Comparison of the Mass Tissue Strength of Strawberry Fruit between Vertical and Horizontal axes

Ansar Ansar (ansar72@unram.ac.id)
University of Mataram https://orcid.org/0000-0002-4802-9799
Murad Murad
Mataram University: Universitas Mataram
Sukmawaty Sukmawaty
Mataram University: Universitas Mataram
Lulu Ilmaknun
Mataram University: Universitas Mataram

Research

Keywords: Compression test, Deformation plastic, Mass tissue, Strawberry

Posted Date: December 8th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-121671/v1

Comparison of the mass tissue strength of strawberry fruit between vertical and horizontal axes

Ansar [*)], Murad, Sukmawaty, Lulu Ilmaknun

Department of Agricultural Engineering, Faculty of Food Technology and Agroindustries

University of Mataram, Indonesia

[*)] Corresponding author: ansar72@unram.ac.id

Abstract

Background

Strawberry fruit has a thin skin layer, so it is very susceptible to tissue mass damage during post-harvest handling. This article compares the strength of the strawberry mass tissue between the vertical and horizontal axes using a compression test at different speeds and compressibility levels.

Results

The results showed that the mass tissue damage of strawberries was greater when compressed from the horizontal axis than from the vertical axis. The loading from the vertical axis obtained a combined mechanical response between the fruit structure and mass tissue cells, while from the horizontal axis the mechanical response was obtained only from the fruit structure. During compression, the fruit undergoes 3 phases of deformation, namely elastic, plastic, and permanent mass tissue damage. In the elastic deformation

phase, the fruit mass tissue has not been damaged. Along with the duration of the compression, mass tissue damage has started to occur.

Conclusion

The outer mass tissue of a strawberry is more susceptible to damage than the deep mass tissue. Therefore, the post-harvest handling process from agricultural land to the hands of consumers requires gentle handling to maintain fruit quality. The percentage of mass tissue damage of strawberries can be minimized if arranged vertically in the package. The percentage of fruit mass tissue damage obtained from this study can be used to predict changes in fruit volume non-destructively.

Keywords: Compression test; Deformation plastic; Mass tissue; Strawberry

Background

Fruit mass tissue damage is one of the most critical attributes in evaluating consumer acceptance of the quality of strawberry fruit (*Fragaria ananassa* Duch.) (Sirisomboon et al., 2012; Huang et al., 2020). This fruit is very susceptible to damage during its post-harvest quality handling (Liang et al., 2020). Damage can occur during picking in the land, the distribution process to traders and consumers, and the storage process in the supply chain (La Scalia et al., 2016; Kelly et al., 2019; Ha et al., 2020). Bruised damage can cause accelerated damage to the whole fruit during subsequent handling (Li and Thomas, 2014). Many fruits with seemingly minor damage during harvest are then discarded by traders

which results in waste and can affect economic benefits for farmers and traders (Yan et al., 2019).

For food technology, damage to fruit tissue is the behavior of tissue damage to cell mass when the fruit was exposed to excessive impact (Li et al., 2017). Fruit mass tissue damage is highly dependent on fruit texture (Sirisomboon et al., 2012). Therefore, it is very important to measure the mass tissue damage of the fruit to assess the quality of postharvest fruit (Duarte-Molina et al., 2017; Contigiani et al., 2018). Several researchers have previously estimated the tissue damage to the fruit mass during the harvesting process (Li, 2013; Li et al., 2017), then developed harvesting tools such as robotic harvesting (Ji et al., 2017).

An effort to minimize the damage to mass tissue in the fruit is an important thing to do to maintain the quality and efficiency of agricultural products. Previous studies related to bruising damage to the surface of the fruit have been investigated by Li et al. (2013) that storing the fruit for several days then evaluating it by touch. Babarinsa and Ige (2012) have described a method for evaluating bruises on tomatoes using mechanical impact parameters related to the energy absorbed. Li et al. (2013) had predicted the distribution of mechanical damage to tomatoes using finite element simulations. Besides, there are several studies on the calculation of the volume of tissue damage to the mass of fruit after harvest by measuring fruit anatomy, such as apples (Celik et al., 2011), oranges (Ihueze and Mgbemena, 2017), passion fruit (Ansar et al., 2019), but this method is not suitable for strawberries because of the color of the mass tissue the broken and the undamaged look the same.

The results of the study Aliasgarian et al. (2015) illustrated that 'Selva' variety of strawberries cannot be sold if the skin has abrasions or bruises on the surface and more than 50% of the strawberries cannot be sold due to damage caused by impact during transportation. Chaiwong and Bishop (2015) reported that a vibration frequency ranging from 3 to 5 Hz affected the quality of the 'Elsanta' strawberry. Kelly et al. (2019) explained that the quality of the strawberries can be maintained by keeping the temperature constant during post-harvest handling.

The results of research on the quality of strawberries were more dominated by changes in fruit quality during post-harvest, such as the freshness of strawberries depending on the fruit variety (Pham and Liou, 2017; Zeliou et al., 2018), storage time and conditions (La Scalia et al., 2016), storage method (Contigiani et al. 2018; Yan et al., 2019; Zhang et al., 2018), while the effect of vibration affects fruit firmness (Chaiwong and Bishop, 2015). The firmness of the fruit is a physical characteristic that describes the most important qualities of a strawberry. Many factors influence the firmness of strawberries, such as genetics, growing conditions, level of maturity, size, postharvest handling, and internal temperature (Doving and Mage, 2002). Fruit strength data is also influenced by the test method used and until now there is no standard test method for the texture strength of strawberries (Fu et al., 2008).

Information about the damage to the mass tissue of strawberries caused by compression, the direction of loading, and the percentage of fruit mass tissue damage is still limited. As a result, it is difficult to quantitatively assess the mass tissue damage and deformation of the strawberry fruit. This gap also hinders the development of non-destructive methods for fruit quality analysis (Zude et al., 2019) and limits the opportunity

to investigate the influence of external stresses during harvest (Zhuang et al., 2019), appropriate packaging and transportation methods for distribution processes (Li et al., 2017). Therefore, this study aimed to compare the strength of the strawberry fruit mass between the vertical and horizontal axes using a compressive test at different speeds and levels of compressibility.

Materials and Methods

Material

The ingredients used are strawberries with Sweet Charlie varieties. This fruit is obtained from agricultural farmers in Sembalun, East Lombok, Indonesia. After being carefully transported to the Bioprocess Engineering Laboratory of the University of Mataram, the fruit is then cleaned manually with water and checked again to make sure it is not damaged and not infected. The test is carried out within 24 hours at room temperature (29±1 °C) and RH 60-65%.

Deformation Test

The sample deformation test used a texture analyzer under the Brookfield brand (Fig. 1). Loading was done from the vertical and horizontal axes. The variations in compression speed are 2, 4, and 6 mm/s, and the compressibility levels are 6, 12, 18, 24, and 30%. Each test was repeated 3 times. The deformation curve of the test results is recorded in real-time.

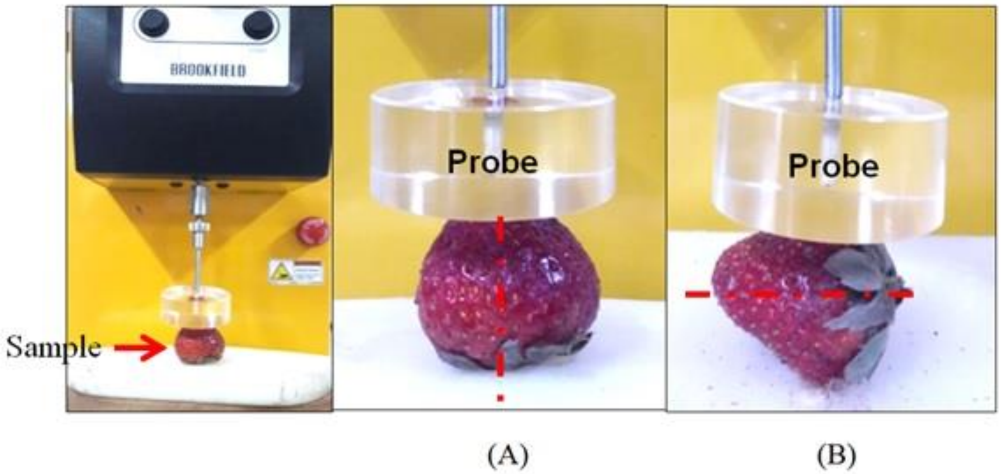

Fig. 1. Strawberry fruit deformation test, (A) compression from vertical axis direction, and (B) compression from horizontal axis direction.

Determination of the percentage of fruit deformation

The percentage of fruit deformation after compression can be calculated using the equation (Tabacu and Ducu, 2020):

$$\varepsilon c = \frac{\Delta L}{L} \times 100 \qquad (1)$$

where εc is the fruit deformation (%), ΔL is the difference in sample length before and after testing (mm), and L is the initial length of the sample (mm).

Determination of the percentage of fruit mass tissue damage

After being compressed, each sample was halved and then placed on a table for 5 hours to wait for the enzymatic browning reaction. Furthermore, the tissue damage to the

sample mass marked with brown color is separated and then weighed using an electronic scale.

The water loss ratio (η) during storage at 5 hours for the control group sample was calculated using Equation (2):

$$\eta = \frac{m_o - \dot{m}_0}{m_0} \qquad (2)$$

where η is the ratio of fresh fruit water loss in the control group (m_0) and ($\dot{m}_0$) is the mass of fresh fruit after 5 hours of storage in the control group.

The brown mass tissue was associated with the mass tissue of the fruit mass damaged during compression and the non-brown mass tissue associated with the mass tissue of the fruit mass that was not damaged. Compressed fruit has the same rate of water loss within 5 hours after splitting. Therefore, the m_4 mass of the damaged mass tissue in each sample and the percentage of damaged mass tissue (R) were calculated using Equations (3) and (4) (Xu et al., 2006).

$$m_4 = m_1 - m_2 - m_3 = m_1 - m_1\eta - m_3 \qquad (3)$$

$$R = \frac{m_4}{m_1} \times 100\% \qquad (4)$$

where m_1 is the initial mass of fresh fruit in the experimental group (g), m_2 is the mass of water loss in the compressed fruit after 5 hours of storage (g), m_3 is the mass of undamaged tissue mass in the compressed fruit after 5 hours of storage (g), m_4 is the mass of tissue mass damaged in the compressed fruit after 5 hours of storage (g), and R is the percentage of the mass of damaged fruit tissue after 5 hours of storage (%).

Statistical analysis

Two-factor analysis of variance was used to determine the ratio of tissue damage to the mass of strawberries between the vertical and horizontal axes after being compressed with different compression speeds and levels of compressibility. The difference is considered significant if the probability value less than 0.05 ($P<0.05$) (Ansar et al., 2020).

Results and Discussion

Effect of compression direction on fruit mass tissue damage

Fruit compressed from the vertical direction showed less tissue mass damage when compared to the horizontal direction (Fig. 2). This is thought to occur because the strawberries are elliptical so that the curvature contour on the horizontal axis is much greater than the vertical axis. As a result, the number of cells was compressed more on the horizontal axis than on the vertical axis, so the damage on the horizontal axis is greater than on the vertical axis. The results showed that the compression direction had a significant effect ($P<0.05$) on the fruit mass tissue damage.

Fruit mass tissue damage always occurs in areas in direct contact with the probe. The mass tissue damage at the equator is always greater than that in the fruit stalk. This is related to the curvature of the fruit contour at the equator, where the contact surface is smaller than that of the fruit stalk. This data is in line with the results of the study reported by An et al. (2020) that the percentage of fruit mass tissue damage was lower in the fruit stalk compared to the mass tissue damage that was near the probe which was compressed on the vertical axis.

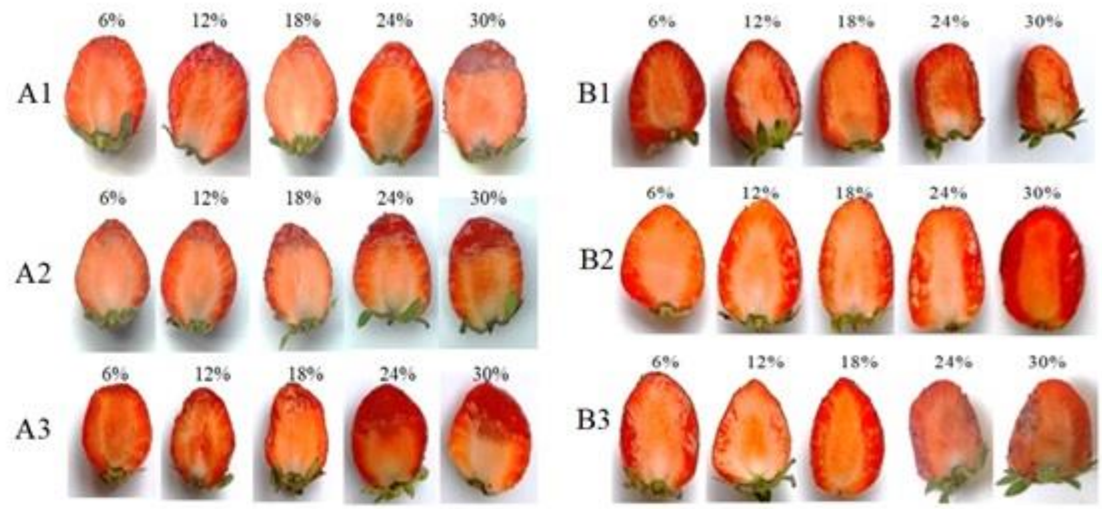

Fig. 2. Fruit mass tissue damage after compression, (A1, A2, and A3) compression from the vertical direction, and (B1, B2, and B3) compression from the horizontal direction at velocities 2, 4, and 6 mm/s.

At the beginning of the loading, the outer mass tissue more quickly receives the compressive force when compressed from the vertical direction because the outer layer is close to the fruit flower. When compressed from the horizontal direction, the probe exerts a compressive force on the outer mass tissue. Therefore, when the fruit is in the plastic deformation stage during compression, the peak force is higher from the vertical than in the horizontal direction. Besides, because the strawberry is elliptical, the curvature of the fruit from the vertical is much smaller than the contour from the horizontal. This shows that strawberries are more susceptible to mass tissue damage when loading is carried out from the horizontal direction than from the vertical direction.

At the time of loading the probe is only able to compress a small portion of the mass network that is from the vertical direction and compress the mass network more widely

when loading from the horizontal direction. As a result, strawberries that experience a loading force from the horizontal direction show a higher resistance than from the vertical direction. These findings indicate that the percentage of tissue damage to the mass of strawberries can be minimized if the fruit is arranged vertically in the package. Similar results have been found by Sadrnia et al. (2008) for watermelons, Li et al. (2015) for tomatoes, Perez-Lopez et al. (2014) for peaches, and Liu et al. (2019) for apples.

When the fruit is compressed, the fruit cells at the bottom of the probe experience a high compression curve, while the adjacent cells experience tension or bending. The direction of compression has a significant effect on tissue damage to the fruit mass. The damage to the fruit mass tissue was greater in the horizontal direction than in the vertical axis. Compression from the direction of the vertical axis produces a combined mechanical response between the fruit structure and cell tissue mass. However, compression from the direction of the horizontal axis of the mechanical response only results from the structure of the fruit. The results of this study are in line with the results of the research reported by Li et al. (2014) that compression from the horizontal axis only provides a mechanical response from the dense biomaterial tissue mass so that the fruit cell structure becomes weak.

This finding is very useful because evaluating the percentage of fruit mass tissue damage is tedious and challenging to produce accurate data, whereas the energy absorbed is easily measured by simply a compressive test. The same thing was revealed by Miraei-Ashtiani et al. (2019) that the tissue damage to fruit mass is closely related to fruit mechanics which can be measured quantitatively using the parameters of the energy absorbed.

3.2. Effect of compression speed on fruit mass tissue damage

The observational data showed that the compression rate had a significant effect on the tissue damage to the fruit mass. Fruit suffers a large percentage of damage at high loading speeds. Fruit compressed from the vertical axis and the horizontal axis always had a greater percentage of damage at a compression speed of 6 mm/s than at 4 and 2 mm/s (Fig. 3).

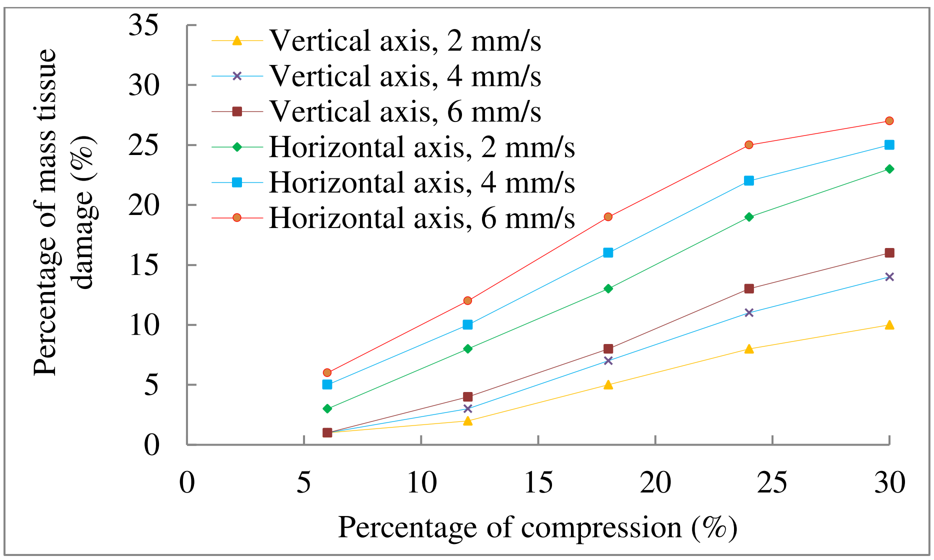

Fig. 3. Percentage curve of fruit mass tissue damage at the compression rate of 2, 4, and 6 mm/s.

The results of the analysis of variance show that the F-count value (78.088) is greater than the F-crit value (2.776) (Table 1). This means that there is a significant effect ($P<0.05$) of compression speed on the damage to fruit mass tissue. When the fruit is compressed from the direction of the vertical or horizontal axis, the damage to the fruit tissue at a compression rate of 6 mm/s is always greater than that of 4 and 2 mm/s. This is presumably because when the fruit is compressed, the mass tissue of the fruit experiences a volume

reduction in a short and fast time. Consequently, the fruit provides a high defensive force to the probe because the impulses applied are the same for all compression rates of 2, 4, and 6 mm/s.

Table 1. Analysis of variance on the effect of compression speed on fruit mass tissue damage.

Source of Variation	SS	df	MS	F	P-value	F-crit
Rows	1424.171	4	356.043	78.088	2.115E-13	2.776
Columns	830	6	138.333	30.339	4.523E-10	2.508
Error	109.429	24	4.560			
Total	2363.600	34				

Another thing that needs to be expressed is that the strawberry fruit is elliptical, so when compressed at high speed, the compressed fruit cells get bigger (Fig. 3). The percentage of damage gradually increases with increasing compression speed. The phenomenon of increasing the percentage of fruit mass tissue damage is similar to the results of studies reported by Kohyama et al. (2013) that the tissue mass of strawberries when compressed at high speed always shows large tissue damage. The tissue damage to the mass of strawberries compressed at high speed was greater than that compressed at low speed (Singh et al., 2014). Therefore, the process of distributing fruit from agricultural land to markets needs to be done carefully to avoid collisions. Based on these results, it is necessary to consider the compression load threshold to maintain the quality of the fruit during post-harvest handling, packaging, and transportation.

Effect of compressibility level on fruit mass tissue damage

The research data showed that the compressibility level had a significant effect ($P<0.05$) on the percentage of fruit mass tissue damage (Fig. 3). At the beginning of compression, the percentage of fruit mass tissue damage increases rapidly then decreases slowly. The percentage of fruit mass tissue damage that is in direct contact with the surface of the probe contact area increases gradually during loading before permanent tissue damage occurs. Likewise, the number of compressed cells increases gradually, and in the end, the fruit undergoes 3 phases of deformation, namely elastic, plastic, and permanent mass tissue damage.

Based on the analysis of variance, it is known that the F-count value (450.571) is greater than the F-Crit value (3.838) (Table 2). This shows that the fruit has different cell structures due to the different physical characteristics of the fruit with different loading directions. This phenomenon is important as the basis for determining the fruit transport design model.

Table 2. Analysis of the variance of the effect of the compressibility level on the damage to fruit mass tissue.

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	841.067	4	210.267	450.571	1.911E-09	3.838
Columns	52.933	6	26.467	56.714	1.882E-05	4.459
Error	3.733	24	4.467			
Total	897.733	34				

Collisions always occur during postharvest handling and transportation because the fruit at the bottom of the container can be subjected to additional compressive forces from the container. Fruit mass tissue damage can occur if the compressive force exceeds the

threshold strength of the fruit mass tissue. Due to its viscoelastic nature, the mass tissue of the fruit can be damaged even with the slightest impact but occurs repeatedly (Link et al., 2018). The compression movement that occurs repeatedly consists of 2 models, namely compression between fruit and fruit and compression from solid to fruit.

Strawberry fruit deformation

The research data show that during compression, there is deformation and the surface contact area increases with increasing compression force (Fig. 4). This phenomenon can be illustrated using a circular contact plane theory approach, where the size of the contact area is smaller than the radius of the contact surface so that the contact surface area is elliptical. Jahanbakhshi et. al. (2018) have explained that contact plane theory can be used to predict the collision behavior between 2 round pieces during compression, but it is difficult to measure and validate the compressive forces and fruit deformations that occur during compression.

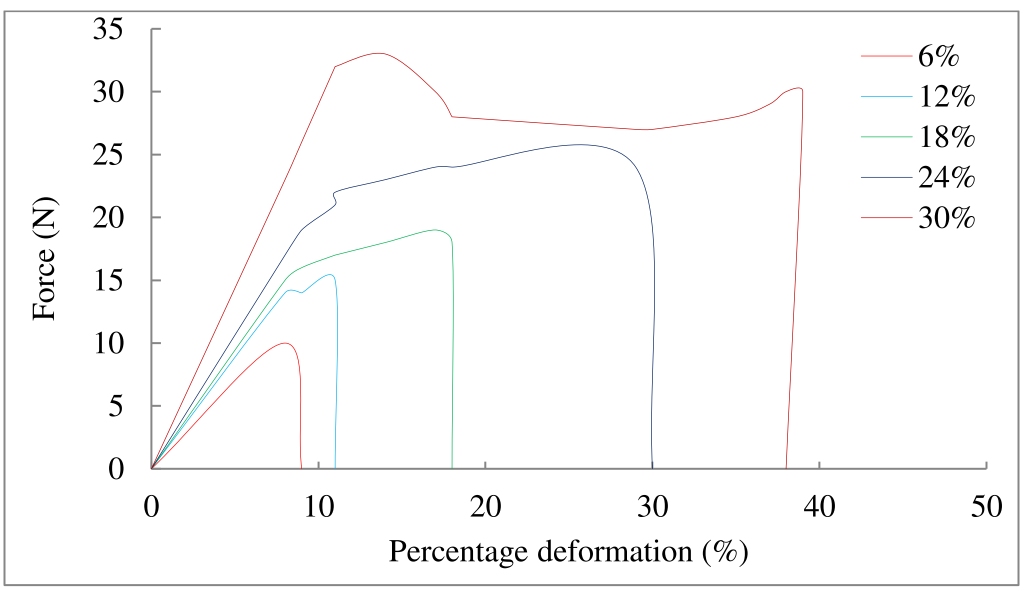

Fig. 4. Deformation curve of the compressed strawberry fruit from the vertical axis at different speeds and compressibility levels.

The compressibility level was 6%, the deformation curve was close to linear and no brown color appeared on the longitudinal equatorial part of the fruit at any load (Fig. 5). This shows that the compressibility level is 6% as the elastic deformation limit for compression in the direction of the vertical axis with velocities of 2, 4, and 6 mm/s. Before the inflection point, the deformation curve looks linear. After the inflection point is reached, the deformation percentage no longer increases, although the loading force tends to increase. However, the percentage of brown color in the longitudinal equatorial portion of each sample increased very rapidly with increasing fruit deformation.

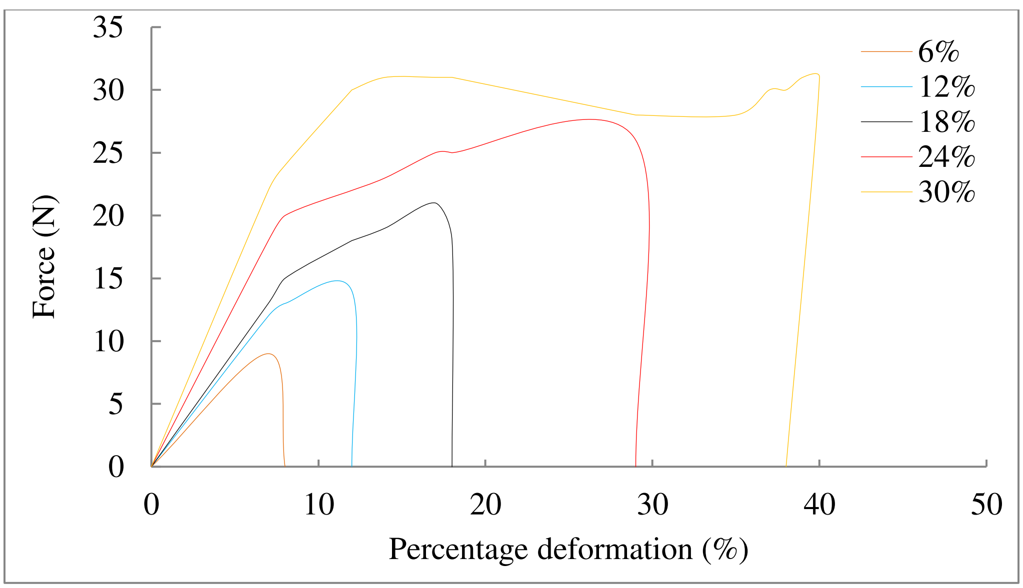

Fig. 5. Deformation curve of strawberry which is compressed from the horizontal axis at different speeds and compressibility levels.

Fig. 5 shows the deformation curve of a strawberry fruit compressed from the horizontal axis at different speeds and degrees of compressibility having a similar pattern to the compressed sample from the vertical axis, where the deformation of 6% is considered the elastic deformation limit. The inflection point is seen at a compression speed of 2 mm/s and a compressibility level of 6%. The point of this curve is the limit of the plastic deformation susceptibility of the sample to the load from the horizontal axis.

The compressibility level of 24% is the limit of the percentage of plastic deformation that causes damage to the inner tissue of the fruit when compressed from the horizontal axis at speeds of 2, 4, and 6 mm/s. When the compressibility level is more than 24% at a compression speed of 2 mm/s or 30% at a compression speed of 6 mm/s, the percentage of fruit brown increases with the increasing percentage of deformation. In contrast, the percentage of brown color decreases at the longitudinal equator when the compressibility is less than 24% at a compression rate of 2 mm/s or 30% at a compression rate of 6 mm/s. The same study had reported by Braun and Ivanez (2020) that the difference in outcome between cell sizes was more pronounced at a 10% damage percentage. However, the difference between the three cell sizes shows a variation of not more than 6% and the highest percentage of damage was around 50%.

During compression, the fruit undergoes 3 phases of deformation, namely elastic, plastic, and permanent mass tissue damage. In the elastic deformation phase, the fruit has not been damaged. As the compression time increases, permanent mass tissue damage begins to occur. In this phase, the fruit cells begin to break and break down on the skin, causing damage to the fruit structure.

Conclusions

Strawberry fruit undergoes three stages of deformation during compression, namely elastic deformation, plasticity, and permanent damage to tissue mass. The amount of energy absorbed depends on the direction of the axis and the speed of compression, whereas the percentage of mass damaged depends only on the direction of the compression axis. Fruit mass tissue damage is greater when compressed from the horizontal axis than the vertical axis. Compression from the direction of the vertical axis produces a combined mechanical response between the fruit structure and cell tissue mass. However, on the horizontal axis, the mechanical response results only from the fruit structure.

The outer mass tissue of a strawberry is more susceptible to damage than the deep mass tissue. Therefore, the post-harvest handling process from agricultural land to the hands of consumers requires gentle handling to maintain fruit quality. The percentage of mass tissue damage of strawberries can be minimized if arranged vertically in the package. The percentage of fruit mass tissue damage obtained from this study can be used to predict changes in fruit volume non-destructively. These findings provide the information needed to develop more efficient and effective packaging methods.

Availability of data and materials

The dataset used and/or analyzed from this study will be provided upon request.

References

Aliasgarian, S., Ghassemzadeh, H. R., Moghaddam, M., and Ghaffari, H. (2015). Mechanical damage of strawberry during harvest and postharvest operations. *Acta Technologica Agriculturae, 18*(1), 1–5.

An, X; Li, Z; Zude-Sasse, M; Tchuenbou-Magaia, F; Yang, Y. (2020). Characterization of textural failure mechanics of strawberry fruit. *Journal of Food Engineering, 282*, 110016.

Ansar, Nazaruddin, and Azis, A. D. (2019). Effect of vacuum freeze-drying condition and maltodextrin on the physical and sensory characteristics of passion fruit (Passiflora edulis Sims) extract. In Iqbal (Ed.), *International Symposium on Agriculture and Biosystem Engineering. 1*, pp. 1-12. Makassar: IOP Conference Series: Earth and Environmental Science.

Ansar, Nazaruddin, and Azis, A. D. (2020). Caking mechanisms of passion fruit powder during storage. *International Journal of Innovation, Creativity, and Change, 13*(2), 618-628.

Babarinsa, F. A., and Ige, M. T. (2012). Strength parameters of packaged roma tomatoes at breakpoint under compressive loading. *International Journal of Scientific and Engineering Research, 3*(10), 1-8.

Braun, M., and Ivanez, I. (2020). Numerical study of damaged micro-lattice blocks subjected to uniaxial compressive loading. *Extreme Mechanics Letters, 39*(100821).

Celik, H. K., Rennie, A. W., and Akinci, I. (2011). Deformation behavior simulation of an apple under drop case by finite element method. *Journal of Food Engineering, 104*(2), 293–298.

Chaiwong, S., and Bishop, C. F. (2015). Effect of vibration damage on the storage quality of 'Elsanta' strawberry. *Australian Journal of Crop Science, 9*(9), 859–864.

Chaves, V. C., Calvete, E., and Reginatto, F. H. (2017). Quality properties and antioxidant activity of seven strawberries (Fragaria x ananassa Duch) cultivars. *Scientia Horticulturae, 225*, 293–298.

Contigiani, E. V., Jaramillo-Sanchez, G., Castro, M. A., Gomez, P. L., and Alzamora, S. M. (2018). Postharvest quality of strawberry fruit (Fragaria x ananassa Duch Cv. Albion) as affected by Ozone washing: fungal spoilage, mechanical properties, and structure. *Food Bioprocess Technology, 11*(9), 1639–1650.

Doving, A., and Mage, F. (2002). Methods of testing strawberry fruit firmness. *Acta Agriculturae Scandinavica, Section B-Soil and Plant Science, 52*(1), 43–51.

Duarte-Molina, F., Gomez, P. L., Castro, M. A., and Alzamora, S. M. (2016). Storage quality of strawberry fruit treated by pulsed light: fungal decay, water loss, and mechanical properties. *Innovative Food Science and Emerging Technologies, 34*, 267–274.

Fu, X., Ying, Y., Zhou, Y., Xie, L., and Xu, H. (2008). Application of NIR spectroscopy for firmness evaluation of peaches. *Journal of Zhejiang University SCIENCE B, 9*(7), 552–557.

Ha, J., Choi, S. M., Shin, B., Lee, M., Jung, W., and Kim, H. Y. (2020). Hygroresponsive coiling of seed awns and soft actuators. *Extreme Mechanics Letters, 38*(1), 1-6.

Huang, X., Pan, Q., Lin, Y., and Gu, T. (2020). A native chromatin immunoprecipitation (ChIP) protocol for studying histone modifications in strawberry fruits. *Plant Methods,* 16, 10. doi: 10.1186/s13007-020-0556-z.

Ihueze, C. C., and Mgbemena, C. E. (2017). Design for limit stresses of Orange fruits (Citrus sinensis) under axial and radial compression as related to transportation and storage design. *Journal of the Saudi Society of Agricultural Sciences, 16*, 72–81.

Jahanbakhshi, A., Abbaspour-Gilandeh, Y., and Gundoshmian, T. M. (2018). Determination of physical and mechanical properties of carrots in order to reduce waste during harvesting and post-harvesting. *Food Science and Nutrition, 6*(7), 1898–1903.

Ji, W., Qian, Z., Xu, B., Tang, W., Li, J., and Zhao, D. (2017). Grasping damage analysis of apple by end-effector in harvesting robot. *Journal of Food Process Engineering, 40*(6), e12589.

Kelly, K., Madden, R., Emond, J. P., and Do Nascimento Nunes, M. C. (2019). A novel approach to determine the impact level of each step along the supply chain on strawberry quality. *Postharvest Biology and Technology, 147*, 78–88.

Kohyama, K., Kato-Nagata, A., Shimada, H., Kazami, Y., and Hayakawa, F. (2013). The texture of sliced cucumbers measured by subjective human-bite and objective instrumental tests. *Journal of Texture Studies, 44*(1), 1–11.

La Scalia, G., Aiello, G., Miceli, A., Nasca, A., Alfonzo, A., and Settanni, L. (2016). Effect of vibration on the quality of strawberry fruits caused by simulated transport. *Journal of Food Process Engineering, 39*(2), 140–156.

Li, Z. (2013). The effect of compressibility, loading position, and probe shape on the rupture probability of tomato fruits. *Journal of Food Engineering, 119*(3), 471–476.

Li, Z., Li, P., Yang, H., and Liu, J. (2013). Internal mechanical damage prediction in tomato compression using multiscale finite element models. *Journal of Food Engineering, 116*(13), 639–647.

Li, Z., Lv, K., Wang, Y., Zhao, B., and Yang, Z. (2015). Multi-scale engineering properties of tomato fruits related to harvesting, simulation, and textural evaluation. *LWT– Food Science and Technology, 61*(2), 444–451.

Li, Z; Andrews, J; Wang, Y. (2017). Mathematical modeling of mechanical damage to tomato fruits. *Postharvest Biology and Technology, 126*, 50–56.

Li, Z; Miao, F; Andrews, J. (2017). Mechanical models of compression and impact on fresh fruits. *Comprehensive Reviews in Food Science and Food Safety, 16*(6), 1296–1312.

Li, Z; Thomas, C. (2014). Quantitative evaluation of mechanical damage to fresh fruits. *Trends Food Science and Technology, 35*(2), 138–150.

Liang, Z., Xu, L., Baerdemaeker, J., Li, Y., and Saeys, W. (2020). Optimization of a multi-duct cleaning device for rice combine harvesters utilizing CFD and experiments. *Biosystems Engineering, 190*, 25–40.

Link, J. V., Tribuzi, G., Oliveira de Moraes, J., and Laurindo, J. B. (2018). Assessment of texture and storage conditions of mangoes slices dried by a conductive multi-flash process. *Journal of Food Engineering, 239*, 8–14.

Liu, S., Yang, H., Bian, Z., Tao, R., Chen, X., and Lu, T. (2019). Regulation on mechanical properties of spherically cellular fruits under osmotic stress. *Journal of the Mechanics and Physics of Solids, 127*, 182–190.

Miraei Ashtiani, S. H., Sadrnia, H., Mohammadinezhad, H., Aghkhani, M. H., Khojastehpour, M., and Abbaspour-Fard, M. H. (2019). FEM-based simulation of the mechanical behavior of grapefruit under compressive loading. *Scientia Horticulturae, 245*, 39–46.

Perez-Lopez, A., Chavez-Franco, S. H., Villaseor-Perea, C. A., Espinosa-Solares, T., Hernandez-Gomez, L. H., and Lobato-Calleros, C. (2014). Respiration rate and mechanical properties of peach fruit during storage at three maturity stages. *Journal of Food Engineering, 142*, 111–117.

Pham, Q. T., and Liou, N. S. (2017). Investigating the texture and mechanical properties of Asian pear flesh by compression tests. *Journal of Mechanical Science and Technology, 31*(8), 3671–3674.

Sadrnia, H., Rajabipour, A., Jafari, A., Javadi, A., Mostofi, Y., Kafashan, J., et al. (2008). Internal bruising prediction in watermelon compression using nonlinear models. *Journal of Food Engineering, 86*(2), 272–280.

Singh, F., Katiyar, V. K., and Singh, B. P. (2014). Analytical study of turgor pressure in apple and potato tissues. *Postharvest Biology and Technology, 89*, 44–48.

Sirisomboon, P., Tanaka, M., and Kojima, T. (2012). Evaluation of tomato textural mechanical properties. *Journal of Food Engineering, 111*(4), 618–624.

Sirisomboon, P; Tanaka, M; Kojima, T. (2012). Evaluation of tomato textural mechanical properties. *Journal of Food Engineering, 111*, 618–624.

Tabacu, S., and Ducu, C. (2020). Numerical investigations of 3D printed structures under compressive loads using damage and fracture criterion: Experiments, parameter identification, and validation. *Extreme Mechanics Letters, 39*(100775), 1-15.

Xu, Y., Zhang, M., Mujumdar, A. S., Duan, X., and Jin-cai, S. (2006). A two-stage vacuum freeze and convective air-drying method for strawberries. *Drying Technology: An International Journal, 24*(8), 1019-1023.

Yan, J., Luo, Z., Ban, Z., Lu, H., Li, D., Yang, D., et al. (2019). The effect of the layer-by-layer (LBL) edible coating on strawberry quality and metabolites during storage. *Postharvest Biology and Technology, 147*, 29–38.

Zeliou, K., Papasotiropoulos, V., Manoussopoulos, Y., and Lamari, F. N. (2018). Physical and chemical quality characteristics and antioxidant properties of strawberry cultivars (*Fragaria ananassa* Duch.) in Greece: assessment of their sensory impact. *Journal of the Science of Food and Agriculture, 98*(11), 4065–4073.

Zhang, C., Li, W., Zhu, B., Chen, H., Chi, H., Li, L., et al. (2018). The quality evaluation of postharvest strawberries stored in Nano-Ag packages at refrigeration temperature. *Polymers, 10*, 1–17.

Zhuang, J., Hou, C., Tang, Y., He, Y., Guo, Q., Zhong, Z., et al. (2019). Computer vision-based localization of picking points for automatic litchi harvesting applications towards natural scenarios. *Biosystems Engineering, 187*, 1–20.

Zude, M., Hashim, N., Hass, R., Polley, N., and Regen, C. (2019). Validation study for measuring absorption and reduced scattering coefficients by means of laser-induced backscattering imaging. *Postharvest Biology and Technology, 153*, 161–168.

Acknowledgments

The authors gratefully acknowledge the Faculty of Food Technology and Agroindustries, the University of Mataram for all supporting facilities in this research.

Funding

Not applicable.

Conflict of Interest

The authors declare that they have not a conflict of interest that could have appeared to influence the work reported in this paper.

Author Information

Ansar, Murad, Sukmawaty, Lulu Ilmaknun

Department of Agricultural Engineering, Faculty of Food Technology and Agroindustries University of Mataram, Indonesia

Contributions

AS and MR conducted the research. SW and LI analyzed the data. SW and LI compiled designed experiments and edited manuscripts. AS and MR wrote the draft manuscript. All authors contributed to writing, correcting, and reviewing the final manuscript. All authors read and approved the final manuscript.

Ethics declarations:

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors claim that they have no competing interests.

Figures

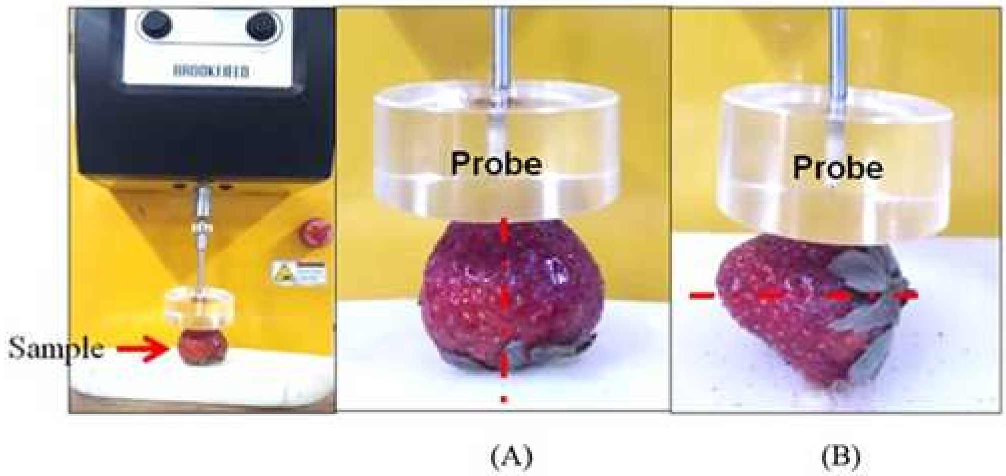

Figure 1

Strawberry fruit deformation test, (A) compression from vertical axis direction, and (B) compression from horizontal axis direction.

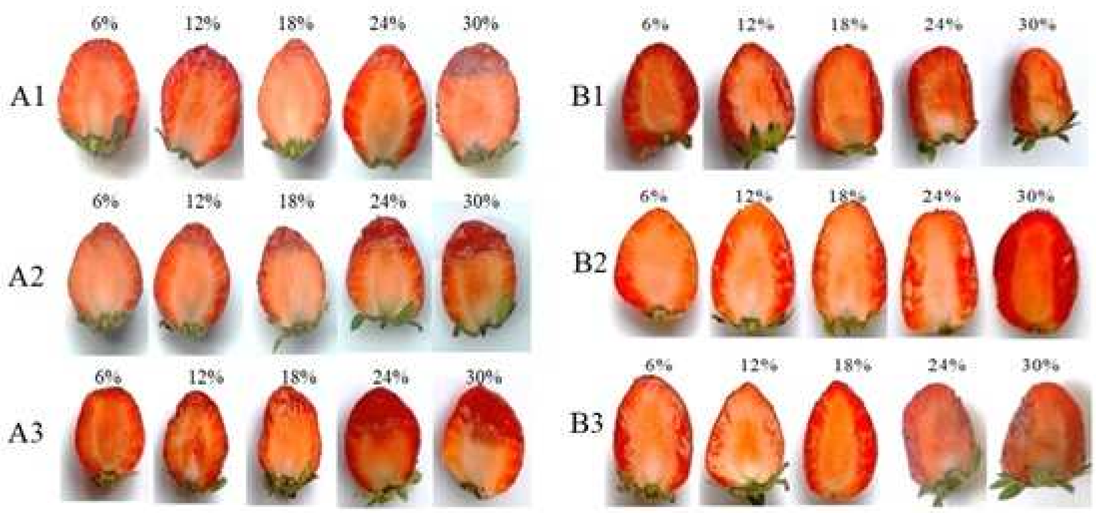

Figure 2

Fruit mass tissue damage after compression, (A1, A2, and A3) compression from the vertical direction, and (B1, B2, and B3) compression from the horizontal direction at velocities 2, 4, and 6 mm/s.

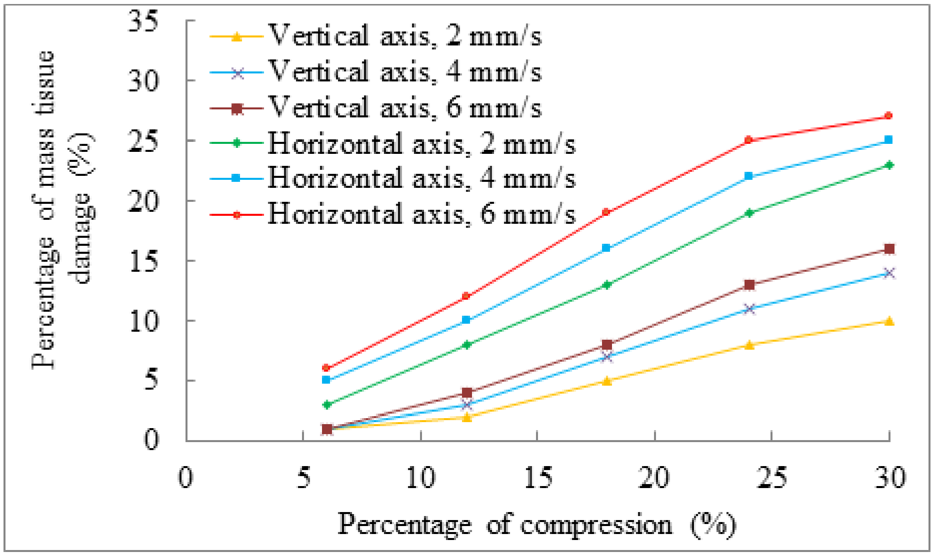

Figure 3

Percentage curve of fruit mass tissue damage at the compression rate of 2, 4, and 6 mm/s.

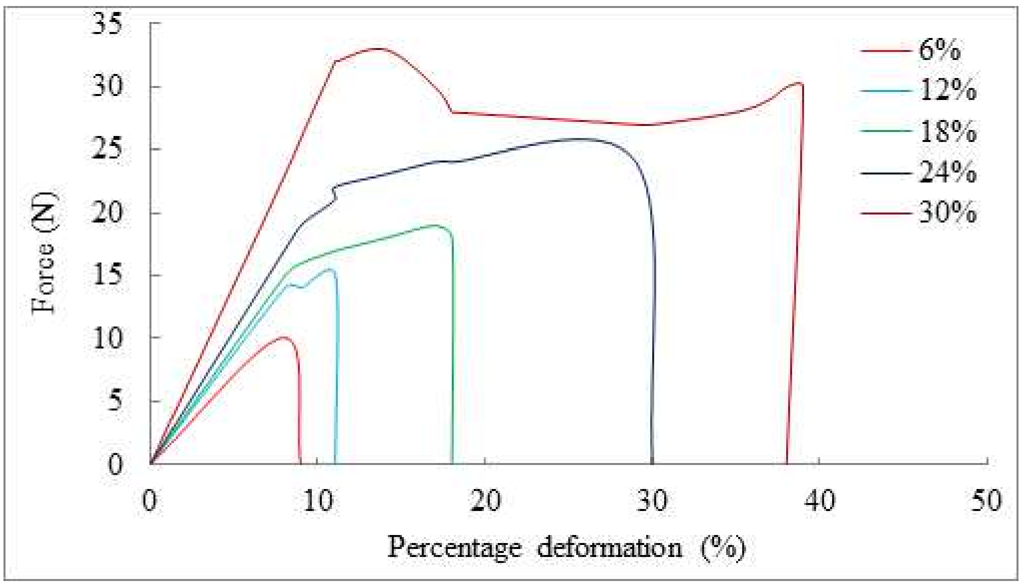

Figure 4

Deformation curve of the compressed strawberry fruit from the vertical axis at different speeds and compressibility levels.

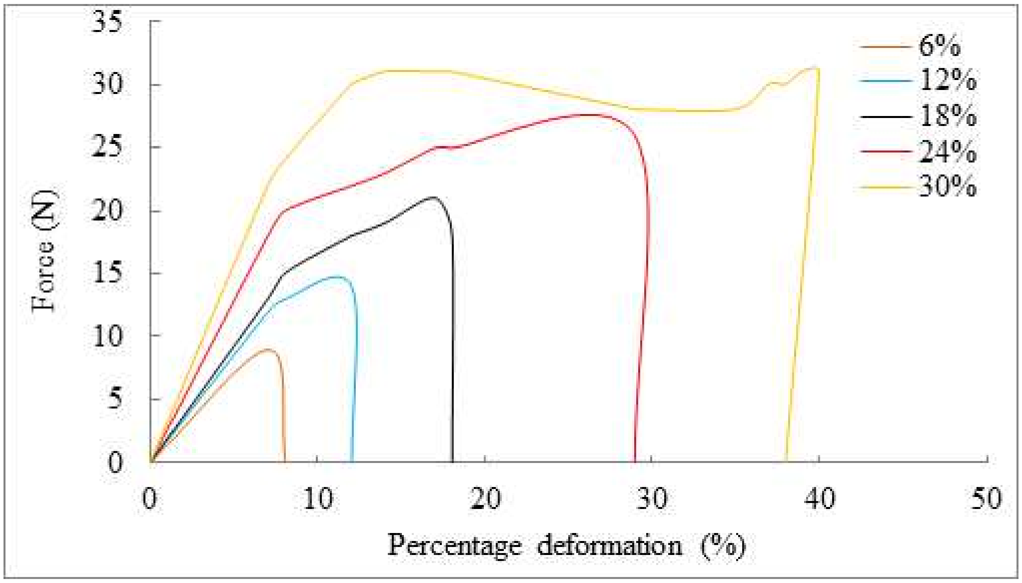

Figure 5

Deformation curve of strawberry which is compressed from the horizontal axis at different speeds and compressibility levels.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- GraphicalAbstract.docx