ภาคผนวก

ภาคผนวก ก

ผลงานที่ได้รับการตีพิมพ์ และนำเสนอในระดับนานาชาติ

Test Method to Evaluate Bruising During Impacts to Apples and Compare Cushioning Materials

B. Jarimopas[1], S. Sayasoonthorn[2], S. P. Singh[3] and Jagjit Singh[4]

[1]Department of Agricultural Engineering, Kamphaengsaen Engineering Faculty, Kasetsart University, Kamphaengsaen, Nakohnpathom, Thailand

[2]Post Graduate Education and Research Development Project in Post-harvest Technology, Kasetsart University, Kamphaengsean, Nakohnpathom, Thailand

[3]School of Packaging, Michigan State University, East Lansing, Michigan, USA

[4]College of Business, Cal Poly State University, San Luis Obispo, California, USA

Abstract

Developing simplified and accurate test methods to quantify and compare performance of impact levels to sensitive produce is a challenge. Despite a variety of packaging options available today bruising damage is commonplace for post-harvest apples throughout the supply chain. The major sources of bruising are compression, impact, or vibration forces. Understanding where these forces occur can help reduce this type of mechanical damage to apples. The purpose of this study was to investigate the impact characteristics of foam net and corrugated board when applied as wrapping for individual apples. Two grades (count numbers 80 and 100) of "Fuji" cultivar apples imported to Thailand from China were studied. A simple ballistic pendulum test device was developed to measure bruise volume to impact energy relationship. A linear relationship for both types of apples was observed. Bruise volume occurrence probability and impact energy relationship fitted by linear regression were created for cushioned and bare apples. Absorbed energy of various cushioning materials was also calculated under compressive forces.

Key words: Apple, Ballistic pendulum, Bruise volume, Cushioning, Impact energy

---

1. Introduction

Apples are a popular and nutritious horticultural product popular worldwide. Consumers insist on a high quality product that is free from any bruises, cuts, punctures, physiological disorders, and pathogens (Matzinger and Tong, 1993). Bruising, which is objectionable to fresh market consumers, can result in a lower grade for any apple. Several studies have been conducted internationally that show that compression, vibration and impact forces cause a majority of the mechanical damage, such as bruising, to apples in the supply chain.

Apples are exposed to compressive forces via forces applied by the picker's body, tree limbs, ladder rungs or rail, bulk bin rails and bottoms. Compressive forces may also get applied to apples by other apples due to excessive bulk bin depth or carton stack height, by operators forcing the cartons shut or into a tight spot, etc (Brown et al., 1993). Vibration forces are the second major cause of mechanical damage to apples in the supply chain and are almost impossible to avoid. If the cartons or bins which carry the apples through the distribution environment hit resonance (their natural frequency matches the forcing frequency of the conveyance), severe accumulated bruise damage is inherent. Impacts impart high forces in an extremely short duration and are often not obvious in mechanical handling systems such as those used in packing lines. The effect of impact forces usually results in bruises, permanent damage and lower perceived quality. Bruise sensitivity has also been reported to increase with storage time (Brown et al., 1993). Effectiveness of cushioning materials on protecting impact damage of apples is the primary objective of this research.

Various packaging materials are in use today to wrap individual apples to provide cushioning so that they may survive the adverse distribution environments effects. In a study, a net made of dry banana string, an agricultural waste wrapping for apples, was shown to save the fruit from damage at the impact energy of 1.1 joule (Jarimopas et al., 2004). This study mentioned problems of fungi attack due to the wrapping on the skin of the fruit. Another research studied paper that is typically applied to line the inner surface of plastic and bamboo fruit containers for protecting fresh fruit from bamboo cuts and moisture loss during transport (Jarimopas et al., 2002). Paper was found not to be a good cushioning material against impact damage. Peleg (1985) describes good interior packaging as that which treats a fruit as separate units, avoids fruit to fruit contact, absorbs the impact energy, and is practical. At present, foam nets function well as one of the commercial packaging solutions (Chonhenchob and Singh, 2004). However, it is not easily degradable in a landfill. (Jarimopas et al., 2004). Figure 1 below shows typical foam net used for apples.

Figure 1 Foam Net Packaging

Impact damage to apples usually materializes as bruising (Bollen et al., 1999). Several researchers have studied apple bruising due to impacts (Jarimopas, 1984; Holt and Schoorl, 1977; Bajema and Hyde, 1998; Schoorl and Holt, 1980; Ragni and Berardinelli, 2001; Chen and Yazdani, 1991). Some researches have found that an apple, when exposed to small impacts, exhibits no bruising but noticeable bruising could be detected beyond a certain amount of impact energy. (Jarimopas, 1984; Jarimopas et al., 2004). Bruises have been evaluated as bruise volume (Mohsenin, 1996; Chen and Yazdani, 1991) and linear correlations have been found between the bruise volume and the impact or absorbed energy (Jarimopas, 1984; Holt and Schoorl, 1977; Ruiz-Altisent, 1991). Shoorl and Holt (1980) define slope of bruise volume and energy as bruise resistance. The threshold of apple bruising has also been studied by several researchers (Shulte et al., 1992; Mathew and Hyde, 1997; Bollen et al., 2001). Shulte et al. (1992) and Bollen et al (2001) expressed the phenomenon of apple bruise threshold as a curve plotted between probability of bruising against the drop height or energy.

Some experts have credited corrugated board wrapping to adequately protect fresh fruit from impact and compression forces (Peleg, 1985; TISTR, 2002). The inherent affinity of corrugated board to moisture, as with any paper based packaging material, compromises its strength and cushioning capabilies. But because of its expedient degradability, high recycling rate and low cost of the recycled paper, corrugated board holds good potential as a cushioning material. No comparative studies on physical properties of new and used corrugated board as cushioning material for wrapping fruit have ever been conducted.

Several testing devices for observing the effect of impact forces on fruits have been developed in recent years. These instrumented devices are generally capable of measuring acceleration, force, displacement, time, and contact area during impact (Bajema and Hyde, 1998; Jarimopas et al., 1990; Chen et al., 1985; Lichtensteiger et al., 1988). Some of these devices are capable of recording, processing and storing impact data during the experimentation. (Siyami et al., 1987; Tennes et al., 1988). Using these instrumented devices measurements can be achieved instantly and accurately, but at a very high expense. Often times a majority of the capabilities of such devices are not utilized and accurate measurements of impact parameters like impact and absorbed energy can be made using a simple and affordable device that provides sufficient repeatability and reproducibility.

The main objectives of this study were:

1. Develop a simple ballistic pendulum type test fixture operable by one person that provides a high sensitivity of energy settings and dependable energy-bruise volume measurements

2. For bare apples, and apples wrapped with plastic foam net and four different types of paper corrugated board materials/orientations provide:

- Comparative bruise volume versus impact energy relationships

- Bruise occurrence probability at various impact energies

- Absorbed energy of cushioning materials under compression

3. Provide recommendations on the best materials and wrapping orientation for package protection against impact forces

2. Materials and Methods

2.1 Apples

The "Fuji" cultivar apples, imported from China to Thailand without any physical injury, were used for the testing because its bruising discoloration is easily detected and it is available in Thailand markets. Two sizes of the apple were used, count number 80 (fruit weight = 240 $\pm$ 20 g) and number 100 (fruit weight = 180 $\pm$ 20 g).

2.2 Simple Instrumented Pendulum

An impact testing device was designed to be a ballistic pendulum featuring 3.84 kg rectangular steel mass hung by four 45 cm long ropes like a cradle (Figure 2), steel frame, sample holder and a laser pointer. The steel frame consisted of a steel rod and two screws, and connected to the supporting ropes to facilitate adjustment of the pendulum impact side to contact the apple sample at θ = 0 and to fasten the rod during the impact. A laser pointer, mounted at the back of the mass, projects a beam to mark 1 mm red circle on a scale (each graduation is equivalent to 7.5 mm/degree of motion) 15 cm under the mass. This facilitates the setting of incident angle and impact energy. The motion of the pendulum mass was curvilinear. Pivot points of the rope at four corners of the mass were set on the same horizontal plane passing a fulcrum providing stable motion without excessive swinging. An apple sample was placed in the sample holder with a pin plugged in to the top of the fruit. There was a small rope placed perpendicular to the pendulum motion plane that connected to the pin in order to prevent the sample from falling down after the impact thereby avoiding any unwanted mechanical injuries. The testing device was operated by a single person and proved to give higher sensitivity of energy setting and better energy-bruise volume curve fitting compared to the pendulum without instrumentation (Jarimopas and Sayasoonthorn, 2004).

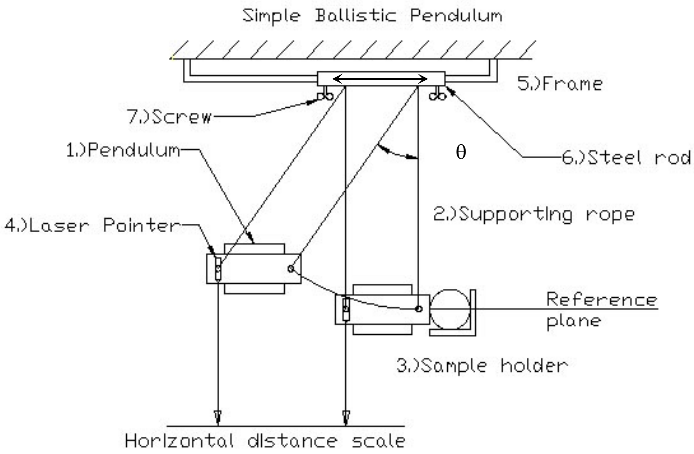


Figure 2 A Schematic Diagram of the Simple Ballistic Pendulum

2.3 Cushioning Wrapping Materials

Two types of cushioning material were used to comparatively test their protective performance. A 2 mm thick typical apple foam net (Figure 3) and corrugated board were used as wrapping for individual apples. Four types of the corrugated board wrapping used were

a. Single face with corrugated medium outside (SFO)
b. Single face with corrugated medium inside (SFI)
c. New double wall corrugated board (NDW)
d. Used double wall corrugated board (UDW).

For the NDW and UDW, 240 mm long by 80 mm wide each, the flutes ran parallel to the length of the wrapping. To facilitate bending when wrapping the corrugated board around the fruit, small perforations across the width giving 3 mm wide strips were made (Figure 4).

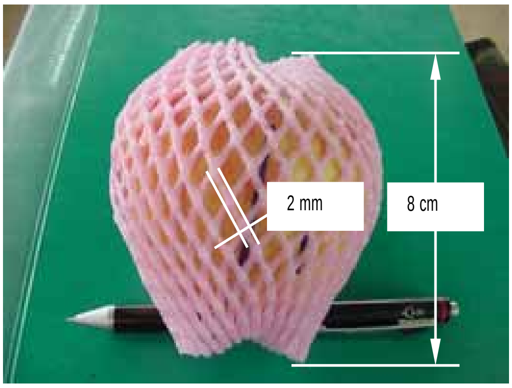


Figure 3 Foam Net Wrapping

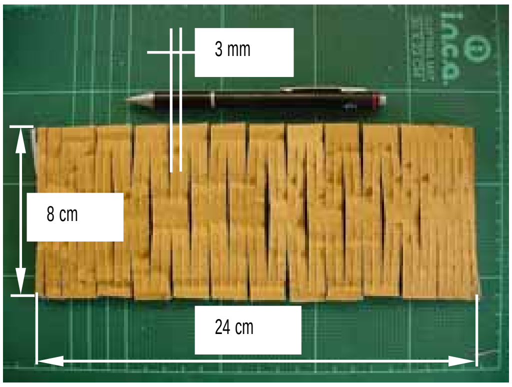


Figure 4 Corrugated Board Wrapping

To cushion an apple sample, foam net was directly put on it while the sheet of each kind of the corrugated board had to be wrapped around the fruit with the sheet edges touching each other.

3. Experimental Design

3.1 Impact Test

The experimental design consisted of two apple sizes tested with and without the five types cushioning materials. Mechanical behaviors of concern were bruise volume and 20 levels of impact energy (ranging from 0.04 to 0.75 Joules) for bruise volume to impact energy threshold determination and 10 levels of impact energy (0.02 to 2.0 Joules) for bruise volume to impact energy relationship beyond threshold.

The cushioned apple was mounted at the sample holder and desired impact energy was located on the scale by the pointer. The pendulum was then released to impact the sample from the corresponding release angle. Bruise volume and the related impact energy were then recorded. Ten replications were conducted for each bruise volume to impact energy threshold and five replications were made for bruise volume to impact energy beyond threshold determination each. Impact energy was calculated from the following equation:

$$E = mgR(1 - \cos\theta_i)$$ …………………….. **(1)** (Jarimopas, 1984)

Where:

E = impact energy (J)

m = mass of pendulum (kg)

g = gravitational constant, 9.81 m/s^2

R = length of hanging rope (m), and

θ_i = angle of incidence (degree)

After the impact, the apples were stored for 24 hours at room temperature to allow the browning/discoloration to be more apparent. After this period the apples were sectioned at the contact area. Bruise volume was calculated as follows:

$$V = (\pi/8)w^2 d$$ …………………… **(2)** (Chen and Sun, 1981)

Where:

V = Bruise volume

w = width of bruise (mm), and

d = depth of bruise (mm).

The probability of bruising was calculated using the following equation:

$$\text{Probability of bruise volume occurrence} = \frac{\text{Number of non-zero bruises}}{\text{Number of replications of the same treatment}} \quad \ldots\ldots (3)$$

3.2 Compression Test

Compression testing for all samples was conducted as per the TAPPI T 808 standard. Ten samples of each cushioning material were cut into 32.2 cm^2 circular pieces and compressed between two parallel flat platens of an Instron Universal Testing Machine (model 5569) at crosshead speed of 12.5 mm/min to determine the flat crush strengths. Force versus deflection values were recorded. A computer program was then used to calculate the area under the curve as an absorbed energy.

4. Results and Discussion

4.1 Bruise Volume to Impact Energy beyond Threshold Relationship

Figures 5 and 6 below show the results as bruise volume to impact energy relationships for both types of apples. (BF = bare fruit; FN = foam net; SFO = single face corrugated board with flute on the outside; SFI = single face corrugated board with flute on the inside; NDW = new double wall corrugated board; UDW = used double wall corrugated board)

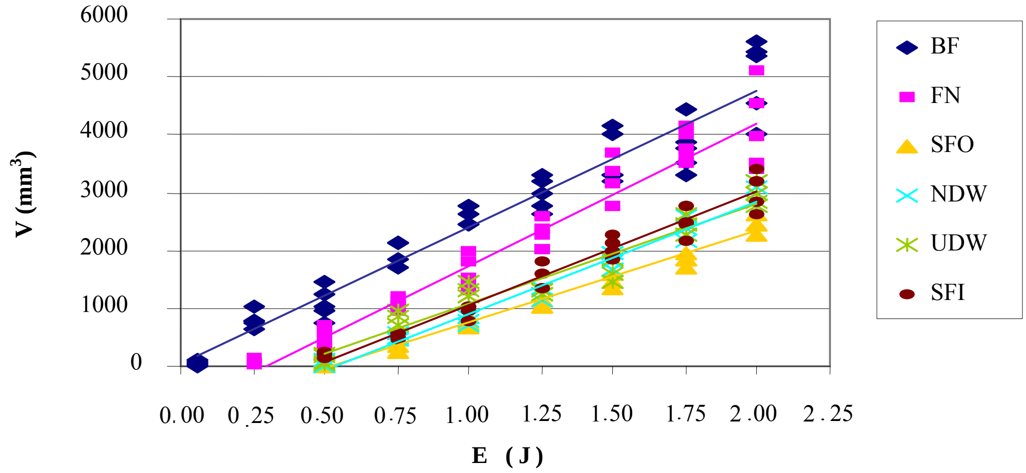


Figure 5 Bruise Volume versus Impact Energy beyond Threshold Relationship for 180 gram Apples

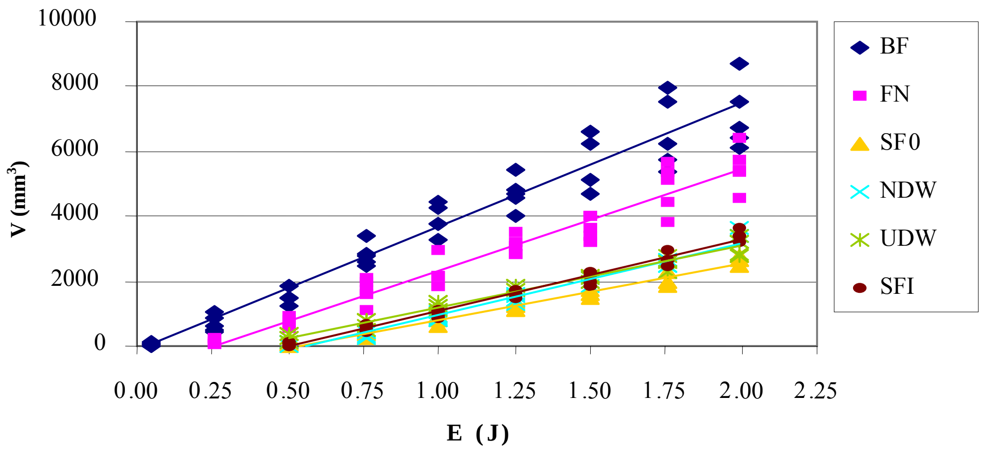


Figure 6 Bruise Volume versus Impact Energy beyond Threshold Relationship for 240 gram Apples

The bruise volume, V, linearly increases with the energy, E, ($R^2 \geq 0.93$) for both sized apples. These findings agree with previous researches (Holt and Schoorl, 1977; Schoorl and Holt, 1980; Ruiz-Altisent, 1991; Jarimopas, 1984).

For impact energies of less than 0.75 Joules, there was very little bruise volume observed for both grades of apples. These small bruise volumes at low impact energies were expected and were true for both cushioned as well as bare apples. The small bruise volumes for impacted cushioned apples was a result of a very small fraction of the impact energy being transferred through the cushioning material to the apples while a large fraction of impact energy was absorbed by the cushioning material. Table 1 shows the bruise volume to impact energy linear expression of the cushioned apples of both sizes. Schoorl and Holt (1980) defined the slope of bruise volume to impact energy regression lines as bruise resistance of the impacted material and apples. This implies that the lower slope, derived from small bruise volume over high impact energy, is considered to have a higher bruise resistance than those materials with high bruise volumes over smaller impact energy (having a high slope). The foam net for which the slope was (2466 mm^3/J) steeper than that for bare apples (2350 mm^3/J), exhibited a lower bruise volume than that for the bare fruit. This indicates that the bruise resistance defined by the slope is perhaps invalid. Such definition would probably be possible if the origin of all the bruise volume to impact energy fitted graphs was at the same point. But bruise volume to impact energy graphs of the cushioned apple are affected by threshold energy so that their origin (V=0) are different. The bruise volume to impact energy relationship beyond the threshold is then insufficient to explain bruise resistance or protective performance of the cushioning materials of apple.

Table 1 Bruise Volume-Impact Energy Relationship Fitted by Linear Regression

Cushioning Material	Equation of Relationship			
	180 g. Apple	R^2	240 g. Apple	R^2
SF0	V = 1595.3E - 854.26	0.98	V = 1748.1E - 945.93	0.98
UDW	V = 1741.5E - 663.97	0.93	V = 1877.5E - 682.14	0.97
NDW	V = 1946.9E - 1051.1	0.97	V = 2179.4E - 1196.3	0.97
SFI	V = 1960.1E - 905.99	0.96	V = 2188.1E - 1117	0.98
FN	V = 2465.6E - 732.95	0.93	V = 3113.2E - 772.83	0.94
BF	V = 2350E + 62.415	0.94	V = 3812.5E - 145.18	0.93

V, bruise volume (mm^3) and E, energy (J)

4.2 Bruise Volume to Impact Energy Relationship Below and at Threshold

Figures 7 and 8, below, show the relationship between probability of bruise volume occurrence and the associated impact energy. Schult et al (1992) and Bollen et al (2001) used the graph of probability versus impact energy to identify the threshold of apples. There are six linear regression graphs ($R^2 \geq 0.88$) corresponding to five cushioning materials and bare fruit as tested using the simple pendulum device. Bruise volume of an apple or cushioned apple can be estimated at various levels of impact energy. The greater the impact energy a cushioned apple received, the higher the bruise occurrence probability was. At the levels where probability is equal to one, the impact energy is estimated to definitely cause bruising. This is called the threshold level.

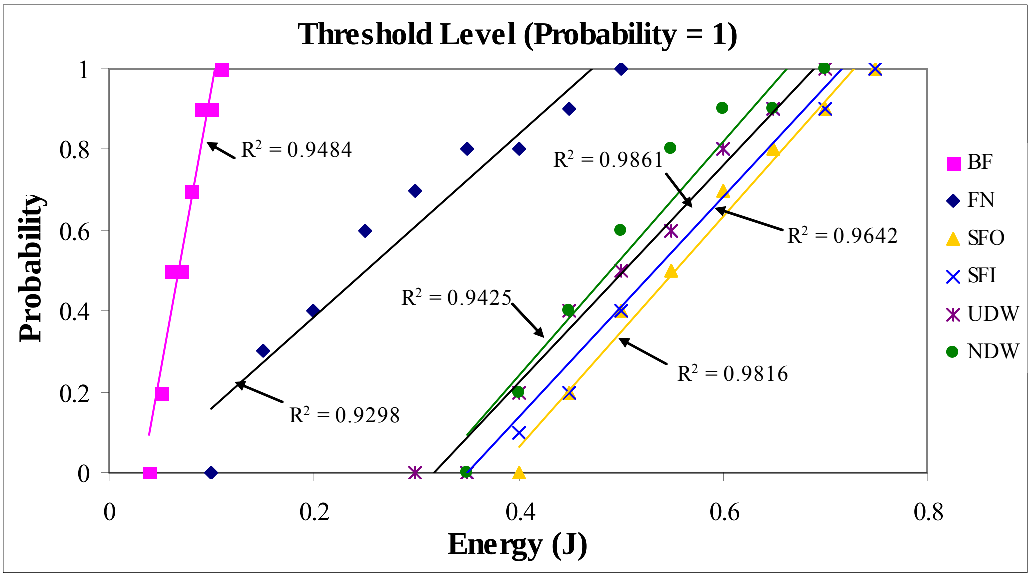


Figure 7 Bruise Occurrence Probability and Impact Energy Relationship Fitted by Linear Regression of Various Cushioned and Bare 180 gram Apples

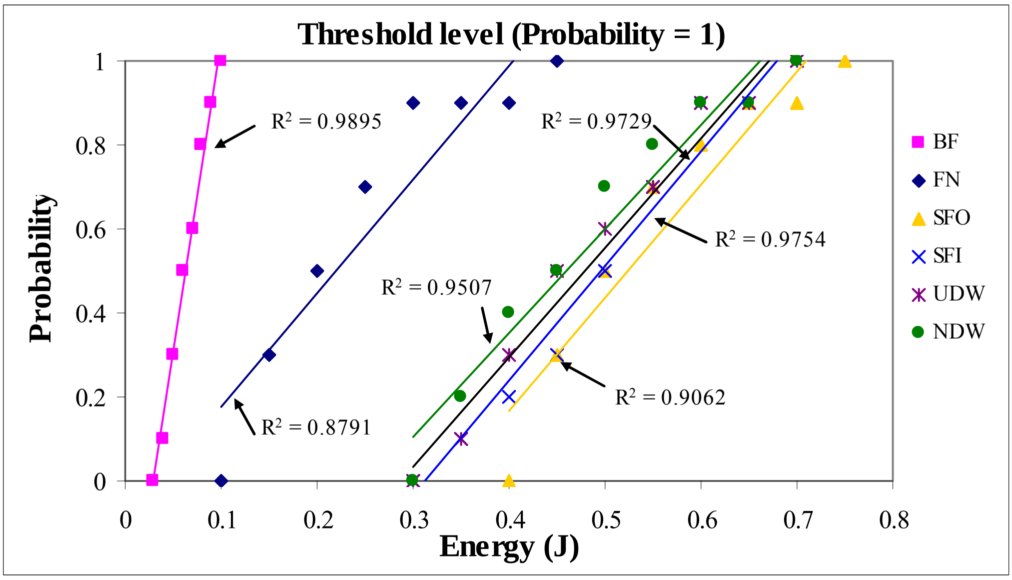


Figure 8 Bruise Occurrence Probability and Impact Energy Relationship Fitted by Linear Regression of Various Cushioned and Bare 240 gram Apples

Table 2 shows threshold energy for the cushioned and bare apples. The cushioned apples could bear higher impact energy than the bare apple. This is because of the cushioning material acting as a shield absorbing a fraction of the impact energy and transferring the rest to apple. If the absorbed energy, E_a, is small and the remaining fraction to impact apple, E_R, is high, the cushioning material is rendered less effective and threshold impact energy, E_{th}, turns out to be low. On the other hand if E_a is large and E_R is low, E_{th} tends to be high and the cushioning material is fairly protective. The corresponding cushioned apples exhibited high bruise resistance. In this research the single face corrugated board wrapping with the flutes on the outside are concluded to be the most protective, giving the highest E_{th} (0.75 J) for both sizes of apples.

Table 2 Bruise Volume and Impact Energy at Threshold (Probability = 1) of Cushioned and Bare Apples

Cushioning Materials	Average bruise volume ± standard deviation (mm^3)		Threshold energy(J)	
	180 g Apples	240 g Apples	180 g Apples	240 g Apples
SF0	280 ± 50	307 ± 60	0.75	0.75
UDW	379 ± 70	398 ± 45	0.70	0.70
NDW	411 ± 55	424 ± 60	0.70	0.70
SFI	419 ± 25	453 ± 50	0.75	0.70
FN	447 ± 50	481 ± 50	0.50	0.45
BF	161 ± 30	165 ± 40	0.11	0.10

4.3 Absorbed Energy of the Cushioning Materials

Table 3 provides the absorbed energy from the force-deflection response of each cushioning material under quasi-static compression. Absorbed energy of the single face corrugated board with flutes on the outside is relatively high (0.11 J), indicating that it could absorb, higher impact energy than other cushioning materials and release the least remaining fraction to the apple, resulting in the smallest bruise to the apples (Table 2). Fig 9 shows contact orientation of the single face corrugated board to apple.

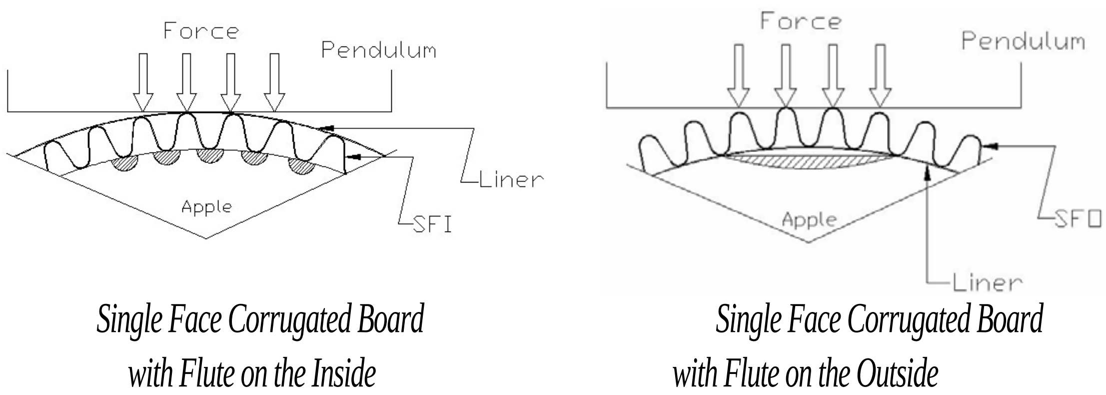


Figure 9 Contact Orientation between Single Face Corrugated Board to the Wrapped Apple

The single face corrugated board with flutes on the outside gave one contact point, lying in the impact line, with apple surface while the single face corrugated board with flutes on the inside exhibited several contact points over the contact area because of the flute contact with the apples. This created greater contact pressure over the small contact points, hence giving rise to bigger bruise volume. Even though the absorbed energies for both the single face corrugated board orientations are the same, difference in contact orientation between the single face corrugated paper and wrapped apple surface differentiated the bruise volume.

Table 3 Absorbed Energy of Cushioning Materials under Quasi-Static Compression

Cushioning Materials	Absorbed Energy (J)
SF0	0.110
UDW	0.090
NDW	0.094
SFI	0.110
FN	0.075

5. Conclusions

This study evaluated the various types of protective cushioning systems that can be used directly on fruits such as apples to reduce bruise injury resulting from post-harvest and transportation to retailers. The study developed a simplified test method that can be accurately used to measure impact resistance strength characteristics of apples or other fruits, and evaluate cushioning materials that can provide shock protection. Both plastic and paper based protective wraps can be effective in providing against bruising from impacts. Results show that the best protection was achieved with the single face corrugated board with flutes on the outside for both sizes of apples. This method can be used with other sensitive fruits and cushioning materials to develop optimum packaging methods.

Acknowledgement

The authors would like to acknowledge the Postgraduate and Research Development Project of Postharvest Technology at Chiang Mai University and National Metal and Materials Technology Center (MTEC) for their financial support. Further thanks to Professor P. Chen, Professor Emeritus, Department of Biological and Agricultural Engineering, University of California, Davis, for his valuable guidance.

References

1. Matzinger, B., Tong, C., 1993. Commercial Postharvest Handling of Fresh Market Apples (Malus sp.), University of Minnesota, Extension Service
2. Brown, G. K., Schulte, N. L., Timm, E. J., Armstrong, P. R., Marshall, D. E., Reduce Apple Bruise Damage, Tree Fruit Postharvest Journal 4(30:6-10, October 1993
3. Jarimopas, B., Mahayosanan, T. and Srianek, N. 2004. Study of capability of net made of banana string for apple protection against impact. Engineering Journal Kasetsart. 17(51): 9-16.
4. Jarimopas, B., Robchanachon, J. and Surin, R. 2002. Study of wholesale package for fruits and vegetables in Bangkok Metropolitan area. Thai Society of Agricultural Engineering Journal. 9(2):23-28.
5. Peleg, K.1985. Produce Handling, Packaging and Distribution. AVI. Pub. Co. Inc Connecticut. 625 p.
6. Chonhenchob, V. and Singh, S.P. 2004. Testing and comparison of various packages for mango distribution. Journal of Testing and Evaluation. ASTM International. 32 (1):69-72.
7. Bollen, A.F., Nguyen, H.X. and Dela Rue, B.T. 1999. Comparison of methods for estimating the bruise volume of apples. J. Agr. Eng. Res. 74: 325-330.
8. Jarimopas, B. 1984. Failure of Apple Under Dynamic Loadings Unpublished D.Sc. Dissertation. Faculty of Agricultural Engineering, Technion, Israel Institute of Technology, Technion City, Haifa, Israel. 157 p.

9. Holt, J.E. and Schoorl, D. 1977. Bruising and energy dissipation in apples. J. Text. Studies. 7:421-432.

10. Bajema, R.W. and Hyde, G.M. 1998. Instrumented pendulum for impact characterization of whole fruit and vegetable specimens. Trans of the ASAE. 41(5):1399-1405.

11. Schoorl, D. and Holt, J.E. 1980. Bruise resistance measurements in apples. J. of Texture Studies. 11:389-394.

12. Chen, P. and Yazdani, R. 1991. Prediction of apple bruising due to impact on different surfaces. Trans of the ASAE. 34(3):956-961.

13. Ragni, L. and Berandinelli, A. 2001. Mechanical behavior of apples and damage during sorting and packaging. J. Agr. Eng. Res. 78(3):273-279.

14. Mohsenin, N.N. 1996. Physical Properties of Plant and Animal Materials. Gordon and Breach Publishers. Thailand. 891 p.

15. Ruiz-Altisent, M. 1991. Damage mechanisms in the handling of fruits. In Progress in Agricultural Physics and Engineering, ed. J. Matthews, 221-257. Silsoe U.K.

16. Jarimopas, B., Sarig, Y., Peiper, U.M., and Manor, G. 1990. Instrumentation for measuring the response of apples subjected to impact loading. Computer and Electronics in Agriculture. 5(1990) : 255-260.

17. Chen, P., Tang, S. and Chen, S. 1985. Instrument for testing the response of fruits to impact. ASAE Paper no. 85-3537 St. Joseph. MI

18. Lichtensteiger, M.J., Holmes, R.G., Hamdy, M.Y., and Blaisdell, J.L. 1988. Impact parameters of spherical viscoelastic object and tomatoes. Trans of the ASAE. 31(2): 595-602.

19. Siyami, S., Tennes, B.R., Zapp, H.R., Brown, G.K., Klug, B. and Clemens, J. 1987. Microcontroller based data acquisition system for impact measurements. Trans of the ASAE. 30(6): 1822-1826.

20. Tennes, B.R., Zapp, H.R., Brown, G.K., and Elhert, S.H. 1988. Self-contained impact detection derice. Calibration and accuracy. Trans of the ASAE 31(6): 1869-1874.

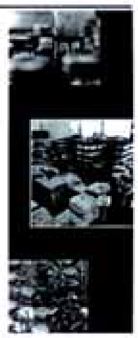
21. Thailand Institute of Scientific and Technological Research (TISTR). 2002. Handbook of Paper Application for Packaging. Arun Printing Co. Ltd. Bangkok. 128 p.(in Thai)

22. Bollen, A.F., Cox, N.R., Dela Rue, B.T., and D.J. Painter. 2001. A Descriptor for Damage Susceptibility of a Population of Produce. J. Agr. Eng. Res. 78(4):391-395.

23. Jarimopas, B., and Sayasoonthorn, S. 2004. Improvement of Ballistic Pendulum Impact Testing Device. Thai Society of Agricultural Engineering Journal. 11(1):51-56.

PACKAGING TECHNOLOGY AND SCIENCE
Packag. Technol. Sci. 2007; **20**: 000–000
Published online in Wiley InterScience (www.interscience.wiley.com). **DOI**: 10.1002/pts.760

Comparison of Package Cushioning Materials to Protect Post-harvest Impact Damage to Apples



By B. Jarimopas,[1] S. P. Singh,[2] S. Sayasoonthorn[3] and Jagjit Singh[4,*]

[1]Department of Agricultural Engineering, Kamphaengsaen Engineering Faculty, Kasetsart University, Kamphaengsaen, Nakohnpathom, Thailand
[2]School of Packaging, Michigan State University, East Lansing, Michigan, USA
[3]The Postgraduate and Research Development Project of Postharvest Technology, Graduate School, Kasetsart University, Kamphaengsaen, Nakohnpathom, Thailand
[4]Industrial Technology, OCOB, Cal Poly State University, San Luis Obispo, CA 93407, USA

Damage to fruits and vegetables continues to be a big challenge as global markets become a reality. Worldwide distribution of sensitive produce is faced with various levels of impacts from shipping and handling. Despite a variety of packaging options available today, bruising damage is commonplace for post-harvest apples throughout the supply chain. The major sources of bruising are compression, impact or vibration forces. Understanding where these forces occur can help reduce this type of mechanical damage to apples. The purpose of this study was to investigate the impact characteristics of foam net and corrugated board when applied as wrapping for individual apples. Two grades (count numbers 80 and 100) of "Fuji" cultivar apples imported to Thailand from China were studied. A simple ballistic pendulum test device was developed to measure bruise volume to impact energy relationship. A linear relationship for both types of apples was observed. Bruise volume occurrence probability and impact energy relationship fitted by linear regression were created for cushioned and bare apples. Absorbed energy of various cushioning materials was also calculated under compressive forces. Copyright © 2007 John Wiley & Sons, Ltd.

Received: 9 April 2006; Revised 2 August 2006; Accepted 20 September 2006

KEY WORDS: apple; ballistic pendulum; bruise volume; cushioning; impact energy

INTRODUCTION

This study focused on developing a simple methodology to compare the performance of cushion wrapping materials that can be used for impact-sensitive fruits and vegetables. Countries such as China and India with low labor rates can use such methods to provide extreme levels of protection to fruits to compete in the global market.

Apples are a popular and nutritious horticultural product popular worldwide. Consumers insist on a high quality product that is free from any bruises, cuts, punctures, physiological disorders and pathogens.[1] Bruising, which is objectionable to fresh-market consumers, can result in a lower grade for any apple. Several studies have been conducted internationally that show that compression, vibration and impact forces cause a

*Correspondence to: J. Singh, Industrial Technology, OCOB, Cal Poly State University, San Luis Obispo, CA 93407, USA.
E-mail: jasingh@calpoly.edu

Color Online, B&W in Print

Figure 1. Foam net packaging.

majority of the mechanical damage, such as bruising, to apples in the supply chain.

Apples are exposed to compressive forces via forces applied by the picker's body, tree limbs, ladder rungs or rail, bulk bin rails and bottoms. Compressive forces may also get applied to apples by other apples because of excessive bulk bin depth or carton stack height, by operators forcing the cartons shut or into a tight spot, etc.[2] Vibration forces are the second major cause of mechanical damage to apples in the supply chain and are almost impossible to avoid. If the cartons or bins that carry the apples through the distribution environment hit resonance (their natural frequency matches the forcing frequency of the conveyance), severe accumulated bruise damage is inherent. Impacts impart high forces in an extremely short duration and are often not obvious in mechanical handling systems such as those used in packing lines. The effect of impact forces usually results in bruises, permanent damage and lower perceived quality. Bruise sensitivity has also been reported to increase with storage time.[2] Effectiveness of cushioning materials in protecting impact damage of apples is the primary objective of this research.

Various packaging materials are in use today to wrap individual apples to provide cushioning so that they may survive the adverse distribution environment effects. In a study, a net made of dry banana string, an agricultural waste wrapping for apples, was shown to save the fruit from damage at the impact energy of 1.1 J.[3] This study mentioned problems of fungi attack due to the wrapping on the skin of the fruit. Another research studied paper that is typically applied to line the inner surface of plastic and bamboo fruit containers for protecting fresh fruit from bamboo cuts and moisture loss during transport.[4] Paper was found not to be a good cushioning material against impact damage. Peleg describes good interior packaging as that which treats a fruit as separate units, avoids fruit-to-fruit contact, absorbs the impact energy and is practical.[5] At present, foam nets function well as one of the commercial packaging solutions.[6] However, it is not easily degradable in a landfill.[1] Figure 1 shows the typical foam net used for apples.

Impact damage to apples usually materializes as bruising.[7] Several researchers have studied apple bruising due to impacts.[8–13] Some researches have found that an apple, when exposed to small impacts, exhibits no bruising but that noticeable bruising could be detected beyond a certain amount of impact energy.[3,8] Bruises have been evaluated as bruise volume,[12,14] and linear correlations have been found between the bruise volume and the impact or absorbed energy.[8,9,15] Schoorl and Holt define slope of bruise volume and energy as bruise resistance.[11] The threshold of apple bruising has also been studied by some researchers. Bollen *et al.* expressed the phenomenon of apple bruise threshold as a curve plotted between the probability of bruising against the drop height or energy.[16]

Some experts have credited corrugated board wrapping with adequately protecting fresh fruit from impact and compression forces.[5,17] The inher-

DOI: 10.1002/pts

ent affinity of corrugated board to moisture, as with any paper-based packaging material, compromises its strength and cushioning capabilities. However, because of its expedient degradability, high recycling rate and low cost of the recycled paper, corrugated board holds good potential as a cushioning material. No comparative studies on physical properties of new and used corrugated board as cushioning material for wrapping fruit have ever been conducted.

Several testing devices for observing the effect of impact forces on fruits have been developed in recent years. These instrumented devices are generally capable of measuring acceleration, force, displacement, time and contact area during impact.[10,16–20] Some of these devices are capable of recording, processing and storing impact data during the experimentation.[21,22] By using these instrumented devices, measurements can be achieved instantly and accurately, but at a very high expense. Often times, a majority of the capabilities of such devices are not utilized, and accurate measurements of impact parameters such as impact and absorbed energy can be made using a simple and affordable device that provides sufficient repeatability and reproducibility.

The main objectives of this study were as follows:

1. Develop a simple ballistic pendulum-type test fixture operable by one person that provides a high sensitivity of energy settings and dependable energy-bruise volume measurements.
2. Compare the impact-absorbing characteristics of the bare apples to apples that are wrapped with various cushioning materials.
3. Recommend best materials and wrapping orientation for protecting against impact forces.

MATERIALS AND METHODS

Apples

"Fuji" cultivar apples imported from China to Thailand without any physical injury were used for the testing because the bruising discoloration of this apple is easily detected, and it is available in Thailand markets. Two sizes of the apple were used: count number 80 (fruit weight = 240 ± 20g) and number 100 (fruit weight = 180 ± 20g).

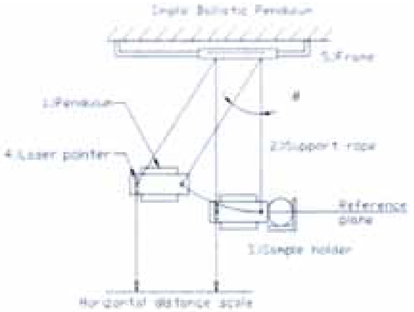


Figure 2. A schematic diagram of the simple ballistic pendulum.

Simple instrumented pendulum

An impact testing device was designed to be a ballistic pendulum featuring 3.84kg rectangular steel mass hung by four 45cm long ropes like a cradle (Figure 2). The motion of the pendulum mass was curvilinear translation. A laser pointer, mounted at the back of the mass, projects a beam to mark a 1 mm red circle on a scale (each graduation is equivalent to 7.5mm/degree of motion) 15cm under the mass. This facilitates the setting of incident angle and impact energy. Pivot points of the rope at four corners of the mass were set on the same horizontal plane, passing a fulcrum providing stable motion without excessive swinging. An apple sample was placed in the sample holder with a pin plugged into the top of the fruit. There was a small rope placed perpendicular to the pendulum motion plane that connected to the pin in order to prevent the sample from falling down after the impact, thereby avoiding any unwanted mechanical injuries. The testing device was operated by a single person and proved to give higher sensitivity of energy setting and better energy-bruise volume curve fitting compared with the pendulum without instrumentation.[23]

DOI: 10.1002/pts

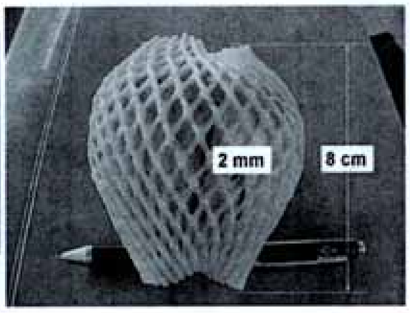


Figure 3. Foam net wrapping.

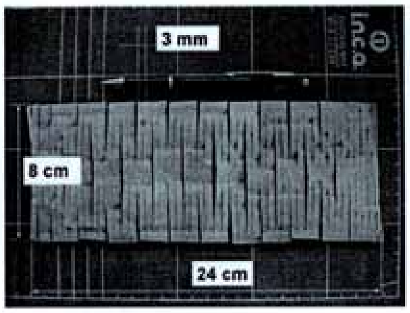


Figure 4. Corrugated board.

Cushioning wrapping materials

Two types of cushioning material were used to comparatively test their protective performance. A 2mm thick typical apple foam net (Figure 3) and corrugated board were used as wrapping for individual apples. Four types of the corrugated board wrapping were used:

- Single face with corrugated medium outside (SFO)
- Single face with corrugated medium inside (SFI)
- New double-wall corrugated board (NDW)
- Used double-wall corrugated board (UDW)

For the NDW and UDW, 240 × 80mm each, the flutes ran parallel to the length of the wrapping. To facilitate bending when wrapping the corrugated board around the fruit, small perforations across the width giving 3mm wide strips were made (Figure 4).

To cushion an apple sample, foam net was directly put on it while the sheet of each type of the corrugated board had to be wrapped around the fruit with the sheet edges touching each other.

EXPERIMENTAL DESIGN

Impact test

The experimental design consisted of two apple sizes tested with and without the five types of cushioning materials. Mechanical behaviours of concern were bruise volume and 20 levels of impact energy (0.04–0.75J) for bruise volume and to impact energy threshold determination and 10 levels of impact energy (0.02–2.0J) for bruise volume to impact energy relationship beyond threshold.

The cushioned apple was mounted at the sample holder, and desired impact energy was located on the scale by the pointer. The pendulum was then released to impact the sample from the corresponding release angle. Bruise volume and the related impact energy were then recorded. Ten replications were conducted for each bruise volume to impact energy threshold and five replications were made for each determination of bruise volume to impact energy beyond threshold. Impact energy was calculated from the following equation:

$$E = mgR(1-\cos\theta_i) \qquad (1)^{[8]}$$

where E is the impact energy (J); m is the mass of the pendulum (kg); g is the gravitational constant (9.81m/s^2); R is the length of the hanging rope (m); and θ_i is the angle of incidence (degree).

After the impact, the apples were stored for 24h at room temperature to allow the browning/discoloration to become more apparent. After this period, the apples were sectioned at the contact area. Bruise volume was calculated as follows:

$$V = (\pi/8)w^2d \qquad (2)^{[18]}$$

Packag. Technol. Sci. 2007; 20: 000–000
DOI: 10.1002/pts

Color Online, B&W in Print

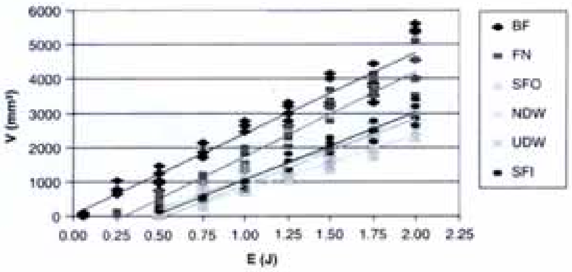


Figure 5. Bruise volume versus impact energy beyond threshold relationship for 180g apples. BF, bare fruit; FN, foam net; NDW, new double-wall corrugated board; SFI, single face corrugated board with flute on the inside; SFO, single face corrugated board with flute on the outside; UDW, used double-wall corrugated board.

where V is the bruise volume; w is the width of the bruise (mm); and d is the depth of the bruise (mm).

The probability of bruising was calculated using the following equation:

$$\text{Probability of bruise volume occurrence} = \frac{\text{Number of non-zero bruises}}{\text{Number of replications of the same treatment}}$$

Compression test

Compression testing for all samples was conducted as per the TAPPI T 808 standard. Ten samples of each cushioning material were cut into 32.2cm^2 circular pieces and compressed between two parallel flat platens of an Instron Universal Testing Machine (model 5569) at a crosshead speed of 12.5mm/min to determine the flat crush strengths. Forces versus deflection values were recorded. A computer program was then used to calculate the area under the curve as an absorbed energy.

RESULTS AND DISCUSSION

Bruise volume to impact energy beyond threshold relationship

Figures 5 and 6 below show the results as bruise volume to impact energy relationships for both types of apples.

The bruise volume, V, linearly increases with the energy, E, ($R^2 \geq 0.93$) for both sizes of apples. These findings agree with previous studies.[5,9,11,15]

For a certain applied energy, a smaller bruise volume was observed with the cushioned apple of lower lines. A small bruise volume for bare apples corresponds to small impact energy. This is true for the cushioned apples as well. The lower bruise volumes of the impacted cushioned apples with respect to the bare apples was a result of a very small fraction of the impact energy being transferred through the cushioning material to the apples while a large fraction of impact energy was absorbed by the cushioning material. The impact of the pendulum caused bruising on the contact face. Besides, bruising occurred on the opposite side of the fruit of the other contact because of

DOI: 10.1002/pts

Color Online, B&W in Print

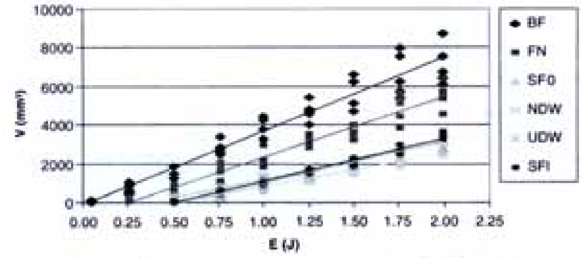


Figure 6. Bruise volume versus impact energy beyond threshold relationship for 240g apples.

Table 1. Bruise volume–impact energy relationship fitted by linear regression

Cushioning material	Equation of relationship			
	180g apples	R^2	240g apples	R^2
SFO	V = 1595.3E − 854.26	0.98	V = 1748.1E − 945.93	0.98
UDW	V = 1741.5E − 663.97	0.93	V = 1877.5E − 682.14	0.97
NDW	V = 1946.9E − 1051.1	0.97	V = 2179.4E − 1196.3	0.97
SFI	V = 1960.1E − 905.99	0.96	V = 2188.1E − 1117	0.98
FN	V = 2465.6E − 732.95	0.93	V = 3113.2E − 772.83	0.94
BF	V = 2350E + 62.415	0.94	V = 3812.5E − 145.18	0.93

BF, bare fruit; E, impact energy (J); FN, foam net; NDW, new double-wall corrugated board; SFI, single face corrugated board with flute on the inside; SFO, single face corrugated board with flute on the outside; UDW, used double-wall corrugated board; V, bruise volume (mm^3).

compression resulting from the impact. The bruise volume of the backside seemed to be less than that of the front side because of less compression due to absorbed impact energy. Table 1 shows the bruise volume to impact energy linear expression of the cushioned apples of both sizes. Schoorl and Holt defined the slope of bruise volume to impact energy regression lines as bruise resistance of the impacted material and apples.[11] This implies that the lower slope, derived from a small bruise volume over high impact energy, is considered to have a higher bruise resistance than those materials with high bruise volumes over small impact energy (having a high slope). The foam net for which the slope was (2466mm³/J) steeper than that for bare apples (2350mm³/J) exhibited a lower bruise volume than that for the bare fruit. This indicates that the bruise resistance defined by the slope is perhaps invalid. Such definition would probably be possible if the origin of all the bruise volume to impact energy fitted graphs was at the same point. But bruise volume to impact energy graphs of the cushioned apple are affected by threshold energy so that their origin (V = 0) are different. The bruise volume to impact energy relationship beyond the threshold is then insufficient to explain the bruise resistance or protective performance of the cushioning materials of apple.

Packag. Technol. Sci. 2007; 20: 000–000
DOI: 10.1002/pts

Color Online, B&W in Print

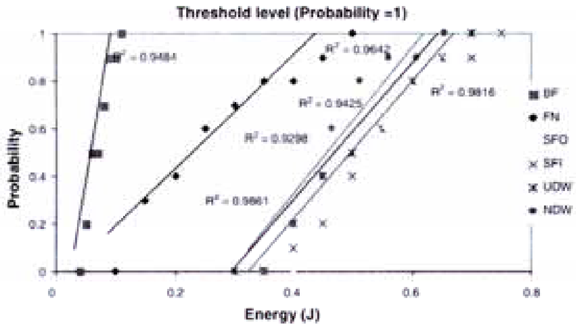


Figure 7. Bruise occurrence probability and impact energy relationship fitted by linear regression of various cushioned and bare 180g apples.

Color Online, B&W in Print

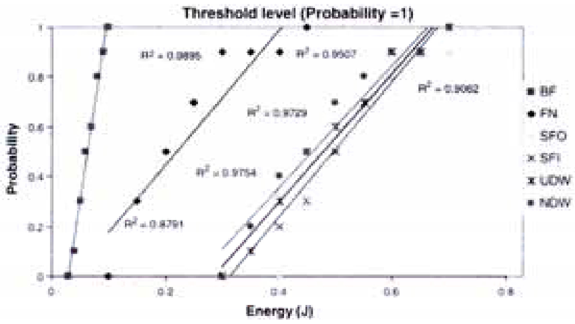


Figure 8. Bruise occurrence probability and impact energy relationship fitted by linear regression of various cushioned and bare 240g apples.

Bruise volume to impact energy relationship below and at threshold

Figures 7 and 8 show the relationship between the probability of bruise volume occurrence and the associated impact energy. Bollen *et al.* used the graph of probability versus impact energy to identify the threshold of apples.[16] There are six linear regression graphs ($R^2 \geq 0.88$) corresponding to five cushioning materials and bare fruit as tested using the simple pendulum device. The bruise volume of an apple or cushioned apple can be estimated at various levels of impact energy. The greater the impact energy a cushioned apple received, the higher the bruise occurrence probability was. At the levels where probability is equal to one, the impact energy is estimated to definitely cause bruising. This is called the threshold level.

Table 2 shows threshold energy for the cushioned and bare apples. The cushioned apples could

Table 2. Bruise volume and impact energy at threshold (probability = 1) of cushioned and bare apples

Cushioning material	Average bruise volume (mm^3) 180g apples	240g apples	Apple threshold energy* (J)
SFO	280 ± 50	307 ± 60	0.75
UDW	379 ± 70	398 ± 45	0.70
NDW	411 ± 55	424 ± 60	0.70
SFI	419 ± 25	453 ± 50	0.725 ± 0.026
FN	447 ± 50	481 ± 50	0.475 ± 0.026
BF	161 ± 30	165 ± 40	0.105 ± 0.005

*Threshold energy for a certain cushioning between the two groups of apples (180 and 240g) was insignificantly different at the confidence level of 99%. BF, bare fruit; FN, foam net; NDW, new double-wall corrugated board; SFI, single face corrugated board with flute on the inside; SFO, single face corrugated board with flute on the outside; UDW, used double-wall corrugated board.

bear a higher impact energy than the bare apple. This is because of the cushioning material acting as a shield absorbing a fraction of the impact energy and transferring the rest to the apple. If the absorbed energy, E_a, is small and the remaining fraction to impact apple, E_R, is high, the cushioning material is rendered less effective and the threshold impact energy, E_{th}, turns out to be low. On the other hand if E_a is large and E_R is low, E_{th} tends to be high and the cushioning material is fairly protective. The corresponding cushioned apples exhibited high bruise resistance. In this research, the single-face corrugated board wrapping with the flutes on the outside are concluded to be the most protective, giving the highest E_{th} (0.75J) for both sizes of apples. The threshold energy for a certain cushioning material between the two groups of apples (180 and 240g) was insignificantly different at the confidence level of 99%.

Absorbed energy of the cushioning materials

Table 3 provides the absorbed energy from the force-deflection response of each cushioning material under quasi-static compression. The absorbed energy of the single face corrugated board with flutes on the outside is relatively high (0.11J), indicating that it could absorb higher impact energy than other cushioning materials and release the least remaining fraction to the apple, resulting in the smallest bruise to the apples (Table 2). Figure 9 shows the contact orientation of the single face corrugated board to the apples.

Table 3. Absorbed energy of cushioning materials under quasi-static compression

Cushioning material	Absorbed energy (J)
SFO	0.110 ± 0.012
UDW	0.090 ± 0.008
NDW	0.094 ± 0.008
SFI	0.110 ± 0.012
FN	0.075 ± 0.008

FN, foam net; NDW, new double-wall corrugated board; SFI, single face corrugated board with flute on the inside; SFO, single face corrugated board with flute on the outside; UDW, used double-wall corrugated board.

8

The single face corrugated board with flutes on the outside gave one contact point, lying in the impact line, with the apple surface, while the single face corrugated board with flutes on the inside exhibited several contact points over the

Packag. Technol. Sci. 2007; **20**: 000–000
DOI: 10.1002/pts

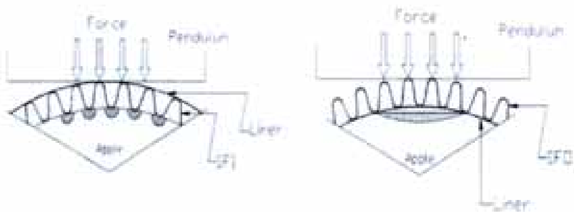


Figure 9. Contact orientation between single face corrugated board to the wrapped apple.

contact area because of the flute contact with the apples. This created greater contact pressure over the small contact points, hence giving rise to bigger bruise volumes. Even though the absorbed energies for both the single face corrugated board orientations are the same, the difference in the contact orientation between the single face corrugated paper and wrapped apple surface differentiated the bruise volume.

CONCLUSIONS

This study evaluated the various types of protective cushioning systems that can be used directly on fruits such as apples to reduce bruise injury resulting from post-harvest and transportation to retailers. The study developed a simplified test method that can be used to measure impact resistance strength characteristics of apples or other fruits, and evaluate cushioning materials that can provide shock protection. Both plastic and paper based protective wraps can be effective in providing against bruising from impacts. Results show that the best protection was achieved with the single face corrugated board with flutes on the outside. Threshold energy for a certain cushioning was insignificantly different between the two sizes of apples.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the Postgraduate and Research Development Project of Postharvest Technology at Chiang Mai University for their financial support. Further thanks to Prof. P. Chen, Professor Emeritus, Department of Agricultural and Biological Engineering, University of California, Davis, for his valuable guidance.

REFERENCES

1. Matzinger B, Tong C. *Commercial Postharvest Handling of Fresh Market Apples (Malus sp.)*, University of Minnesota, Extension Service: ■■, MN. 1993.
2. Brown GK, Schulte NL, Timm EJ, Armstrong PR, Marshall DE. Reduce apple bruise damage. *Tree Fruit Postharvest J*. 1993; **4**(3): 6–10
3. Jarimopas B, Mahayosanan T, Srianek N. Study of capability of net made of banana string for apple protection against impact. *Eng. J. Kasetsart*. 2004; **17**(51): 9–16.
4. Jarimopas B, Robchanachon J, Surin R. Study of wholesale package for fruits and vegetables in Bangkok metropolitan area. *Thai Society of Agricultural Engineering Journal*. 2002; **9**(2): 23–28.
5. Peleg K. *Produce Handling, Packaging and Distribution*. AVI Publishing Company Inc.: ■■, 1985.
6. Chonhenchob V, Singh SP. Testing and comparison of various packages for mango distribution. *J. Test. Eval.* 2004; **32**(1): 69–72.
7. Bollen AF, Nguyen HX, Dela Rue BT. Comparison of methods for estimating the bruise volume of apples. *J. Agri. Eng. Res.* 1999; **74**(0): 325–330.
8. Jarimopas B. Failure of apple under dynamic loadings. Unpublished D.Sc. Dissertation, Faculty of Agricultural Engineering, Technion, Israel Institute of Technology, 1984.
9. Holt JE, Schoorl D. Bruising and energy dissipation in apples. *J. Texture Studies*. 1977; **7**(0): 421–432.
10. Bajema RW, Hyde GM. Instrumented pendulum for impact characterization of whole fruit and vegetable specimens. *Trans. Am. Soc. Agri. Eng.* 1998; **41**(5): 1399–1405.

DOI: 10.1002/pts

[15] 11. Schoorl D, Holt JE. Bruise resistance measurements in apples. *J. Texture Studies*. 1980; **11**(0): 389–394.
12. Chen P, Yazdani R. Prediction of apple bruising due to impact on different surfaces. *Trans. Am. Soc. Agri. Eng*. 1991; **34**(3): 956–961.
13. Ragni L, Berandinelli A. Mechanical behavior of apples and damage during sorting and packaging. *J. Agri. Eng. Res*. 2001; **78**(3): 273–279.
[16] 14. Mohsenin NN. *Physical Properties of Plant and Animal Materials*. Gordon and Breach Publishers: [redacted], Thailand, 1996.
15. Ruiz Altisent M. Damage mechanisms in the handling of fruits. In *Progress in Agricultural Physics and Engineering*, Matthews J (ed.). Silsoe Research Institute C.A.B International: Oxon, UK, 1991; [17] 221–257.
16. Bollen AF, Cox NR, Dela Rue BT, Painter DJ. A descriptor for damage susceptibility of a population of produce. *J. Agri. Eng. Res*. 2001; **78**(4): 391–395.
17. Thailand Institute of Scientific and Technological Research (TISTR). *Handbook of Paper Application for Packaging* (in Thai). Arun Printing Co. Ltd.: Bangkok, 2002.
18. Jarimopas B, Sarig Y, Peiper UM, Manor G. Instrumentation for measuring the response of apples subjected to impact loading. *Comp. Elec. Ag*. **5**(1990): 255–260. [18]
19. Chen P, Tang S, Chen S. Instrument for testing the response of fruits to impact. *American Society of Agricultural Engineers Paper* No. 85–3537 1985. [redacted]: St. Joseph, MI, 1985. [19]
20. Lichtensteiger MJ, Holmes RG, Hamdy MY, Blaisdell JL. impact parameters of spherical viscoelastic object and tomatoes. *Trans. Am. Soc. Agri. Eng*. 1988; **31**(2): 595–602.
21. Siyami S, Tennes BR, Zapp HR *et al*. Microcontroller based data acquisition system for impact measurements. *Trans. Am. Soc. Agri. Eng*. 1987; **30**(6): 1822–1826.
22. Tennes BR, Zapp HR, Brown GK, Elhert SH. Self-contained impact detection device. calibration and accuracy. *Trans. Am. Soc. Agri. Eng*. 1988; **31**(6): 1869–1874.
23. Jarimopas B, Sayasoonthorn S. Improvement of ballistic pendulum impact testing device. *Thai Society of Agricultural Engineering Journal*. 2004; **11**(1): 51–56.

DOI: 10.1002/pts

The 15th IAPRI World Conference on Packaging

Effectiveness of Cushioning Materials on Protecting Impact Damage of Apples

Supakit Sayasoonthorn, Sher Paul Singh and Bundit Jarimopas

ABSTRACT

Foam net is popularly used in Thailand as fruit cushioning material from wholesaler through transport, retailer to customer. It is poorly degradable and prohibited in some countries which impeded fruit export. An attempt to investigate alternative cushioning material which is recyclable, cheap and easily degradable was conducted. Banana string, water hyacinth, single face and double wall corrugated papers and typical foam net were selected to wrap up apples. The cushioned fruits were impacted by a ballistic pendulum and the resulting impact bruising was analyzed. Results showed that the single face paper wrapping an apple with its liner outside could bear the greatest impact threshold energy of 0.75 J, which is 50% higher than that of the foam net.

INTRODUCTION

Dry banana string, an agricultural waste wrapping up an apple, was shown to save the fruit from damage at the impact energy of 1.1 joule (Jarimopas et al., 2004). Application of the string as cushioning material may encounter the problems like fungi attack or direct impact of chemical treatment protecting fungi formation on fruit skin. At present, foam net (Fig 1) well functions as the commercial cushioning wrapping material (Chonhenchob and Singh, 2004). However, it is not easily degradable. (Jarimopas et al., 2004). The corrugated paper was proved to protect fresh fruit from impact and compression (Peleg, 1985). There has been sofar no comparative study on physical properties of various types of the new and used corrugated paper as cushioning material for wrapping fruit.

Figure 1 Foam Net Packaging

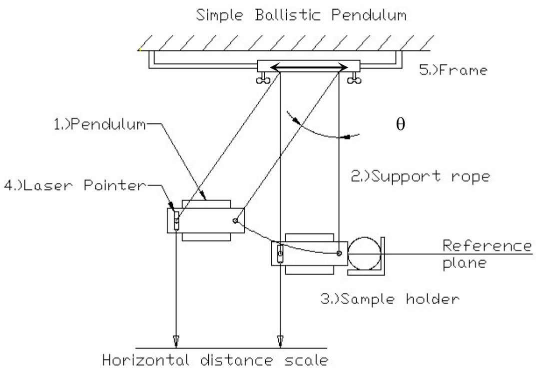


Figure 2 A schematic diagram of simple ballistic pendulum

Impact damage of apple mostly appeared as bruising (Bollen et al., 1999). Several researchers studied impact apple bruising (Jarimopas, 1984; Holt and Schoorl, 1977; Schoorl and Holt, 1980). Bruise was evaluated as bruise volume and linear correlation was found between bruise volume and impact or absorbed energy (Holt and Schoorl, 1977). Schoorl and Holt (1980) defined slope of bruise volume and energy as bruise resistance. Shulte et al. (1992) expressed the phenomenon of apple bruise threshold as a curve plotted between probability of bruising against drop height or energy.

Several impact testing devices of fruits have been developed sofar. They are well equipped with sensors capable of measuring acceleration, force, displacement, and time, contact area during impact (Jarimopas et al., 1990). Measurement could be achieved quickly, accurately but the testing device was expensive. Impact measurement of fruit sometimes requires a few impact parameters like impact and absorbed energies with appropriate level of accuracy but at limited budget. Improvement of the available fundamental impact test set-up (drop or pendulum) with cheap simple commercial electronic device to give a sufficient effective measuring instrument would be an alternative.

The purpose of this research is to comparatively test and evaluate various kinds of cushioning materials wrapping apple and propose the proper material.

MATERIALS AND METHOD

Apple

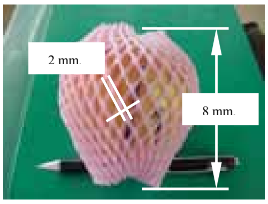
The stored apple “Fuji” cultivar, imported from china and without any injury, was used as sample of testing because its symptom of bruising discoloration was easily detected and it is available in Thailand market. Two sizes of the apple were used, i.e. count no.80 (fruit weight=240$\pm$20 g) and no.100 (fruit weight=180$\pm$ 20 g)

Simple Instrumented Pendulum

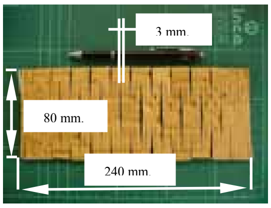
An impact testing device was designed to be a ballistic pendulum featuring 3.84 kg rectangular steel mass hung by four 45 cm long ropes like cradle (Fig 2). The motion of pendulum mass was curvilinear. A Laser pointer, mounted at the back of the mass, projected laser beam to mark 1 mm red circle on a scale 15 cm under the mass. This facilitated the setting of incident angle and impact energy and the reading of reflected angle and absorbed energy calculation as sensitively as a fraction of degree. Pivot points of the rope at four corners of the mass were set on the same horizontal plane passing fulcrum providing stable motion without excessive swing. The testing device was operated by a single person and proved to give higher sensitivity of energy setting and better energy-bruise volume curve fitting compared to the pendulum without instrumentation (Jarimopas and Sayasoonthorn, 2004).

Cushioning Wrapping Materials

Three types of cushioning material were used to comparatively test their protective performance. The first type was 2 mm thick typical apple foam net (FN) (Fig 3a), the second type was corrugated board used as wrapping for individual apples. Four types of corrugated board wrapping used were a.) Single face with corrugated medium outside (SFO), b.) Single face with corrugated medium inside (SFI), c.) New double wall corrugated board (NDW) and d.) Used double wall corrugated board (UDW). For the NDW and UDW, 240 mm long by 80 mm wide each, the fruit ran parallel to the length of the wrapping. To facilitate bending when wrapping the corrugated board around the fruit, small peroration across the width giving 3 mm wide strips were made (Fig 3b). The last type was a agricultural waste such as Water Hyacinth and Banana string with 2 types weaving individual around the apples(Fig 4a,b), including Water Hyacinth type 1(W1), Water Hyacinth type 2(W2), Banana string type 1(B1) and Banana string type 2(B2).



a.) Foam net.



b.) Double wall corrugated paper

Figure 3 Foam net & Double wall Corrugated paper

a.) Type 1 weaving.

b.) Type 2 weaving.

Figure 4 Wrapping apple by agricultural waste

Impact Test

The experiment design consisted of two apple sizes tested without and with nine types cushioning materials. Mechanical behaviors of concern were bruise volume and 20 levels of impact energy E (ranging from 0.04 to 0.75 Joules) for bruise volume to impact energy threshold determination and 10 levels of E (0.02 to 2.0 Joules) for bruise volume to impact energy relationship beyond threshold. Ten replications were conducted for each bruise volume to impact energy threshold and five replications were made for bruise volume to impact energy beyond threshold determination each. Impact energy was calculated from the following equation:

$$E = mgR\,(1-\cos\theta_i) \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)\ \text{(Jarimopas,1984)}$$

Where E = impact energy (J), m = mass of pendulum (kg), g = gravitational constant, 9.81 m/s^2, R = length of hanging rope (m), and θ_i = angle of incidence (degree)

After impacted apple was stored for 24 hours at room temperature to allow browning discoloration. After this period apple were sectioned at the contact area. Bruise volume was calculated as follows:

$$V = (\pi/8)\, w^2 d \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)\ \text{(Chen and Sun, 1981)}$$

Where w = width of bruise (mm) and d = depth of bruise (mm).

The Probability of Bruise was calculated using from

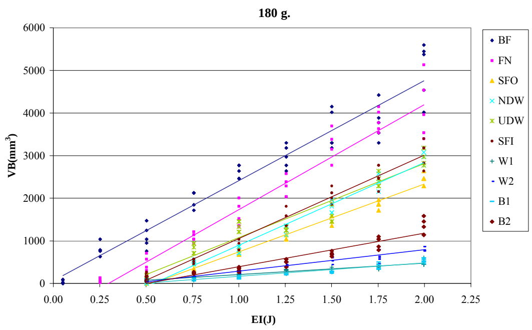
$$\text{Probability of V occurrence} = \frac{\text{Number of non-zero V}}{\text{Number of replications of the same treatment}} \quad \text{.........(3)}$$

Compression Test

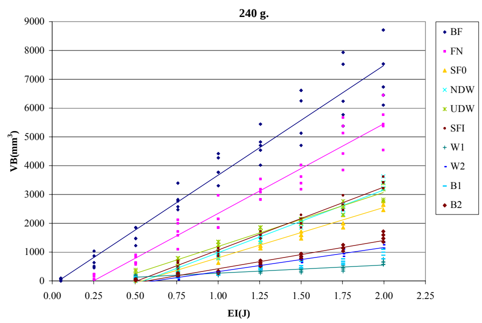
Compression testing for all samples was conducted by the TAPPI T 808 standard. Ten samples of each cushioning materials and compressed between two parallel flat plates of an Instron universal testing machine (model 5569) to determine the flat crush strengths. Forces versus deflection values were recorded. A computer program was then used to calculate the area under the curve as an absorbed energy.

RESULTS AND DISCUSSION

Bruise Volume to Impact Energy beyond Threshold Relationship



a.) 180 g. apple



b.) 240 g. apple

Figure 5 Bruise volume vs. impact energy beyond threshold relationship for 180 and 240 gram apple

Fig 5. show the results as bruise volume to impact energy relationship for both types of apples. The bruise volume, V, linearly increases with the energy E ($R^2 \geq 0.93$) for both sized apples.

For impact energy of less than 0.75 Joules, there was little bruise volume observed for both grades of apples. The small bruise volumes of impacted cushioned apple was a result of the small fraction of the impact energy being transferred through the cushioning material to apple while the large fraction of impact energy was absorbed by the cushioning material(Jarimopas et al., 2006). Table 1 shows the bruise volume(V) to impact energy(E) linear expression of the cushioned apple of both sizes. The bruise volume to impact energy relationship beyond the threshold is then insufficient to explain bruise resistance or protective performance of the cushioning materials of apple.

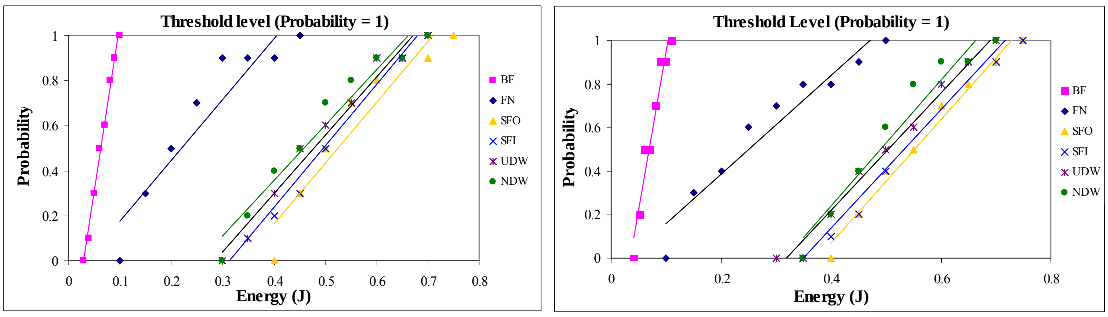
Table 1 Bruise volume to impact energy relationship fitted by linear regression

Cushioning Material	Equation of Relationship			
	180 g. Apple	**R^2**	**240 g. Apple**	**R^2**
W1	V = 268.55E - 60.627	0.88	V = 284.03E - 14.473	0.78
B1	V = 315.3E - 145.05	0.90	V = 564.43E - 266.43	0.90
W2	V = 502.47E - 213.82	0.92	V = 834.64E - 508.64	0.95
B2	V = 790.15E - 395.95	0.90	V = 981.95E - 560.74	0.95
SF0	V = 1595.3E - 854.26	0.98	V = 1748.1E - 945.93	0.98
UDW	V = 1741.5E - 663.97	0.93	V = 1877.5E - 682.14	0.97
NDW	V = 1946.9E - 1051.1	0.97	V = 2179.4E - 1196.3	0.97
SFI	V = 1960.1E - 905.99	0.96	V = 2188.1E - 1117	0.98
FN	V = 2465.6E - 732.95	0.93	V = 3113.2E - 772.83	0.94
BF	V = 2350E + 62.415	0.94	V = 3812.5E - 145.18	0.93

The cause of lower slope in the agricultural waste cushioned apple of both sizes was a result from weaving character of cushioning materials. The waving does not make a knot, however it's made a rough surface and swell, when contact with apple the rough surface become to a small plunger stab to apple and make a several small bruise spread to apple (Fig 7).

Bruise Volume to Impact Energy below and at Threshold Relationship

Fig 6 shows the relationship between probability of bruise volume occurrence and the associated impact energy. Bollen et. al. (2001) used the graph of probability versus impact energy to identify the threshold of apples. There are six linear regression graphs ($R^2 \geq 0.88$) corresponding five cushioning materials and bare fruit as tested using the simple pendulum device. The greater impact energy a cushioned apple received, the higher the bruise occurrence probability was. At the level where probability is equal to 1, the impact energy is estimated to definitely cause bruising. This level is called threshold.



a) 180 g. apple b) 240 g. apple

Figure 6 Bruise occurrence probability and impact energy relationship fitted by linear regression of various cushioned and bare apples.

Table 2 below shows threshold energy of the cushioned and bare apples. The cushioned apples could bear higher impact energy than the bare apple. This is because of the cushioning material acting as a shield absorbing some fraction of the impact energy and transferring the rest to apple. The corresponding cushioning apples exhibited high bruise resistance. In this research the single face with corrugated medium outside is concluded to be the best protective, giving the highest E_{th} = 0.75 J for both sizes of apples.

Table 2 Bruise volume and impact energy at threshold (Probability = 1) of cushioned and bare apple & Absorbed energy of cushioning materials under slow compression

Cushioning Materials	Average bruise volume ± standard deviation (mm^3)		Threshold energy(J)				Absorbed Energy (J)
	180*	240*	180*	R^2	240*	R^2	
SF0	280 ± 50	307 ± 60	0.75	0.9816	0.75	0.9602	0.110
UDW	379 ± 70	398 ± 45	0.70	0.9861	0.70	0.9729	0.090
NDW	411 ± 55	424 ± 60	0.70	0.9425	0.70	0.9507	0.094
SFI	419 ± 25	453 ± 50	0.75	0.9642	0.70	0.9754	0.110
FN	447 ± 50	481 ± 50	0.50	0.9298	0.45	0.8791	0.075
BF	161 ± 30	165 ± 40	0.11	0.9484	0.10	0.9895	-

* 180 = 180 g. apple ; 240 = 240 g. apple

Absorbed energy of the cushioning materials

Table 2 provides absorbed energy from the force-deflection response of each cushioning material under quasi-static compression. Absorbed energy of the single face corrugated board with flutes on the outside is relatively high (0.11 J), indicating that it could absorb, higher impact energy than other cushioning materials and release the least remaining fraction to apple, resulting in the smallest the bruise to the apples. Fig 8 shows contact orientation of the single face corrugated board to apple.

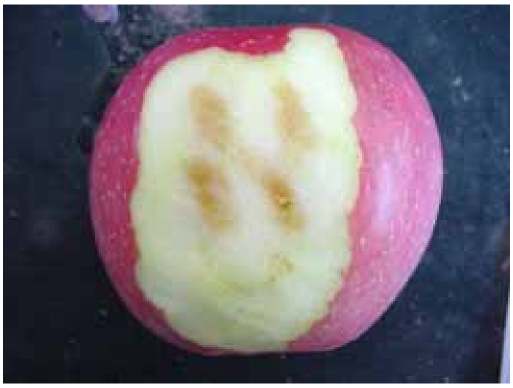
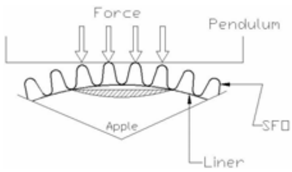
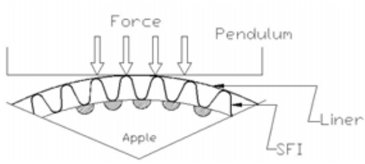


Figure 7 Bruising of apple wrapped agricultural waste



a.) SFO



b.) SFI

Figure 8 Contact orientation between SFO and SFI to the wrapped apple

The single face corrugated boards with flutes on the outside give one contact point, lying in the impact line, with apple surface while the single face corrugated board with flutes on the inside exhibited several contact points over the contact area because of flute contact with the apples. This created greater contact pressure over the small contact points. Even though absorbed energies for both the of the single face corrugated board orientations are the same, difference in contact orientation between the single face corrugated paper and wrapped apple surface differentiated bruised volume.

CONCLUSIONS

This study evaluated the various types of protective cushioning systems that can be used directly on fruits such as apples to reduce bruise injury resulting from post-harvest and transportation to retailers. The study developed a simplified test method that can be used to measure impact resistance strength characteristics of apples or other fruits, and evaluate cushioning materials that can provide shock protection. Agricultural waste can not be an appropriate for cushioned apple. Both plastic and paper based protective wraps can be effective in providing against bruising from impacts. Results show that the best protection was achieved with Single face with corrugated medium outside for both sizes of apples.

ACKNOWLEDGMENTS

The authors would like to acknowledge the Post Graduate Education and Research Development Project in Post-harvest Technology at Chiang Mai University and National Metal and Materials Technology Center (MTEC) for their financial support. Further thanks to Professor P. Chen, Professor Emeritus, Department of Biological and Agricultural Engineering, University of California, Davis, for his valuable guidance.

REFERENCE

1. Bollen, A.F.; Cox, N.R.; Dela Rue, B.T.; Painter, D.J.; A Descriptor for Damage Susceptibility of a Population of Produce. Journal of Agricultural Engineering and Research 2001, 78(4):391-395.
2. Bollen, A.F.; Nguyen, H.X.; Dela Rue, B.T.; Comparison of methods for estimating the bruise volume of apples, Journal of Agricultural Engineering and Research 1999, 74: 325-330.
3. Chen P.; Sun, Z.; Impact Parameters Related to Bruise Injury in Apples, ASAE Paper No. 81-3041 St. Joseph. MI, 1981

4. Chonhenchob, V.; Singh, S.P.; Testing and comparison of various packages for mango distribution, Journal of Testing and Evaluation 2004, 32 (1):69-72

5. Holt, J.E.; Schoorl, D.; Bruising and energy dissipation in apples, Journal of Texture and Studies 1977, 7:421-432.

6. Jarimopas, B.; Failure of Apple under Dynamic Loadings Unpublished D.Sc. Dissertation. Faculty of Agricultural Engineering, Israel Institute of Technology, Technion, Haifa, Israel 1984. 157 p.

7. Jarimopas, B.; Mahayosanan, T.; Srianek, N.; Study of capability of net made of banana string for apple protection against impact, Engineering Journal Kasetsart 2004, 17(51): 9-16.

8. Jarimopas, B.; Sarig, Y.; Peiper, U.M.; Manor, G.; Instrumentation for measuring the response of apples subjected to impact loading. Computer and Electronics in Agriculture 1990, 5: 255-260.

9. Jarimopas, B.; Sayasoonthorn, S; Improvement of Ballistic Pendulum Impact Testing Device. Thai Society of Agricultural Engineering Journal 2004, 11(1):51-56.

10. Jarimopas, B.; Singh, S.P.; Sayasoonthorn. S.; Singh, J.; Comparison of Package Cushioning Materials to Protect Post-Harvest Impact Damage to Apples. Packaging Technology and Science. 2006, Submitted

11. Peleg, K. Produce Handling, Packaging and Distribution. AVI. Pub. Co. Inc Connecticut. 1985.625 p.

12. Schoorl, D.; Holt, J.E.; Bruise resistance measurements in apples, Journal of Texture and Studies 1980, 11:389-394.

13. Schulte, N. L.; Brown, G. K.; Tim, E. J.; Apple Impact Damage Thresholds. Applied Engineering. 1992, 8(1) : 55 – 60.

CONTACT

Supakit Sayasoonthorn, Graduate Student, Kasetsart University

Sher Paul Singh, Professor, Michigan State University

Bundit Jarimopas, Associate Professor, Kasetsart University

Kasetsart University, Post Graduate Education and Research Development Project in Post-harvest Technology, Kamphaengsean, Nakohnpathom, 73140, Thailand

Tel: +6634-281-099, Fax: 6634-281-099, e-mail: g4689014@ku.ac.th

Michigan State University, School of Packaging, East Lansing, MI 48824-1223.

Tel: +517-355-7614, Fax: 517-353-8999, e-mail: singh@msu.edu

Kasetsart University, Department of Agricultural Engineering, Kamphaengsean, Nakohnpathom, 73140, Thailand

Tel: +6634-281-099, Fax: 6634-281-099, e-mail: fengbdj@ku.ac.th

การปรับปรุงเครื่องทดสอบการกระแทกแบบ Ballistic Pendulum

Improvement of Ballistic Pendulum Impact Testing Device

บัณฑิต จริโมภาส[1] ศุภกิตต์ สายสุนทร[2]

Bundit Jarimopas[1] Supakit Sayasoonthorn[2]

Abstract

This study was to improve the performance of ballistic pendulum testing device. The result showed that the improved device 1) can read minimum scale from 5 degree to 1 degree compare to average horizontal distance 1 degree from 0.33 cm to 0.75 cm, 2) is easy to use by changing from sight inspection to light beam by laser diode to indicate the position with more accuracy, 3) can test at low impact energy (low angle), 4) pendulum have a better stablility after impacting (reduce the pendulum swings). And 5) R^2 of regression lines of input energy vs. bruise volume and absorbed energy vs. bruise volume increased from 0.9082 to 0.9726 and 0.9012 to 0.9557 respectively.

บทคัดย่อ

งานนี้เพื่อปรับปรุงเครื่องทดสอบการกระแทกแบบ Ballistic Pendulum ให้มีสมรรถนะในการใช้งานดีขึ้น ผลที่ได้คือ 1) สามารถอ่านค่าความละเอียดของสเกลเพิ่มขึ้น จากเดิมช่องละ 5 องศา เป็น 1 องศา เทียบเป็นระยะทางพื้นราบเฉลี่ย 1 องศา จาก 0.33 ซม. เป็น 0.75 ซม. 2) มีความสะดวกในการใช้งานดีขึ้น จากที่ใช้สายตาเล็งผ่านเชือกไปยังแผ่นวัดมุม เป็นใช้แสงจากเลเซอร์ไดโอด ในการชี้ตำแหน่ง และมีความแม่นยำในการอ่านค่าดีขึ้น 3) สามารถทำการทดสอบการกระแทกได้ที่พลังงานกระแทกต่ำๆ (มุมกระแทกน้อยๆ) 4) ลูกตุ้มมีเสถียรภาพในการแกว่งหลังจากกระแทกดีขึ้น (ลูกตุ้มแกว่งน้อยลง) และ 5) ค่า R^2 ของเส้นกราฟแนวโน้มถดถอยของ พลังงานกระแทก - ปริมาตรเนื้อช้ำ และพลังงานดูดกลืน - ปริมาตรเนื้อช้ำ เพิ่มขึ้นจาก 0.9082 เป็น 0.9726 และ 0.9012 เป็น 0.9557 ตามลำดับ

บทนำ

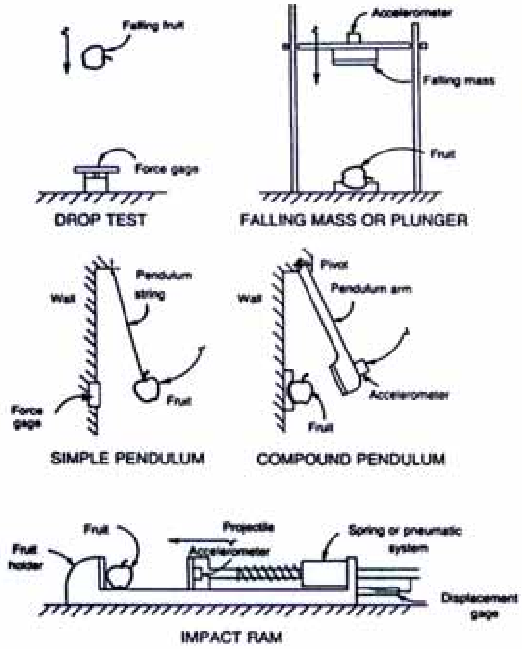
ปกติผักผลไม้จะถูกภาระกระแทกกระทำระหว่างการจัดการหลังเก็บเกี่ยว การขนส่ง การกระจายสินค้าไปสู่ผู้บริโภค มีนักวิจัยจำนวนมาก (Mohsenin et al., 1978 ; Mathew and Hyde, 1997 ; Bajima and Hyde, 1998 ; Jindal and Mohsenin, 1976 ; Holt and Schoorl, 1977) ได้พยายามศึกษาสมบัติทางกายภาพ และเชิงกลของผลไม้เมื่อถูกกระแทก และพยายามหาวิธีป้องกันผลิตผลไม่ให้ช้ำเสียหาย หรือช้ำน้อยที่สุดระหว่าง การจัดการหลังการเก็บเกี่ยวและขนส่ง

การทดสอบการกระแทกเป็นวิธีหนึ่งที่ใช้ทดสอบความสามารถของบรรจุภัณฑ์ในการป้องกันผลไม้จากความเสียหาย การทดสอบการกระแทกมีหลายวิธี (Mohsenin, 1986) แต่วิธีที่นิยมใช้มี 5 วิธี ดังแสดงในภาพที่ 1 คือ 1) drop Test ทำโดยการปล่อยผลไม้ให้ตก (กระแทก) อย่างอิสระในแนวดิ่ง ใส่ที่รองรับ (Mohsenin et al., 1978) 2) falling mass ทำโดยการวางผลไม้อยู่กับที่ แล้วปล่อยให้วัตถุตกลงอย่างอิสระในแนวดิ่งสู่ผลไม้ 3) simple pendulum ทำโดยผูกผลไม้ไว้กับเชือก จากนั้นปล่อยให้ผลไม้กระแทกเข้ากับพื้นผิวที่กระแทก โดยลักษณะการเคลื่อนที่ของผลไม้คล้ายกับการแกว่งของลูกตุ้มนาฬิกา (Mathew and Hyde, 1997 ; Bajima and Hyde, 1998) 4) compound pendulum ลักษณะตรงกันข้ามกับ simple pendulum คือ วางผลไม้อยู่กับที่ ปล่อยวัตถุกระแทกที่มีลักษณะคล้ายคานแข็ง กระแทกเข้ากับผลไม้ โดยลักษณะการเคลื่อนที่ของวัตถุ คล้ายกับการแกว่งของลูกตุ้มนาฬิกา (Jindal and Mohsenin, 1976) และ

1) รองศาสตราจารย์ ภาควิชาวิศวกรรมเกษตร คณะวิศวกรรมศาสตร์ มหาวิทยาลัยเกษตรศาสตร์ อ.กำแพงแสน จ. นครปฐม 73140
Associate professor, Department of Agricultural Engineering, Faculty of Engineering, Kasetsart University, Kampangsean, Nakornpratom. 73140

2) นิสิตปริญญาเอก โครงการพัฒนาบัณฑิตศึกษาและวิจัยเทคโนโลยีหลังการเก็บเกี่ยว มหาวิทยาลัยเกษตรศาสตร์ อ.กำแพงแสน จ. นครปฐม 73140
Ph.D. Student, Post Graduate Education and Research Development Project in Post-harvest Technology, Kasetsart University , Kampangsean, Nakornpratom. 73140

*Corresponding author Tel. : 0-3428-1099; fax : 0-3435-1842. E-mail address : fengbdj@ku.ac.th

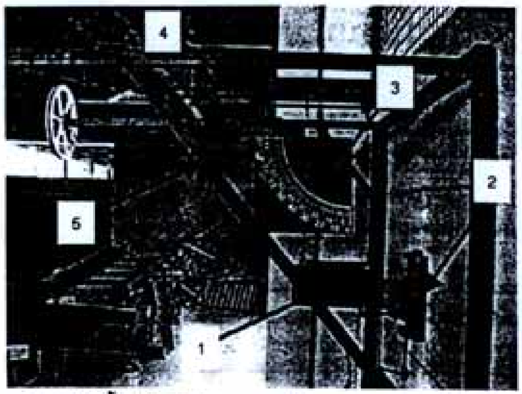


ภาพที่ 1 การทดสอบการกระแทกแบบต่าง ๆ

5) impact ram ทำโดยวางผลไม้อยู่กับที่ ใช้ ram (จากสปริง, นิวแมติกส์ หรือ อิ เลคโทรนิคส์) กระแทกกับผลไม้ (Holt and Schoorl, 1977)

ในการศึกษาวิจัยก่อนๆ ได้ใช้เครื่องทดสอบการกระแทกหลายแบบ และแบบ ballistic pendulum ที่ใช้ก้อนน้ำหนักรูปสี่เหลี่ยม เคลื่อนที่ในระนาบแบบเชิงเส้นโค้ง (curvilinear translation motion) ไปกระแทกผลิตผล โดยปรับระดับพลังงานกระแทกได้จากมุมตกกระทบ ก็เป็นแบบที่นิยมใช้กันอยู่ (Jarimopas, 1984 ; Jarimopas et al., 1990 ; บัณฑิต และคณะ, 2546 ; บัณฑิต และคณะ , 2547) ปัญหาของเครื่อง ballistic pendulum ก็คือความไม่ละเอียดในการตั้ง และอ่านค่ามุมตกกระทบและมุมสะท้อน ซึ่งส่งผลกระทบต่อการเก็บข้อมูล การวิเคราะห์ และการเข้าใจปรากฏการณ์ที่แท้จริง

เครื่องทดสอบการกระแทกแบบ ballistic pendulum ที่ใช้อยู่ในปัจจุบัน (ภาพที่ 2) มีอุปกรณ์ประกอบด้วย ลูกตุ้มน้ำหนัก 3.8 กิโลกรัม ฐานรองผลไม้ แผ่นวัดมุม เชือกยาว 0.45 เมตร และโครงเหล็ก การใช้งานทำโดยปล่อยลูกตุ้มที่มุมตกกระทบใดๆ ให้กระแทกเข้ากับผลไม้ โดยลักษณะการเคลื่อนที่ของลูกตุ้มคล้ายกับการเคลื่อนที่ของลูกตุ้มนาฬิกา เมื่อลูกตุ้มกระแทกเข้ากับผลไม้แล้ว ลูกตุ้มจะสะท้อนกลับมาด้วยมุมสะท้อนหนึ่งๆ นำค่ามุมตกกระทบ, มุมสะท้อน และ



1. ลูกตุ้มน้ำหนัก 3.8 กก.
2. ฐานรองผลไม้
3. แผ่นวัดมุม
4. เชือกยาว 0.45 เมตร
5. โครงเหล็ก

ภาพที่ 2 เครื่องทดสอบการกระแทกแบบ ballistic pendulum

รอยช้ำของผลไม้ มาวิเคราะห์ผล หาความสัมพันธ์ระหว่างปริมาตรเนื้อช้ำ(bruise volume) กับพลังงานกระแทก (impact energy) และพลังงานดูดกลืน (absorbed energy)

เครื่อง ballistic pendulum ยังมีข้อจำกัดในการใช้งานบางประการ คือ

1) ความละเอียดในการอ่านค่าที่แผ่นวัดมุม เนื่องจากตัวแปรที่เครื่องหาได้ล้วนเป็นฟังก์ชันของมุม และเชือกที่ใช้มีขนาดใหญ่, แผ่นวัดมุม และสเกลบนแผ่นวัดมุมมีขนาดเล็ก ทำให้อ่านค่าความละเอียดสูงสุดได้เพียงช่องละ 5 องศา

2) ในขั้นตอนของการปล่อยลูกตุ้มน้ำหนัก และการอ่านค่ามุมสะท้อน ต้องใช้สายตาเล็งผ่านเชือกไปยังแผ่นวัดมุม ซึ่งทำให้เกิดความแม่นยำได้ยาก ต้องอ่านค่าด้วยความระมัดระวังเป็นอย่างมาก ในกรณีที่ทดลองกับตัวอย่างจำนวนมากอาจทำให้เกิดสายตาล้า และอ่านผิดพลาดได้ง่าย

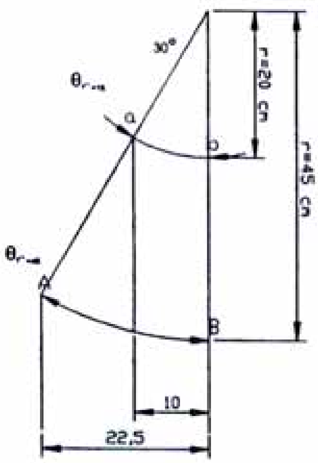
3) ลูกตุ้มขาดเสถียรภาพ เมื่อเกิดการกระแทกลูกตุ้มจะแกว่งมาก ทำให้การอ่านค่ามุมสะท้อนกลับของลูกตุ้มทำได้ยาก

จากข้อจำกัดข้างต้น จึงได้ดำเนินการปรับปรุงเครื่องทดสอบการกระแทกแบบ ballistic pendulum ให้สามารถอ่านค่าได้ละเอียด และแม่นยำยิ่งขึ้น รวมไปถึงการปรับปรุงให้ลูกตุ้มน้ำหนักมีเสถียรภาพอีกด้วย

อุปกรณ์และวิธีการ

อุปกรณ์

1. เครื่องทดสอบการกระแทก (ballistic pendulum)
2. เครื่องวัดรัศมีความโค้ง (radius of curvature)
3. เครื่องชั่งน้ำหนัก Sartorious รุ่น BA2100s



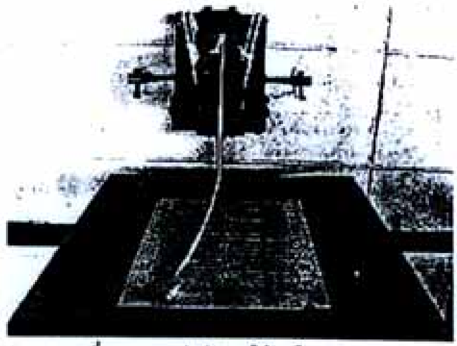
ภาพที่ 3 ขยายระยะสเกลจาก 20 ซม. เป็น 45 ซม.

4. เวอร์เนียคาลิเปอร์ (vernier caliper)
5. เลเซอร์ไดโอด (laser diode)
6. ผลแอปเปิ้ลจีนพันธ์ Fuji

วิธีการ

การปรับปรุงเครื่องทดสอบการกระแทกแบ่งเป็น 3 ขั้นตอน คือ

1. การปรับปรุงความละเอียดในการอ่านค่า เริ่มจากการขยายระยะสเกลจากเดิมซึ่งมีรัศมี 20 เซนติเมตร เป็น 45 เซนติเมตร (เท่ากับความยาวเชือก) (ภาพที่ 3) กำหนดให้มุมตกกระทบสูงสุดที่ 30 องศา จะได้อัตราส่วนในการขยาย AB/ab เท่ากับ 2.25 ทำให้สามารถอ่านค่าความละเอียดจากเดิมช่องละ 5 องศา เป็น 1 องศา เทียบเป็นระยะทางพื้นราบเฉลี่ย 1 องศา จาก 0.33 เซนติเมตร เป็น 0.75 เซนติเมตร ทำให้ได้ช่องว่างระหว่างสเกลมากขึ้น จากนั้นฉายสเกลจากแผ่นวัดมุมในแนวตั้ง ให้มาอยู่ในแนวนอน (ภาพที่ 4)

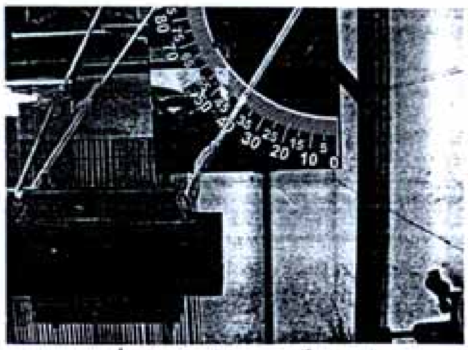


ภาพที่ 4 ฉายแผ่นวัดมุมให้อยู่ในแนวนอน

2. การปรับปรุงความแม่นยำในการอ่านค่า เครื่องทดสอบการกระแทกแบบเดิม ต้องใช้สายตาเล็งผ่านเชือกไปยังแผ่นอ่านค่ามุม (ภาพที่ 5) ซึ่งจะอ่านมุมเป็นสเกลองศาลำบากมาก จึงปรับปรุง โดยใช้การติดตั้งเลเซอร์ไดโอดไว้ที่ลูกตุ้ม และใช้แสงจากเลเซอร์ไดโอดในการชี้ตำแหน่ง (ภาพที่ 6) ทำให้อ่านค่าได้สะดวก ไม่ต้องเพ่งสายตา และแม่นยำขึ้น

3. การปรับปรุงเสถียรภาพในการแกว่งของลูกตุ้ม เมื่อลูกตุ้มน้ำหนักแบบเดิม (ภาพที่ 7) กระแทกเข้ากับผลไม้ จะเกิดการแกว่งขณะสะท้อนกลับ เป็นผลเนื่องจากเชือกที่ผูกอยู่สูงเกินไป ทำให้ลูกตุ้มขาดเสถียรภาพ จึงปรับปรุงโดยเจาะรูและผูกเชือกที่กึ่งกลางของลูกตุ้ม (ภาพที่ 8) ทำให้ลูกตุ้มมีเสถียรภาพมากขึ้น ส่งผลให้ลูกตุ้มแกว่งตัวหลังจากการกระแทกน้อยลง

เมื่อปรับปรุงความละเอียด ความแม่นยำ และเสถียรภาพในการแกว่งของลูกตุ้มแล้ว นำลูกตุ้มที่ได้ปรับปรุงมาทดสอบการกระแทกกับแอปเปิ้ลจีนพันธุ์ Fuji เพื่อเปรียบเทียบผล ก่อนและหลังปรับปรุง ทดสอบ 5 ซ้ำ/มุม ที่มุม 1-10 , 15, 20, 25 และ 30 องศา เมื่อ มวลของลูกตุ้ม = 3.84 กิโลกรัม, เชือกยาว 0.45 เมตร และค่าแรงโน้มถ่วงโลก (g) = 9.81 นิวตัน

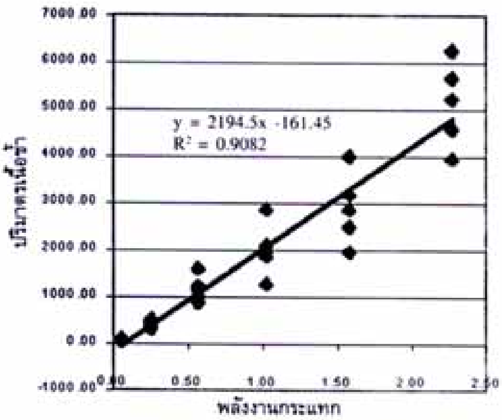


ภาพที่ 5 อ่านโดยใช้สายตาเล็งผ่านเชือก

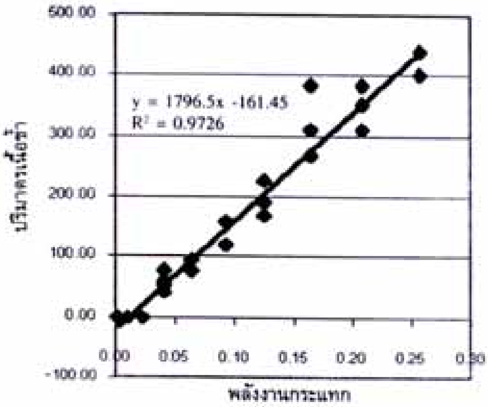
ภาพที่ 6 อ่านโดยใช้เลเซอร์ไดโอด

ตารางที่ 1 เปรียบเทียบผลก่อนและหลังปรับปรุง

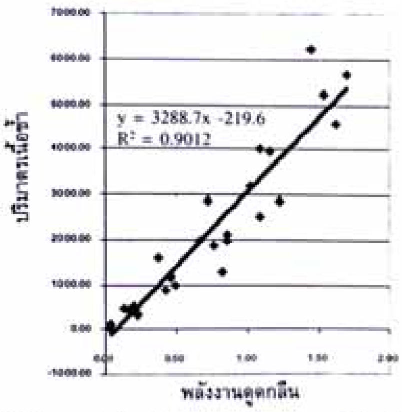
ก่อนปรับปรุง					หลังปรับปรุง				
มุมตกกระทบ (องศา)	มุมสะท้อนเฉลี่ย (องศา)	พลังงานกระแทก (จูลน์)	พลังงานดูดกลืนเฉลี่ย (จูลน์)	ปริมาตรช้ำเฉลี่ย (ตร.ซม.)	มุมตกกระทบ (องศา)	มุมสะท้อนเฉลี่ย (องศา)	พลังงานกระแทก (จูลน์)	พลังงานดูดกลืน (จูลน์)	ปริมาตรช้ำเฉลี่ย (ตร.ซม.)
5	2.8	0.064	0.032	75.87	1	-	0.0026	-	0
10	5.2	0.258	0.185	419.58	2	1.0	0.0103	0.008	0
15	7.4	0.578	0.435	1158.26	3	1.6	0.0232	0.023	0
20	10	1.024	0.763	2005.36	4	2.2	0.0413	0.028	55.19
25	14.4	1.588	1.053	2899.00	5	2.8	0.0644	0.041	79.36
30	17.4	2.276	1.490	5139.31	6	3.2	0.0928	0.066	141.30
-	-	-	-	-	7	3.8	0.1262	0.089	200.33
-	-	-	-	-	8	4.2	0.1648	0.119	306.15
-	-	-	-	-	9	4.6	0.2085	0.153	356.70
-	-	-	-	-	10	5.4	0.2573	0.187	425.70



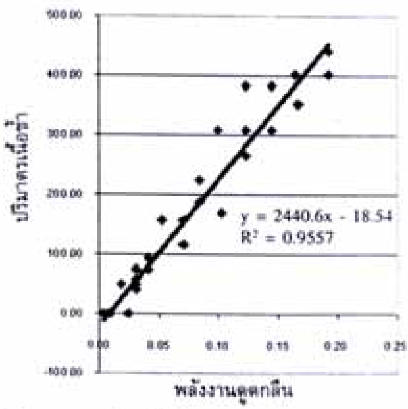
ภาพที่ 9 ความสัมพันธ์ระหว่าง พลังงานกระแทก - ปริมาตรเนื้อช้ำ ก่อนปรับปรุง



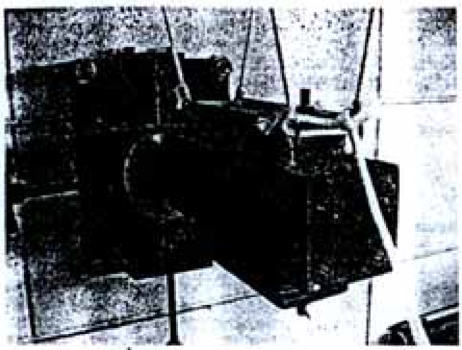
ภาพที่ 10 ความสัมพันธ์ระหว่าง พลังงานกระแทก - ปริมาตรเนื้อช้ำ หลังปรับปรุง



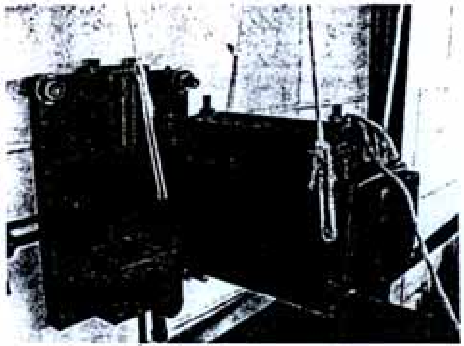
ภาพที่ 11 ความสัมพันธ์ระหว่าง พลังงานดูดกลืน - ปริมาตรเนื้อช้ำ ก่อนปรับปรุง



ภาพที่ 12 ความสัมพันธ์ระหว่าง พลังงานดูดกลืน - ปริมาตรเนื้อช้ำ ก่อนปรับปรุง



ภาพที่ 7 ก่อนปรับปรุงการเสถียรภาพ



ภาพที่ 8 หลังปรับปรุงการเสถียรภาพ

การวิเคราะห์

เครื่องทดสอบการกระแทกแบบ ballistic pendulum เป็นเครื่องมือที่ใช้งานง่าย อาศัยตัวแปรพื้นฐานในการคำนวณค่าต่างๆ เช่น มวลของลูกตุ้ม, ความยาวเชือก, มุมในการกระแทก และมุมสะท้อนกลับ ไม่มีกลไกซับซ้อน สามารถหาตัวแปรที่ใช้ในการวิเคราะห์ข้อมูลด้านสมบัติเชิงกลได้ดังนี้ (บัณฑิต และคณะ, 2543)

พลังงานที่ใส่ให้ (input energy) หรือ พลังงานกระแทก (impact energy)

$= mgh_1 = mgR(1 - \cos\theta_I)$ ....(1)

พลังงานคืนกลับ (recovery energy)

$= mgh_2 = mgR(1 - \cos\theta_R)$ ....(2)

พลังงานดูดกลืน (absorbed energy)

= input energy - recovery energy

$= mgh_1 - mgh_2$

$= mgR(1 - \cos\theta_I) - mgR(1 - \cos\theta_R)$ ....(3)

เมื่อ

m = มวลลูกตุ้ม (กิโลกรัม)

R = ความยาวเชือก (เมตร)

h_1 = ความสูงของตุ้มน้ำหนักก่อนปล่อย(เมตร)

h_2 = ความสูงของตุ้มน้ำหนักเมื่อสะท้อนกลับสูงสุด (เมตร)

θ_I = มุมที่เส้นเชือกทำกับแนวดิ่งก่อนปล่อย (มุมตกกระทบ,องศา)

θ_R = มุมที่เส้นเชือกทำกับแนวดิ่งเมื่อสะท้อนกลับสูงสุด (มุมสะท้อน,องศา)

ผลการทดลองและวิจารณ์

จากตารางที่ 1 พบว่า ก่อนปรับปรุง ค่ามุมตกกระทบที่ทำให้ผลแอปเปิ้ลเริ่มช้ำ (threshold angle) มีค่าเท่ากับ 5 องศา หลังการปรับปรุง พบว่าค่ามุมตกกระทบที่ทำให้ผลแอปเปิ้ลเริ่มช้ำ มีค่าเริ่มต้นที่ 4 องศา จะเห็นได้ว่าเมื่อปรับปรุงลูกตุ้มแล้ว สามารถอ่านค่าได้ละเอียดขึ้น นำค่าความสัมพันธ์ของพลังงานกระแทกกับปริมาตรเนื้อช้ำ และพลังงานดูดกลืนกับปริมาตรเนื้อช้ำ ทั้งก่อนและหลังปรับปรุงมาพล็อตกราฟ จะได้ภาพที่ 9, 10, 11 และ 12

เมื่อนำกราฟพลังงานกระแทกกับปริมาตรเนื้อช้ำ ก่อนปรับปรุง (ภาพที่ 9) เปรียบเทียบกับกราฟพลังงานกระแทกกับปริมาตรเนื้อช้ำ หลังปรับปรุง (ภาพที่ 10) พบว่า ก่อนปรับปรุง ต้องทดสอบการกระแทกด้วยมุม 5-30 องศา จึงสามารถพล็อตกราฟความสัมพันธ์ระหว่างพลังงานกระแทกกับปริมาตรเนื้อช้ำ ได้ ในขณะที่หลังปรับปรุง ใช้มุมกระแทกเพียง 1-10 องศา ก็สามารถพล็อตกราฟได้แล้ว สำหรับผลไม้ขนาดเล็ก การใช้มุมกระแทกสูง จะให้พลังงานกระแทกสูง อาจทำให้ผลไม้เกิดการเสียรูป ก่อนจะได้ข้อมูลเพียงพอต่อการวิเคราะห์ นอกจากนี้แล้วค่า R^2 ยังเพิ่มขึ้นอีกด้วย คือ จาก 0.9082 เป็น 0.9726 ซึ่งเป็นผลมาจากการอ่านค่ามุมตกกระทบได้ละเอียด แม่นยำขึ้น ทำให้จุด co-ordinate ที่ได้ เกาะกลุ่มชิดกันในกราฟภาพที่ 10 มากกว่าในกราฟภาพที่ 9

ทำนองเดียวกัน เมื่อพิจารณากราฟพลังงานดูดกลืนกับปริมาตรเนื้อช้ำ ก่อนปรับปรุง (ภาพที่ 11) เปรียบเทียบกับ กราฟพลังงานดูดกลืนกับปริมาตรเนื้อช้ำ หลังปรับปรุง (ภาพที่ 12) พบว่า ค่า R^2 เพิ่มขึ้นจาก 0.9012 เป็น 0.9557 ซึ่งเป็นผลมาจากการแกว่งของลูกตุ้มน้ำหนักในขณะสะท้อนกลับลดลง และการอ่านค่าบนสเกลได้ละเอียดขึ้น มากกว่าการคาดคะเนด้วยสายตา

สรุป

จากการปรับปรุงเครื่องทดสอบการกระแทกแบบ ballistic pendulum พบว่า

1. สามารถอ่านค่าความละเอียดของสเกล เพิ่มมากขึ้น

จากเดิมช่องละ 5 องศา เป็น 1 องศา เทียบเป็นระยะทางพื้นราบเฉลี่ย 1 องศา จาก 0.33 ซม. เป็น 0.75 ซม.

2. มีความสะดวกในการใช้งานดีขึ้น จากที่ใช้สายตาเล็งผ่านเชือกไปยังแผ่นวัดมุม เป็นใช้แสงจากเลเซอร์ไดโอดในการชี้ตำแหน่ง และมีความแม่นยำในการอ่านค่าดีขึ้น

3. สามารถทำการทดสอบการกระแทกได้ที่พลังงานกระแทกต่ำๆ (มุมกระแทกน้อยๆ)

4. ลูกตุ้มมีเสถียรภาพในการแกว่งหลังจากกระแทกดีขึ้น(ลูกตุ้มแกว่งน้อยลง)

5. ค่า R^2 ของกราฟของพลังงานกระแทกกับปริมาตรเนื้อช้ำ เพิ่มขึ้นจาก 0.9082 เป็น 0.9726 และค่า R^2 ของกราฟของพลังงานดูดกลืนกับปริมาตรเนื้อช้ำ เพิ่มขึ้นจาก 0.9012 เป็น 0.9557

กิตติกรรมประกาศ

ผู้วิจัยขอขอบคุณ โครงการพัฒนาบัณฑิตศึกษาและวิจัยเทคโนโลยีหลังการเก็บเกี่ยวผักผลไม้ (ADB) ของมหาวิทยาลัยเชียงใหม่ ที่กรุณาสนับสนุนทุนวิจัย

เอกสารอ้างอิง

บัณฑิต จริโมภาส, ณัฏฐา เปี่ยมคล้า และปวีณา สว่างเนตร. 2546. การศึกษาเปรียบเทียบความสามารถของโฟมตาข่ายในการป้องกันผลแอปเปิ้ลจากการกระแทก. วารสารสมาคมวิศวกรรมเกษตรแห่งประเทศไทย 10 (1) : 44 - 49.

บัณฑิต จริโมภาส, ธาริณี มหายศนันท์ และนงเยาว์ ศรีเอนก. 2547. การศึกษาความสามารถของตาข่ายที่ทำจากเชือกกล้วยเพื่อป้องกันผลแอปเปิ้ลจากการกระแทก. วิศวกรรมสาร มก. 17 (51) : 9 - 16.

บัณฑิต จริโมภาส, วสันต์ แสงนิล และศุภลักษณ์ วรรณพงษ์. 2543. การศึกษาการใช้โฟมตาข่ายห่อหุ้มผลไม้ที่ถูกกระทำด้วยภาระการกระแทก. วารสารวิชาการเกษตร 18 (2) : 126 - 136.

Bajima, R. W. and G. M. Hyde. 1998. Instrumented Pendulum for Impact Characteristic of Whole Fruit and Vegetable Specimens. Transaction of ASAE. Vol. 41(5) : 1399-1405.

Holt, J. E. and D. Schoorl. 1977. Bruising and Energy Dissipation in Apples. Journal of Texture Studies. Vol. 7(4): 421-432.

Jarimopas, B. 1984. Failure of Apples under Dynamic Loading. D.Sc. Thesis, Technion-Israel Institute of Technology, Haifa. Israel, 157 p.

Jarimopas, B., Y. Sarig, U. M. Peiper, and G. Manor. 1990. Instrumentation for Measuring the Response of Apples Subjected to Impact Loading. Journal of Computers and Electronics in Agriculture. Vol 5 : 255-260

Jindal, V. K. and N. N. Mohsenin. 1976. Analysis of a Simple Pendulum Impacting Device for Determining Strength of Selected Food Material. Transaction of ASAE. Vol. 19(4) : 766-770.

Mathew, R. and G. M. Hyde. 1997. Potato Impact Damage Thresholds. Transaction of ASAE. Vol. 40(3) : 705-709.

Mohsenin, N. N. 1986. Physical Properties of Plant and Animal Materials. Gordon and Breach, Science Publishers, Inc. New York. USA, 841 p.

Mohsenin, N. N., V. K. Jindal and A. Manor. 1978. Mechanics of Impact of Fruit on a Cushioned Surface. Transaction of ASAE. Vol. 21 : 594-600.

ภาคผนวก ข

ตัวอย่างตารางบันทึกผลการทดลอง

<u>ตารางผนวกที่ 1</u> ตารางบันทึกผลลักษณะทางกายภาพของผลแอปเปิ้ล

ทดลองวันที่……………อุณหภูมิ……………ความชื้นสัมพัทธ์……………..…..

ขนาดแอปเปิ้ล…………..วัสดุกันกระแทก…………………………….

ลำดับที่	น้ำหนัก (กรัม)	ขนาด (กว้าง x สูง)		รัศมี (x 0.001 นิ้ว)		รัศมีเฉลี่ย (มม.)
		แกน x	แกน y	แกน x	แกน y	
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
ค่าเฉลี่ย						
std						
CV%						

<u>ตารางผนวกที่ 2</u> ตารางบันทึกผลการทดสอบการกระแทก Beyond Threshold และ Below Threshold

ลำดับที่	มุมตกกระทบ (องศา)	มุมสะท้อน (องศา)	ความช้ำผลผลิต				EI (จูล)	ER (จูล)	EA (จูล)	ปริมาตรช้ำ	
			ด้านหน้า		ด้านหลัง					ด้านหน้า	ด้านหลัง
			ความกว้างรอยช้ำ w (มม.)	ความลึกรอยช้ำ d (มม.)	ความกว้างรอยช้ำ w (มม.)	ความลึกรอยช้ำ d (มม.)				mm^3	mm^3
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											

ประวัติการศึกษาและการทำงาน

ชื่อ-นามสกุล	นายศุภกิตต์ สายสุนทร
วัน เดือน ปี ที่เกิด	วันศุกร์ที่ 10 ธันวาคม พศ. 2519
สถานที่เกิด	กรุงเทพมหานคร
ประวัติการศึกษา	วศ.บ. (วิศวกรรมหลังการเก็บเกี่ยวและแปรสภาพ) ศูนย์กลางสถาบันเทคโนโลยีราชมงคล ต.คลองหก จ.ปทุมธานี วศ.ม. (วิศวกรรมเกษตร) มหาวิทยาลัยเกษตรศาสตร์ วข. กำแพงแสน จ.นครปฐม
ตำแหน่งหน้าที่ปัจจุบัน	อาจารย์
สถานที่ทำงานปัจจุบัน	ภาควิชาวิศวกรรมเกษตร คณะวิศวกรรมศาสตร์ มหาวิทยาลัยเทคโนโลยีราชมงคลธัญบุรี ต.คลองหก อ.ธัญบุรี จ.ปทุมธานี 12110
ทุนการศึกษาที่ได้รับ	โครงการพัฒนาบัณฑิตศึกษาและวิจัยเทคโนโลยี หลังการเก็บเกี่ยว (ADB)