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Dielectric technique combined with artificial neural network and support vector regression in moisture content prediction of olive

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Abstract: Olives are one of the most important agriculture crops in the world, which are harvested in different stages of growth for various uses. One of the ways to detect the adequate time to process the olives is to determine their moisture content. In this study, to determine the moisture content of olives, a dielectric technique was used in seven periods of harvesting and three different varieties of olive including *Oily*, *Mary* and *Fishemi*. The dielectric properties of the olive fruits were measured using an electronic device in the range of 0.1–30 MHz. Artificial Neural Network (ANN) and Support Vector Regression (SVR) methods were applied to develop the prediction models by using the obtained data acquired by the system. The best results (R = 0.999 and MSE = 0.014) were obtained by the ANN model with a topology of 384–12–1 (384 features in the input vector, 12 neurons in the hidden layer and 1 output). The results obtained indicated the acceptable accuracy of the dielectric technique combined with the ANN model.

Keywords: capacitive sensor; data mining; estimation; quality factor

Olives are one of the most valuable fruits that have a high nutritional value and have a high popularity in many countries in the world (Bernardi et al. 2016). Olive tree grows slowly and yield fruits from when the trees are 5 to 10 years old (Bernardi et al. 2018). If the climatic conditions are favourable, about 65 kg of olives can be harvested on average from each olive tree, and from about four to five kilograms of fruit, it can produce about one litre of oil (Castro-Garcia et al. 2015). In the world, about 1 200 varieties of olive trees are planted (Leone et al. 2015). Olive crops are cultivated in countries with favourable weather conditions as a strategic product (Rigacci, Stefani 2016). Olive fruits are elliptical and contain a kernel and their colour depends on the species. In the varieties that are special for oil extraction, the colour of the fruit is initially bright and its colour becomes darker during the ripening period (López-López et al. 2016). The weight of each olive fruit with a high oil content is 2–12 g. Olive fruits are considered to be a significant source of human nutrition in terms of its significant oil content (Luque-Sierra et al. 2018). Over the past few decades, the medicinal properties of olives have been identified more than ever. Olive oil is a product in rich vitamins and antioxidants and helps to prevent heart attacks and brain strokes (Jurado-Ruiz et al. 2017). The olive harvesting time is dependent on the weather conditions, the type of olive as well as the type of consumption (for edible or oil extraction) (Alowaiesh et al. 2016). One of the most common methods to determine the harvesting time is the colour of the olive. This is especially important in

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harvesting the olives used for the oil extraction. The moisture content is one of the important factors in detecting the olive processing that can help farmers identify the stage of the process (Zipori et al. 2016). The oven drying technique is a standard method for determining the moisture content of fruits (O'Kelly, Sivakumar 2014). However, due to fact that the oven drying process is time-consuming, farmers prefer to recognize and harvest the olives by relying only on their vision. Dielectric properties are one of the most important physical characteristics of agricultural products and food materials (Rashvand et al. 2016). The association of these properties with many quantitative and qualitative components of the product has made it a popular technique as a fast, low cost and non-destructive technology among researchers (Rashvand et al. 2017). Based on the dielectric method, when a material is placed inside an alternating electric field, the positive and negative charged particles tend to move. The dielectric properties of agricultural products have always been the subject of research by many scientists. Dielectric properties play an important role in determining the quality of many things (Nelson 2015). Ismail and Alyahya (2003) used the dielectric method to estimate the moisture content of four varieties of dates at two frequencies of 1 and 5 MHz, and they reached a 95% accuracy level. Schmilovitch et al. (2006) also conducted research on the moisture content of dates. By measuring the dielectric coefficients in the range of 8 to 12 MHz, they were able to estimate the moisture content of the *Namul* variety with a precision of 95% by means of a parallel plate dielectric detector. Osman et al. (2003) developed and evaluated a capacitive base moisture sensor for forage under constant conditions. There was good correlation between the sensor output and the amount of water inside the capacitor chamber. They reported R^2 equal to 0.92 and 0.67 for rice and alfalfa, respectively. Berbert et al. (2004) measured the dielectric properties and moisture content of bean seeds. They proposed three models for the seed moisture prediction. They reported the proposed model with a standard deviation of 1–1.3% and a maximum error of 1.9–1.5%, which was able to estimate the moisture content of the bean seeds. Afzal et al. (2010) estimated the moisture content of leaves by measuring the dielectric constant of the leaves for five different product types. They used two half-elliptical copper plates as the electrodes and a Keithly 590 C-V analyser as the capacitance measuring devices that were able to measure the capacitor's capacities at two frequencies of 100 kHz and 1 MHz. Soltani and Alimardani (2011) utilised a cylindrical capacitor and investigated the effect of moisture on the dielectric coefficient of peas and beans in a range of 1 kHz to 1 MHz. The results of this study showed that in all the frequencies, the dielectric constant has a relatively strong relationship with the moisture content of these two products, however, the best results were obtained at a frequency of 1 MHz. Zhu et al. (2012) observed the effect of the moisture content, frequency and temperature on the dielectric properties of oak flour and reported that both the relative and detached dielectric constant decreased with an increasing frequency, but increased with an increasing moisture content. Also, using some equations, they found a relationship between the moisture content and the permeation at a temperature of 20 and 11 °C, and the frequency of 315 and 2151 MHz with a good correlation coefficient.

Considering the above, it can be claimed that the moisture content is a very important factor in relation to the issue of the fruit's ripeness. The dielectric detector is also a very effective means for detecting the moisture content of agricultural products. The purpose of this study was to determine the feasibility of determining the olive fruit ripeness using a dielectric technique. By this method, it is possible to estimate the moisture content of the olive fruit which is strongly related to its ripening stage and to determine the appropriate time for olive harvesting according to the type of consumption.

MATERIAL AND METHODS

Preparation of samples. In this study, three olive varieties including *Oily*, *Fishemi* and *Mary* were provided. The olive samples were harvested at seven times (the 10^{th}, 15^{th}, 20^{th}, 25^{th} and 30^{th} of October, as well as on the 5^{th} and 10^{th} of November) from the farm of the Iranian Research Organization for Science and Technology (IROST). The samples were immediately transferred to the laboratory and placed in a refrigerator at the ambient temperature of 7 °C. Among the samples, nine olives were randomly selected with the same size of each variety. Before starting the experiment, the olive samples were kept at room temperature (25 °C) for 3 hours. After testing with the dielectric system and acquiring the dielectric data, the moisture content of the samples was

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destructively measured. To measure the moisture content based on the standard oven drying method, the olive samples were placed in an oven at 101 °C for 24 h and the percentage weight loss was calculated based on the wet weight of the sample.

Dielectric measuring system. The dielectric sensor was used in the design and fabrication of the device in order to measure the dielectric parameters of the olive fruits. Therefore, the body of the device should be selected from a material that does not cause any interference in the electric field. In this study, a flat parallel dielectric detector with an outer periphery polymer support was selected according to the maximum size of the olive samples. To generate a voltage of + 5 V, a KA7805 regulator (Fairchild Semiconductor, USA) was used, a KA7905 (Fairchild Semiconductor, USA) regulator was also used to generate a – 5 V current. For the voltage, in order to pass through the capacitive sensor, an alternating current is required to feed into the sensor. For the device to be designed as a complete unit where it does not require a separate signal generator system, it was necessary to have a single generator unit, so that a Max038 chip (Maxim Integrated, USA) was used to generate the sinusoidal signal (Figure 1). Finally, a combination of input resistance and capacitor variations can produce different frequencies in the range of 0.1 Hz to 20 MHz. The output voltage of the dielectric sensor was sent to the AD8302 module and compared with the input signal. The AD8302 module is a fully integrated chip for measuring the dielectric properties of the material up to 2.7 GHz and provides an accurate measurement of either a gain or loss over a ± 30 dB and a phase difference over 0–180°. The outputs from the AD8302 module were

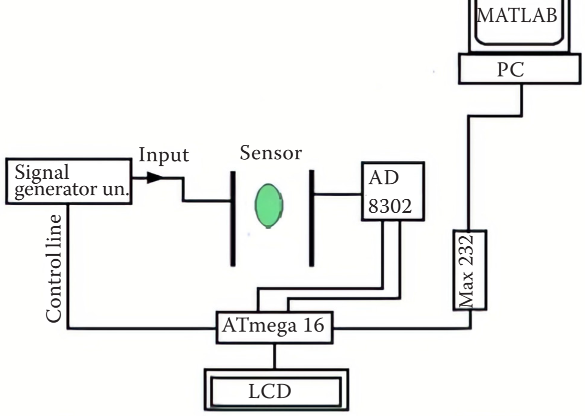

Figure1. The overall schematic of the dielectric measurement system

connected to the ADC unit of an ATMega16 (Atmel, USA). In the construction of the device, an ATmega 16 microcontroller (Atmel, USA), which is located in the megaAVR category, was also used, and due to the large amount of feature extractions during the data acquisition process, it was necessary for the device to send the measured parameters to a computer, so a Max232 chip was used. All the tests were performed at room temperature (25 °C).

Artificial Neural Network (ANN). Nowadays, ANN applications are observed in different industries. Modelling a system using an ANN means defining the proper network architecture and defining different optimal weights and neurons (Yousefi 2017). In this research, 70% of the data was used to train the neural network, the ANN training is intended to determine the set of weights, so that the designed network function is approximately at the actual performance of the system and the difference between the predicted values and the actual values is minimised (Pan et al. 2016). According to the system used with the huge amount of data, the Levenberg–Marquardt (LM) algorithm was used, which has the appropriate speed for the evaluation (Hao, Wang 2017).

Support Vector Regression (SVR). Unlike the ANN method, which is designed to minimise the error on the training data set, the supporting vector machine is based on minimising the structural error (Zhang et al. 2018). In the ANN models, the structure of the network prior to training is clear and practically no optimisation is performed, but, in the support vector machine (SVM) models, the structure of the network is also optimised along with the weights (Wijewardane et al. 2016). The SVR is a subset of the SVM, which is a new and powerful way of estimating parameters.

RESULTS AND DISCUSSION

Considering that the objective of this research is to predict the moisture content of olives, and that measuring the dissipation factor and dielectric coefficient were not considered, therefore, to extract the phase shift and the gain, only the voltages associated with these two parameters were found to be adequate in predicting the moisture content. The operation was repeated 192 times and the two parameters' phase change and gain voltage were measured at 192 frequencies in the range of 40 kHz–20 MHz and stored. The average of voltage gain of the olive samples is shown in Figure 2. Due to the fact that

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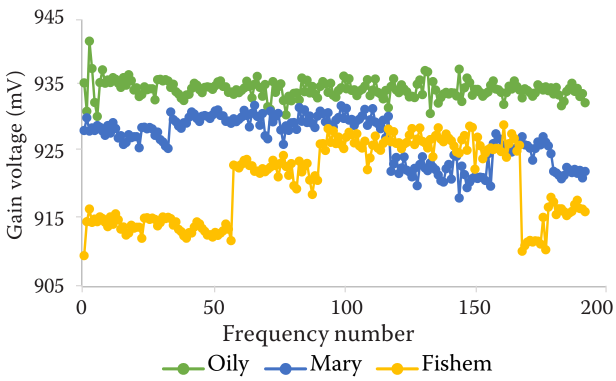

Figure 2. The average values of the voltage gain of the samples

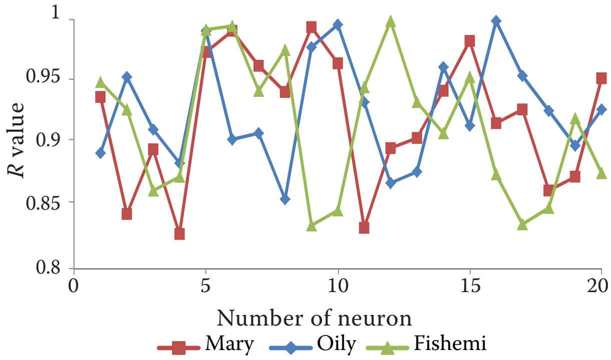

Figure 3. The results of the ANN modelling with the different neuron numbers

the *Oily* olive moisture content was higher than the moisture content of the *Mari* and *Fishemi* samples in all of the harvesting days, the device received and stored a higher voltage gain. The *Oily* olive has a higher moisture content due to the amount of oil in the *Mary* and *Fishemi* type. Based on the output of the device in terms of the voltage gain, it was observed that increasing the moisture content also increased the dielectric coefficient. For example, the maximum voltage gain in the *Oily* was 943 mV, while the maximum voltage gain was about 928 mV in the *Fishemi* varieties in the lower-fisheye model.

ANN. A single-layer ANN with 384 inputs (phase shift voltage and voltage gain in 192 frequencies), a hidden layer and an output (moisture content) were used to predict the moisture content of the olives. 70% of the data was used for the network training, 15% for the validation and 15% for the network testing. In order to select the best model, the number of hidden layer neurons varied from 1 to 20. The results of the modelling the networks with different neurons are shown in Figure 3.

In this research, the process of selecting the appropriate geometry for the data was performed from a single-layer network. Also, the best topology for the *Oily*, *Mary* and *Fishemi* samples were 384–16–1, 384–9–1 and 384–12–1 with R equal to 0.999, 0.994, 0.999 and the Mean squared error (MSE) equal to 0.071, 0.109, 0.014, respectively (Figure 4).

SVR. SVR was used for modelling the moisture content of the different varieties of olive, and Fine Tree, Gaussian, Linear and Quadratic models were used and the R and MSE are also presented in Table 1. In all the olive samples, the Gaussian model provided the best accuracy in the prediction and the Fine Tree model showed the highest error. The moisture content of the olive is one of factors for the prediction of ripeness. During the time (in the ripening period), the amount of olive oil increases. Hence, the moisture content of the olive decreases. Obviously, the moisture content and the olive oil affect the dielectric properties of the olive and we can predict the ripeness of the olive using the moisture content and dielectric properties. Also, in the SVR section, the predicted values versus the measured ones is shown in Figure 5.

The Gaussian model had the best result for predicting the *Oily* olive moisture content (R = 0.99, MSE = 0.4) and the weakest model was related to the Fine Tree model in predicting the *Fishemi* olive moisture content (R = 0.94, MSE = 2.04). Furthermore, the best regression model for any olive varieties are shown in Figure 5.

According to the comparison of the methods used to predict the amount of the olive moisture content,

Table 1. The results of the SVR for the different varieties

Mode	Oily		Mary		Fishemi	
	R	MSE	R	MSE	R	MSE
Fine Tree	0.96	1.6	0.96	1.4	0.94	2.04
Gaussian	0.99	0.4	0.98	0.53	0.98	0.66
Linear	0.98	0.7	0.97	0.93	0.96	1.3
Quadratic	0.98	0.8	0.97	0.8	0.96	1.1

R – regression coefficient, MSE – Mean squared error

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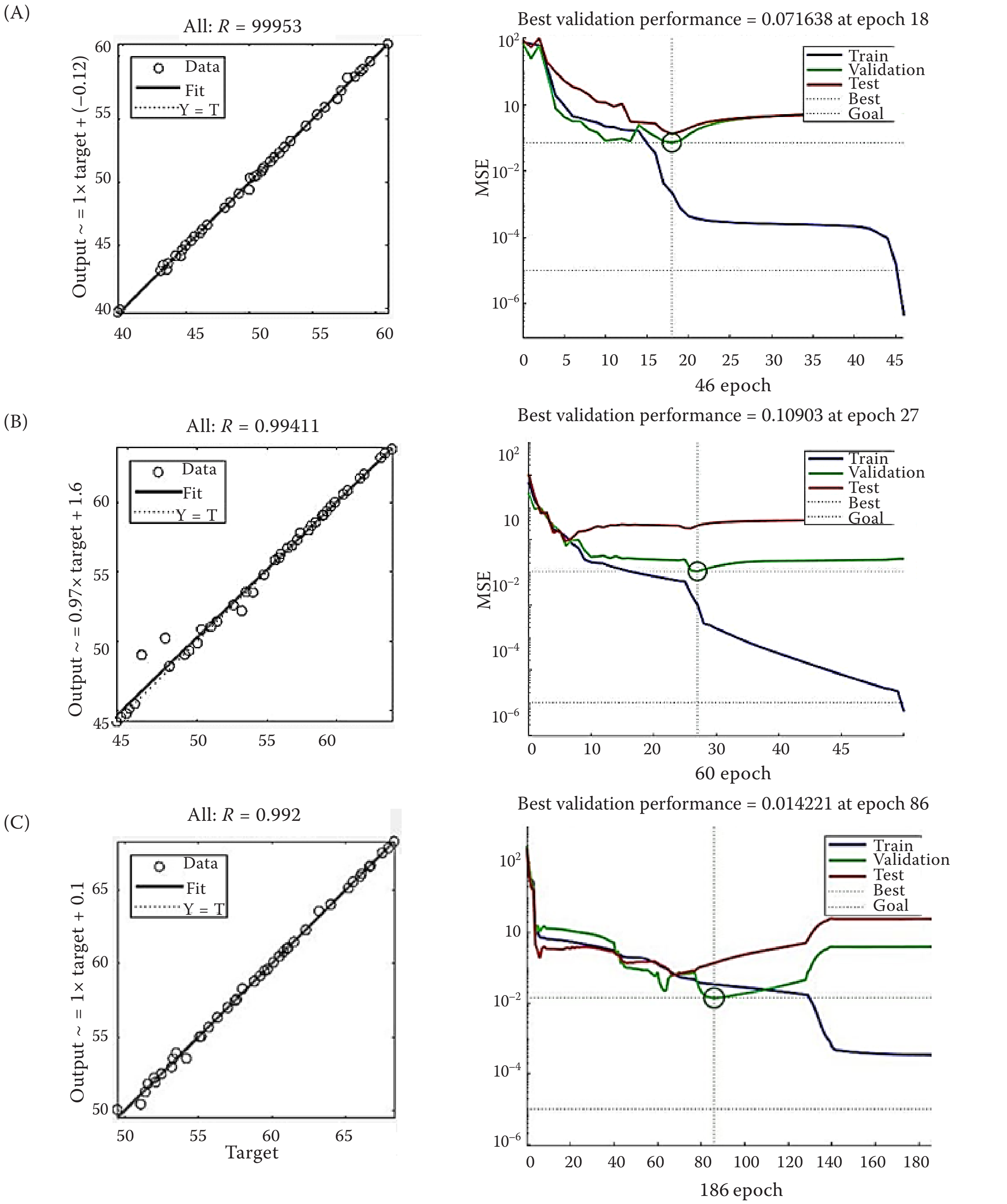

Figure 4. The best *R* and MSE obtained from the ANN modelling for the different samples varieties (A) *Oily*, (B) *Mary* and (C) *Fishemi*

it can be argued that ANN is more accurate than the SVR algorithms. The highest value of *R* in the ANN was 0.9995, while the best result obtained in the SVR models, through the Gaussian algorithm was 0.9913. Also, Yeow et al. (2010) tested the amount of the olive moisture content using microwave wavelengths between 1 and 5 GHz, and they developed a model to predict the good moisture content. The dielectric method has been also used to predict the moisture content of other agricultural products. Guo et al.

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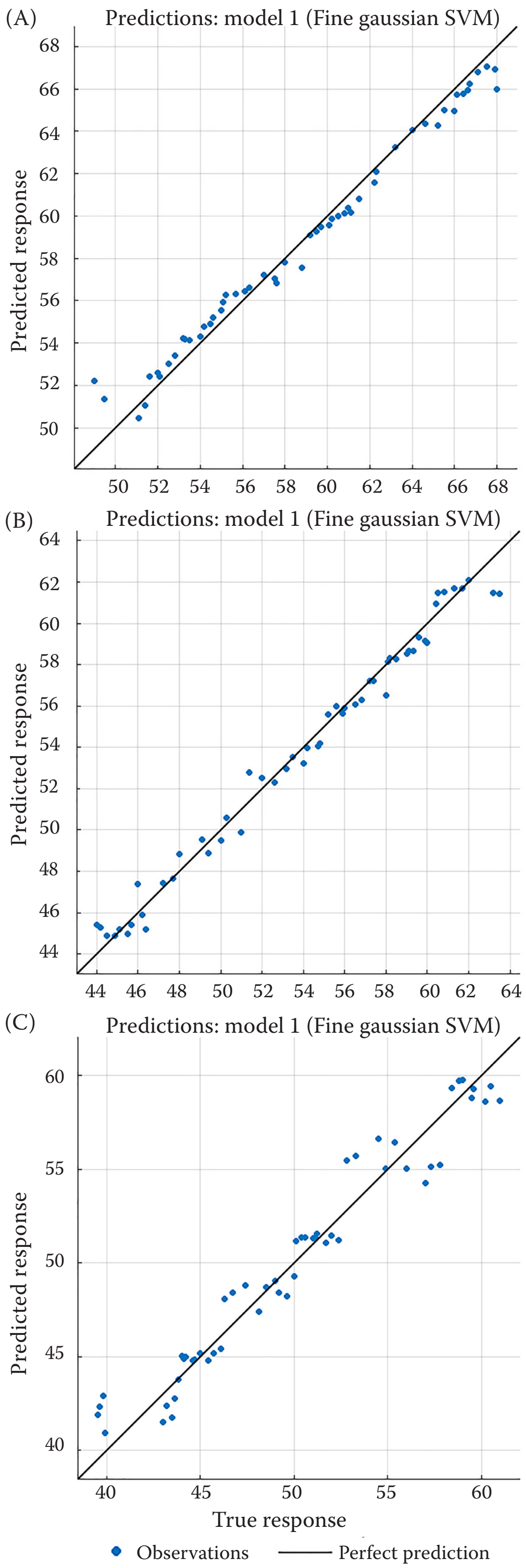

Figure 5. The best regression model for the moisture content of the different varieties of the olives (A) *Oily*, (B) *Mary* and (C) *Fishemi*

(2011) examined the amount of the apple fruit moisture content using a 4 500MHz based frequency capacitive sensor. They used a linear regression method to evaluate the results and reported the best value of *R* = 67%. However, Reyes et al. (2017) reported excellent results with a 1 GHz frequency that managed to get a great result in predicting the moisture content of apples. Using a regression method, they reported the value of *R* = 98%.

CONCLUSION

One of the most important factors in determining the amount of olives to be harvested in addition to the colour is their moisture content. A dielectric based system was used to predict the olive fruit's moisture content. In the ANN method, a number of different neurons (1–20) were used and the best result for the different varieties were different. In the SVR method, four different algorithms were used and the best results were related to the Gaussian, Quadratic, Linear and Fine Tree methods. Both the ANN and SVR methods provided acceptable results for predicting the moisture content of the olive fruit. Using the dielectric method, as well as the use of devices with higher frequencies more accurate results would be achieved. This technique can be used to determine the appropriate harvesting time of the olives.

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