Journal of Engineering Science and Technology
Vol. 12, No. 2 (2017) 460 - 470


# VARIABILITY AND PREDICTABILITY OF MALAYSIAN EXPORT-GRADE STARFRUIT PROPERTIES

NORHASHILA HASHIM[1*], RIMFIEL B. JANIUS[1],
AZIZAH OSMAN[2], JAMAREI OTHMAN[1]

[1]Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor Darul Ehsan, Malaysia
[2]Faculty of Food Science and Technology, Universiti Putra Malaysia, 43400 Serdang, Selangor Darul Ehsan, Malaysia
*Corresponding Author: norhashila@upm.edu.my

**Abstract**

The properties of commercially-graded B10 cultivar starfruit (Averrhoa carambola) namely length, diameter, mass, volume, the five colours values (L, a*, b*, C, h°), firmness, total soluble solids (TSS), titratable acidity (TA) and pH were measured. Coefficients of variation (CV), correlation and property tolerances were evaluated to develop a relationship between the non-destructively measurable external properties and the non-destructively immeasurable internal properties. The length, diameter, mass and hue were found to have low CV levels. Mass appears to have a very strong correlation with volume while hue has a strong correlation with firmness.

Keywords: Variation Coefficient, Starfruit, Fruit Quality, Predictability.

## 1. Introduction

Starfruit (*Averrhoa carambola*) was introduced and commercialised for the world market over 100 years ago and is a tropical fruit that is well established in the market. Starfruit is Malaysia's most exported exotic fruit and is mostly marketed overseas. The demand for this fruit increases yearly and sometimes exceeds the supply capacity [1]. Currently in Malaysia the sorting and grading of starfruit are done manually. Should the grade tolerances be exceeded, the packed fruits will be rejected, necessitating regrading and repackaging at either the wholesaler or retailer levels. This results in increased production cost and wastage of time. The fruits are sorted and graded based only on mass and colour [2]. The internal qualities at this stage such as sweetness and sourness are therefore not determinable. The researchers in [3] reported the composition of starfruit varied widely during maturation. The physical and chemical properties such as length, diameter, fresh weight, dry weight, pH and total sugars increased as the fruits mature and ripen. However, to date, suitable non-destructive measurement methods for internal qualities are unavailable.

Non-destructive techniques would allow each and every one of the fruits to be re-tested several times throughout their shelf life, and thus wastage and disposal or mess problems due to the need to dispose of destroyed fruits could be reduced or even eliminated [4 - 7]. One of the important requirements of a property as a practical quality indicator is that the property must be non-destructively measurable. The destructive methods are impractical as they involve impairment of the physical conditions of the fruits, rendering them unsuitable for sale and such methods are time-consuming [8]. Consequently, a destructive method can be carried out on random samples only, reducing the accuracy of the sorting and grading processes. Even if the results of the measurements are favourable, they are true only for the destroyed samples. If fruit internal quality measurements can be correlated well with some non-destructively measurable external qualities then a reliable and rigorous non-destructive quality prediction regime has been found.

Compared to the point when they were sorted and graded, visual and taste uniformities are expected to be different at the retail stage when the fruits are expected to be riper. Then, while the perception of visual uniformity in the physical properties such as length, diameter, mass and hue can be expected to be quite objective, the perception of uniformity in firmness and taste properties such as sweetness, acidity, palatability and texture would probably be more varied and depend on the subjective acceptance level of the individual [9]. Therefore, the aim of this study is to investigate, among the graded starfruits, how internal properties such as firmness, sugar content, total acidity and pH are related to physical properties such as size, mass and colour and the extent of their variation.

## 2. Materials and Methods

Measurements of the said properties were conducted on export-ready, commercially-graded, B10 variety of starfruits bought from a fruit marketer which sorts and grades the produce according to the standard provided by the Federal Agricultural Marketing Authority (FAMA) of Malaysia. Although commercially graded starfruits vary from colour index 2 to colour index 4, no differentiation between the levels of colour index was made in the experiment since in the real market the graded fruits were actually packed together without any colour category separation. The fruits were stored at a constant temperature of 7 °C and a relative humidity of between 85 % and 95 % to maintain and preserve its quality.

### 2.1. Physical and physicochemical property measurements

Measurement of length, diameter, mass, volume and colour do not damage the physical conditions of the fruits and were carried out first. This was followed by the measurement of firmness and the physico-chemical properties of the total soluble solids (TSS), titratable acidity (TA) and pH. Of these, firmness was measured before the TSS, TA and pH because firmness had to be measured destructively with the fruits in an intact condition while the TSS, TA and pH needed to be measured from the juice of the fruits.

Fruit circumference was measured around the mid-section while the volume was measured by the method of water displacement. Colour measurement was made using a Minolta Chromameter (CR-300, Konika Minolta, Japan). The starfruit skin colour values, expressed as Y, x and y readings of the chroma meter, were converted to L, a*, b*, C and h° values using colour converter software (RGB software). Firmness was measured using a texture analyser (TA.XT Plus, Stable Micro Systems, Japan) with a 2 mm cylindrical probe at three places (base, middle and apex) on the ribs of fruit. The lowest value was taken as the firmness reading.

TSS values were measured using a digital refractometer (PAL-1, Atago, U.S.A.) while TA was measured by manually titrating 10 mm of sample aliquot against 0.1M NaOH using two to three drops of phenolphthalein as indicator. Before titrating, a 10 g sample from each fruit was taken in a 100 ml beaker and then 50 ml of distilled water was added. The mixture was boiled for 1 hour before it was transferred to a 100 ml volumetric flask and made up to volume. Filtered sample aliquot was then used for the titration process. The results were expressed as a percentage of oxalic acid which is the dominant acid in starfruit. Measurements of pH values were made using a pH meter (DPH-2, Atago, Japan). TA is related to pH but the concepts are not identical. While pH measures acid strength, TA measures the amount of the dominant acid present.

## 2.2. Data analysis

The data obtained was subjected to descriptive, coefficient of variation (CV) and correlation analyses. Statistical analyses were carried out using SPSS statistical software.

# 3. Results and Discussion

Thirteen properties were measured directly namely, length, diameter, mass, volume, the five colour values (i.e., L, a*, b*, C, h°), firmness, TSS (total soluble solids), TA (titratable acidity) and pH. From these, 18 derived properties were calculated and listed together with the original 13 to make up a total of 31 properties investigated.

Table 1 shows the 31 properties, ranked in order of increasing coefficient of variation. Following the work of Wilding et al. [10], the CV values of these properties were categorised into low, moderate and high, and for convenience, coloured in three different shades from light to dark respectively in Table 1.

The CV gives a measure of uniformity in a particular property. To be a good quality indicator, a non-destructively measureable property should have a low CV value. This means that the variation of that property among the fruits is small and uniformity can be easily achieved. The fruits in this study are commercially graded ones by hue (h°) and mass (respectively ranked 3rd and 15th by CV).

**Table 1. Malaysian starfruit properties (B10 Cultivar) ranked by coefficient of variation.**

| Rank in terms of CV | Properties | Mean ± Standard Deviation | Coefficient of Variation (%) |
|---|---|---|---|
| 1 | Length (mm) | 108.977 ± 5.843 | 5.362 |
| 2 | Density (kg/m$^3$) | 1014.770 ± 58.598 | 5.775 |
| 3 | Hue, h° | 106.544 ± 8.145 | 7.644 |
| 4 | L | 50.669 ± 3.987 | 7.869 |
| 5 | Diameter (mm) | 65.966 ± 5.253 | 7.963 |
| 6 | pH[a] | 3.296 ± 0.298 | 9.035 |
| 7 | Length/Density | 107.861 ± 9.790 | 9.077 |
| 8 | Length/Diameter | 1.662 ± 0.153 | 9.206 |
| 9 | TSS[a] | 7.083 ± 0.721 | 10.184 |
| 10 | Diameter/Density | 65.250 ± 6.715 | 10.291 |
| 11 | Length/Mass (mm/g) | 0.833 ± 0.091 | 10.873 |
| 12 | (Length/Diameter)/Density | 1.644 ± 0.187 | 11.385 |
| 13 | Diameter/Mass (mm/g) | 0.505 ± 0.064 | 12.719 |
| 14 | Length/Volume (mm/ml) | 0.847 ± 0.114 | 13.52 |
| 15 | Mass (g) | 132.730 ± 19.469 | 14.668 |
| 16 | C | 25.166 ± 3.797 | 15.086 |
| 17 | Diameter/Volume (mm/ml) | 0.513 ± 0.080 | 15.534 |
| 18 | Volume (ml) | 131.555 ± 22.659 | 17.224 |
| 19 | b* | 23.957 ± 4.212 | 17.58 |
| 20 | TA[a] | 0.290 ± 0.067 | 23.271 |
| 21 | TSS/TA | 25.881 ± 7.084 | 27.37 |
| 22 | Firmness[a] (N) | 3.188 ± 1.412 | 44.283 |
| 23 | a* | -6.844 ± 3.070 | 44.858 |
| 24 | Firmness/Density[a] (Nm³/kg) | 0.003 ± 0.0014 | 46.667 |
| 25 | Firmness/TSS | 0.457 ± 0.215 | 47.046 |
| 26 | Firmness/Mass (N/g) | 0.025 ± 0.012 | 48.352 |
| 27 | Firmness/Volume (N/ml) | 0.025 ± 0.013 | 50.960 |
| 28 | Firmness/TA | 11.467 ± 5.889 | 51.327 |
| 29 | Firmness /pH | 1.002 ± 0.515 | 51.408 |
| 30 | a*/b* | -0.304 ± 0.157 | 51.489 |
| 31 | Firmness/(TSS/TA) | 0.135 ± 0.724 | 53.602 |

[a]Destructive Measurements; ☐ Low; ☐ Medium; ☐ High

Table 1 shows that sorting and grading starfruits based on hue (low CV) does not necessarily result in the graded fruits demonstrating a low CV for other properties such as length, diameter, mass, colour, firmness, TSS, TA, pH, etc. Similarly using a property with a high CV as a basis does not necessarily result in the graded fruits exhibiting a high CV in the other properties. Also by virtue of the fruits being commercially graded, it therefore follows that all the CVs of the respective properties are acceptable for the starfruit variety studied. It can be inferred further from Table 1 that an acceptable CV value depends solely on the particular property of interest. While a CV value of 44.283 % is acceptable for firmness, it may not be so for hue.

Length, diameter and mass are basic size properties and are shown to have CVs in the low category in Table 1. Singh et al. [11] reported that the mass properties of graded oranges and graded sweet lemons for commercial use varied with CVs of 22.8 % and 24.7 % respectively and were categorised as moderate. The CV value of starfruit, i.e., 7.96 % is quite similar to those of graded oranges and graded sweet lemons which are 9.59 % and 8.88 % respectively.

Hue (h°) and lightness (L) show the lowest CVs with the values of 7.644% and 7.869% among the five colour properties (L, a*, b*, C, h°) (Table 1). The mean and standard deviation values of h° indicate that the colour of starfruit at the packaging stage for the export market varies from light green to yellowish-green which is in agreement with the colour scale for ripening stage 2 to 4 provided by FAMA. Hue is identical to colour observed by the naked eye and whose variation is easily understood by all, making hue a people-friendly and practical property as a quality indicator [7]. While hue can be readily seen and appreciated, lay people will see L, a*, b*, and C as only numbers measured by a device and not translatable into what is perceived in the real world.

Although density can be measured non-destructively and has a small CV value (5.775%), the water displacement technique used to measure the volume component of density may restrict its applicability. Measuring volume using water displacement can promote microbial growth due to the moistening of the surface of the fruits [12]. The fruits may be infected later and their quality affected. On the other hand, the application of advance techniques such as computer vision for volume measurement is expensive and difficult [12, 13].

For pH, TSS and TA, although showing low CVs with 9.035%, 10.184% and 23.271% respectively, and for firmness (CV = 44 %), the destructive measurement techniques required make them unsuitable as quality indicators. Similar findings have been published for pineapples [14], wild plums [15], pomegranate [16] and strawberries [17]. These properties are vital components as varying concentrations of these components could affect the flavour perception of the fruit [18]. If a quality indicator, says TSS, cannot be determined non-destructively, an alternative way would be to predict it through its relationship with a non-destructively measured property, say mass. Then mass will be called the predictor property. Similarly, freshness and taste are important quality criteria that cannot be seen, though readily understood, and can be described by firmness, pH, TSS and TA. If correlations between these properties and any of length, diameter, mass or hue could be established, then the former could be predicted from the latter (predictor properties).

Three important requirements have been considered in the selection of the best properties as predictor properties. They are: i) The relationship between the predicted and the predictor properties must be direct and not through other properties such as by way of derived properties; ii) The predictor properties must be measurable non-destructively; iii) The predictor properties must have strong correlations with the properties to be predicted.

Requirement (i) eliminates all indirect relationships as they provide huge errors by compounding the error from the prediction of the intermediate property/properties with that of the prediction of the final property. For requirement (ii), from the 13 properties measured directly namely length, diameter, mass, volume, the five colour values (L*, a*, b*, C, h°), firmness, TSS (total soluble solids), TA (titratable acidity) and pH, only the first nine properties can be considered. However, volume also has to be excluded since the commonly-used technique of water displacement can cause microbial growth. Thus, there are eight remaining potential predictors of starfruit properties and after discounting for requirement (iii), the final results of the correlation study appear as shown in Table 2. The strength of the correlation coefficients, R, were categorised as strong (0.75 - 1.0), moderately high (0.50 - 0.74), moderately low (0.25 - 0.49) and weak (0.00 - 0.24) after the work in [19].

**Table 2. Potential predictors of starfruit properties.**

| Potential Predictor | Predicted Property | R |
|---|---|---|
| Length | None | - |
| Diameter | None | - |
| Mass | Volume | 0.949 |
| L | None | - |
| a* | Firmness | -0.799 |
| | h° | -0.944 |
| b* | C | 0.979 |
| C | b* | 0.979 |
| Hue, h° | Firmness (N) | 0.878 |
| | a* | -0.944 |

In the volume-mass relationship, almost 95 % of the variation in volume is explained by the relationship. The result is in-line with the results obtained by the researchers in [3], who reported that there was an increase in mass and volume parameters as the maturity level increased. The strong volume-mass relationship can also provide for the prediction of density by determining the gradient of the linear regression line of volume against mass.

The property L shows no strong correlation to any other property (Table 2), indicating that lightness is not significantly affected by the changes in other quality parameters. The properties b* and C are strongly correlated to each other but since they are not correlated to other properties, they are most probably not useful as predictors. Hue predicts a* well but this predicted value is not readily visualised as a quality factor, hence it is not relevant. Firmness can be best predicted from its relationship with hue (R = 0.878). Table 3 summarises the volume-mass and firmness-hue relationships.

**Table 3. Potential predictors of volume and firmness of starfruit.**

| Relationship | Equation | R | $R^2$ |
|---|---|---|---|
| Mass and Volume | Volume (ml) = -14.994 + 1.104 Mass (g) | 0.949 | 0.900 |
| Hue and Firmness | Firmness (N) = -13.036 + 0.152 Hue (h°) | 0.878 | 0.772 |

The suitability of the predictors was analysed by making a comparison between the calculated and experimental values of volume (Fig. 1) and of firmness (Fig. 2). The calculated values are those obtained using the equations in Table 3. In Fig. 1, $\text{Volume}_{\text{calculated}}$ has very strong correlation with

Volume$_{experiment}$. This means that the property, mass, could be used to predict volume and subsequently density from the gradient of the straight line. In Fig. 2, Firmness$_{calculated}$ has a strong relationship with Firmness$_{experiment}$.

To accept or reject a fruit, the property tolerance of a quantity can be employed. The widely-accepted measure of property tolerance in the selection of anything is the quantity [mean ± standard deviation]. However, this quantity is unsuitable for use in the selection of starfruit.

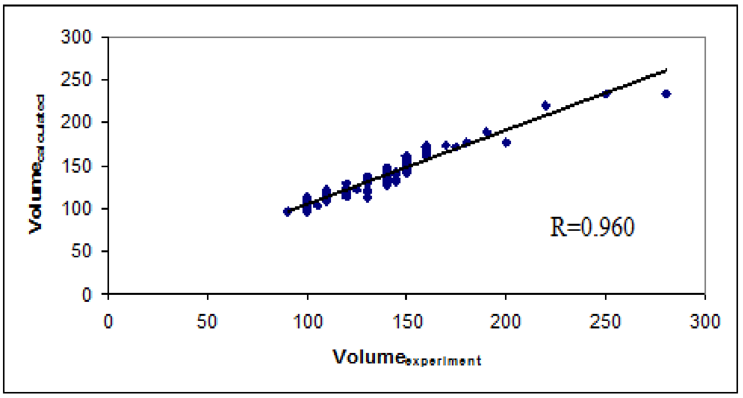


**Fig. 1. Relationship between Volume$_{calculated}$ and Volume$_{experiment}$. Volume$_{calculated}$ was obtained from the relationship between mass and volume.**

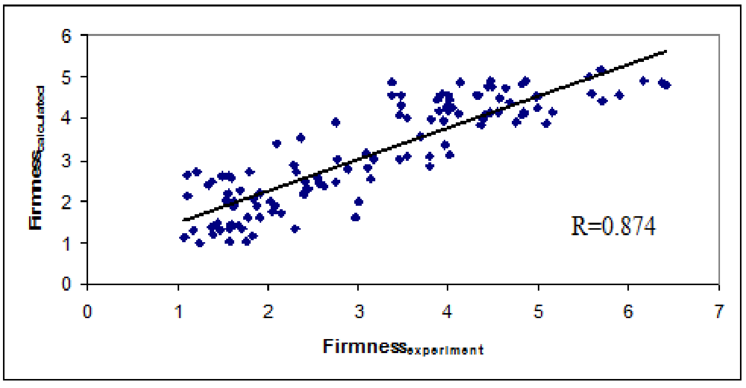


**Fig. 2. Relationship between Firmness$_{calculated}$ and Firmness$_{experiment}$. Firmness$_{calculated}$ was obtained from the relationship between hue and firmness.**

Results for mass and hue are shown in Figs. 3 and 4 where the values of [mean ± standard deviation] fall between the vertical lines in each figure such that by this measure 31.9 % and 56.3 % respectively of the graded starfruits would have to be removed.

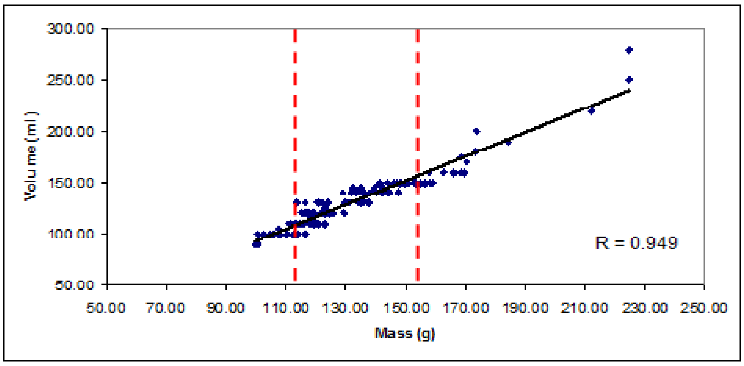


**Fig. 3. Samples within mean ± standard deviation for mass are between the two vertical broken lines.**

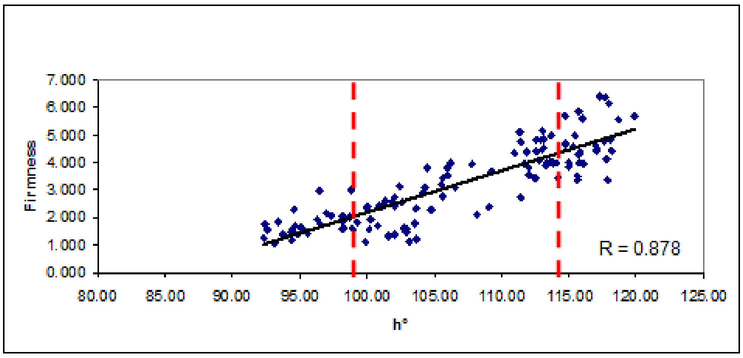


**Fig. 4. Samples within mean ± standard deviation for hue are between the two vertical broken lines.**

For a production of between 15 and 30 million fruits per week, the number of starfruits that must be removed would be between 4.8 and 9.6 million fruits when graded based on mass and between 8.4 and 16.9 million when graded based on hue. However, these fruits have already been graded and their quality has already been accepted in the market. Hence the millions of fruits to be removed are commercially accepted ones. Thus, it can only be said that the quantity [mean ± standard deviation] is not practical as a property tolerance for the establishment of baseline values for acceptance. Rather, the all-encompassing measure would simply be the range (i.e., max - min) which closely represents the real practice. For this, the minimum and maximum acceptable values of mass and hue will have to be established prior to the sorting and grading process as these are the desired limits of the marketer.

The minimum and maximum limits of a property tolerance influence the CV of that property. Depending on the average slope of the regression line (which may also be nonlinear) of the underlying correlation, the predicted property may have smaller or larger variability than the base predictor property (Figs. 5 and 6).

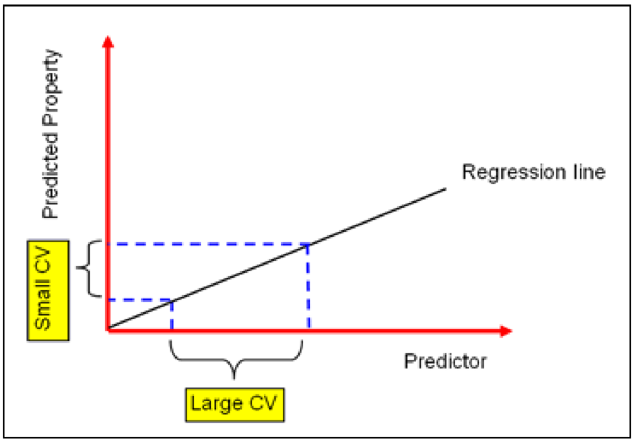


**Fig. 5. The large CV of a predictor may produce a small CV in the predicted property.**

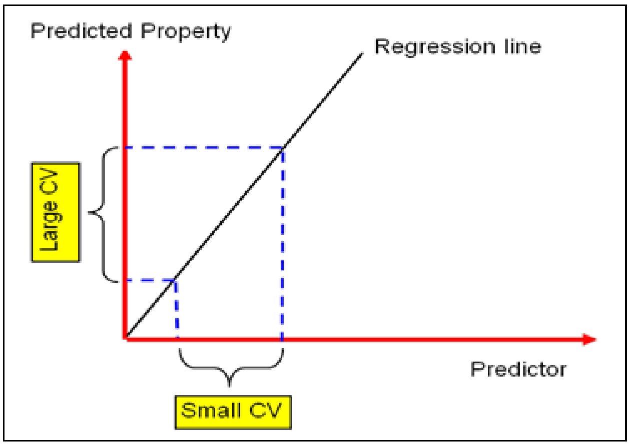


**Fig. 6. The small CV of a predictor may produce a large CV in the predicted property.**

The baseline properties for sorting and grading can either be the physical properties which are external or the taste properties (if non-destructive tests are available) which are internal. In both cases, the resulting CV values of each non-base property may be quite different.

## 4. Conclusions

An investigation into the variability and predictability of Malaysian export-grade starfruit properties has been conducted and the results can be concluded as follows:

- The use of only mass (CV=14.7) and hue (CV=7.6) as the basis for sorting and grading the B10 variety of Malaysian starfruits is sufficient to achieve export-grade quality.

- Other properties of the graded fruits resulting from the use of these bases are of acceptable levels even though their CV values are in excess of 40 % in some cases. The acceptance of variability is different for each property.
- Starfruits selected based on a low-CV property will be almost uniform in that property but not necessarily so in other properties. Visual uniformity can be achieved through the use of the CV for length, diameter, mass or hue.
- Hue is found to be strongly correlated to firmness.
- Therefore, hue and mass can be used as an indicator for sorting and grading starfruit quality.

## References

1. Dass, M.J.; and Chaik, G. (2005). *Star attraction*. The Sun Weekend. September 3-4, 2005.
2. FAMA. (2003). *Menuju ke arah kualiti Malaysia 'Best'*. Federal Agricultural and Marketing Authority
3. Patil, A.G.; Patil, D.A.; Phatak, A.V.; and Chandra, N. (2010). Physical and chemical characteristics of carambola (Averrhoa carambola L.) fruit at three stages of maturity. *International Journal of Applied Biology and Pharmaceutical Technology*, 1(2), 624-629.
4. Chen, P.; and Sun, Z. (1991). A review of non-destructive methods for quality evaluation and sorting of agricultural products. *Journal of Agricultural Engineering Research*, 49, 85-98.
5. Du, C.-J.; and Sun, D.-W. (2004). Recent developments in the application of image processing techniques for food quality evaluation. *Trends in Food Science and Technology*, 15(5), 230-249.
6. Cubero, S.; Aleixos, N.; Moltó, E.; Gómez-Sanchis, J.; and Blasco, J. (2011). Advances in machine vision applications for automatic inspection and quality evaluation of fruits and vegetables. *Food and Bioprocess Technology*, 4(4), 487-504.
7. Hashim, N.; Janius, R.B.; Baranyai, L.; Abdul Rahman, R.; Osman, A.; and Zude, M. (2012). Kinetic model for colour changes in bananas during the appearance of chilling injury symptoms. *Food and Bioprocess Technology*, 5(8), 2952-2963.
8. Abbott, J.A. (1999). Quality measurement of fruit and vegetables. *Postharvest Biology and Technology*, 15(3), 207-225.
9. Bollen, F.; Prussia, S.E.; and Lidror, A. (1993). *Postharvest handling: A systems approach*. Elsevier Science Publishing Co Inc., San Diego
10. Wilding, L.P.; Smeck, N.E.; and Hall, G.F. (1983). *Pedogenesis and soil taxonomy* (1st ed). Elsevier Science Publishers, New York
11. Singh, K.K.; Reddy, B.S.; Varshney, A.C; and Mangraj, S. (2004). Physical and frictional properties of orange and sweet lemon. *Applied Engineering in Agriculture*, 20(6), 821-825
12. Jarimopas, B.; Nunak, T.; and Nunak, N. (2005). Electronic device for measuring volume of selected fruit and vegetables. *Postharvest Biology and Technology*, 35(1), 25-31.

13. Hahn, F. (2002). Automatic Jalapeno chili grading by width. *Biosystem Engineering*, 83(4), 433-440.
14. Lu, X.H.; Sun, D.Q.; Wu, Q.S.; Liu, S.H.; and Sun, G.M. (2014). Physico-Chemical properties, antioxidant activity and mineral contents of pineapple genotypes grown in China. *Molecules*, 19(6), 8518-8532.
15. Forough, S.; Amlashi, S.N.; and Bakhshi, D. (2014). Evaluation of some qualitative characteristics of wild plum genotypes in Northern Iran. *Biological Forum - An International Journal*, 6(1): 92-99
16. Fawole, O.A.; and Opara, U.L. (2013). Seasonal variation in chemical composition, aroma volatiles and antioxidant capacity of pomegranate during fruit development. *African Journal of Biotechnology*, 12(25), 4006-4019.
17. Asadpoor, M.; and Travallali, V. (2015). Performance of six strawberry cultivars in tropical climate. *Journal of Biodiversity and Environmental Sciences*, 6 (3), 444-452.
18. Malundo, T.M.M.; Shewfelt, R.L.; Ware, G.O.; and Baldwin, E.A. (2001). Sugars and avids influence flavor properties of mango (Mangifera indica). *Journal of the American Society for Horticultural Science*, 126(1), 115-121.
19. Raymondo, J.C. (1999). *Statistical analysis in the behavioural sciences*. MacGraw-Hill, USA