Bruise susceptibilities of kiwifruit as affected by impact and fruit properties

E. Ahmadi

Department of Agricultural Machinery Engineering, Faculty of Agriculture, Bu-Ali Sina University, Hamedan, Iran

Abstract

Ahmadi E., 2012. **Bruise susceptibilities of kiwifruit as affected by impact and fruit properties**. Res. Agr. Eng., *58*: 107–113.

Kiwifruit bruise damage is a common postharvest disorder that substantially reduces fruit quality and marketability. Fruit bruise cause tissue softening and make them more susceptible to undesired agents such as diseases-inducing agents. Factors that affect kiwifruit bruise susceptibility such as impact properties and fruit properties were investigated. Two bruise prediction models were constructed for the damage susceptibility of kiwifruit (measured by absorbed energy) using multiple linear regression analyses. Kiwifruits were subjected to dynamic loading by means of a pendulum at three levels of impact. Significant effects of acoustic stiffness, temperature and the radius of curvature and some interactions on bruising were obtained at 5% probability level.

Keywords: absorbed energy; dynamic impact; mechanical damage; postharvest; regression models

Fruit bruising is one of the most important factors limiting mechanization and automation in harvesting, sorting and transport of fruit and vegetables (Blahovec, Paprštein 2005). The three factors which can physically cause fruit bruising are impact, vibration, and compression load (Vergano et al. 1991).

When kiwifruit tissue is damaged by physical agents such as impact mechanical, it becomes water soaked but does not turn brown due to its low content of polyphenol and high concentration of ascorbic acid as oxidation inhibitor.

Mechanical damage during fruit processing for marketing affects texture quality of plant materials. Fruit texture is considered a major contributor to the susceptibility to bruising and might vary considerably within the fruit (Van Linden et al. 2006b). Texture is one of the most important quality attributes of fruits and vegetables. Moreover, the texture of biological materials is strongly influenced by their underlying tissue and cellular structure (Gerschenson et al. 2001). The cell walls rupture results in enzyme biochemical activity and can contribute to the mechanical damage (Talens et al. 2001).

The bruise susceptibility of fruit and vegetables is a measure for response to external loading and depends on a number of elements such as variety, texture, maturity, water status, firmness, temperature, size, shape and a series of fruit internal factor such as cell wall strength and elasticity, cell shape and internal structure (Van Linden et al. 2006b).

Fruits bruising prediction models for peach, apple, tomato and potatoes according to impact properties (peak contact force, impact energy or drop height) and fruit properties (temperature, stiffness, radius of curvature, etc.) are well documented in literature (Bajema, Hyde 1998; Menesatti et al. 1999; Opara 2007; Van Linden et al. 2006a; Van Zeebroeck et al. 2007a, b; Ahmadi et al. 2010). According to our knowledge there is no available information for kiwifruit bruising prediction models but a few independent researches explained destructive and non-destructive technologies for determining the firmness of kiwifruit (Abbott, Massie 1995; Davie et al. 1996; Mencarelli et al. 1996; McGlone, Kawano 1998). The objective of this study was to develop bruise prediction models for kiwifruit using impact energy or peak contact force together with the fruit properties such as fruit temperature, acoustic stiffness and radius of curvature of independent variables. In this research absorbed energy was used to quantify bruise damage. For one experimental object, it can be stated that higher absorbed energy indicates higher bruise damage (Van Zeebroeck et al. 2007a).

MATERIAL AND METHODS

Experimental setup

All experiments were carried out using kiwifruit Hayward cultivar which was harvested in 2008 from the Mazandaran province in Northern Iran. Uniform, ground color and healthy fruits were used in this experiment and they were kept in optimal conditions (3°C, 85% RH) during measurement, with maximum seven days of storage before measurement. At least 12 h before the actual measurement, the kiwifruits were stored at the desired temperature. Kiwifruits at 3°C were measured within 10 min to minimize fruit warming in the measuring room at 20°C. A total of 150 kiwifruit were used for conducting the experiments. The fruits were divided into six groups and, consequently, 25 kiwifruits were tested for each treatment (temperature × impact level combination) and each fruit was impacted once. Kiwifruits were mounted on a pendulum (Ahmadi et al. 2010) and impacted by a spherical steel indenter (R = 25 mm) (Fig. 1).

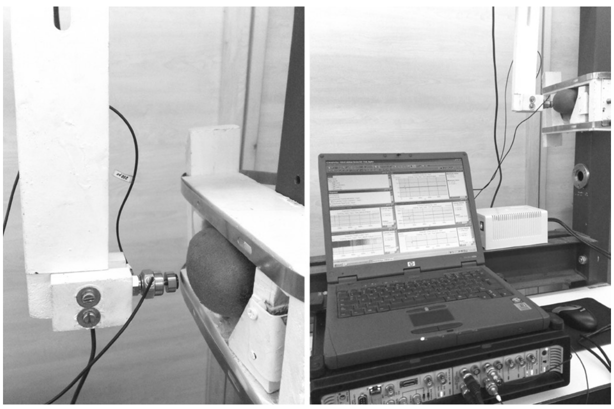

Fig. 1. General view of the pendulum device for measuring impact force and impact velocity of the kiwifruit

Normally bruise is visible on the surface of most fruits such as apple, pear and potato, while generally it is invisible in kiwifruit. The absorbed energy was used as a dependent variable in the bruise prediction model. Absorbed energy is calculated by subtracting rebound energy of the impact energy. The impact and elastic energy are obtained from the calculated kinetic energy of the pendulum arm just before and just after impact:

$$E_{impact} = E_{kin}(t_{-1})$$
$$E_{elastic} = E_{kin}(t_{n+1})$$
$$E_{absorbed} = E_{impact} - E_{elastic}$$

where:
E_{impact} – impact energy (J)
E_{kin} – kinetic energy (J)
t_{-1} – time of the final signal before impact (s)
$E_{elastic}$ – elastic energy (J)
t_{n+1} – time of the first signal after the impact (s)
$E_{absorbed}$ – absorbed energy (J)

Bruise prediction models contained either the impact energy (kinetic energy of the pendulum rod just before impact) or the peak contact force as independent variables along with the other input variables. The independent variables that were used in the regression models were:
– impact energy (E) (J),
– peak contact force (PF) (N),
– two kiwifruit temperatures (T): 3 and 20°C,
– kiwifruit radius of curvature (R) at the location of impact (mm),
– kiwifruit acoustic stiffness (S) ($kg^{2/3}/s^2$).

Three nominal impact levels were applied as outlined in Table 1. The impact energy levels in the experiment were chosen above the critical impact level of kiwifruit. All three impact level was recorded during mechanical harvest, handling and transporting. The lower limit of the applied impact level was based

Table 1. Overview of different nominal impact levels applied on the kiwifruit (average ± SD*)

	Impact energy (J)	Peak contact force (N)
Level 1	0.014 ± 1.4	23.73 ± 12.6
Level 2	0.072 ± 1.7	41.57 ± 16.3
Level 3	0.16 ± 2.5	76.16 ± 10.9

*standard deviation as percent of the average on the measured impact force and acceleration during handling and transporting, but the higher impact level was in mechanical harvester. For each impact the exact impact energy and peak contact force were measured and logged to a data file.

The radius of curvature was measured locally at the point of impact by a curvature meter. To measure radius of curvature of kiwifruit the same equipment was used as for peaches (Ahmadi et al. 2010).

The kiwifruit acoustic stiffness was determined on preconditioned fruit based on the acoustic impulse response technique. Acoustic measurements were made with a prepolarised free-field 12 mm microphone (type 4189, Bruel and Kjaer, Naerum, Denmark; frequency range from 6.3 Hz to 20 kHz and a sensitivity of 50 mV Pa-1). The signals of this microphone were collected and processed using a PULSE® program (type 3564, B&K®, Naerum, Denmark). A Fast Fourier transform (FFT) of the signal was performed to determine the frequency spectrum, and subsequently, the first resonance frequency of the peach was determined.

The acoustic stiffness was calculated as:

$$S = f^2 m^{2/3}$$

where:

S – acoustic stiffness ($kg^{2/3}/s^2$)

m – mass of the kiwifruit (kg)

f – first resonance frequency (1/s)

Statistical analyses

The dependent variable was the absorbed energy (*AE*) of kiwifruit. In the first model, independent variables were peak contact force (*PF*), radius of curvature at the location of impact (*R*), kiwifruit acoustic stiffness (*S*) and temperature (*T*). The second model was similar to the first model except that *PF* was replaced by the impact energy (*E*). A backward multiple regression procedure was conducted to select the relevant independent variables influencing the dependent variable using 5% significance level. Furthermore, in order to verify the accuracy of multiple regression models, a χ^2-test was carried out using the predicted and experimental data. SAS software v. 8.2 (SAS Institute Inc., Tulsa, USA) was used for data analysis.

Table 2. Regression equation of absorbed energy (J) of the kiwifruit (*AE*) in relation to peak contact force (*PF*), temperature (*T*), acoustic stiffness (*S*) and radius of curvature (*R*) as independent variables

Model 1	R^2
$AE = 4.532 \times 10^{-3} + 8.725 \times 10^{-3} PF + 3.347 \times 10^{-4} T - 3.635 S - 5.273 \times 10^{-3} R + 4.574 \times 10^{-4} PF \times R + 1.714 \times 10^{-4} PF \times S$	0.91

minimum probability threshold $P \leq 0.05$

RESULTS AND DISCUSSION

Bruise will occur in the area where stresses are equal or more than failure stress of kiwifruit. The mechanical impact, fruit properties and their interactions put substantial effect on the bruise susceptibility of kiwifruit. When fruit impacted at high impact level, the possibility of bruise developing will greatly increased. Severity of damage depends on fruit physiological and biochemical properties, such as plant cell chemical oxidation reactions (Strehmel et al. 2010). The mechanical stress which is provoked by mechanical impact induces cell wall and membrane rupture.

Bruise prediction model with the peak contact force as independent variable

The results of a multiple linear regression analysis between absorbed energy and series of independent variables (peak contact force, radius of curvature, temperature and acoustic stiffness) are presented in Table 2. All of the terms in the model 1 were significant at 5% probability level. Fig. 2 presents the predicted absorbed energy plotted against the measured absorbed energy in relation

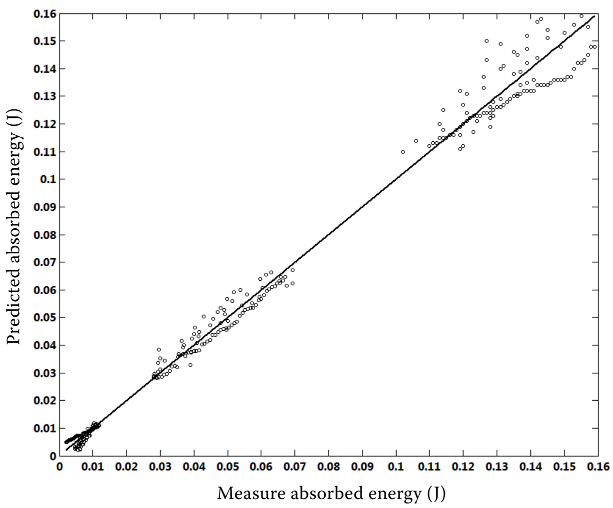

Fig. 2. Measured absorbed energy vs. absorbed energy predicted by model 1

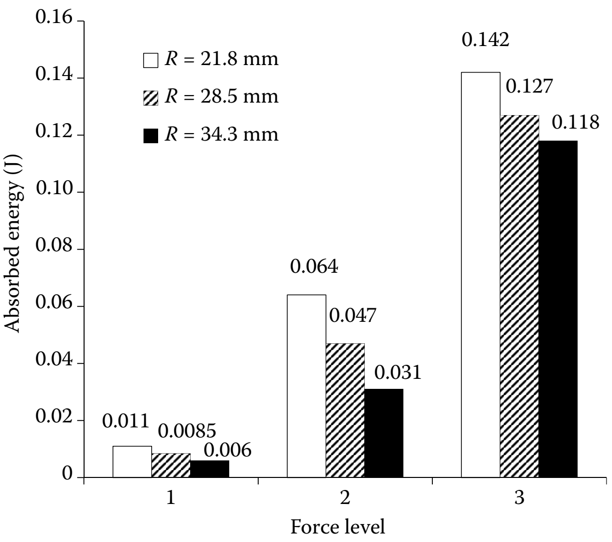

Fig. 3. Effect of curvature radius on the absorbed energy (J) of kiwifruit at 3°C for each peak contact force level in relation to model 1

Standard deviation as percent of the average in force level 1 for *R* = 21.8 was 10.3%, *R* = 28.5 was 9.6%, *R* = 34.3 was 4.6%; in force level 2 for *R* = 21.8 was 5.6%, *R* = 28.5 was 4.7%, *R* = 34.3 was 10%; in force level 3 for *R* = 21.8 was 5.2%, *R* = 28.5 was 3.7%, *R* = 34.3 was 9.3%

to model 1. A good fit was obtained between the measured and predicted absorbed energy.

Effect of kiwifruit radius of curvature on absorbed energy

In this study we observed more absorbed energy with low radius of curvature. In fact, kiwifruits with small radius of curvature had more bruising than those with a larger radius of curvature (at the location of impact). The significant interaction ($P < 0.05$) between radius of curvature and peak contact force indicated that the absorbed energy at different peak contact forces differ by the increase in radius of curvature. However, the relative difference decreased with the increase in peak contact force (Fig. 3). The difference in absorbed energy between two extremes of kiwifruit curvature radius (21.8 and 34.3 mm) was 83% at the low impact (19.2 N) but only 20% at the high impact (70.6 N).

An explanation of the effect of radius of curvature on absorbed energy could be that the higher peak contact stress for fruit with smaller radius of curvature dominates the lower contact area during impact (based on the Hertz theory for elastic bodies) (Van Zeebroeck et al. 2007a). It can be seen that a large radius of curvature results in a lower peak stress and thus leads to less bruise damage. This was confirmed by our results about impact levels where small radius of curvature led to more bruise damage. The rate of kiwifruit softening is related to fruit size and storage atmosphere. Large size kiwifruit showed slow rate of softening compared to small size (Crisosto et al. 1999). Thus, small size kiwifruit have longer bruise damage potential than large fruit. This result predicts and explains the patterns of changes during bruising damage according to the radius of curvature as reported for peach (Ahmadi et al. 2010).

Effect of kiwifruit acoustic stiffness on absorbed energy

Kiwifruit with low acoustic stiffness led to more absorbed energy than fruit with higher acoustic stiffness. Stiffer kiwifruit showed less bruise damage. More damage with advanced ripeness was observed. The significant interaction ($P < 0.05$) between acoustic stiffness and peak contact force indicated that the difference in absolute value of the absorbed energy between ripe and unripe kiwifruit increased with peak contact force. However, the relative difference decreased with increasing peak contact force (Fig. 4). The absorbed energy for the acoustic stiffness of 16.7 $kg^{2/3}/s^2$ was up to 58%

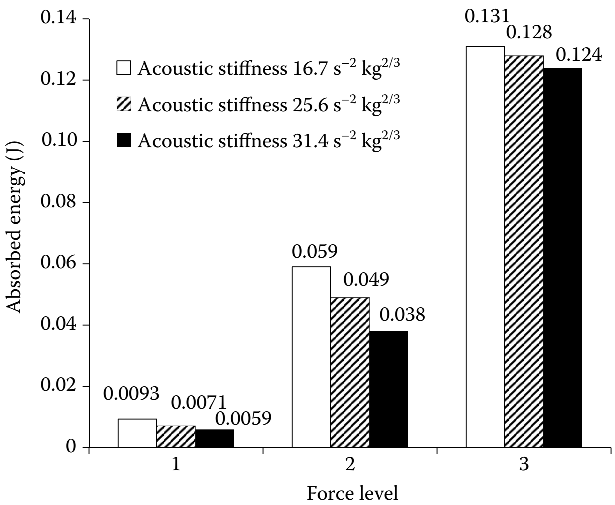

Fig. 4. Effect of acoustic stiffness on the absorbed energy (J) of kiwifruit at 3°C for each peak contact force level in relation to model 1

Standard deviation as percent of the average in force level 1 for *S* = 16.7 was 9.2%, S = 25.6 was 6.2%, *S* = 31.4 was 9.8%; in force level 2 for *S* = 16.7 was 3.7%, *S* = 25.6 was 10.4%, *S* = 31.4 was 8.7%; in force level 3 for *S* = 16.7 was 11.3%, S = 25.6 was 9.5%, *S* = 31.4 was 5.2%

higher than 31.4 $kg^{2/3}/s^2$ at low impacts (19.2 N) and up to 6% higher at high impacts (70.6 N).

Firmness is considered the primary indicator of kiwifruit eating ripeness. Soft kiwifruit can be excessively sensitive to bruises (Davie et al. 1996). Three major tissue types can be identified in kiwi fruit, namely, outer pericarp, inner pericarp and core. Fruit softening in the inner tissue may start before softening of the fruit surface. Elasticity module decreased during ripening of kiwifruit as an expression of tissue damage in mechanical impact (Gerschenson et al. 2001). The acoustic stiffness is positively related to the elastic module (Duprat et al. 1997). A higher firmness or failure stress for stiffer fruits means that they are more resistant to bruising. The softening process during kiwifruit normal ripening is also associated with decrease in the cell wall resistance and porosity (Bauchot et al. 1999). The effect of ripeness on bruise susceptibility is the same of the effect for peaches (Ahmadi et al. 2010).

Effect of kiwifruit temperature on absorbed energy

Temperature had a positive effect on the absorbed energy (Table 2, Fig. 5) and a higher temperature caused more bruising. No significant interaction was obtained between temperature and

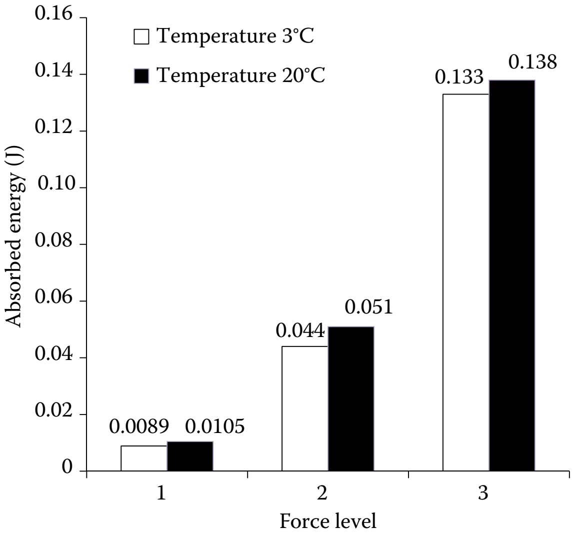

Fig. 5. Effect of temperature on the absorbed energy (J) of kiwifruit for each impact peak contact force level

Standard deviation as percent of the average in force level 1 for T = 3°C was 3.7%, T = 20°C was 5.9%; in force level 2 for T = 3°C was 9.3%, T = 20°C was 8.7%; in force level 3 for T = 3°C was 10.2%, T = 20°C was 7.1%

peak contact force. The difference in absorbed energy between two temperatures was not similar at low and high impact forces. This difference ranged from 18% for the lowest impact (19.2 N) to only 3% for the highest impact (70.6 N).

The kiwifruit as a group is very responsive to high temperature exposure, such as delays between harvests and cooling (Sfakiotakis et al. 2005). A physical explanation of the effect of temperature on firmness of tissue is given by Hertog et al. (2004). The relationship between firmness and temperature was liner for kiwifruit (Jeffery, Banks 1994). Kiwifruit had higher soluble solids content and firmness during storage at low temperature (Manolopoulou, Papadopoulou 1998). Low temperature reduces the bruise damage while metabolic activity thus softening rate increases in higher storage temperature. The softening process in kiwifruit is temperature-dependent. Kiwifruits are highly susceptible to water loss (leading to shriveling) during storage in higher temperature. Agar et al. (1999) reported that softening of kiwifruit increases as storage temperature increases. During low temperature storage, kiwifruit underwent a cell wall change which is associated with normal fruit softening (Bauchot et al. 1999).

Bruise prediction models with impact energy as independent variable

The significance of main effects (impact energy, temperature, acoustic stiffness and radius of curvature) and some interactions were observed at the 5% significance level. Table 3 shows the final model having all of the independent variables. A good fit was observed between the measured and predicted absorbed energy. No important differences were observed between the predicted absorbed energy of model 1 and model 2 at all impact levels.

Table 3. Regression equation of absorbed energy (J) of the kiwifruit (AE) in relation to impact energy (E), temperature (T), acoustic stiffness (S) and radius of curvature (R) as independent variables

Model 2	R^2
$AE = -3.731 \times 10^{-3} + 7.139 \times 10^{-3} E + 6.514 \times 10^{-4} T - 1.817 S - 9.245 \times 10^{-3} R - 3.753 \times 10^{-4} E \times T + 5.287 \times 10^{-4} E \times S$	0.88

minimum probability threshold $P \leq 0.05$

Effect of kiwifruit radius of curvature on absorbed energy

The same conclusions can be drawn for the model 1 which includes the peak contact force. However, kiwifruits with small radius of curvature had more absorbed energy than those with a larger radius of curvature (at the location of impact). No significant interaction between radius of curvature and peak contact force was present. The difference in absorbed energy between two extremes of kiwifruit curvature radius (21.8 and 34.3 mm) was 41% at the low impact energy (0.013 J) but only 27% at the high impact (0.19 J).

Effect of kiwifruit acoustic stiffness on absorbed energy

Stiffer kiwifruit showed less absorbed energy. The interaction of the acoustic stiffness with the impact energy was significant ($P < 0.05$). Similar difference in the absorbed energy between low and high acoustic stiffness was observed for model 1 (peak contact force) and model 2 (impact energy). For the kiwifruit of 16.7 $kg^{2/3}/s^2$, the absorbed energy was up to 61% higher than kiwifruit with 31.4 $kg^{2/3}/s^2$ at the low impact energy (0.013 J) and up to 11% higher at the high impact (0.11 J).

Effect of kiwifruit temperature on absorbed energy

The effect of kiwifruit temperature on absorbed energy for impact energy was similar to the peak contact force. A higher temperature resulted in more absorbed energy. The significant interaction ($P < 0.05$) between kiwifruit temperature and impact energy indicated that the effect of temperature on the absorbed energy was higher at the low impact energy. This difference ranged from 12% for the lowest impact (0.013 J) to only 2% for the highest impact (0.11 J).

CONCLUSIONS

The aim of the study was to determine the best reliable statistic model among linear multiple regressions, to estimate the kiwifruit bruising susceptibility by absorbed energy. Absorbed energy is a good estimation property to quantify bruise damage in kiwifruit. Significant main effects and also significant interactions between fruit properties and the impact properties (peak contact force or impact energy) were observed. Softer kiwifruit developed higher amount of the absorbed energy. Damage of the fruit decreased with the increase of acoustic stiffness. Kiwifruit at low temperature absorb less energy compared to high temperature. Higher kiwifruit temperature was found to increase bruising. Smaller radii of curvature led to more bruise damage.

References

Abbott J.A., Massie D.R., 1995. Nondestructive dynamic force/deformation measurement of kiwifruit firmness. Transactions of the ASAE, *38*: 1809–1812.

Agar I.T., Massantini R., Hess Pierce B., Kader A.A., 1999. Postharvest CO_2 and ethylene production and quality maintenance of fresh-cut kiwifruit slices. Journal of Food Science, *64*: 433–440.

Ahmadi E., Ghassemzadeh H.R., Sadeghi M., Moghaddam M., Zarif Neshat S., 2010. The effect of impact and fruit properties on the bruising of peach. Journal of Food Engineering, *97*: 110–117.

Bajema R.W., Hyde G.M., 1998. Instrumented pendulum for impact characterization of whole fruit and vegetable specimens. Transactions of the ASAE, *41*: 1399–1405.

Bauchot A.D., Hallett I.C., Redgwell R.J., Lallu N., 1999. Cell wall properties of kiwifruit affected by low temperature breakdown. Postharvest Biology and Technology, *16*: 245–255.

Blahovec J., Paprštein F., 2005. Susceptibility of pear varieties to bruising. Postharvest Biology and Technology, *38*: 231–238.

Crisosto C.H., Garner D., Saez K., 1999. Kiwifruit size influences softening rate during storage. California Agriculture, *53*: 29–32.

Davie I.J., Banks N.H., Jeffery P.B., Studman C.J., 1996. Nondestructive measurement of kiwifruit firmness. New Zealand Journal of Crop and Horticultural Science, *24*: 151–157.

Duprat F., Grotte M., Pietri E., Loonis D., 1997. The acoustic impulse response method for measuring the overall firmness of fruit. Journal of Agricultural Engineering Research, *66*: 251–259.

Gerschenson L.N., Rojas A.M., Marangoni A.G., 2001. Effects of processing on kiwifruit dynamic rheological behavior and tissue structure. Food Research International, *34*: 1–6.

Hertog M.L.A.T.M., Ben-Arie R., Roth E., Nicolai B.M., 2004. Humidity and temperature effects on invasive and non-invasive firmness measures. Postharvest Biology and Technology, *33*: 79–91.

Jeffry P.B., Banks N.H., 1994. Firmness – temperature coefficient of kiwifruit. New Zealand Journal of Crop and Horticultural Science, *22*: 97–101.

Manolopoulou H., Papadopoulou P., 1998. A study of respiratory and physico-chemical changes of four kiwi fruit cultivars during cool-storage. Food Chemistry, *63*: 529–534.

McGlone V.A., Kawano S., 1998. Firmness, dry-matter and soluble-solids assessment of postharvest kiwifruit by NIR spectroscopy. Postharvest Biology and Technology, *13*: 131–141.

Mencarelli F., Massantini R., Botondi R., 1996. Influence of impact surface and temperature on the ripening response of kiwifruit. Postharvest Biology and Technology, *8*: 165–177.

Menesatti P., Beni C., Paglia G., Marcelli S., Dandrea S., 1999. Predictive statistical model for the analysis of drop impact damage on peach. Journal of Agricultural Engineering Research, *73*: 275–282.

Opara L.U., 2007. Bruise susceptibilities of Gala apples as affected by orchard management practices and harvest date. Postharvest Biology and Technology, *43*: 47–54.

Sfakiotakis E., Chlioumis G., Gerasopoulos D., 2005. Preharvest chilling reduces low temperature breakdown incidence of kiwifruit. Postharvest Biology and Technology, *38*: 169–174.

Strehmel N., Praeger U., Konig C., Fehrle I., Erban A., Geyer M., Kopka J., Dongen J., 2010. Time course effects on primary metabolism of potato (*Solanum tuberosum*) tuber tissue after mechanical impact. Postharvest Biology and Technology, *56*: 109–116.

Talens P., Martinez-Navarrete N., Fito P., Chiralt A., 2001. Changes in optical and mechanical properties during osmodehydrofreezing of kiwifruit. Innovative Food Science & Emerging Technologies, *3*: 191–199.

Van Linden V., Ketelaere B., Desmet M., De Baerdemaeker J., 2006a. Determination of bruise susceptibility of tomato fruit by means of an instrumented pendulum. Postharvest Biology and Technology, *40*: 7–14.

Van Linden V., Scheerlinck N., Desmet M., De Baerdemaeker J., 2006b. Factors that affect tomato bruise development as a result of mechanical impact. Postharvest Biology and Technology, *42*: 260–270.

Van Zeebroeck M., Van Linden V., Darius P., De Ketelaere B., Ramon H., Tijskens E., 2007a. The effect of fruit properties on the bruise susceptibility of tomatoes. Postharvest Biology and Technology, *45*: 168–175.

Van Zeebroeck M., Van linden V., Darius P., De Ketelaere B., Ramon H., Tijskens E., 2007b. The effect of fruit factors on the bruise susceptibility of apples. Postharvest Biology and Technology, *46*: 10–19.

Vergano P.J., Testin R.F., Newall W.C., 1991. Peach bruising: Susceptibility to impact, vibration, and compression abuse. Transaction of the ASAE, *34*: 2110–2116.

Received for publication September 14, 2011
Accepted after corrections November 8, 2011

Corresponding author:

Dr. Ebrahim Ahmadi, Bu-Ali Sina University, Faculty of Agriculture,
Department of Agricultural Machinery Engineering, 65174 Hamedan, Iran
phone/fax: + 98 811 442 4012, e-mail: eahmadi@basu.ac.ir