).

3. Results and discussion

3.1. Effects of package design and drop height

3.1.1. Bruise size

The results in Fig. 5 show the total apple bruise area and volume for each package design after impact. Bruise size in both package designs increased as the drop height increased. These results agree with the findings in a previous study by Lu et al. (2012) who reported that the bruise area and volume increased relative to drop heights and number of drops. The fundamental damage of bruise to apples in packages is energy transformation as some of the kinetic energy of drops is absorbed by bruising (Schoorl and Holt, 1982; Holt and Schoorl, 1984; Jarimopas et al., 2007; Zarifneshat et al., 2010). Irrespective of drop height, fruit inside polyethylene plastic bags experienced more bruising than those on trays. This suggests that the energy being transferred to fruit on trays is less than the energy absorbed by fruit inside the polyethylene plastic bags. Furthermore, the result suggests that aside from the energy absorbed by the fruit due to the impact load, the pattern in which the apples were packed in the two package designs influenced the bruising incurred by the fruit. The higher bruise damage obtained from fruit inside the polyethylene plastic bags indicates that there was fruit-to-fruit contact due to the bulk arrangement of the apples in the package as compared to the fruit on trays where individual apple fruits were located in pockets moulded in the trays, preventing apple-to-apple contact.

Furthermore, there was a significant difference in total bruise volume between the different drop heights for the two package designs, while, with regard to the bruise area, there was no significant difference between MK4 package, with tray arrangement dropped at height 50 cm and Econo package, with bulk arrangement dropped at height 30 cm. There was an increase of about 50% in the bruising from height 30 cm to height 50 cm for both package designs as more energy was transferred to the fruit at height 50 cm. The overall damage to the fruit which is higher in the bulk arrangement package than the tray arrangement package indicates that the package with tray arrangement could absorb more energy than the bulk arrangement package, and releases less of the remaining energy to the fruit, thus resulting in fewer bruises on the fruit. The energy absorbed by the apple fruit determines the quality of the fruit during handling and storage to a large extent because, the bruising which results from the impact increases the subsequent deterioration of the fruit. Hence, minimizing impact that results in the damage ensures the quality of the fruit (Jarimopas et al., 2007; Ahmadi et al., 2010; Ahmadi, 2012; Opara and Pathare, 2014).

Figs. 6 and 7 show the percentage of bruising of fruit placed on trays and inside polyethylene plastic bags, respectively. The percentage of bruising in trays B and C were higher than in the other trays, A and D. At both heights, the highest percentage of bruising occurred at tray B, which was between the ranges of 30–40% of the total bruising, while on the other hand, top tray D had the lowest bruise percentage in the range 11–17% of the total bruise.

For the bulk arrangement package, packs 1–4 and packs 5–8 were considered as the lower and upper layers, respectively. The fruit in the lower layer at both heights had the highest bruise percentage, in the range of 59–71%. The damage at height 50 cm was almost 75% of the total bruise area and volume, which shows how apples are damaged severely with respect to the height and the position in the package. The fruit in the upper layer at both heights exhibited a bruise percentage in the range 29–41%. The bruise percentage at the different positions occurred as a result of less impact energy being transferred to the fruit after impact.

3.1.2. Bruise susceptibility

Table 1 shows the impact energy on the package designs. The impact energy increased with an increase in drop height. There was an increase of more than 50% in the impact energy as the height was increased from 30 cm to 50 cm. From the results obtained, the impact energy on the package with tray internal arrangement was at both heights higher than the impact energy for the bulk arrangement package. From this, the bruise susceptibility which indicates the extent of bruising on fruit under impact conditions, in terms of the ratio of the bruise volume to the impact energy (Pang et al., 1996), was found to also increase with increase in drop height. The fruit packed inside polyethylene plastic bags had higher bruise susceptibility than fruit on trays (Fig. 8), indicating that the fruit inside plastic bags was more susceptible and prone to bruising than the fruit on trays. Although, as shown in Table 1, the impact energy on the package with bulk arrangement was lower than the impact energy on the package with tray arrangement, bruise susceptibility of fruit on the tray arrangement package was higher. This suggested that more of the impact energy was absorbed by the package with tray arrangement than the energy it transferred to the fruit. The trays inside the package were very effective in minimising the bruising in the apple fruit. The combination of the tray and the package absorbs energy in four ways (Holt and Schoorl, 1984; Van Zeebroeck et al., 2007c). On dropping the package, there is a lengthwise stretch of the trays resulting in a tear failure, a crosswise stretch of the tray, and compression between the apple contact surfaces. The package walls also buckle sideways absorbing some of the energy. This observation is attributed to better cushioning material to protect the apple fruit in the package with tray arrangement. Fig. 9 shows the typical acceleration–duration curve of the package at both heights. The maximum acceleration increased by 35% from height 30 cm to 50 cm for the bulk arrangement package, while for the tray arrangement package, the maximum acceleration increased by 30% from height 30 cm to 50 cm (Fig. 10a), with a significant

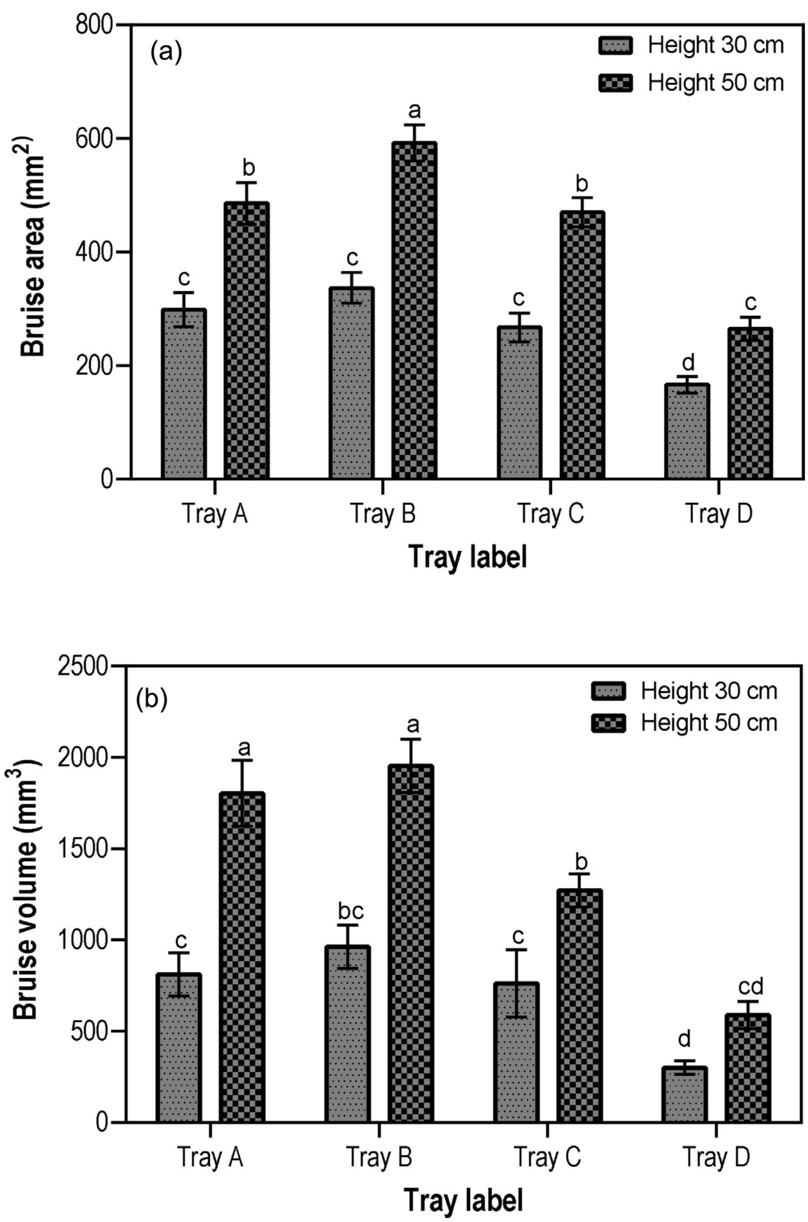


Fig. 12. Spatial variation in bruise area and volume inside MK4 package with apples on trays.

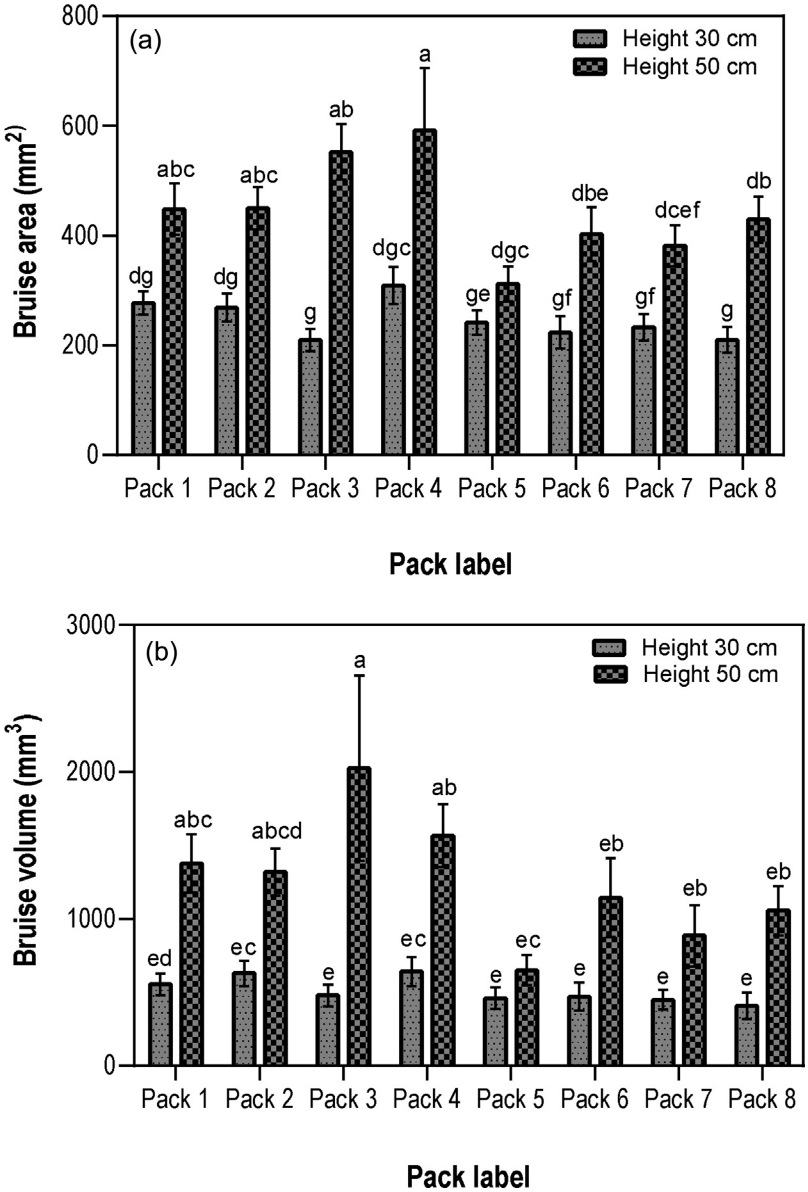


Fig. 13. Spatial variation in bruise area and volume for Econo package with apples placed in bulk inside polyethylene plastic bags.

difference for both package designs. The impact duration at both heights was longer in the bulk arrangement package than in the tray arrangement package (Fig. 10b) with a significant difference observed for both package designs. This suggests why the bruising incurred by the fruit placed inside polyethylene plastic bags was more than the bruising incurred by the fruit packed on trays, as longer contact duration will result in more damage (Van linden et al., 2006).

3.1.3. Package damage

Ideally, a good package should absorb most of the kinetic energy, thereby protecting the fruit and reducing the amount of bruising incurred. The package being an integral and important part of the distribution system, requires an acceptable damage at a minimum cost. After the impact test, a subjective evaluation of both package designs was done. There was no visible damage to either type of packaging at both heights; however, at height 50 cm, there was a crack in the trays inside the package with tray internal arrangement, and in the case of the bulk arrangement package, there was a tear in the polyethylene plastic bag used for the packaging (Fig. 11). The trays absorbed energy due to impact. Hence, the apple fruit in the package incurred less damage than the fruit inside polyethylene plastic bag.

3.2. Effects of fruit position inside the package

Results on the effect of drop height on bruise damage in the tray arrangement package showed that the amount of fruit damage increased with drop height. Both the bruise area and the bruise volume increased with drop height as shown in Fig. 12. At height 30 cm, there was no significant difference between trays A, B and C for the bruise area and bruise volume, but there was a significant difference between tray D and the other trays A, B and C in the package. The least damage to the apple fruit occurred at tray D on the top of the stack, while the largest damage to the apple fruit occurred at tray B. Bruise area at tray B and tray D were

336.68 mm^2 and 166.33 mm^2 respectively at height 30 cm, indicating a percentage difference of 68% while the bruise volumes were 961.81 mm^3 and 266.69 mm^3, indicating a percentage difference of 113%. At height of 50 cm, similar to the occurrence at height 30 cm, apple fruit on trays D and B had the least and the largest damage respectively. Bruise area at tray B and tray D were 592.01 mm^2 and 264.64 mm^2 respectively at height 50 cm, indicating a percentage difference of 76% while the bruise volumes were 1953.07 mm^3 and 588.55 mm^3, indicating a percentage difference of 107%. The damage to the fruit on tray D was significantly lower than the damage on trays A, B and C with respect to both the bruise area and the bruise volume. Also, the damage at tray B which was notably the largest compared to the other trays is most likely due to more of the energy that was absorbed by the package was released to the fruit on tray B. At both heights, there was a significant increase in damage to the fruit of about 50%. This result agrees with the findings in a previous study by Lu et al. (2010a,b). The authors studied the incidence of damage and damaged area for apples in corrugated fibreboard boxes and found that the damage to apples in the boxes increased with an increase in drop height.

When comparing the bruise area and the bruise volume of the corresponding tray positions for the two heights (30 cm and 50 cm), it can be seen that there was a significant difference between the trays of the same position at the two heights except for top tray D at 50 cm. Also, the damage to the apples on tray B at 30 cm was statistically not different from the damage to apples on tray C at 50 cm. This indicated the effect of height on the susceptibility of the fruit to mechanical damage caused by impact as more energy was released to the fruit as the height increased (Lu et al., 2010a,b).

There was a similar trend of spatial variation of bruising inside the bulk arrangement package (Fig. 13). The damage incurred on the apple fruit increased with drop height. The highest level of bruising occurred in the packs arranged at the bottom of the package (packs 1–4), while the lowest level of bruising occurred in the packs arranged at the top of the package (packs 5–8). There was no significant difference in the bruise volume of apple fruit in the package at height 30 cm; however, the bruise areas at height 30 cm are almost evenly distributed as there was no significant difference between packs 5–8 at the bottom of the package. A similar trend occurred at height 50 cm. With regard to the bruise area, there was no significant difference between packs 5, 6 and 7, but pack 4 did differ. The bruise area in pack 3 also differed from those in packs 5 and 7.

When comparing the bruise area and the bruise volume of the corresponding pack positions for the two heights (30 cm and 50 cm), it can be seen that the drop height had significant impact on both the bruise area and the bruise volume. Also, the pack location in the bulk arrangement package had a slight influence on the bruise area and the bruise volume.

4. Conclusions

In this research, the susceptibility of apple fruit to mechanical damage inside two designs of ventilated corrugated paperboard packages (tray and bulk arrangements) was investigated. The induced force on the packages led to bruise damage, thereby reducing the quality of fruit. The mechanical force acting on the apple fruit at the bottom of the package was significant and had more influence on the apples than the force at the top of the package. Hence, it will be economical if force absorbing material such as polypropylene foams or bubble wraps is placed at the bottom of the package to reduce the damage incurred by the fruit. Based on the data obtained from this present study, package design and packaging pattern had a significant influence on the bruising incurred by the apple fruit. The bulk arrangement package released more energy to the fruit while the tray arrangement package absorbed more of the impact energy and transferred less to the fruit packed inside, thereby protecting the fruit from bruise damage. Furthermore, the drop heights had significant effect on the level of damage to the fruit as the damage increased with an increase in drop height. This research can be of great help to packaging designers, and handlers of various types of processing equipment at different distribution stages in order to minimise the mechanical damage due to impact, thereby ensuring a quality product to the ultimate users.

Acknowledgements

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