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Comprehensive Evaluation of Dynamic Impact as a Measure of Potato Quality

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Abstract: Comprehensive evaluation of dynamic impact (free fall) of potato tubers were conducted to ascertain relation of drop height, impact surface, water irrigation also the size of tubers on impact parameters such as (bruise area, impact energy, absorbed energy, coefficient of restitution and dynamic stiffness factor). In addition, five different impact surfaces were used namely (cardboard, wood, steel, plastic and foam) on the platform of the equipment. Potato tubers under different water irrigation (fresh water and treated water) were divided into two mass groups (90 -180 g), M_1, and (1- 90 g), M_2. Tubers dropped from four heights (40, 30, 20, 10 cm) onto the different surfaces and the different impact parameters were measured. Results showed impact damage measured in terms of bruise diameter is highly influenced by the impact surfaces. Steel surface inflicted the greatest impact damage on the tubers. Impact energy of tuber is greatly influenced by drop height and mass of tuber. Tuber, which dropped from heights (40 cm), absorbed the greatest energy indicating that they suffered the most impact damage. Dynamic stiffness factor for tuber was decreased by increasing storage period. Tuber with low dynamic stiffness factor led to more absorbed energy than tuber with higher dynamic stiffness factor. Moreover, designers of potato harvesters, packaging materials, processing plants and handlers of potato tubers to reduce mechanical damage, especially those due to impact and ensure good quality products, can use results obtained.

Keywords: Bruise Area, Dynamic Stiffness Factor, Impact Energy, Coefficient of Restitution, Treated Water

1. Introduction

The potato (*Solanumtuberosum L.*) is the most important food crop in the world after wheat, rice and maize. Over one billion people consume worldwide and potatoes are part of the diet of half a billion people in the developing counties. Potato is produced on about 310 million tons in the world every year. The largest potato producer of the world is the China. This country produces nearly 60 million tons of the total world production, followed by Russian, India and USA (FAO, 2009).

Each technological system of harvest and post-harvest handling requires the use of machines whose operating elements bring about plant material load, thus permitting the product to be satisfactory both in terms of quantity and in terms of quality (Figure 1). On the one hand, mechanical impact is required in order to permit the machine to function according to its purpose, but on the other hand, this often causes undesired effects (loss). The desire to increase machine output is connected with the ever more aggressive impact of machines on material, which usually leads to greater damage being caused to crops. The rational use of machines for harvest and post-harvest handling may take place by appropriate selection and by steering the operating parameters, and by selecting the best time for performing the technological process in two ways

Potato tubers are collected with the use of harvesters only for processing purposes. Collection for consumption purposes until takes place by hand. That does not mean that with this technology the fruit does not come in direct contact with mechanical elements. During collection, various types of devices are used in order to facilitate manual collection and increase output (conveyors, elevators). In recent times, the use of autonomous robots for collecting tuber considerably decreases load impact, which is the reason why tuber is damaged. Further development of these robots will undoubtedly help reduce the damage caused to tuber, particularly if collected for direct consumption purposes.

Yadav S., 2014, reviewed that during harvest, transport and storage operations potato tuber are exposed to impact damage, which ranges from internal black spot brushing, which reduce to quality and increase loss. At the time of different operations of handling potato, the potato moves in random directions and strikes on side walls, rods of conveyor or impact one potato to another potato and causing both internal bruising and external damage. In order to minimize mechanical damage during handling the stress must be kept under certain value. Therefore, it is necessary to measure the resonance frequency, modulus of elasticity and damping factor. It will help in designing the potato handling equipment and loading the potato during transportation and reducing the internal and external damage of potato.

Mechanical damage is the major cause of postharvest losses in fruits and vegetables (FAO. 1989) especially in undeveloped countries and considerable research efforts are required in this relation. Mechanical damage occurs in the postharvest handling system primarily in two ways: impact forces and compressive forces. Excessive impact occurs during harvesting, grading, handling and transportation (Shafiur Rahman, M., 1999).

The major cause of losses in fruits and vegetables are mechanical damage (bruising) due to impact. This impact could result from either vibration or sudden drop of the produce from certain heights. Over the years, several studies were carried out to assess the mechanical properties and susceptibility to bruising of fruits and vegetables (Holt and Schoorl 1985; Olorunda and Tung 1985; Jones *et al*. 1991; Roudot, *et al*. 1991; Singh and Singh 1992; Hyde *et al*. 1993; Ogut, *et al*.1999; Vursavus and Ozguven 2004; Berardinelli *et al*. 2005). Impact sensitivity of fruits and vegetables was defined as having components namely bruise threshold and bruise resistance (Bajema and Hyde 1998). Bruising in fruits and vegetables occurs when the produce rubs against each other, packaging containers, parts of processing equipment and the tree (Altisent 1991).

Fruit and/or tuber bruising is one of the most important factors limiting mechanization and automation in harvesting, sorting and transport of soft fruits and vegetables, including potatoes. Dark spots appearing near the product surface are due to previous forceful mechanical contacts of the products with other bodies. Bruise extent is usually described in terms of bruise volume (Blahovec et al. 2004), which is closely related to product quality. The bruises belong to the whole scale of potato mechanical damage leading to yield losses expressed in tens of percent (Baritelle et al. 1999).

Mechanical impact on potato tubers during harvest and subsequent handling not only causes external damage such as cracking and scuffing of the skin (Hughes, 1980), but can also result in a bluish-grey to black internal discoloration of the tuber tissue. This so-called black spot bruising is hardly visible from the outside as it is located about 2mmbeneath the surface of the tuber in the region of the vascular ring. Black spot bruising typically occurs within 1–3 d after mechanical impact (Burton, 1989; Molema, 1999) and is considered a significant impediment for the utilization of tuber harvests throughout the world as it severely influences consumer acceptance (Peters, 1996).

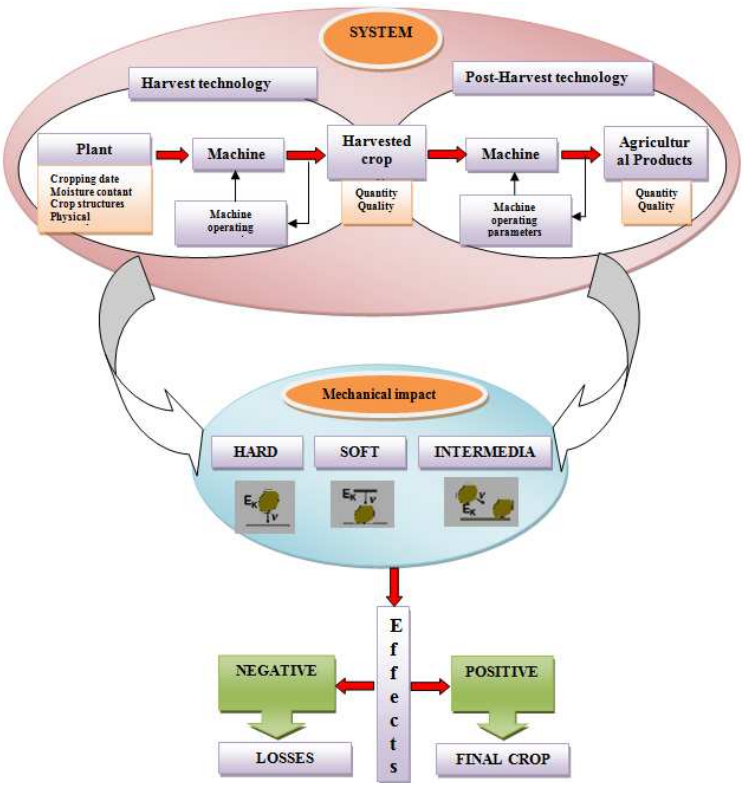

Fig. 1. *Machine plant material system relations.*

In order to evaluate the contact-impact forces resulting from collisions in handling and transportation efficiently, special attention must be paid to the physical and mechanical properties of biomaterial product. Information on the impact velocity, material properties of the colliding bodies and geometric characteristics of the contact surface must be included in the dynamic behavior. Within the recent years of fruit impact damage researches, different test equipment was developed to assess the dynamic stresses in fruits. Among the dynamic apparatuses, there are two main types of design: drop and pendulum design. Currently, experimental methods such as pendulum experiments are used to study the impact behavior of fruit and to determine the contact parameters to be used with the DEM models (Pang et al., 1992; Bajema and Hyde, 1998; Van Zeebroeck et al., 2003; Ahmadi et al., 2012). Because of the precise stiffness and lack of fruit damping determination (viscoelastic material), dynamic analysis research of biomaterial is rare.

Numerous methods have been applied to investigate fruit behaviour during impact. These have used drop tests (Brusewitz, 1994; Yuwana and Duprat, 1998; Ragni and Berardinelli, 2001; Lewis et al., 2007), and pendulum tests, which enable a better control of impact course (Puchalski and Brusewitz, 2000; Bollen et al., 2001; Yen and Wan, 2003; Ahmadi et al., 2010; Esehaghbeygi, 2010). Other techniques involve fruit impact against a small steel sphere with a specific mass and a curvature radius (Jaren and Garcia-Pardo, 2002), or a flat impactor of a given mass (Aviara et al., 2007).

Several stiffness coefficients are used to estimate the firmness of fruits. Among them, the most used for round shaped fruits is the stiffness coefficient proposed by (Abbott et al, 1968) and (Cooke and Rand, 1973): $S = f^2 \times m^{2/3}$ where f is the resonance frequency also called dominant frequency (corresponding to the greatest amplitude in the spectra) and m is the mass of the product.

Acoustic measurements have also allowed to identify external defaults in eggs (Cho, H, et al, 2000) pistachio nuts (Pearson, T. et al, 2001) and internal defaults in pears (Schrevens, E. et al, 1996), watermelons (Armstrong, P. et al, 1997), (Diezma-Iglesias, B. et al, 2004) and potatoes (Elbatawi, I., 2008).The use of acoustic impulse response is increasing asa valuable tool to evaluate changes during harvest and postharvest (De Belie., et al, 2000), (Herppich, W. et al, 2003), (Shmulevich, I. et al, 2003). Therefore, study the effect of impact surfaces and drop heights on bruise area, impact energy, absorbed energy, rebound energy, coefficient of restitution and acoustic stiffness factor must be investigated with the view to generate basic data/information that can be used in designing and management of handling and transport devices that will minimize mechanical damage of potato tubers.

2. Material and Methods

Fresh potato tubers (*Dimont* vf) with two types of irrigation water: the first is plain water (fresh) used to irrigate inside station training and other water drainage (processor) is supplied from outside the station's headquarters (according to the specifications approved by the Ministry of Agriculture) were obtained from a farm in station training and agricultural research and veterinary, King Faisal University. The samples were divided into two mass groups, (M_1: 90 -180 g) and (M_2: 1- 90 g). An impact testing equipment, which used to drop the tubers from heights on to the impact surfaces placed on the impact platform of the equipment. In addition, five different impact surfaces (cardboard-A; wood-B; steel-C; plastic-D and foam-E) were used. Five samples from each of the mass groups were dropped on to each of the different surfaces placed on the platform of the equipment from four different heights: H_1-40 cm; H_2-30 cm; H_3-20 cm and H_4-10 cm. In order to ascertain the correct dimensions of the impacted area. The impacted tubers were coded and stored for 48 hours and the dimensions (diameters and depths) of the bruised areas were measured.

2.1. Dynamic Tests

Machine–plant interaction that takes place during the post-harvest collection and handling process is primarily of an impact nature. Concerning the physical description of interaction that occurs in such situations, it is necessary to take into account the mechanics of impact and its implication to plant materials (Mohsenin, 1986).

In order to indicate the presence of forces during impact it is necessary to consider the mechanical properties of both the impacting object and the object being impacted. A typical characteristic of impact is the occurrence of so-called instantaneous forces, which act very briefly ($\Delta t \to 0$) and attain high values in comparison to other forces that occur.

The measure for instantaneous forces is the impact pulse:

$$S = \int_{t_0}^{t_0+\Delta t} P(t)dt$$

where S – impact pulse, t_0 – moment of occurrence of the instantaneous force Δt – time of operation of the instantaneous force P (t) – instantaneous force.

The course of impact may be divided into two phases: compression and restitution (Gilardi and Sharf, 2002). The first phase, which involves a sudden increase in force, starts as soon as the bodies encounter each other at t_0 point and end at t_m point when distortion attains maximum value (Figure 2a). The relative velocity of both bodies is then equal to zero. In the second phase instantaneous force decreases. The shape of the P (t) curve depends on:

- The elastic–plastic properties and dimensions of the impacting bodies
- Body surface shape (particularly at the point of contact)
- The direction of the velocity vector
- Impact energy value
- Freedom of distortion

For plant materials, this curve is determined empirically. S_1 and S_2, impact pulse values, respectively in phases one and two of impact, serve the purpose of determining the restitution coefficient (e):

$$e = S_1/S_2 = \left(h_{reb}/h_{drop}\right)^{1/2}$$

It defines the proportion between elastic and plastic distortion. If e = 1 we have to do with ideally elastic impact; however for e = 0 impact is ideally plastic. For true plant materials “e” belongs to the (0; 1) range and to a very large degree depends on the moisture content of the material (the lower the moisture content the greater the restitution coefficient). It is determined when a body affects a motionless obstacle (Figure 2b). In such cases, normal velocity is defined: initial v_{in} and final v_{fin}, while the restitution coefficient is calculated as the ratio of both velocities.

Total distortion e that takes place during impact is the sum of elastic distortion is and plastic distortion ep. The magnitude of these distortions depends on anatomical and morphological structure and the physical properties of plant material. The anisotropicity of these types of materials hinders any clear definition of mechanical and endurance parameters, which are very strongly correlated with moisture, which has a decisive influence on elastic and plastic properties (and therefore on the type of distortion). Plant materials with large water content are dominated by plastic traits, while dry material contains elastic or brittle characteristics. This is reflected in the effects of impact. Concerning materials with large water content, the energy of elastic distortions constitutes only a small part of overall distortion energy. During harvest and post-harvest handling, one may distinguish the following types of load (Figure 1):

- Hard – these are manifest when the initial value of E_{in} impact kinetic energy is dissipated by the impacting body fig. 5, (e.g., the fall of an apple, tomato, potato, or melon onto the hard surface of a crate leads only to the distortion of the impacting fruit).
- Soft – this is the kind of impact in which distortion of the impacted body is considerably greater than distortion of the impacting body fig. 5, (e.g., the impact of a beater against threshed material leads only to the distortion of the impacted plant mass).
- Intermediate – this is the simultaneous distortion of the impacting body and of the impacted body (e.g., the fall of a single piece of fruit onto a pile of fruit kept in a container leads to all of the impacted bodies being distorted).

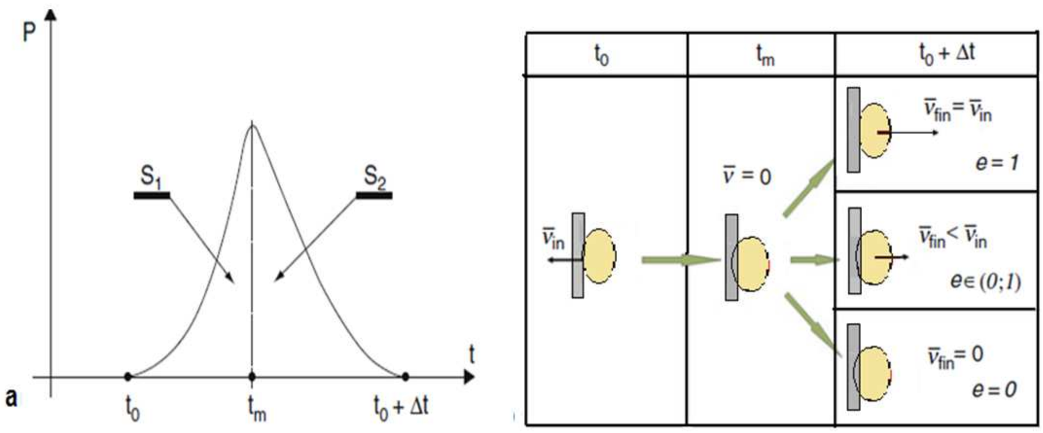

Fig. 2. *Body impact against a motionless obstade (a) change of instantaneous force; (b) type of impacts.*

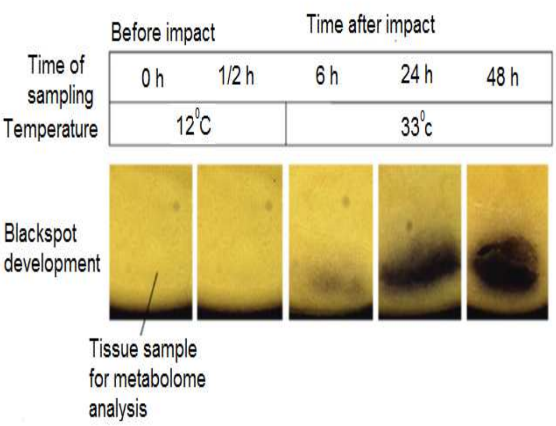

Fig. 3. *Development of black spot bruising in tuber.*

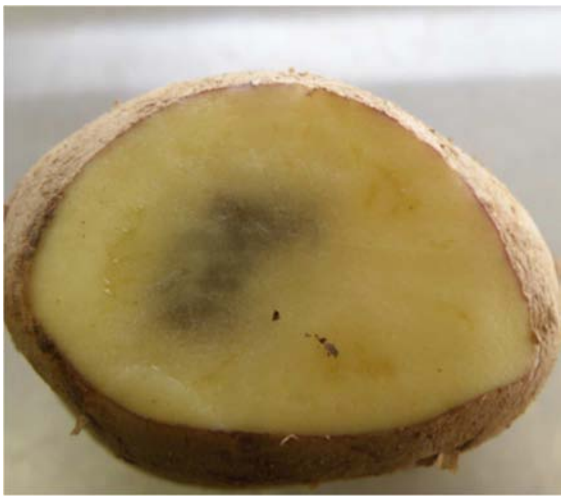

Fig. 4. *Black spot on potato tuber.*

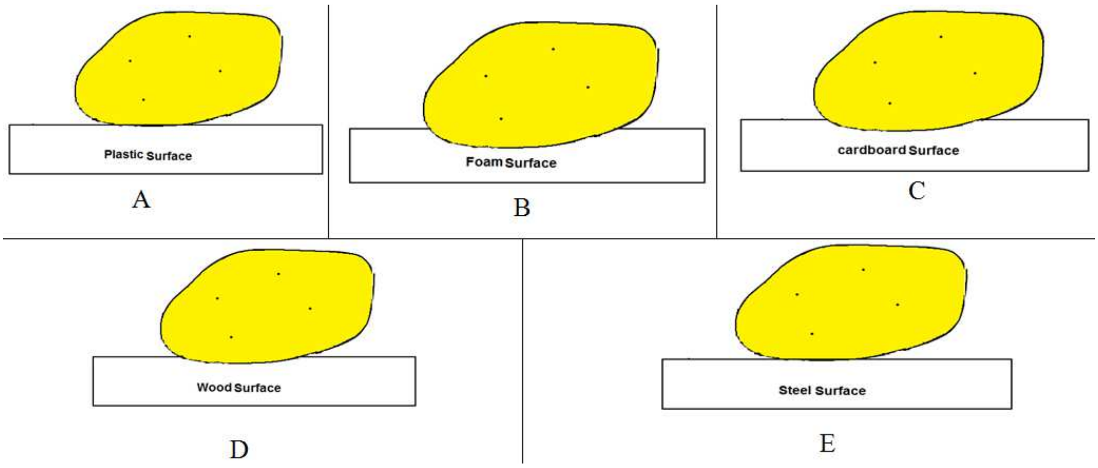

Fig. 5. *Relation between potato tuber and surface at moment of sudden impact, (A) plastic, (B) foam, (C) cardboard, (D) wood, (E) steel surface.*

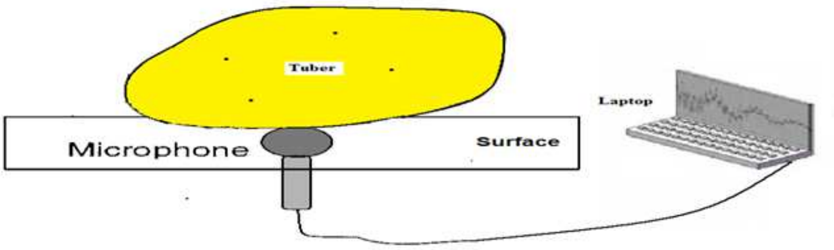

Fig.6. *Schematic representation of the acoustic response technique for determination of dynamic stiffness factor.*

They differed in size, shape and mechanical properties from those tested in the fall under static loading will affect the impact characteristics to that from drop height, one of these two parameters must be known or estimated. By mathematical dependency, the known or estimated parameter can be derived from one of the following: impact velocity, rebound velocity, velocity ratio (coefficient of restitution), drop height and rebound height. The impact loads were expressed in terms of total energy, energy absorbed, rebound energy and impact energy. For user convenience, maximum and minimum values for each of these parameters are displayed for each impact. Once any one of the above parameter was estimated. These properties may all be displayed simultaneously. These were defined by,

- E_{imp} = W h_{drop} = total energy or energy of impact, (N.m= J)
- E_{abs} = W ($h_{drop} - h_{reb}$) = energy absorbed by the sample, (N.m= J)

W = Weight of potato tubers, kg

h_{drop} = the height of drop, m

h_{reb} = the height of rebound, m

Following impact, all samples were left at a temperature of 20 c^o for 10 days there are both chemical and physical aspects of impact damage in fruits and vegetables. Bruising in potato is the result of mechanical impact damage sufficient to cause mixing of a substrate and an enzyme (tyrosine and polyphenol oxidase) to form the black discoloration, melanin figs (2, 3). However, the discoloration may not occur if the substrate and/or the enzyme are not present in sufficient quantities, (*Mathew and Hyde 1997*).

The acoustical stiffness of tuber was calculated based on acoustical response method (Praeger et al., 2009) Fig (6).Tubers were failed fall from different height (10, 20, 30, 40 cm). A microphone was fixed on a support at a few millimeters off the tuber and was directed upward. The resulting sound was recorded with a microphone connect to a computer. Measurements were repeated 5 times at each position. The mean frequencies at the first local maximum (*f*) of the frequency spectrum obtained after a Fast Fourier Transform (FFT) was performed and consequently, and the respective tuber fresh mass was determined. The acoustical stiffness factor was calculated as:

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

2.2. Data Analyses

All properties were measured at least in five replications, unless stated otherwise. Maximum, minimum, range, mean, standard deviation, regression equations and coefficient of determination were obtained by spreadsheet software program namely Microsoft Excel, 2007).

3. Results and Discussion

3.1. Bruise Area

Fig.7, showed effect of impact surface, irrigation water and tuber size on the area of bruise tubers. In general, the parameter, which used in determining impact damage in tubers, is the bruise diameter. Average bruise diameters were obtained between 15 mm and 35 mm from which the bruise areas were computed. Earlier studies graded degree of impact damage in relation to average bruise diameter as follows (Vurasvus and Ozguven, 2004).

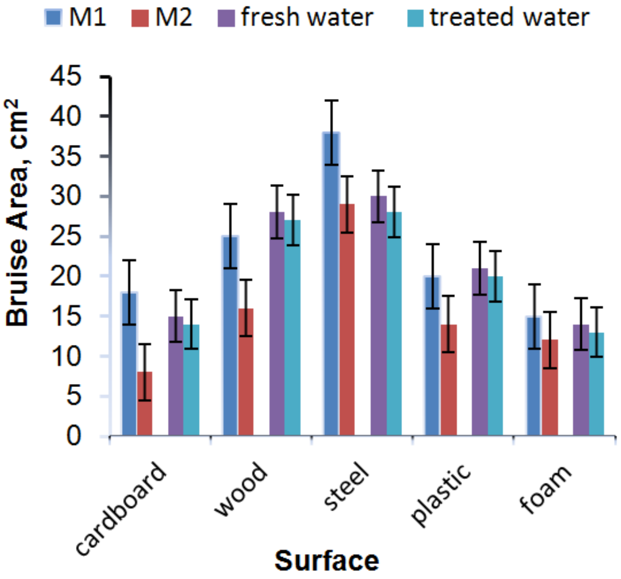

Fig. 7. Effects of impact surfaces, water types and mass tuber on the bruise area of tuber.

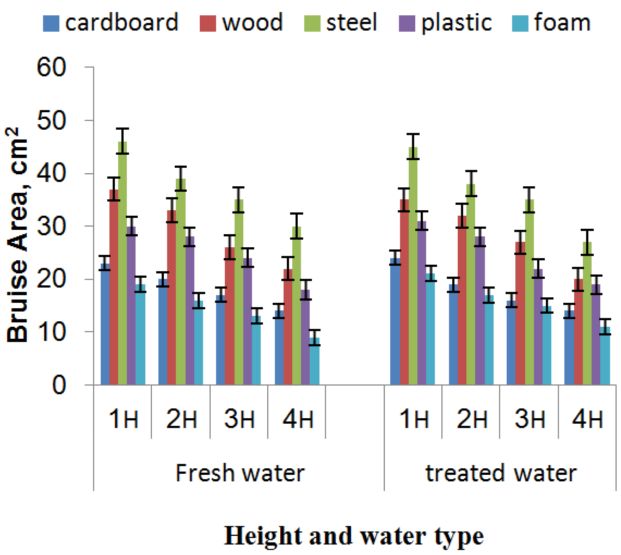

Fig. 8. Relation between impact heights, water types and type of surface on the bruise area of tuber.

Evidently, from results that showed, samples, which dropped onto the surface steel, wood and plastic, respectively suffered severe damages. Hence, steel surface assuredly inflicted the greatest impact damage on the potato tubers, which dropped onto it comparing other surfaces followed by wood surface, these surfaces generally rougher and harder than others do. Conversely, the foam surface inflicted the least impact damage.

An equally significant aspect of tubers that irrigated by fresh water and bigger tubers are more susceptible to impact damage than the small and tubers that irrigated by processor water. These results agree with other studies which conducted by Altisent (1991), which revealed that severity of impact damage to tubers is primarily related to the type impact surface and size of tuber in addition to the physical properties of the tubers. Since the foam surface inflicted the least impact damage, it can be inferred from the study that in considering materials that can be used as cushioning materials in packaging potato tubers.

At the same time, relation between impact height, water type and impact surfaces on the bruise area showed in Fig. 8. Tubers which dropped from height H_1 (40 cm) on the steel surface suffered the greatest impact damage, followed this which dropped onto wood surface closely. It has been noted that damage inflicted on tubers is related to energy available for bruising and the characteristics of the products.

3.2. Impact Energy

Another significant factor which affected by drop heights, water type and impact surfaces were the impact energy available for bruising. Its relations between them showed in Fig. 9, accordingly, tubers that dropped from height H_1 (40 cm) absorbed the greatest energy. These results agree with other studies which conducted by, Hyde *et al*. 1993, revealed that by increasing drop height, type of tuber damage changed from black-spot to a combination of shatter bruise and tissue cracking.

Likewise, another significant factor which affected by drop heights, mass tuber and impact surfaces were absorbed energy. Fig. 10. Accordingly, tubers which dropped from height H_1 (40 cm) absorbed the greatest energy, and the bigger tuber (M_1) generally absorbed more energy than the smaller ones (M_2). Energy absorbed by tubers greatly determines the quality of the tubers during handling and storage process because the bruising of the tissues, which results from such impact, enhance subsequent deterioration of the tubers. Hence, if quality is to be ensured, this impact resulting in such damage must be minimized.

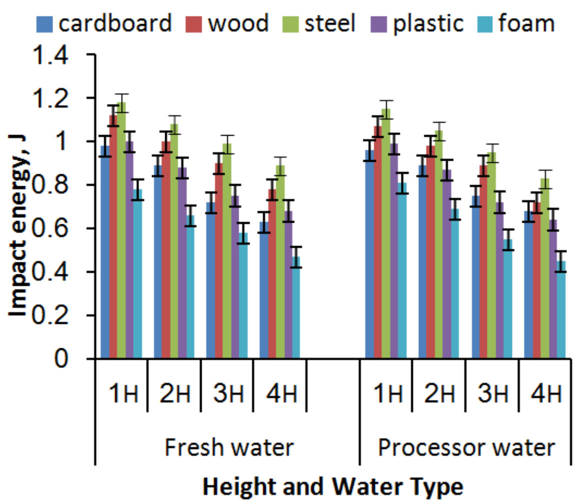

Fig. 9. Relation between impact height and impact surfaces on the impact energy of potato tubers.

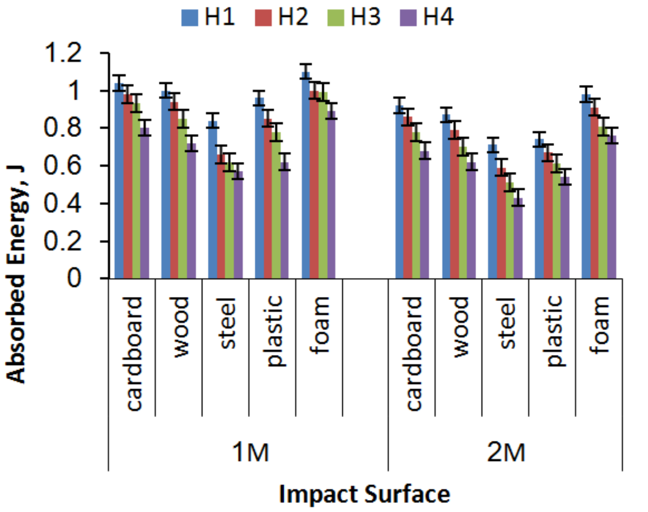

Fig. 10. Relation between mass tuber and impact surfaces on the energy absorbed by potato tubers.

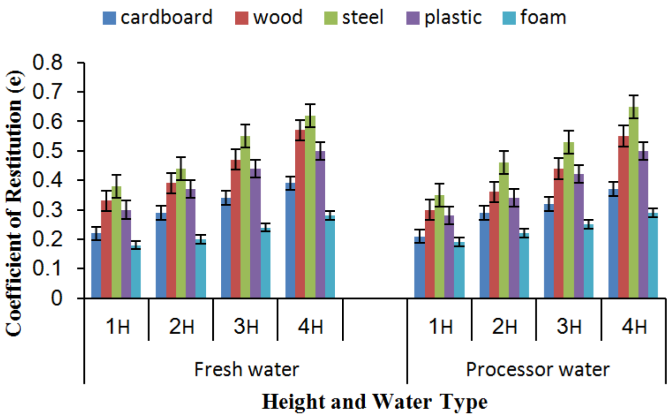

Fig. 11. Relation between impact height, impact surface and the coefficient of restitution for tubers.

Our data in fig.10, Showed that foam surfaces were the most efficient in alleviating impact intensity during handling. This phenomenon could be due to the texture of foam surfaces, which had more elasticity and springiness than another surfaces. Therefore, the foam surfaces were able to improve the quality and safety of potato tubers after harvest and postharvest process.

3.3. Coefficient of Restitution (e)

The relation between impact heights, water type and impact surfaces on the coefficient of restitution were showed in fig. 11. As a consequence, the tubers which dropped from height H_1 (40 cm) recorded the highest coefficient of restitution value than other impact heights. AS data showed that foam surfaces were the most efficient in alleviating impact intensity during handling which recorded the lowest values of coefficient of restitution than another surfaces fig (11). This phenomenon could be due to the texture of foam surfaces, which had more elasticity and springiness than another surfaces. So the foam surfaces were able to absorb some of impact energy than another surfaces, which help to decrease the coefficient of restitution and that reflect on the quality and safety of potato tubers after harvest and postharvest process. However, the effects of water type on the coefficient of restitution can be seen from fig. 11, which showed that no difference found for water type on the coefficient of restitution of tubers.

The relation between coefficient of restitution and storage time was showed in Fig. (13), which showed increasing the values of coefficient of restitution with increasing storage time of potato tubers.

3.4. Dynamic Stiffness Factor (s)

The dynamic stiffness factor decreased with storage time in tubers for different of both type of water (fresh, treated) (Fig. 12). Although fresh water and steel surface were significantly stiffer, they had higher values of stiffness factor than those of treated water and other surfaces they tended to be slightly more elastic during the rest of the experiment.

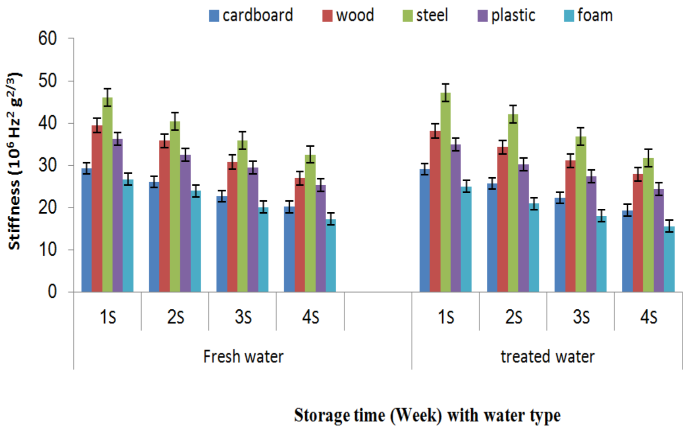

Fig. 12. Effect of storage time (week), impact surface and water type on the dynamic stiffness factor of potato tubers.

Stiffness however, is a rather complex texture trait, which differs with storage periods. It is mainly a mechanical stiffness measurement of the fruit tissue that depends on the cell wall turgidity and cell wall mechanical strength (Hertog et al., 2004). Both reduce during storage process by moisture loss and by enzymatic alterations of cell wall. Since the dynamic stiffness factor is positively and directly associated to the modulus of elasticity (Duprat et al., 1997; Van Zeebroeck et al., 2007). Baritelle and Hyde (2001) demonstrated that stiffness of tissue decreases with the decrease of turgor and in apple and potato diminished stiffness results in the raise of failure strain, as well as increasing tissue strength. Hence, tissues that are both stronger and less stiff enhance bruise threshold.

The relation between dynamic stiffness factor and storage time was showed in Fig. (13), which showed decreasing the values of dynamic stiffness factor with increasing storage time of potato tubers. On the other hand, reducing relative turgor (i.e., during storage) can decrease tissue modulus of elasticity (stiffness) which in turn becomes a specimen more self-cushioning, by redistributing an applied force over a larger area of the tuber's surface.

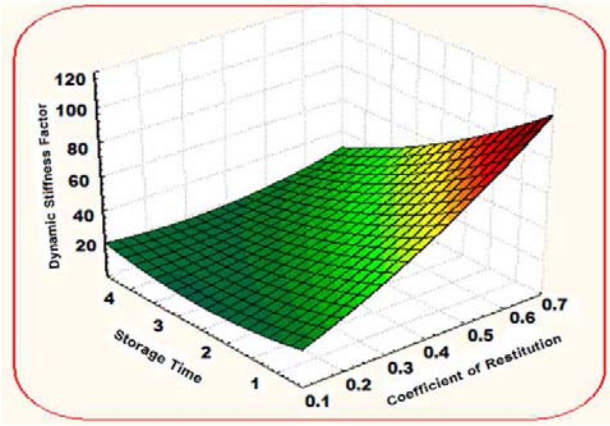

Fig. 13. Effect of storage time (W) on dynamic stiffness factor ($Hz^2kg^{2/3}$) and coefficient of restitution for tubers during dynamic impact test.

The variations in mechanical properties of tuber might be highly tissue-specific. Starch might be an important factor influencing mechanical properties of tubers (Van Dijk et al., 2002). Starch is particularly localized in the outer zone of tubers (Schick and Klinkowski, 1961). Hence, the decrease in the dynamic stiffness factor might be at least partially due to the degradation of starch and its conversion into soluble sugars in storage stage (Nourain et al., 2003; Gottschalk and Ezekiel, 2006).

It is also probable that the cortex tissue below the periderm, which has been directly compressed during the measurements, had lower water content towards the end of storage period.

4. Conclusion

The obtained data showed that the effect of impact height and surface on degree of tuber mechanical damage is essential to the steady gripping strategy of harvesting and postharvest processes. The practice of throwing the fresh potato tubers package from very high point is not healthy for this produce as this can inflict higher impact damage. Accordingly, this study has been conducted to display the fact, that increasing impact energy decreasing shelf life. Increasing impact energy applied to product, as a reason of destroying effect and mechanical damage to cell walls, cause to a loss of quality through texture softening, following by decreasing texture firmness of potato. Additionally, the data can be of great help for designers of end-effector and processing equipment in minimizing the mechanical damage resulting from mechanical collision and providing products with high quality for consumers and processors.

References

[1] Abbott, J. A., Bachman, G. S., Childers, N. F., Fitzgerald, J. V. and Matusik, F. J., 1968. Sonic technique for measuring texture of fruits and vegetables, Food Technology, 22(5), 101-112.

[2] Ahmadi, E., Ghassemzadeh, H.R., Sadeghi, M., Moghaddam, M, and Neshat, S. Z, 2010. The effect of impact and fruit properties on the bruising of peach. J. Food Eng. 97, 110－117.

[3] Ahmadi E, Ghassemzadeh HR, Sadeghi M, Moghaddam M, and Neshat S. Z, 2012. Dynamic modeling of peach fruit during normal impact. J. Food Eng. 35: 483-504.

[4] Altisent, M.R. 1991. Damage mechanisms in the handling of fruits: Progress in agricultural physics and engineering. John Matthew (Ed.), Commonwealth Agricultural Bureaux (CAB) International, Willingford, UK, pp. 231-255.

[5] Antihus Hernández Gómez, Annia García Pereira, and Wang Jun y He Yong, 2005. Acoustic testing for peach fruit ripeness evaluation during peach storage stage. Revista Ciencias Técnicas Agropecuarias, Vol. 14, No. 2.

[6] Armstrong, P. R., Stone, M. L. and Brusewitz, G.H., 1997. Nondestructive acoustic and compression measurements of watermelon for internal damage detection. Applied Engineering in Agriculture, 13(5),641-645.

[7] Aviara, N.A., Shittu, S.K, and Haque, M.A., 2007. Physical properties of guna fruits relevant in bulk handling and mechanical processing. Int. Agro physics 21, 7－16.

[8] Ayman H. Amer Eissa, Nabil S. Albaloushi, and Mostafa M. Azam, 2013. Vibration analysis influence during crisis transport of the quality of fresh fruit on food security. CIGR Journal., Vol. 15, No.3, 181:190.

[9] Bajema, R.H.; and Hyde, G.M. 1998. Instrumented pendulum for impact characteization of whole fruit and vegetable specimen. Transactions of the ASAE 41: 1399-1405.

[10] Baritelle A., Hyde G.M., Thornton R, and Bajemar., 1999. A classification system for impact related defects in potato tubers. Presented at 38th Annual Washington State Potato Conference & Trade Fair. In: Amer. J. Potato Res.,2000, 77: 143–148.

[11] Baritelle A, and Hyde GM, 2001. Commodity conditioning to reduce impact bruising. Postharvest Bio Technol 21: 331-339.

[12] Berardinelli A; Donati, V.; Giunchi, A.; Guarnieri, A; and Ragni, L. 2005. Damage to pears caused by simulated transport. J. Food Engin. 66: 219-26.

[13] Blahovec J., 2004. Shape of bruise spots in impacted potatoes. To be published. 8, 389－392.

[14] Bollen, A.F., Cox, N.R., Dela Rue, B. T, and Painter, D.J, 2001. A descriptor for damage susceptibility of population of produce. J. Agric. Eng. Res. 78, 391－395.

[15] Brusewitz, G.H., 1994. Drop impact testing applications to fruit quality. Int. Agro physics.

[16] Cho, H.-K., Choi, W.-K. and Paek, J.-H, 2000. Detection of surface cracks in shell eggs by acoustic impulse method, Transactions of the American Society of Agricultural Engineers, 43(6), 1921-1926.

[17] De Belie, N., Schotte, S., Lammertyn, J.,Nicolai, B. and De Baerdemaeker, J, 2000. Firmness Changes of Pear Fruit before and after Harvest with the Acoustic Impulse Response Technique, Journal of Agricultural Engineering Research, 77(2), 183-191.

[18] Diezma-Iglesias, B., Ruiz-Altisent, M. and Barreiro, P, 2004. Detection of Internal Quality in Seedless Watermelon by Acoustic Impulse Response, Bio-systems engineering, 88(2), 221-230.

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

[20] Elbatawi, I. E, 2008. An acoustic impact method to detect hollow heart of potato tubers, Biosystems Engineering, 100 (2), 206-213.

[21] Esehaghbeygi, A., 2010. Physical properties of common beans. Int. Agrophysics 24, 423 – 426.

[22] FAO, 2009. Faostat, http://faostat.fao.org/site/339/default.aspx, 04.01.2011.

[23] FAO,1989. Prevention of postharvest food losses: fruits, vegetables and root crops. FAO Training Series No. 17/2. Food and Agriculture Organization of the United Nations, Rome, Italy.

[24] Gilardi, G., and Sharf, I, 2002. Literature survey of contact dynamics modelling. Mechanism and Machine Theory, 37, 1213–1239.

[25] Gottschalk, K, and Ezekiel, R., 2006. Storage, In: Gopal, J., Khurana, S.M.P. (eds.), Handbook of potato production, improvement and postharvest management, 489-517, Harworth Press, Oxford, UK.

[26] Herppich, W. B., Landahl, S., Herold, B, and De-Baerdemaeker, J, 2003. Interactive effects of water status and produce texture - An evaluation of nondestructive methods, In Proceedings of the International Conference: Postharvest Unlimited, Leuven, Belgium.

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

[28] Holt, J.E.; and Schoorl, D. 1985. A theoretical and experimental analysis of effects of suspension and road profile on bruising in multilayered apple packs. J. Agric. Engin. Res. 31: 297-308.

[29] Hughes, J.C. 1980. Potatoes I: Factors affecting susceptibility of tubers to damage. Span 23: 65-75.

[30] Hyde, G.M.; Bajema, R.W.; and Zhang, W. 1993. Measurement of impact damage thresholds in fruits and vegetables. Proc. IV Int. Symp. Fruits, Nut and Vegetable Production Engineering, Valencia- Zaragoza, Spain, 22-26 March, pp. 1-9.

[31] Jaren, C, and Garcia-Pardo, E, 2002. Using non-destructive impact testing for sorting fruits. J. Food Eng. 53, 89 – 95.

[32] Jones, C.S.; Holt, J.E.; and Schoorl, D. 1991. A model to predict damage to horticultural produce during transport. J. Agric. Engin. Res. 50: 259-72.

[33] Lewis, R., Yoxall, A., Canty, L.A, and Reina Romo, E., 2007. Development of engineering design tools to help reduce apple bruising. J. Food Eng. 83, 356 – 365.

[34] Mateev, L. M., and Kostadinov, G. D., 2004. Probabilistic model of fruit removal during vibratory morello harvesting. Biosystems Engineering, 87, 425–435.

[35] Mathew, R. and Hyde. M. G, 1997. Potato impact damage thresholds. Trans. of the ASAE 40:705-709.

[36] Mohsenin, N. N. 1986. Physical properties of plant and animal materials, Vol. 1. Gordon and Breach Science Publ., New York, NY, USA.

[37] Nourain, F., Ramaswamy, H.S, and Kushalappa, A.C, 2003. Kinetics of quality changes associated with potatoes stored at different temperatures. Lebensm. Wiss. Technol. 36, 49-65.

[38] Ogut, H.; Peker, A, and Aydin, C. 1999. Simulated transit studies on peaches: Effects of containers cushion materials and vibration on elasticity modulus. J. Agric. Mechan. in Asia, Africa and Latin America 30: 59-62.

[39] Olorunda, A.O.; and Tung, M.A. 1985. Simulated transit studies on tomatoes: Effects of compressive load, container vibration and maturity on mechanical damage. J. Food Tech. 20:669-78.

[40] Pang W, Studman CJ and Ward GT., 1992. Bruising damage in apple-to-apple impact. J Agric Eng. 52: 229-240.

[41] Pearson, T. C., 2001. Detection of pistachio nuts with closed shells using impact acoustics, Applied Engineering in Agriculture, 17(2), 249-253.

[42] Praeger, U, Herppich, W. B, König, C, Herold, B and Geyer, M. 2009. Changes of water status, elastic properties and blackspot incidence during storage of potato tubers. Journal of applied botany and food quality. 83, 1-8.

[43] Puchalski, C, and Brusewitz, G.H., 2000. Apple bruise resistance determination using an electrical universal bridge. Int. Agrophysics 14, 411 – 416.

[44] Ragni, L, and Berardinelli, A., 2001. Mechanical behaviour of apples and damage during sorting and packaging. J. Agric. Eng. Res. 78, 273 – 279.

[45] Roudot, A.C.; Duprat, F.; and Wenian, C. 1991. Modeling the response of apples to loads. J. Agric. Engin. Res. 48: 249-59.

[46] Schick, R., Klinkowski, M., 1961: Die Kartoffel, VEB Deutscher Land-wirtschaftsverlag, Berlin.

[47] Schrevens, E., De Busscher, R., Verstreken, L. and De Baerdemaeker, J, 1996. Detection of hollow pears by tree based modelling on non-destructive acoustic impulse response spectra, In Proceedings of the International Post-Harvest Science Conference, Taupo, New Zealand, 1996.

[48] Shafiur Rahman, M., 1999. Handbook of Food Preservation. In: Food Science and Technology, Vol. 94., CRC Press.

[49] Shmulevich, I., Galili, N. and Howarth, M. S.,2003. Nondestructive dynamic testing of apples for firmness evaluation, Postharvest Biology and Technology, 29(3), 287-299.

[50] Singh, A.; and Singh, Y. 1992. Effect of vibration during transportation on the quality of tomatoes. J. Agric. Mechan. Asia, Africa and Latin America 23: 70-2.

[51] Van Dijk, C., Beekhuizen, J.G., Gibcens, T., Boeriu, C., Fischer, M., and Stolle-Smits, T., 2002. Texture of Cooked Potatoes (*Solanumtuberosum), 2*. Changes in Pectin Composition during Storage of Potatoes. J. Agric. Food Chem, 50,5089-5097.

[52] Van Zeebroeck M, Tijskens E, Vanliedekerke P, Deli V, De Baerdemaeker J, and Ramon H., 2003. Determination of the dynamical behavior of biological materials during impact using a pendulum device. J Sound Vibra. 266: 465–480.

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

[54] Vursavus, K.; and Ozguven, F. 2004. Determining the effects of vibration and packaging method on mechanical damage in golden delicious apples. Turkish J. Agric. 28: 311-20.

[55] Yadav S.S., 2014. Measurement of dynamic mechanical properties and resonance frequency range of different varieties of potato. DAMA International. Vol- 1 Issue-1; 2348 – 6058.

[56] Yen, M., and Wan, Y., 2003. Determination of textural indices of guava fruit using discriminate analysis by impact force. Trans. ASAE 46, 1161 – 1166.

[57] Yuwana, Y., and Duprat, F., 1998. Prediction of apple bruising based on the instantaneous impact shear stress and energy absorbed. Int. Agro physics 12, 133 – 140.