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Texture estimation model for mulberry fruit from linear measurements

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ABSTRACT

Purpose: The texture is an essential feature of the nutritional value of fruit and vegetables and plays a critical role in the acceptance and success of these products by the consumer. However, mechanical injuries cause softening and abrasion in the mulberry fruit tissue during harvesting, difficult to assess. The experiment was conducted to estimate the mulberry fruit texture model by linear measurements for several harvesting conditions. **Research method:** The mulberry may fall from the highest or middle branches or harvest by hand since three heights, including 0, 1.5, and 3 meters, were considered for both maturity stage, including purple and black stage, for dynamic loading experiments to measure texture in an orchard simulated ambiance. Mulberry fruits were stored at 3 °C for seven days. The abrasion area of mulberry fruit was determined by image analysis. Also, TA-XT PLUS Texture Analyzer (micro stable system, England) was used to perform the compression tests of mulberry fruits. Regression analysis of abrasion area versus practical factors (harvesting method, maturity stage, and storage time) was used to develop several models for assessing the area of fruit abrasion. **Findings:** The combined effect of hot water for 3 minutes with 3% citric acid resulted in better quality fruits (less mass loss, less degradation of soluble solids, organic acids, and vitamin C), in addition to delaying the development of browning pericarp and pulp until the sixth day of storage. **Limitations:** No limitations were founded. **Originality/Value:** These models promisingly and accurately estimate the abrasion area of fruit without applying any inaccurate procedures, e.g., using a caliper in many experimental comparisons.

INTRODUCTION

The texture is one of the quality characteristics of most fresh fruits. There is a high biological difference between fresh products in this regard. Today, as consumer awareness and purchasing power increase, demand for fruits of high and uniform quality has increased. It is therefore perceived as a severe issue for producers to provide consistent quality products. Accordingly, the expectations of the food industry from fast on-line and at-line procedures include: (1) before the fruits are entered to processing stage, the raw material should be sorted into several texture categories, (2) optimal consumption of raw materials should be predicted, and (3) for obtaining the optimal quality of processed fruit product, the processing should be appropriately adjusted.

The most areas, including tropical, subtropical, temperate and, sub-arctic zones, have favorable environmental conditions for growing mulberry (genus *Morus* of the Moraceae family), which is broadly observed in Northwest of South America, South of North America, South Europe, West, East, and Southeast Asia and some regions of Africa (Sánchez, 2002; Watson & Dallwitz, 2007; Sánchez-Salcedo et al., 2015). In addition to the nutritional qualities and flavor, Black mulberry (*Morus nigra*) have a high content of active therapeutic compounds that led to use it in natural medicine. For instance, mulberry can be used as a traditional medicine to treat tonsillitis, sore mouth, tongue and, throat inflammations (Weaver, 2001; Afsharnia et al., 2017). Mulberry fruit is a good source of several phytonutrients and contains high amounts of total phenolics, total flavonoids, and ascorbic acid. Additionally, this fruit has a pleasant taste with a slightly acidic flavor and an attractive dark red color (Koyuncu, 2004; Özgen et al., 2009). The harvested mulberries can often be consumed as raw, dried, or processed. Nowadays, a sheet is spread over the ground and, the fruits are then collected by shaking the branches of the tree. During shaking the tree and fruit dropping, the created energy can be transferred to the mulberry. Meanwhile, fruit tissue absorbed the energy; so fruit tissue is damaged by the part of this energy which duration, type, and intensity of energy shift are the most critical determinant factors of absorbed energy (Pitt, 1992). Different texture measurement methods may give different results, some expressed as single values such as fruit firmness measured by hand held penetrometer (Ioannides et al., 2007), while others provide more in depth information on the history of deformation, such as time-series data on texture measurement (Derington et al., 2011; Taniwaki et al., 2010). Pinheiro and Almeida (2008) employed the simple linear regression model to analyze the relationships between tomato pericarp firmness and pH and calcium. Partial Least Square Regression model was adopted to correlate the data on firmness of tomato, banana, mango, guava, peach and kiwifruit to the near infrared spectral data (Subedi & Walsh, 2009; Van Dijk et al., 2006a; b; Zhang et al., 2017; Khoje, 2018), waveguide spectral data (Ragni et al., 2012) and natural frequencies (Hou et al., 2017). Furthermore, Bonneau et al. (2018) investigated the impact of fruit texture on the release and perception of aroma compounds during in vivo consumption using fresh and processed mango fruits. Besides that, Watcharasing et al. (2019) developed an effective classification of fruit in a box by considering the color and texture features from the images. This study has been conducted to estimate the effects of variations in fruit maturity, drop height and, storage time on the characteristics of mulberry fruit as a case study.

MATERIALS AND METHODS

Sample collection and preparation

Mulberry (*Morus alba* var. nigra) fruits were harvested at both purple and black maturity stages from the gardens surrounding the agricultural sciences and natural resources university of Khuzestan, Ahvaz, Khuzestan province, Iran in May, during the spring growing season in 2019 and 2020, and supported by the department of horticulture. At the orchard, the medium-sized fruits were manually harvested to minimize any abrasion. Once put in a foam hinged container, they were rapidly transferred to the laboratory. Also, very large or small mulberries were removed. For ensuring that the mulberries were non-damaged and uniform, they were inspected again after careful transportation to the laboratory, then were placed in the refrigerator at 3°C and high RH before further experiments.

In the garden, the mulberry trees' height was on average 3 meters. For the mulberry harvest, first, a sheet is placed beneath the trees, then the trees are shaken to collect the mulberries. This method of harvesting causes scuffs, abrasions, shrinkage, and resulting decay in the mulberry fruit. Assuming the mulberry may fall from the highest or middle branches or harvest by hand, since three heights, including 0, 1.5, and 3 meters, were considered for dynamic loading experiments to measure texture in an orchard simulated ambiance. Mulberry fruits were stored at 3 °C for seven days. Fifty grams of mulberries were selected for each treatment, so that every sample was applied only once.

Compression test

Fruit softening always starts from the interior tissue and then appears on the softening of the fruit, hence it is not detected for any consumer. So, TA-XT PLUS Texture Analyzer (micro stable system, England) was used to accomplish the compression tests of mulberry fruits; once calibrated the texture analyzer using a 5 kg weight, a 25 mm diameter plate probe was installed on the texture analyzer for the test. Test speed and strain of probe were set 1.7 mm/s (quasi-static loading) and 40%, respectively. Once placed fruit on the base plate, the plating probe was parallelly moved until the fruit pressed and then ruptured. Finally, the firmness was obtained from the force-time curve that was saved in real-time.

Image processing

Image acquisition

In this study, illumination, camera, hardware, and software are four essential components of an image acquisition system. Vision systems need to apply an appropriate light source due to prevent glitter and acquire sharp contrasts at the border of the sample image (Hong et al., 2001). For illumination, four fluorescent lamps of 60 cm (Pars Shahab, T10-20 series 90, 20W/230) were considered that the angle between the axis of the camera lens and the lightning source axis was 45° to capture (Papadakis et al., 2000). The image of mulberry fruit was taken directly from the white painted tiles as background by an EOS digital SLR and compact system camera (EOS T7, Canon, USA). Images were 1800×1200 jpeg pixels in which the scaling factor of one centimeter was equal to 205 pixels. The axis of the digital camera formed an angle of 90° tiles with the plane of the sample, and the distance between the lens and sample was 20 cm. The obtained digital images were directly shifted to a PC (Pentium 4, 120 GB, 800MHz) by a USB cable. Images were processed and analyzed by the Matlab R2018b (Mathworks, Inc.).

Abrasion area measurement

For determining the morphological parameter, the area was measured on the segmented image. Abrasion area measurement by the planimeter for fruit such as mulberry, which is a soft and small fruit, leads to more damage and abrasion on fruit surface and required a great deal of time. Therefore, digital image processing was performed as a more rapid and accurate technique for measuring the abrasion area of damaged fruits (Fig. 1). For the abrasion area calculation, the final area was subtracted from the initial area at each level.

Modeling method

The linear regression procedure was used to estimate the relationships by fitting regression models of IBM SPSS Statistics 19.0 and the stepwise elimination option, according to Miranda and Royo (2003a). For validating the model's test, mean square error (MSE), coefficient of determination (R^2), and predicted residual error sum of squares (PRESS) were calculated. Also, the presence of outliers and non-constant error variance were determined to analyzing the residuals. The outlier is obtained as Eq. (1):

$$\text{Outlier} = \begin{cases} 0 & \text{if } |r_i| \le k\sigma \\ 1 & \text{otherwise} \end{cases} \quad (1)$$

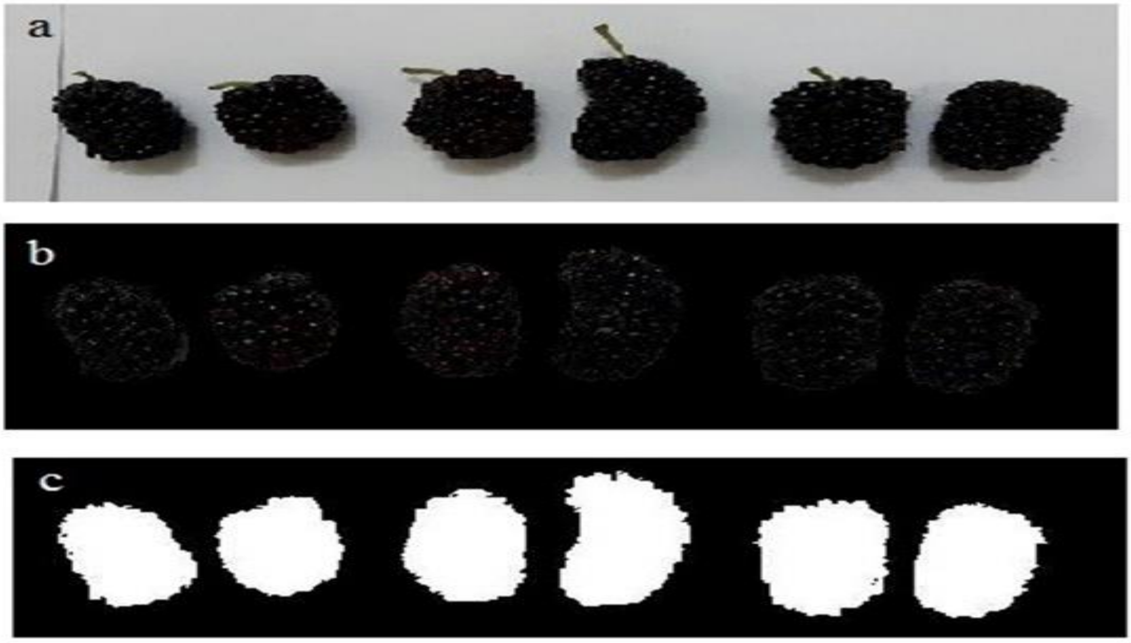


Fig. 1. Abrasion area measurement: a) Original color, b) Grayscale, and c) Binary image.

Where, by default, k = 3 and scale σ are calculated as a corrected median of the absolute residuals (Peksen, 2007; Marquardt, 1970; Fallovo et al., 2008). Firmness was the dependent variable, and R, S_1, S_4, H_0, and H_3 were the independent variables. Significant values, including constants (a), the values of the coefficients (b, c, d, e, f), SSE, MSE, and PRESS, were also calculated. For selecting the final model, a combination of the lowest MSE, the highest R^2, and the lowest PRESS was considered that the values of PRESS and SSE are reasonably close to each other. Individualized models for each variable of the different mulberries' texture attributes have been estimated. Besides, the result of the Wilkes Shapiro W statistic test depicted that data pooled from two variables are normally distributed. To this end, data were pooled, and a single relationship computed to achieve the firmness and abrasion area prediction model for mulberry fruit. Finally, using all factors (i.e., harvesting method, maturity stage, and storage times) introduced the potential of collinearity that led to decreasing the precision of estimates for the coefficients of corresponding regression. The variance inflation factor (VIF), and the tolerance values (T) were computed to detect collinearity (Gill, 1986; Miranda & Royo, 2003a).

$$\mathrm{VIF} = \frac{1}{(1 - r^2)} \qquad (2)$$

$$\mathrm{T} = \frac{1}{\mathrm{VIF}} \qquad (3)$$

In this formula, r is defined as the correlation coefficient. If the T value was smaller than 0.10, or if the VIF value was higher than 10, then collinearity may have more than a trivial impact on the estimates of the parameters. Consequently, one of them should be excluded from the model.

Miranda and Royo have reported two techniques (Cankaya et al., 2006; Miranda & Royo, 2003b; Miranda & Royo, 2004) which were utilized to validate the models for fruit texture attribute: 1) for producing a validation model, the model parameters were re-estimated using the stepwise regression option approach for a validation data set to develop the estimation model and the models were compared for consistency; 2) for predicting outcomes from the validation data set, first, the best estimation model was identified based on MSPR and MSE of the regression fit, then this model was used to obtaining the regression parameters (Neter et al., 1996). Also, the predicted texture (PT) was compared with the observed texture (OT) based on graphical methods for the cultivars of mulberry fruit during the 2019-20 growing season (Bland & Altman, 1986).

RESULTS

Progress in storage was concomitant with a significant increase in fruit softening ($p \leq 0.05$) (Fig. 2a and b). Increasing the dropping height significantly led to more decrease in fruit firmness during the storage period. According to Figure 3, the abrasion area increased by raising the dropping height in the form of cell bursting on the fruit surface and leaving the red juice, which was easily visible. Moreover, increasing the storage time led to an increase in the abrasion area.

On the other hand, after 24 h, a weak darkening of the fruit surface appeared and the color of the tissue changed (slightly darker) and became softer.

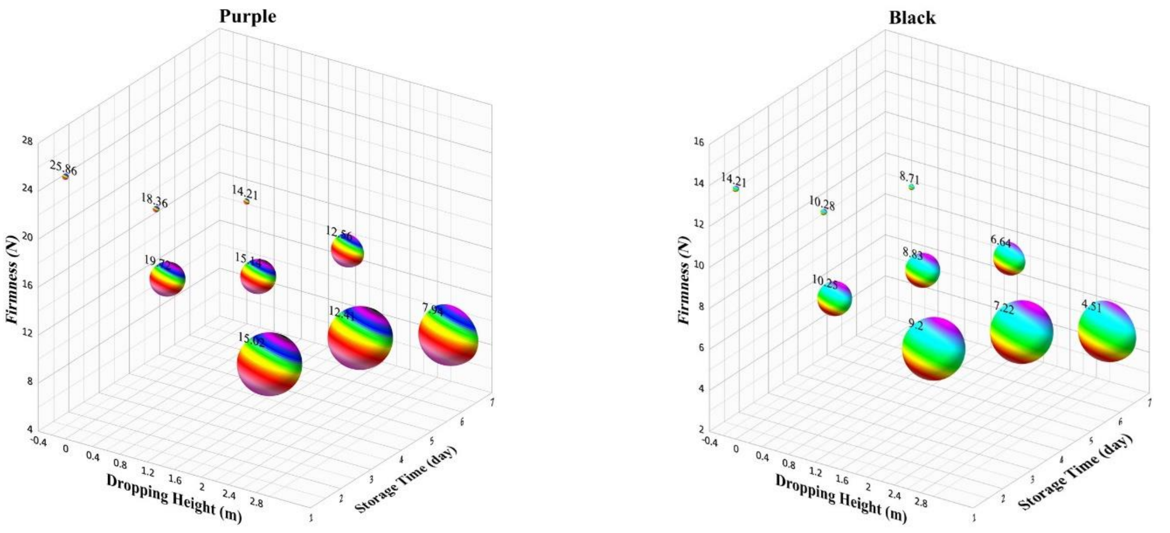


Fig 2. Effect of dropping height and storage time levels on the firmness (N) for both purple and black mulberries.

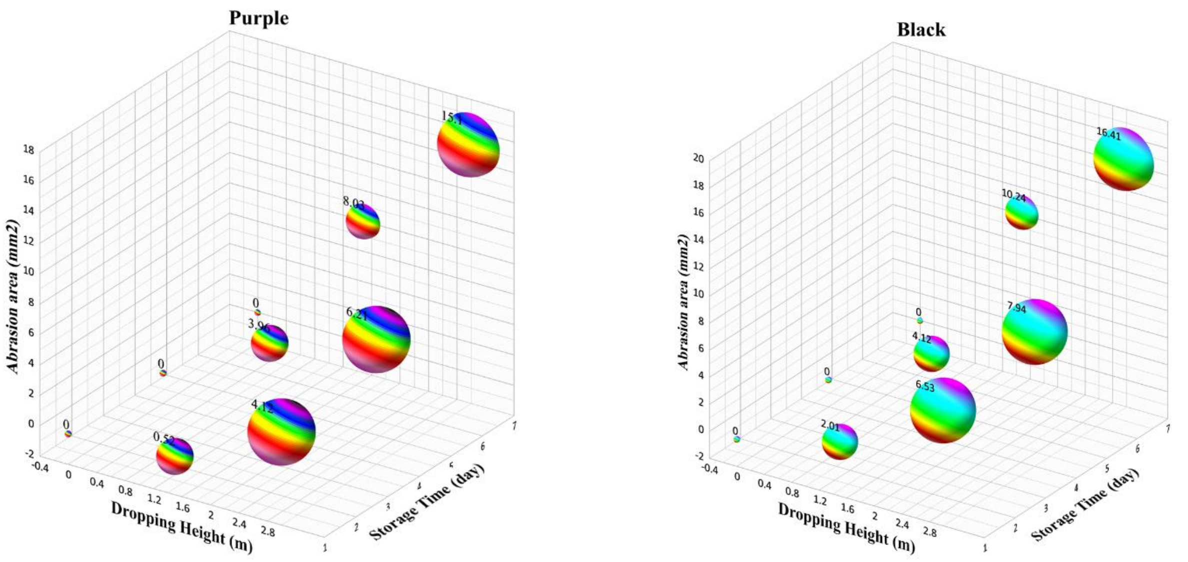


Fig 3. Effect of dropping height and storage time levels on the abrasion area (mm^2) for both purple and black mulberries.

An initial step of model calibration, the degree of collinearity among R, S, and H, was analyzed. The ranges of abrasion area and firmness variables were 1 to 1.33 for VIF, respectively. Moreover, the T value for both variables ranged from 0.75 to 1. In these variables, VIF was less than ten and T was more significant than 0.10, showing that the collinearity between R, S, and H is negligible (Gill, 1986), and these variables can be both entered into the model.

For model calibration, regression analysis indicated strong relationships (p <0.001) between R, H_0, H_3, S_1, and S_4 (Table 1). However, the variation in suitability of these models is based on the selection criteria as previously explained. All models produced a coefficient of determination (R^2) greater than 0.3 irrespective of model 1 for abrasion (Table 1). Based on selection criteria, as previously demonstrated (lower MSE, higher R^2, lower PRESS, and when the values of PRESS were advisedly close to SSE), this study illustrated that the models with a single measurement of R (Model 1, Table 1) for abrasion and model 3 for firmness were less admitted for evaluating A and F of mulberry fruit according to selection criteria due to their lowest coefficient of determination (R^2), higher MSE, and higher PRESS values. An improvement was possible for single F and A estimation when R, S_1, S_4, H_0, and H_3 (Model 7) were used as the independent variables (Table 1). According to model accuracy, criteria included highest R^2 (greater than 0.93 for firmness and 0.785 for abrasion), smallest MSE, smallest PRESS, and to the reasonably close PRESS value to SSE, this linear model ($F=a+ bR+ cS_1+dS_4+ eH_0+fH_3$ for firmness and $A=a+ bR+ cS_1+dS_4+ eH_0+fH_3$ for abrasion) was preferred (Table 1). PRESS criterion and SSE are the measures of how well the fitted values for a subset model can estimate the observed responses, Y_i. Some procedures of the internal validity of the fitted model are for comparing PRESS and SSE (Cankaya et al., 2006; Fallovo et al., 2008). PRESS value is always higher than SSE because the regression fit for the i^th^ case when this case is deleted in fitting can never be as good as when the i^th^ case is included. In this study, the PRESS value of all small fruit berries was reasonably close to SSE for the A and F Model 7 (Table 1); therefore, this ensures the validity of the fitted regression model (Fallovo et al., 2008; Neter et al., 1996). Regarding these considerations, each three R, S, and H measurements were essential for accurate estimation of mulberries' F and A. As can be seen from Table 1, every three factors include R (ripeness), S_4 (storage time in the fourth day), and H_3 (harvesting height at 3 meters), had a significant and negative effect on the firmness of mulberry texture.

Table 1. Fitted coefficient (b, c, d, e, f) and constant (a) values of the models used to estimate the mulberry fruit firmness (F) and texture (T)

	Model no.	Form of the model tested	Fitted coefficient and constant						R^2	MSE	PRESS	SSE
			a	b	c	d	e	f				
Firmness	1	$F= a+bR$	8.78	-6.91					0.63	18.13	1016.8	942.96
	2	$F=a+bS_1+cS_4$	11.89	3.75	-2.71				0.48	23.7	1354.5	1208.2
	3	$F=a+bH_0+cH_3$	12.15	3.21	-2.96				0.46	24.4	1395.2	1244.5
	4	$F=a+bR+ cS_1+dS_4$	8.43	-6.91	3.75	-2.71			0.80	11.26	656.65	562.97
	5	$F=a+bR+ cH_0+dH_3$	8.7	-6.91	3.21	-2.96			0.78	11.98	699.04	599.31
	6	$F=a+ bS_1+cS_4+ dH_0+eH_3$	11.81	3.75	-2.71	3.21	-2.96		0.67	17.64	1050	864.55
	7	$F=a+ bR+ cS_1+dS_4+ eH_0+fH_3$	8.35	-6.91	3.21	-2.71	3.21	-2.96	0.93	4.57	277.58	219.32
Abrasion	1	$A= a+bR$	5.87	-1.27					0.01	23.66	1327.0	1230.6
	2	$A=a+bS_1+cS_4$	4.24	-2.25	5.25				0.42	14.08	805.42	718.41
	3	$A=a+bH_0+cH_3$	4.86	-2.85	4				0.34	16.18	925.51	825.53
	4	$A=a+bR+ cS_1+dS_4$	4.88	-1.27	-2.25	5.25			0.44	13.93	812.43	696.53
	5	$A=a+bR+ cH_0+dH_3$	5.5	-1.27	-2.85	4			0.35	16.07	937.38	803.65
	6	$A=a+ bS_1+cS_4+ dH_0+eH_3$	3.86	-2.25	5.25	-2.85	4		0.76	5.94	353.98	291.46
	7	$A=a+ bR+ cS_1+dS_4+ eH_0+fH_3$	4.49	-1.27	-2.25	5.25	-2.85	4	0.78	5.61	341.19	269.58

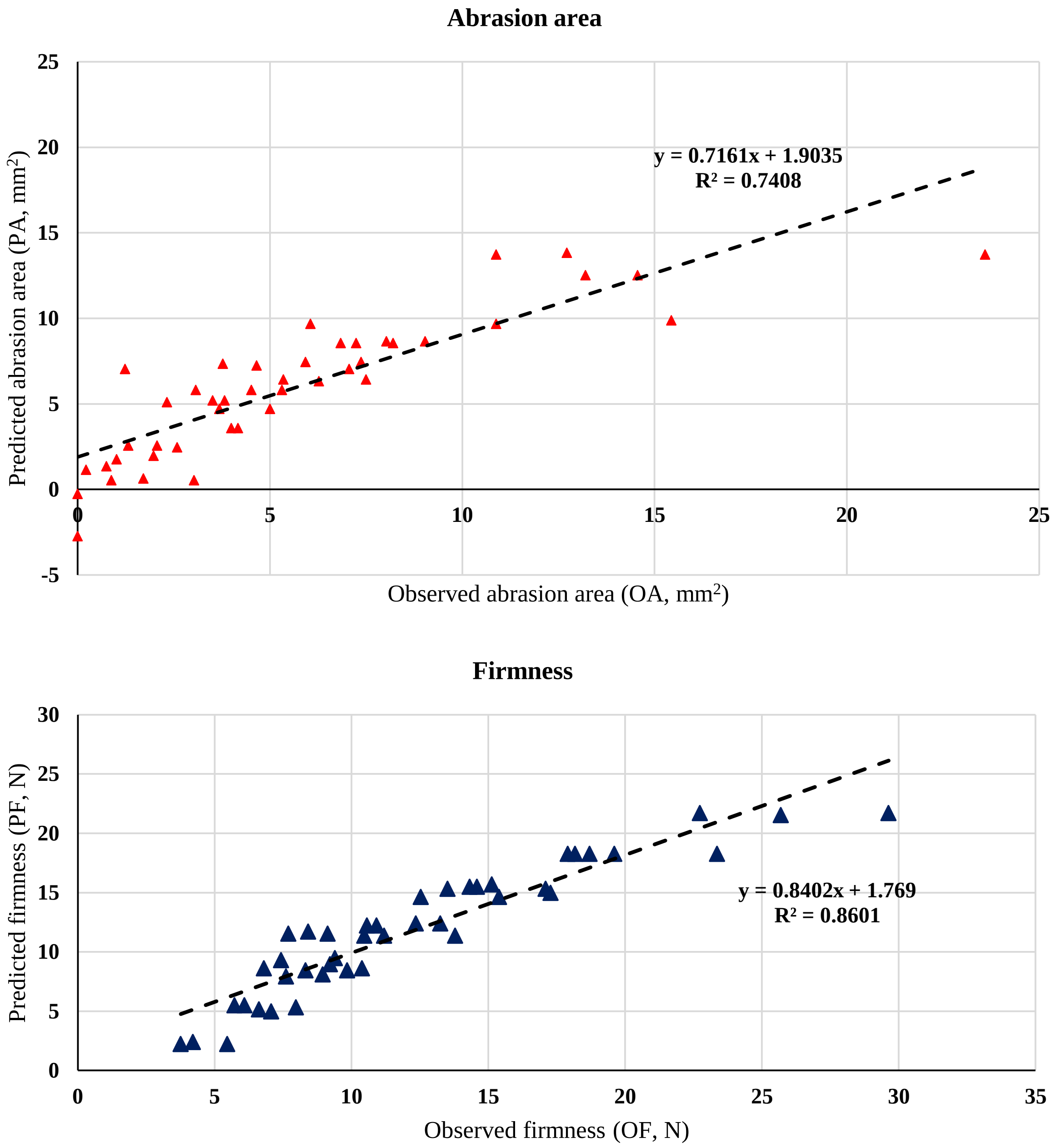
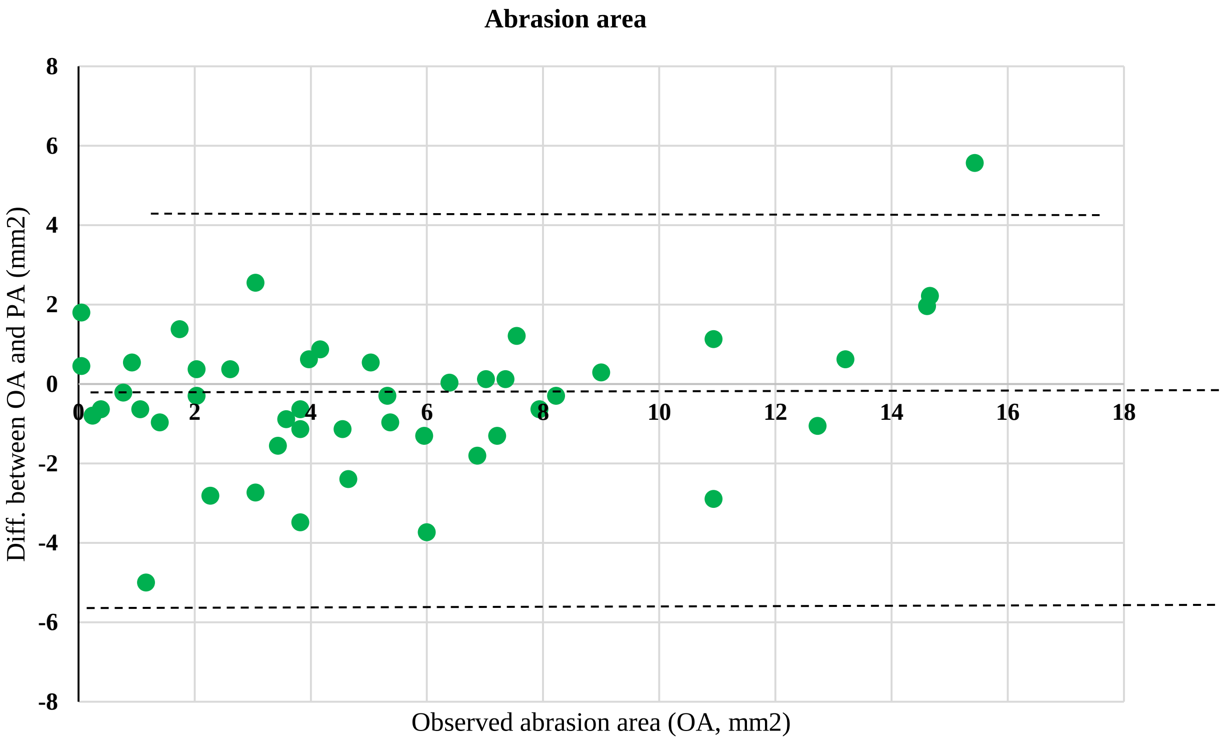


Fig. 4. The plot of predicted firmness (PF) and abrasion area (PA) using Model 7 versus observed values of firmness (OF) and abrasion area (OA) of mulberry fruit.



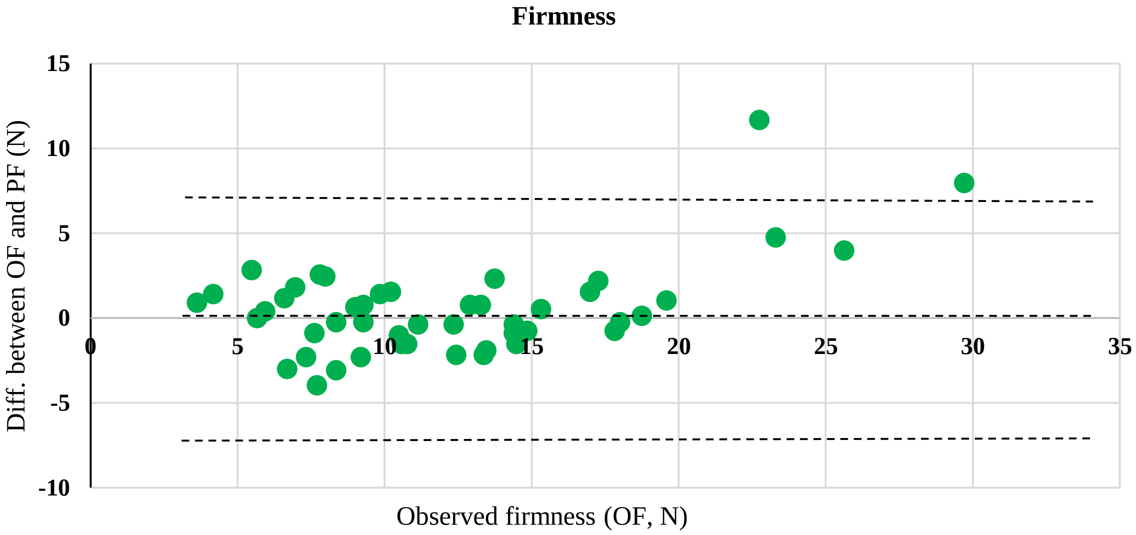


Fig. 5. The difference between predicted firmness (PF) and abrasion area (PA) estimated by Model 7 from pooled data from 54 mulberry fruits and observed values of firmness (OF) and abrasion area (OA).

Based on Model 7 and for the validation test, comparisons between OF and OA versus PF and PA, derived from the 2019 experiment, illustrated a strong correlation (r = 0.86, $p < 0.0001$), also the predicted values includes PF and PA values, were very close to the OF and OA values for firmness and abrasion, respectively (Fig. 4). However, correlation is not an appropriate analysis to describe the relationship between predicted and observed values of variables, and a part of the differences between PF and OF against OF may be more informative (Neter et al., 1996; Marini, 2001). Moreover, the investigation of possible relationships between measured error and the actual values can be provided by plotting differences against observed values. Lack of settlement between estimation predicted and observed values of firmness and abrasion area can be measured by computing the bias, and then be evaluated by the mean of the differences (d) and the SD of the differences. As given in Figure 5, a solid line illustrated the mean of the differences. Based on this figure, almost up to 98% of the differences will lie between d ± 3 SD, if the differences were typically distributed; furthermore, no plot for abrasion area and only one plot for firmness were out of these lines, whereas the rest of the plots were placed between lines.

DISCUSSION

In recent years, fruit quality preservation and increasing storage life have been of great interest in the food industry, and postharvest technology. Based on Figure 1 and according to Ball (1997) suggestion, postharvest loss of moisture through transpiration and also enzymatic activities could change the fruit firmness. Based on Maia et al. (2011) research, fruit tissue injuries including, abrasion, impact, and cutting are increased the enzyme activity of fruits. Also, hemicelluloses and pectin become more soluble that led to disruption and loosening of the cell walls (Paull, 1999). Moreover, Gómez and Camelo (2002) showed that the effect of storage time on fruit firmness was significant. According to detailed analysis shown in Figure 1a and b, increasing dropping height and storage time led to significant loss in fruit firmness ($p \leq 0.05$). Therefore, abrasion probability and lesion occurrence can be increased by increasing dropping height and storage time. Fruit injuries due to fruit impaction including intracellular bond degradation or cell rupture may be dependent to the cell wall conformation (Holt & Schoorl, 1976; 1982). Mulberry tissue is an arrangement of a liquid-filled, spherical cells bounded by viscoelastic membranes with air-filled interstitial spaces. The cell wall is affected by the impact of bursting the tissue cell, especially when the effect of dropping is high, meanwhile, intense dehydration is occurred in the injured cells created by scuffs and abrasions that it increases water loss and wilting during storage. Localized shrivel gradually developed symptom around wounded parts. Consequently, increasing the severity of scuffs and abrasion would increase the severity of water loss and fruit shrivel.

As founded, the average firmness was 15.63 and 8.87 N for purple and black mulberries, respectively. Also, the abrasion area of black and purple mulberries was calculated as 7.88 and 5.32 mm^2, respectively. Once mulberry fruit ripened, fruit sensitivity to softening was doubled as compared to the purple stage. Also, the selective permeability of membranes is gradually lost during ripening stages that it results in the break and developing of the abrasion area (Kay & Pallas, 1991; Maia et al., 2011). Many types of the research reported that the fruit firmness was gradually lost during ripening in which both the enzymatic breakdown of cell walls and their components change occurs (Huber, 1983). So it is very likely that many epidermis cells are disrupted by the abrasion due to injury, since water loss, fruit shrivel, and developed severe symptoms of black mulberry was more than purple mulberry. So as a result, the abrasion area is increased by increasing the ripeness of mulberry fruit. It is in agreement with the study of Mohammadi-Aylar et al. (2010) on the effect of ripening stages on mechanical damage in tomato fruits. Furthermore, storing mulberry fruit and dropping height were two factors that decrease the firmness of mulberry texture. Unlikely, increasing the firmness of fruit texture results in the conditions of fruit storing on the first day and direct hand-harvesting without dropping from a height. No study included the same variable and statistical model as in our study.

CONCLUSION

According to the obtained results, it can be concluded that this model can represent more accurate evaluations of mulberry texture than those based on single factor measurements. By this model, researchers would enable to make non-destructive repeatable measures on the same fruits, because factors such as harvesting method, maturity stage, and storage time could be easily considered. Thus, the texture of small fruits can be precisely and in large quantities estimated by such models without applying any inaccurate procedures, e.g. the use of a caliper in many experimental studies.

Acknowledgment

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Conflict of interest

The authors have no conflict of interest to report.

REFERENCES

Afsharnia, F., Mehdizadeh, S.A., Ghaseminejad, M. & Heidari, M. (2017). The effect of dynamic loading on abrasion of mulberry fruit using digital image analysis. *Information Processing in Agriculture*, *4*(4), 291-299.

Ball, J. A. (1997). *Evaluation of two lipid-based edible coatings for their ability to preserve post-harvest quality of green bell peppers*. (Doctoral dissertation, Virginia Tech).

Bland, J. M., & Altman, D. G. (1986). Statistical methods for assessing agreement between two methods of clinical measurements, *Lanceti*, *327*(8476), 307-310. https://doi.org/10.1016/S0140-6736 (86)90837-8

Bonneau, A., Boulanger, R., Lebrun, M., Maraval, I., Valette, J., Guichard, É., & Gunata, Z. (2018). Impact of fruit texture on the release and perception of aroma compounds during in vivo consumption using fresh and processed mango fruits. *Food Chemistry*, *239*, 806-815. https://doi.org/10.1016/j.foodchem.2017.07.017

Cankaya, S., Kayaalp, G. Y., Sangun, L., Tahtali, Y., & Akar, M. (2006). A comparative study of estimation methods for parameters in multiple linear regression model. *Journal of Applied Animal Research*, *29*, 43-47. http://dx.doi.org/10.1080/09712119.2006.9706568.

Derington, A. J., Brooks, J. C., Garmyn, A. J., Thompson, L. D., Wester, D. B., & Miller, M. (2011). Relationships of slice shear force and Warner–Bratzler shear force of beef strip loin steaks as related to the tenderness gradient of the strip loin. *Meat Science*, *88*(1), 203-208. https://doi.org/10.1016/j.meatsci.2010.12.030

Fallovo, C., Cristofori, V., de-Gyves, E. M., Rivera, C. M., Rea, R., Fanasca, S., Bignami, C., Sassine, Y., & Rouphael, Y. (2008). Leaf area estimation model for small fruits from linear measurements. *Horticulturae Science*, *43*(7), 2263-2267. https://doi.org/10.21273/HORTSCI.43.7.2263

Gill, J. L. (1986). Outliers, residuals, and influence in multiple regression. *Journal of Animal Breeding and Genetics*, *103*(1-5), 161-175. http://dx.doi.org/10.1111/j.1439-0388.1986.tb00079.x

Gómez, P. A., & Camelo, A. F. (2002). Calidad postcosecha de tomates almacenados en atmósferas controladas. *Horticultura Brasileira*, *20*(1), 38-43. http://dx.doi.org/10.1590/S0102-05362002000100007.

Holt, J. E., & Schoorl, D. (1976). Bruising and energy dissipation in apples. *Journal of Texture Studies*, *7*, 411-432. https://doi.org/10.1111/j.1745-4603.1977.tb01149.x

Holt, J. E., & Schoorl, D. (1982). Strawberry bruising and energy dissipation. *Journal of Texture Studies*, *13*(3), 349-357. https://doi.org/10.1111/j.1745-4603.1982.tb00888.x

Hong, G., Luo, M. R., & Rhodes, P. A. (2001). A study of digital camera colorimetric characterization based on polynomial modelling. *Color Research and Application, 26*(1), 76-84. http://dx.doi.org/10.1002/1520-6378(200102)26:1<76::AID-COL8>3.0.CO;2-3.

Hou, J., Sun, Y., Chen, F., Wang, L., Bai, X., Wang, M., & Mao, Q. (2017). Application of natural frequencies for prediction of apple texture based on partial least squares regression. *International Journal of Food Engineering*, *13*(10), 20160390. https://doi.org/10.1515/ijfe-2016-0390

Huber, D. J. (1983). The role of cell wall hydrolases in fruit softening. *Horticultural Reviews, 5,* 169-219. http://dx.doi.org/10.1002/9781118060728.ch4

Ioannides, Y., Howarth, M. S., Raithatha, C., Defernez, M., Kemsley, E. K., & Smith, A. C. (2007). Texture analysis of red delicious fruit: towards multiple measurements on individual fruit. *Food Quality and Preference*, *18*(6), 825-833. https://doi.org/10.1016/j.foodqual.2005.09.012

Kay, J., & Pallas, J. (1991). *Postharvest physiology of perishable plant produce*. University of Georgia, USA, 226.

Khoje, S. (2018). Appearance and characterization of fruit image textures for quality sorting using wavelet transform and genetic algorithms. *Journal of Texture Studies, 49*(1), 65-83. https://doi.org/10.1111/jtxs.12284

Koyuncu, F. (2004). Organic acid composition of native black mulberry fruit. *Chemistry of Natural Compounds, 40*(4), 367-369. http://dx.doi.org/10.1023/B:CONC.0000048249.44206.e2

Maia, V. M., Salomão, L. C. C., Siqueira, D. L., Puschman, R., Mota Filho, V. J. G., & Cecon, P. R. (2011). Physical and metabolic alterations in" Prata Anã" banana induced by mechanical damage at room temperature. *Scientia Agricola, 68*(1), 31-36. http://dx.doi.org/10.1590/S0103-90162011000100005.

Marini, R. P. (2001). Estimating mean fruit weight and mean fruit value for apple trees: Comparison of two sampling methods with the true mean. *Journal of the American Society for Horticultural Science*, *126*, 503-510. http://dx.doi.org/10.21273/jashs.126.4.503

Marquardt, D. W. (1970). Generalized inverse, ridge regression and biased linear estimation. *Technometrics*, *12*, 591-612. http://dx.doi.org/10.2307/1267205.

Miranda, C., & Royo, J. B. (2003a). A statistical model to estimate potential yields in peach before bloom. *Journal of the American Society for Horticultural Science, 128*, 297-301. https://doi.org/10.21273/JASHS.128.3.0297

Miranda, C., & Royo, J. B. (2003b). Statistical model estimates potential yields in pear cultivars ‘Blanquilla’ and ‘Conference’ before bloom. *Journal of the American Society for Horticultural Science*, *128*, 452-457. https://doi.org/10.21273/JASHS.128.4.0452

Miranda, C., & Royo, J. B. (2004). Statistical model estimates potential yield in ‘Golden Delicious’and ‘Royal Gala’ apples before bloom. *Journal of the American Society for Horticultural Science*, *129*, 20-25. https://doi.org/10.21273/JASHS.129.1.0020

Mohammadi-Aylar, S., Jamaati-e-Somarin, S., & Azimi, J. (2010). Effect of stage of ripening on mechanical damage in tomato fruits. *American-Eurasian Journal of Agricultural and Environmental Science*, *9*(3), 297-302.

Neter, J., Kutner, M. H., Nachtshein, C. J., & Wasserman, W. (1996). *Applied linear regression models*. 3rd Ed., Homewood, Ill., Irwin.

Özgen, M., Güneş, M., Akça, Y., Türemiş, N., Ilgin, M., Kizilci, G., Erdoğan, Ü., & Serçe, S. (2009). Morphological characterization of several Morus species from Turkey. *Horticulture Environment and Biotechnology*, *50*(1), 9-13.

Papadakis, S. E., Abdul-Malek, S., Kamdem, R. E., & Yam, K. L. (2000). A versatile and inexpensive technique for measuring color of foods. *Food Technology*, *54*(12), 48-51.

Paull, R. (1999). Effect of temperature and relative humidity on fresh commodity quality. *Postharvest Biology and Technology*, *15*(3), 263-277. http://dx.doi.org/10.1016/S0925-5214(98)00090-8.

Peksen, E. (2007). Non-destructive leaf area estimation model for faba bean (*Vicia faba* L.). *Scientia Horticulturae*, *113*, 322-328. http://dx.doi.org/10.1016/j.scienta.2007.04.003

Pinheiro, S. C. F. & Almeida, D. P. F., (2008). Modulation of tomato pericarp firmness through pH and calcium: Implications for the texture of fresh-cut fruit. *Postharvest Biology and Technology*, *47*(1), 119-125. https://doi.org/10.1016/j.postharvbio.2007.06.002

Pitt, R. (1992). Viscoelastic properties of fruits and vegetables. *Viscoelastic Properties of Foods*, 49-76.

Ragni, L., Cevoli, C., Berardinelli, A., & Silaghi, F. A. (2012). Non-destructive internal quality assessment of “Hayward” kiwifruit by waveguide spectroscopy. *Journal of Food Engineering, 109*(1), 32-37.

Sánchez, M. D. (2002). World distribution and utilization of mulberry and its potential for animal. Proceedings of Electronic Conference on *Mulberry for Animal Production*. May and August 2000. Food and Agriculture Organization. http://www.fao.org/ DOCREP/005/X9895E/x9895e02.htm

Sánchez-Salcedo, E. M., Mena, P., García-Viguera, C., Martínez, J. J. & Hernández, F. (2015). Phytochemical evaluation of white (*Morus alba* L.) and black (*Morus nigra* L.) mulberry fruits, a starting point for the assessment of their beneficial properties. *Journal of Functional Foods, 12*, 399-408.

Subedi, P. P., & Walsh, K. B. (2009). Non-invasive techniques for measurement of fresh fruit firmness. *Postharvest Biology and Technology*, *51*(3), 297-304. https://doi.org/10.1016/j.postharvbio.2008.03.004

Taniwaki, M., Sakura, N., & Kato, H. (2010). Texture measurement of potato chips using a novel analysis technique for acoustic vibration measurements. *Food Research International*, *43*(3), 814-818. https://doi.org/10.1016/j.foodres.2009.11.021

Van Dijk, C., Boeriu, C., Peter, F., Stolle-Smits, T., & Tijskens, L. M. M. (2006a). The firmness of stored tomatoes (cv. Tradiro). 1. Kinetic and near infrared models to describe firmness and moisture loss. *Journal of Food Engineering*, *77*(3), 575-584. https://doi.org/10.1016/j.jfoodeng.2005.07.029

Van Dijk, C., Boeriu, C., Stolle-Smits, T., & Tijskens, L. M. M. (2006b). The firmness of stored tomatoes (cv. Tradiro). 2. Kinetic and near infrared models to describe pectin degrading enzymes and firmness loss. *Journal of Food Engineering*, *77*(3), 585-593. https://doi.org/10.1016/j.jfoodeng.2005.07.017

Watcharasing, J., Thiralertphanich, T., Panthuwadeethorn, S., & Phimoltares, S. (2019). Classification of fruit in a box (FIB) using hybridization of color and texture features. *16th International Joint Conference on Computer Science and Software Engineering (JCSSE)*. Chonburi, Thailand (pp. 303-308). https://doi.org/10.1109/JCSSE.2019.8864164.

Watson, L., & Dallwitz, M. J. (2007). Moraceae. The families of flowering plants: Descriptions, illustrations, identification, and information RetrieVal. 1992 onward. CABI.

Weaver, W.W. (2001). *Sauer's herbal cures: America's first book of botanic healing*, 1762-1778. Taylor and Francis.

Zhang, B., Peng, B., Zhang, C., Song, Z., & Ma, R. (2017). Determination of fruit maturity and its prediction model based on the pericarp index of absorbance difference (I AD) for peaches. *PloS One*, *12*(5), p.e0177511. https://doi.org/10.1371/journal.pone.0177511