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Dielectric spectroscopy as a potential technique for prediction of kiwifruit quality indices during storage

Atefeh Fazayeli [a,*], *Saadat Kamgar* [a], *Seyed Mehdi Nassiri* [a], *Hassan Fazayeli* [b], *Miguel de la Guardia* [c]

[a] *Biosystems Engineering Department, Shiraz University, Shiraz, Iran*
[b] *School of Computer Science, Universiti Sains Malaysia 11800 USM, Pulau Pinang, Malaysia*
[c] *Department of Analytical Chemistry, University of Valencia, 46100 Burjassot, Spain*

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ABSTRACT

Dielectric spectroscopy has been employed as a simple, low cost and a non-destructive way for prediction of some physicochemical indices of kiwifruit during storage. A parallel-plate capacitor was developed and supplied with sinusoidal voltage waves within a frequency range of 40 kHz – 20 MHz. Dielectric properties of samples were measured by the dielectric sensor. Additionally, changes associated with fruit ripening properties, including firmness, total soluble solid (TSS) and pH were determined as a function of time at 2 °C. The results showed that storage time significantly affected the quality characteristics of kiwifruit. Artificial neural networks (ANNs) were employed to develop models for prediction of quality indices from dielectric properties at the swept frequencies. Dielectric property features were selected as inputs while the quality indices including firmness, TSS and pH were chosen as output for the ANNs. The obtained models were able to predict the firmness, soluble solids content, and pH of kiwifruit non-destructively. Among predictive models, an ANN with a topology of 20-19-1 gave a perfect capability to predict the kiwifruit firmness with R^2 value of 0.92. Results of this research show that this technique can be used as an efficient and non-destructive method for kiwifruit quality evaluation and monitoring the ripening.

1. Introduction

Kiwifruit is a semi-tropical fruit belonging to Actinidiaceae family, and Hayward is the most important commercial cultivars of this species [1]. It is considered as a source of phytochemicals, such as phenolics, flavonoids and chlorophyll, increased consumption of which can have substantial health benefits for consumers [2]. In commercial trade, kiwifruit is harvested mature but unripe while it ripens either slowly during long-term storage or may be accelerated by ethylene treatment. Therefore, proper postharvest handling and shelf life extension is important to improve the yield of high-quality kiwifruits [3].

* Corresponding author.
E-mail address: afazayeli@shirazu.ac.ir (A. Fazayeli).
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Several studies indicate that firmness, total soluble solids (TSS) and pH are the most important indices affecting the quality of kiwifruit and the stage of ripeness is well correlated with these parameters [4–7]. Traditionally, the assessment of firmness, TSS and pH is destructive and hence unable to be used for quality inspection of kiwifruit in the warehouse as it damages fruit tissue and a piece of fruit must be measured as a representative of the whole. Development of a non-destructive technique may overcome these problems and allow prediction of fruit quality as these methods increase the number of fruit pieces that can be analysed, repeat several times the same analysis on the same fruit during its storage and obtain real-time assessment without damaging the sample.

Different non-destructive techniques have been used for the assessment of internal and external quality attributes of fruits and vegetables. These include magnetic resonance imaging (MRI) [8], X-ray and computed tomography (CT) [9], machine vision [10], laser-induced fluorescence spectroscopy (LIFS) [11], time-resolved reflectance spectroscopy [12], near-infrared spectroscopy (NIRS) [13], acoustic impulse technique [14], impedance spectroscopy [15–17] and dielectric spectroscopy [18].

Dealing with the non-destructive monitoring of kiwifruit quality, researchers utilized Vis–NIR and NIR spectroscopy to predict the firmness, and soluble solid contents of kiwifruit. Results showed good correlations between Vis-NIR and NIR spectra and TSS (R^2 up to 0.98) [19] and dry matter (R^2 up to 0.97) [20]. Lower robust models were shown for the assessment of kiwifruit acidity (R^2 up to 0.89) [21], flesh hue angle (R^2 up to 0.82) and firmness (R^2 up to 0.76) [22].

For evaluating kiwifruit firmness, methods based on acoustic [23] and non-contact laser air-puff [24] were also proposed. The cited experiences showed that the sound transmission through fruit tissues increases according to the days of treatment with ethylene, and appreciable correlations (R^2 of 0.80) between the kiwifruit flesh firmness and the peak deformation consequent to the air-puff application were observed. By means of an impact device and artificial neural network (ANN) statistical analysis, Magness–Taylor flesh firmness (MTf) was also predicted from the impact time history (R^2 = up to 0.82) [25].

The internal quality of fruit during storage has been also investigated by analyzing the dielectric properties in the range of MHz and GHz. Many studies have illustrated that dielectric properties are influenced by moisture content, density, temperature, chemical composition, structure and the frequency of the applied alternating electric field [26]. The dielectric spectroscopy in the range of MHz and GHz has been studied for evaluation of mango ripening [27]; apple firmness prediction [28]; detection of egg freshness [29]; maturity effects on dielectric properties of apples [30]; quality characterization of olive oil during storage [31]; determination of milk concentration and freshness [32]; banana ripening [33]; characterization of sugar concentration in watermelon [34]; moisture content of date [35].

The literature shows that this method is practical, simple, and reliable for assessment and prediction of different quality indices of agricultural products, foods and fruits [36]. Several techniques such as parallel plate, resistivity cell, coaxial probe, lumped circuit, transmission line, resonant cavity, and time-domain spectroscopy, have been proposed in the literature for dielectric properties measurement. While each technique has its own pros and cons [26] the decisions of measurement technique strongly depend upon the dielectric materials and the frequency range [27].

This research was conducted to develop a low cost, simple, non-destructive technique based on dielectric spectroscopy for characterization of kiwifruit quality indices during storage such as firmness, TSS and pH. To achieve this goal several artificial neural networks were developed to provide the most robust predictive models.

2. Methods and materials

2.1. Sample preparation and storage conditions

360 kiwifruit samples, with moisture contents of 83.2 ± 0.3% (w/w) from one harvest season were used to build and apply the models. Kiwifruits were selected to be stored for one month at 2 ± 0.1 °C with 45 ± 1% relative humidity. A refrigerator was used to store the samples at 2 °C. In order to investigate the effect of storage duration on changes in physicochemical properties of kiwifruit, the dielectric properties and destructive measurements (firmness, TSS, pH) were carried out to evaluate firmness, TSS and pH in eleven stages at intervals of three days. Samples were selected randomly and kept in a room for 12 h before the experiment. The room environmental conditions were 20 °C with a relative humidity of 20%.

2.2. Physicochemical properties measurement

Firmness, Total soluble solids (TSS), and pH are physicochemical indices that are used to assess the changes in quality of kiwifruit during storage. The firmness of each kiwifruit was measured by using an Instron Universal Testing Machine (Santam Model MT-20). Penetration tests were conducted with a probe diameter of 8 mm by penetrating in 10 mm and a speed of 180 mm/min. A piece of skin about 2 mm thick was removed using a cutting device with a fixed blade. Results, in terms of Newton, were recorded by the STM-Controller program and transferred to an Excel spreadsheet and the force-deformation diagrams were plotted by the device.

Total soluble solids (TSS) were then measured using a digital desktop refractometer (Japan Refractometers WYA-2S). The two ends of the fruit were cut to 10 mm and samples were taken from the fruit juice [22].

The pH of the samples was measured by a pH meter (pH Meter744 Metrohn). Initially, the pH meter was calibrated with 4 and 7 buffer solutions, then the probe of the device was placed in the samples and readings were recorded after stabilization. Quality indices were measured with three replications for each stage.

2.3. Dielectric properties measurement

In this study changes in dielectric properties were measured by using a laboratory system made of a parallel-plate capaci-

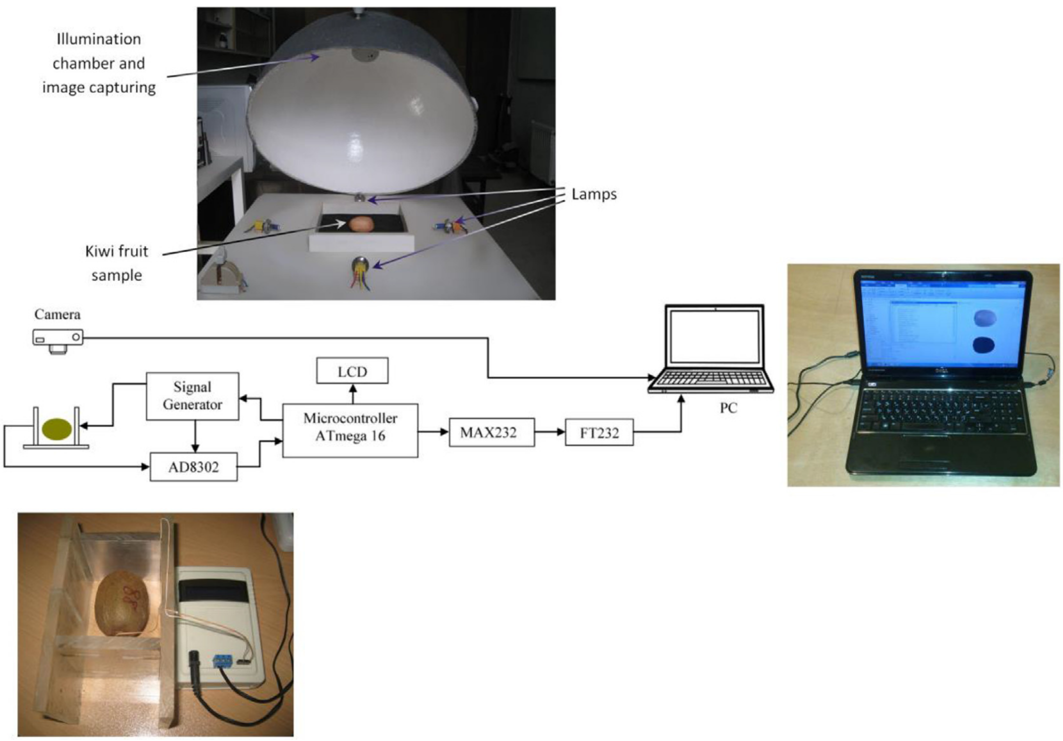

Fig. 1 – Experimental set up for measuring dielectric properties of kiwifruit.

tive sensor with two aluminium plates of 5 mm thickness and 80 × 80 mm dimensions (Fig. 1). Plates were installed on an insulated Plexiglas base with a 60 mm gap between them. The measurement device consisted of an ATMEGA 16 microcontroller, serial transmitter and receiver port, signal generator and LCD display. In order to generate the sinusoidal signal in this integrated system, MAX038 and CD4066 were used. The MAX038 is a precision function generator producing accurate, and high-frequency sinusoidal waveforms. In addition, an external resistor and variable capacitor can adjust the output frequency in the range of 0.1 Hz – 20 MHz by using an internal 2.5 V band gap voltage reference. Different frequencies were generated by changing the resistance and capacitance values of the circuit with a chip CD4066, which is a quad bilateral switch, intended to put a resistor or capacitor in or out of the circuit. By using some independent controls connected to the microcontroller it was possible to turn on and off the independent controls in a specific order to generate 192 different frequencies in the range of 40 kHz to 20 MHz. The AD8302 is a fully integrated RF IC for measuring amplitude and the phase between two independent input signals. The device can be used from low frequencies up to 2.7 GHz. The AD8302 output provides an accurate amplitude measurement over ±30 dB range scaled to 30 $\frac{mV}{dB}$ and the phase measurement over a 0–180° range scaled to 10 $\frac{mV}{degree}$. The outputs were connected to the 10-bit ADC unit of the microcontroller.

The dielectric properties or permittivity of agricultural products is a complex quantity which can be represented as:

$$\varepsilon = \varepsilon' - j\varepsilon'' \tag{1}$$

where the real part ε' is called the dielectric constant and the imaginary part ε'' is the dielectric loss factor.

The dielectric constant ε' is associated with the ability of a material to store energy in the electric field in the material, and the loss factor ε'' is associated with the ability of the material to absorb or dissipate energy, that is, to convert electric energy into heat energy [34].

$$\varepsilon' = \left[1 + \frac{\Delta\varnothing}{360\mathrm{d}}\frac{\mathrm{c}}{\mathrm{f}}\right]^2 \tag{2}$$

$$\varepsilon'' = \frac{\Delta A}{8.68\pi \mathrm{d}}\frac{\mathrm{c}}{\mathrm{f}}\sqrt{\varepsilon'} \tag{3}$$

where c is the speed of light in m/s, f is the frequency in Hz, d the thickness of the layer of material in meters, ΔA is the gain or loss in decibels, and $\Delta\phi$ is the phase shift in degrees.

As it can be seen in Eqs. (2) and (3) there is a fixed relationship between the phase shift and dielectric constant as well as the loss factor and gain. Therefore, instead of measuring ε' and ε'', the corresponding voltages and frequencies were fed into the neural network for prediction of the quality parameters of kiwifruit.

Since the amount of capacitance (c) and, consequently, the frequency read from the device is related to the kiwifruit placed in the device and the surrounding air, to remove the air effect, the image processing technique for measuring the exact dimensions of the fruit was used.

Machine vision was employed to determine the volume of the kiwifruits in order to normalise the readings of dielectric constants. Because of the axial symmetry of the kiwifruit around its longitudinal axis, the volume could be readily estimated through 2D images taken from the top of the fruit.

The indirect lighting chamber, so called the cloudy sky, was used to provide even illumination for taking the photos.

The chamber was made up of a 90 cm diameter dome. To obtain colour images, a digital CCD camera Canon IXUS 960IS was used with a resolution of 12 megapixels (3000 × 4000 pixels) at a height of 45 cm above the tested specimens. Digital images taken from kiwifruits were transmitted to the computer for processing in MATLAB environment.

Since the space between the capacitor plates is occupied by the kiwifruit and its surrounding air, the measurement partially corresponds to the fruit. Therefore the net measurement was calculated based on the ratio of the fruit to the surrounding air. The vision system was employed to measure the air and fruit ratio.

2.4. *Feature selection*

The 192 frequencies in the range of 40 kHz – 20 MHz were generated to measure the total 384 voltage values as dielectric properties of each kiwifruit sample. After extracting the dielectric features, the most effective features were selected from the resulting feature vector. Some of these features may not have a good correlation with group classes. Therefore to improve the performance of the ANNs, it was necessary to identify and remove less relevant information and select the most effective features for monitoring quality characteristics of kiwifruit. For this purpose, principal component analysis (PCA) was used to reduce data dimensions. PCA is one of the non-supervised dimension reduction methods most commonly used in multivariate analyses and is a well-known method for compressing data and extracted features. This method converts the input vector components into the main components that are not correlated with each other [37].

Before PCA, the data were normalized to be within the range of −1 to +1 using the Eq. (4).

$$X_i = \frac{x_i - \mu}{\sigma} \quad i = 1, \cdots, n \tag{4}$$

where μ and σ are the average and the standard deviation of the data respectively.

Selected features by PCA were fed as input to the neural networks and the best network model was selected to predict physicochemical properties of kiwifruit during storage under controlled temperature and pressure.

2.5. *Artificial neural network (ANN)*

ANNs are one of the well-known techniques that are widely used in data analysis and modelling. Various types of ANNs have been designed. The most commonly used ANN for classification and prediction tasks is the multilayer perceptron network (MLP) [38,39]. In this study, a feed-forward neural network (FFNN) with back-propagation algorithm was chosen as the best option after trial and errors. The gradient descent with momentum (GDM) algorithm was examined for error minimization and momentum coefficient was set to 0.2. The structure of ANNs has a significant influence on the performance of a network. The main factors for designing MLP networks are the number of hidden layers and the number of their neurons. Increasing the number of hidden layers leads to a more complex ANN which is susceptible to overfitting as well. So in this study, one hidden layer was used in the structure of MLP. Dielectric property features were selected as inputs while the quality indices including firmness, TSS and pH were chosen as output for ANNs.

2.6. *Data analysis*

For analysing the collected data, different artificial neural networks were developed and compared to find the best model for quality prediction of kiwifruit. 60% of the data set was randomly selected as the training set, 20% for cross-validation and the remaining 20% of the data set was used as the test set. The correlation coefficient (R) and Root Mean Square Error (RMSE) were used to evaluate the models and determine the best model for the prediction of the quality indices of kiwifruits (Eqs. (5) and (6)).

$$R^2 = \frac{\sum \left(x_{act} - \widehat{x_{act}}\right)\left(x_{pre} - \widehat{x_{pre}}\right)}{\sqrt{\sum \left(x_{act} - \widehat{x_{act}}\right)^2 \sum \left(x_{pre} - \widehat{x_{pre}}\right)^2}} \tag{5}$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x_{act} - x_{pre}\right)^2} \tag{6}$$

where x_{act} correspond to the actual values and x_{pre} to the predicted values of the parameters and n is the total number of data. The statistical design used for reference data obtained from destructive tests (firmness, TSS and pH) was a factorial experiment in a completely randomized design with SPSS software.

3. Results and discussion

3.1. *Evaluation of physicochemical properties during storage*

The changes in the kiwifruit quality indices during the storage are shown in Fig. 2. Storage time significantly affected fruit firmness. The firmness decreased 58.5% during a period of 30 days. The decreased firmness can be due to the decomposition of cell wall polysaccharides. Cell wall polysaccharides degrade by the action of hydrolyzing pectin methylesterase (PME), polygalacturonase (PG) and cellulose [25]. The TSS content increased from 10.2% Brix to 15.1% Brix in 30 days storage at 2 °C. Increased soluble solids occur frequently due to the conversion of starch into soluble sugars [40]. During storage, a slight increase in the pH of the kiwifruit can be observed as shown in Fig. 2. The pH is directly related to the concentration of organic acids in the sample, which is an important quality factor of the fruit [24]. By ripening progressing and decaying the fruit, the respiratory activity of the fruit continues, which results in the consumption of organic acids and, consequently, the increase of the pH.

3.2. *The effect of frequency on dielectric properties*

As it was mentioned before the output voltage of the measurement system was sufficient to be fed to the Ann. Therefore there was no need to calculate ε′ and ε″ from the corresponding voltages. It can be seen in Figs. 3 and 4, the output voltage has decreased by increasing the frequency.

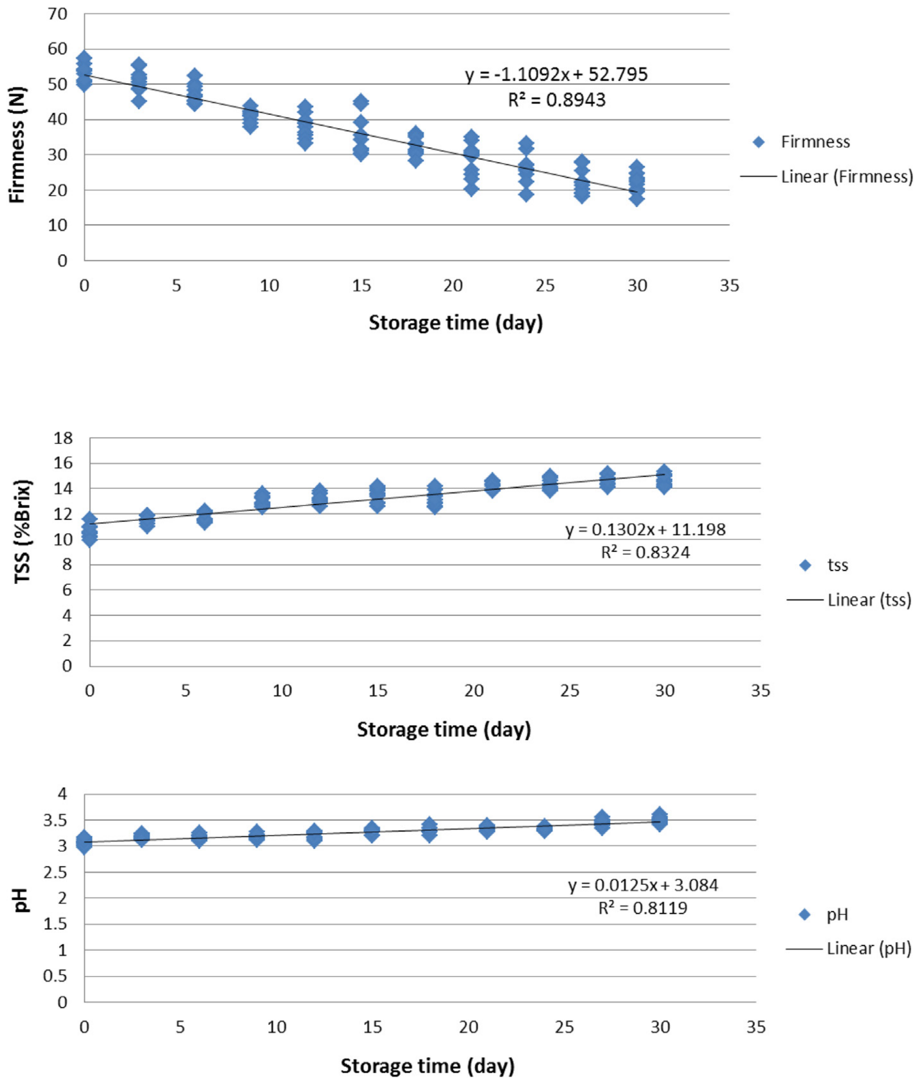

Fig. 2 – The effect of storage time on quality indices of kiwifruit.

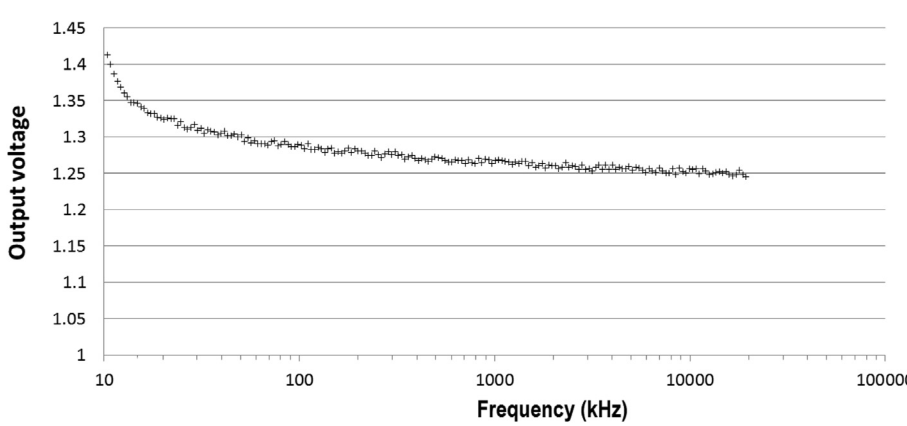

Fig. 3 – Output voltage corresponding to the dielectric constant of a single Kiwifruit at frequencies from 40 KHz to 20 MHz.

3.3. *ANN results*

Different ANN models were developed to predict firmness, TSS and pH as kiwifruit quality indices during storage. The optimum combination of features was extracted to predict the quality indices by using the PCA (Table 1). The selected features were fed as the input while the quality indices including firmness; TSS and pH were chosen as the output

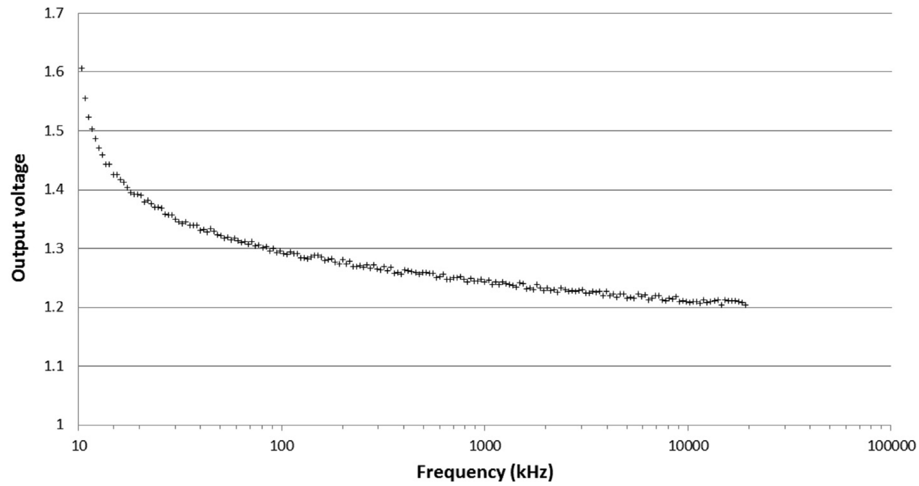

Fig. 4 – Output voltage corresponding to the loss factor of a single Kiwifruit at frequencies from 40 KHz to 20 MHz.

Table 1 – Number of selected features using PCA.

Quality index	Number of selected features
Firmness	20
TSS	31
pH	42

Table 2 – The best network structure of ANNs for predicting kiwifruit quality indices.

Quality index	Network structure	R^2	RMSE
Firmness	20-19-1	0.92	4.8912
TSS	31-8-1	0.91	1.3411
pH	42-11-1	0.86	0.2141

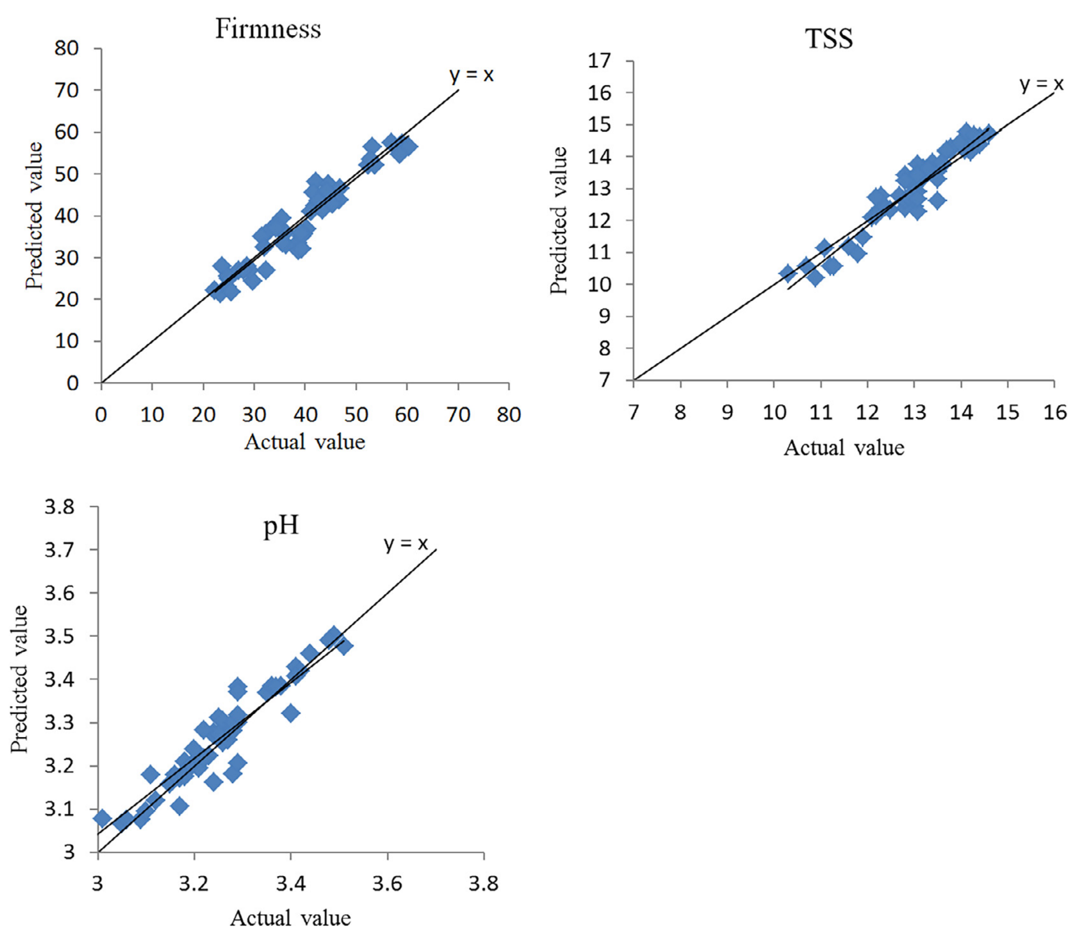

Fig. 5 – Correlation between actual and predicted kiwifruit quality indices obtained by using ANN.

of the ANNs. To evaluate the performance of the developed models, RMSE and R values were computed for each model. In order to achieve the best ANN structure with the highest performance, the different number of neurons (1–25) in the hidden layer was examined. The ANN structures with the lowest RMSE and the highest R^2 were selected as the final models for prediction of each quality indices. Results showed that the hidden layers with 19, 8 and 11 neurons provided the best performance for prediction of firmness, TSS and pH respectively compared to the other structures. The optimal ANN topologies for the prediction of each quality parameter are shown in Table 2. Based on the values of R^2 and RMSE in Table 2, it can be concluded that the proposed models with R^2 values higher than 86% have a good capability for quality indices prediction of kiwifruit based on dielectric properties. However, the best model with $R^2 = 0.92$ and RMSE = 4.8912 was related to fruit firmness.

Correlation between the measured and ANN predicted values of physicochemical properties of kiwifruits are shown in Fig. 5. Based on the values of R^2 and RMSE, it can be concluded that the proposed models showed acceptable performance in prediction of kiwifruit quality indices.

4. Conclusion

In this study, dielectric spectroscopy with a parallel-plate capacitor was used in a frequency range of 40 kHz – 20 MHz as a low-cost, non-destructive and rapid way to predict kiwifruit quality indices during their storage. It was found that the obtained dielectric data contain appropriate information about firmness, TSS and pH. PCA was used to extract the most relevant dielectric features to reduce the dimension of the input vector and enhance the speed of model building. The refined data were used to train ANN models to predict firmness, TSS and pH.

Almost all of the developed models showed good prediction ability. Among the predictive models, the ANN with a topology 20-19-1 provided the best result (R = 0.92 and RMSE = 4.8912) for modelling the fruit firmness. The results of this study indicated that this technique can be used to predict quality indices with a high estimation accuracy and short computation time.

The main innovation in this paper was the integration of two different kinds of information i.e. machine vision and dielectric spectroscopy. While the literature showed that mere use of each method was not able to achieve a high accuracy, the combination of two inherently different feature vectors in this study increased the chance of having orthogonal features which made a more discriminating signature for each stage of kiwifruit ripening and storage.

REFERENCES

[1] Li M, Pullanagari RR, Pranamornkith T, Yule IJ, East AR. Quantitative prediction of post storage ‘Hayward’kiwifruit attributes using at harvest Vis-NIR spectroscopy. J Food Eng 2017;202:46–55.

[2] Hwang JS, Cho CH, Baik MY, Park SK, Heo HJ, Cho YS, et al. Effects of freeze-drying on antioxidant and anticholinesterase activities in various cultivars of kiwifruit (Actinidia spp.). Food Sci Biotechnol 2017;26(1):221–8.

[3] Zhou X, Li R, Lyng JG, Wang S. Dielectric properties of kiwifruit associated with a combined radio frequency vacuum and osmotic drying. J Food Eng 2018;239:72–82.

[4] Farzam E, Shahbazi H, Imani AA, Gheshlaghi EA. Effect of harvest time on some qualitative and quantitative characteristics of hayward Kiwifruit in the West of Gilan. Iran Int J Farm Allied Sci 2013;11(2):296–301.

[5] Vivek K, Subbarao KV, Srivastava B. Optimization of postharvest ultrasonic treatment of kiwifruit using RSM. Ultrason Sonochem 2016;32:328–35.

[6] Cangi R, Altuntas E, Kaya C, Saracoglu O. Some chemical and physical properties at physiological maturity and ripening period of kiwifruit (‘Hayward’). Afr J Biotechnol 2011;10 (27):5304–10.

[7] Burdon J, Lallu N. Kiwifruit (Actinidia spp.). In: Yahia EM, editors. Postharvest biology and technology of tropical and subtropical fruits: Cocona to Mango. Elsevier; 2011. p. 326-62e.

[8] Melado-Herreros A, Munoz-García MA, Blanco A, Val J, Fernández-Valle ME, Barreiro P. Assessment of watercore development in apples with MRI: Effect of fruit location in the canopy. Postharvest Biol Technol 2013;86:125–33.

[9] Arendse E, Fawole OA, Magwaza LS, Opara UL. Non-destructive characterization and volume estimation of pomegranate fruit external and internal morphological fractions using X-ray computed tomography. J Food Eng 2016;186:42–9.

[10] Jafari A, Bakhshipour A. Inspection of quince slice dehydration stages based on extractable image features. Czech J Food Sci 2014;32(5):456–63.

[11] Kubota TM, Magalhaes AB, da Silva MN, Boas PR, Novelli VM, Bastianel M, Sagawa CH, Cristofani-Yaly M, Milori DM. Laser-induced fluorescence spectroscopy (LIFS) for discrimination of genetically close sweet orange accessions (citrus sinensis l. osbeck). Appl Spectrosc 2017;71(2):203–14.

[12] Vanoli M, Rizzolo A, Grassi M, Spinelli L, Verlinden BE, Torricelli A. Studies on classification models to discriminate ‘Braeburn’apples affected by internal browning using the optical properties measured by time-resolved reflectance spectroscopy. Postharvest Biol Technol 2014;91:112–21.

[13] Huang L, Meng L, Zhu N, Wu D. A primary study on forecasting the days before decay of peach fruit using near-infrared spectroscopy and electronic nose techniques. Postharvest Biol Technol 2017;133:104–12.

[14] Lashgari M, Maleki A, Amiriparian J. Application of acoustic impulse response in discrimination of apple storage time using neural network. Int Food Res J 2017;24(3):1075.

[15] Neto AF, Olivier NC, Cordeiro ER, de Oliveira HP. Determination of mango ripening degree by electrical impedance spectroscopy. Comput Electron Agric 2017;143:222–6.

[16] Ren P, Fan H, Wang X. Impedance spectroscopy studies of bulk electrical conduction in A-site acceptor (K)-doped BaTiO3. J Mater Sci 2013;48(20):7028–35.

[17] Tian H, Fan H, Ma J, Ma L, Dong G. Noble metal-free modified electrode of exfoliated graphitic carbon nitride/ZnO nanosheets for highly efficient hydrogen peroxide sensing. Electrochim Acta 2017;247:787–94.

[18] Naderi-Boldaji M, Fazeliyan-Dehkordi M, Mireei SA, Ghasemi-Varnamkhasti M. Dielectric power spectroscopy as a potential technique for the non-destructive measurement of sugar concentration in sugarcane. Biosyst Eng 2015;140:1–10.

[19] Clark CJ, McGlone VA, De Silva HN, Manning MA, Burdon J, Mowat AD. Prediction of storage disorders of kiwifruit (Actinidia chinensis) based on visible-NIR spectral characteristics at harvest. Postharvest Biol Technol 2004;32 (2):147–58.
[20] McGlone VA, Clark CJ, Jordan RB. Comparing density and VNIR methods for predicting quality parameters of yellow-fleshed kiwifruit (Actinidia chinensis). Postharvest Biol Technol 2007;46(1):1–9.
[21] Moghimi A, Aghkhani MH, Sazgarnia A, Sarmad M. Vis/NIR spectroscopy and chemometrics for the prediction of soluble solids content and acidity (pH) of kiwifruit. Biosyst Eng 2010;106(3):295–302.
[22] Ragni L, Cevoli C, Berardinelli A, Silaghi FA. Non-destructive internal quality assessment of "Hayward" kiwifruit by waveguide spectroscopy. J Food Eng 2012;109(1):32–7.
[23] Javadi S, Nasiri SM. Application of acoustic method for estimation of kiwifruit firmness during storage. J Food Sci Technol 2016;13:143–50.
[24] McGlone VA, Jordan RB. Kiwifruit and apricot firmness measurement by the non-contact laser air-puff method. Postharvest Biol Technol 2000;19(1):47–54.
[25] Ragni L, Berardinelli A, Guarnieri A. Impact device for measuring the flesh firmness of kiwifruits. J Food Eng 2010;96 (4):591–7.
[26] Nelson SO. Fundamentals of dielectric properties measurements and agricultural applications. J Microw Power Electromagn Energy 2010;44(2):98–113.
[27] Sosa-Morales M, Tiwari G, Wang S, Tang J, Garcia H, Lopez-Malo A. Dielectric heating as a potential post-harvest treatment of disinfesting mangoes, Part I: Relation between dielectric properties and ripening. Biosyst Eng 2009;103 (3):297–303.
[28] Kafarski M, Wilczek A, Szypłowska A, Lewandowski A, Pieczywek P, Janik G, et al. Evaluation of apple maturity with two types of dielectric probes. Sensors 2018;18(1):121–34.
[29] Soltani M, Omid M. Detection of poultry egg freshness by dielectric spectroscopy and machine learning techniques. LWT-Food Sci Technol 2015;62(2):1034–42.
[30] Guo W, Zhu X, Nelson SO, Yue R, Liu H, Liu Y. Maturity effects on dielectric properties of apples from 10 to 4500 MHz. LWT-Food Sci Technol 2011;44(1):224–30.
[31] Sanaeifar A, Jafari A, Golmakani M-T. Fusion of dielectric spectroscopy and computer vision for quality characterization of olive oil during storage. Comput Electron Agric 2018;145:142–52.
[32] Guo W, Zhu X, Liu H, Yue R, Wang S. Effects of milk concentration and freshness on microwave dielectric properties. J Food Eng 2010;99(3):344–50.
[33] Soltani M, Alimardani R, Omid M. Evaluating banana ripening status from measuring dielectric properties. J Food Eng 2011;105(4):625–31.
[34] Nelson SO, W-c Guo, Trabelsi S, Kays SJ. Dielectric spectroscopy of watermelons for quality sensing. Meas Sci Technol 2007;18(7):1887.
[35] Mireei SA, Bagheri R, Sadeghi M, Shahraki A. Developing an electronic portable device based on dielectric power spectroscopy for non-destructive prediction of date moisture content. Sens Actuators, A 2016;247:289–97.
[36] Öztürk S, Şakıyan Ö, Özlem Alifakı Y. Dielectric properties and microwave and infrared-microwave combination drying characteristics of banana and kiwifruit. J Food Process Eng 2017;40(3) e12502.
[37] Bakhshipour A, Jafari A, Nassiri SM, Zare D. Weed segmentation using texture features extracted from wavelet sub-images. Biosyst Eng 2017;157:1–12.
[38] Jafari A, Fazayeli A, Zarezadeh MR. Estimation of orange skin thickness based on visual texture coarseness. Biosyst Eng 2014;117:73–82.
[39] Fan H, Liu L. Optimizing design of the microstructure of sol-gel derived BaTiO 3 ceramics by artificial neural networks. J Electroceram 2009;22(1–3):291–6.
[40] Kazemi M. Influence of foliar application of iron, calcium and zinc sulfate on vegetative growth and reproductive characteristics of strawberry cv. 'Pajaro'. Trakia J Sci 2014;1:21–6.