# Prediction of Methyl Salicylate Effects on Pomegranate Fruit Quality and Chilling Injuries using Adaptive Neuro-Fuzzy Inference System and Artificial Neural Network

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ABSTRACT: Adaptive neuro-fuzzy inference system (ANFIS) and genetic algorithm–artificial neural network (GA-ANN) were investigated for predicting methyl salicylate (MeSA) effects on chilling injuries and quality changes of pomegranate fruits during storage. Fruits were treated with MeSA at three concentrations(0, 0.01 and 0.1 mM) and stored under chilling temperature for 84 days. ANFIS and GA-ANN models were used to predict the effect of MeSA application and storage time (0, 14, 28, 42, 56, 70 and 84 days) on chilling injuries, quality parameters and physiological changes of pomegranate during storage. The GA-ANN and ANFIS were fed with 2 inputs of MeSA and time. The developed GA–ANN, which included 20 hidden neurons, could predict physiological changes and quality parameters of pomegranate fruit (weight loss, pH, titratable acidity, chilling injury index, ion leakage, ethylene, respiration, polyphenols, anthocyanins, total antioxidant activity) with average correlation coefficient of 0.89. The overall agreement between ANFIS predictions and experimental data was also significant (r=0.87).In addition, sensitivity analysis results showed that storage time was the most sensitive factor for prediction of MeSA effects on pomegranate fruit quality attributes during postharvest storage.

**Keywords**: *Chilling Injury, Fuzzy Inference, Genetic Algorithm, Neural Network, Sensitivity Analysis.*

## Introduction

Quality and bioactive compound loss usually occurs in the edible parts of pomegranate (arils) during postharvest storage. Therefore, refrigeration is necessary to prolong the storability, decreasing respiration and preserving fruit quality, but fruits are susceptible to chilling which the injuries being increased with lower temperatures (from 3°C to 5°C) and longer durations. Chilling injury in pomegranate fruit includes husk browning and scald, loss of firmness, pitting and decay (Mirdehghan *et al.*, 2007). To reduce chilling injury

incidence and to extend storability and marketing of pomegranates, good results were obtained with salicylic acid and methyl salicylate (MeSA) treatments prior to cold storage (Sayyari *et al.*, 2011; Sayyari *et al.*, 2009).

MeSA,as naturally-occurring compound in plant organs, is a volatile plant compound synthesized from salicylic acid having a role in the plant defence-mechanism, as well as during plant growth and development which could be converted back to salicylic acid (Giménez *et al.*, 2016; Hayat *et al.*, 2007; Wang *et al.*, 2015). MeSA has been described as signal molecule in plant stress responses, both biotic and a biotic types

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(Hayat *et al.*, 2007). Treatment with exogenous MeSA increased resistance of tomato (Fung *et al.*, 2006), peach (Han *et al.*, 2006) and pomegranate (Sayyari *et al.*, 2011) fruits to low temperature stress throughout the enhancement antioxidant enzymes activity and inhibition main physiological changes. Effect of MeSA treatment on reducing chilling injury in stored pomegranates has been studied by Sayyari *et al.* (2009).

The physiological changes of fruits following postharvest treatments is a highly nonlinear one involving respiration and quality loss. The need to capture these nonlinearities demands, the use of intelligent models is necessary. Adaptive neuro-fuzzy inference system (ANFIS) and artificial Neural Networks (ANN) are analytical alternative to conventional modeling techniques, which are frequently limited by strict assumptions of normality, linearity, homogeneity, and variable independence (Salehi, 2014). Fuzzy inference systems (FIS) and ANNs are model-free numerical estimators. To apply the effectiveness of both, FISs and ANNs could be combined into an integrated system called ANFIS that uses both ANNs and FISs systems (Bahram-Parvar *et al.*, 2017; Ramzi *et al.*, 2015; Salehi & Razavi, 2016).

ANN techniques are currently being used in identification and classification of agricultural produce and prediction of defects incidence during storage. Some studies demonstrated the importance of new modeling techniques in predicting the quality of stored produce as well as the validity of well-recognized storage parameters like temperature and time to be more important in quality considerations (Abdulquadri Oluwo *et al.*, 2013; Kavdır & Guyer, 2004; Ramzi *et al.*, 2015; Salehi & Razavi, 2016). Neural network model for a potato storage process was normalized using the standard deviation technique and optimized through different combinations of network configurations by Abdulquadri Oluwo *et al.* (2013). The optimum model had a mean squared error value of 0.83 and a coefficient of determination ($R^2$) value of 0.73. The proposed model would be useful in simulation processes involving intelligent controllers. A back-propagation neural network with the textural features extracted from spatial distribution of color/gray levels was developed by Kavdır and Guyer (2004) to detect defects (leaf roller, bitter pit, russet, puncture and bruises) in Empire and Golden Delicious apples. Gottschalk *et al.* (2003) improved the climate control for stored potato using a fuzzy controller supported by genetic algorithm (GA). Here the GA was used to fit some parameters to the criteria to minimize the total storing cost. Javadikia *et al.* (2011) compared a fuzzy controller and a neur-fuzzy controller on drying of olive stones. They concluded that in terms of stability and set point, tracking the Neuro fuzzy performed better than the fuzzy logic controller, but the fuzzy did better at higher initial moisture content. Lu *et al.* (2006) applied a fuzzy logic controller in a microwave based Chinese herbs drying equipment. Good results were obtained from matlab simulations in the fuzzy logic Toolbox. Mansor *et al.* (2010) applied fuzzy logic control technique to grain drying. Simulation results obtained, proved to be good in comparison with those obtained in literature in the areas of settling time and steady state error. FG Areed *et al.* (2012) developed a dynamic model for the rotary drying plant and a neuro-fuzzy controller for the drying process and compared it with a fuzzy logic and PID controllers. Simulations results proved that the neuro-fuzzy controller yielded the best dynamic performance followed by the fuzzy logic controller, in terms of rising time, settling time, maximum overshoot and steady-state error.

As far as we know, there is no study available in the literature relating to the use

of computing technology for predicting the effect of MeSA on pomegranate fruit quality attributes during storage under chilling conditions. Therefore, the goal of this study was to investigate the performance of ANFIS and GA-ANN models to modeling MeSA effects on pomegranates quality parameters including, weight loss, pH, titratable acidity, chilling injury index, ion leakage, ethylene, respiration, polyphenols, anthocyanins and total antioxidant activity during storage.

**Materials and Methods**
*- Pomegranate preparation and storage*
Pomegranates (*Punicagranatum L. cv. Mollar de Elche*) fruits after harvesting at fully mature stage based on the skin color changes immediately transported to the laboratory (Sayyari *et al.*, 2011). 240 homogeneous fruits without any defects (sunburn, crack, bruise and cut in the husk) were selected and from which15 were used to determine the initial characteristics at pre-storage stage and the remained225 fruits were randomized and divided into 3 lots for MeSA (purchased from Sigma, Sigma–Aldrich, Madrid, Spain) treatments at three concentration (0, 0.1 and 0.01 mM). Treatments were performed by placing the pomegranates in 120L sealed container at 20°C in triplicate, in which the appropriated volume of MeSA to reach the desired concentration was deposited on filter paper at the bottom of the container for 16 h. Then the fruits from each replicate were randomized and sorted into three fruit lots. All fruits (treated and un-treated) were stored at chilling temperature of 2°C and permanent darkness with relative humidity of 90%. Every 2 weeks one lot from each replicate and treatment was transferred to a chamber at 20°C for 4 days to visualize chilling symptoms and then analytical determinations were performed. After determining the chilling injury and fruit

firmness in the whole fruit, each husk was carefully cut at the equatorial zone and electrolyte leakage was measured in the skin and arils were manually extracted. The arils obtained from fruits of each replicate were combined and frozen in liquid nitrogen and stored at -20°C for other determinations. Chilling injury index, ion leakage and quality parameters including, weight loss, pH, titratable acidity, ethylene, respiration, polyphenols, anthocyanins and total antioxidant activity were individually evaluated in each fruit according to our previous reports (Sayyari *et al.*, 2011; Sayyari *et al.*, 2009) and were determined according to previously reported protocols (Arnao *et al.*, 2001; Serrano *et al.*, 2005; Tomás-Barberán *et al.*, 2001).

*- GA-ANN Model*
A schematic description of the 3-layers network structure used in this study is shown in Figure 1. The number of input neurons corresponds to the number of input variables into the neural network, and the number of output neurons is similar to the number of target output variables. Between the input and the output layers, there is at least one hidden layer, which can have any number of neurons and depends on the application of the network. Determination of optimum number of hidden layer neurons is usually performed by trial and error method (Bahramparvar *et al.*, 2014; Ramzi *et al.*, 2015; Salehi & Razavi, 2016). Genetic algorithm (GA) optimization technique can be used to overcome this inherent limitation of ANN. GA are search techniques for an optimal value, mimicking the mechanism of biological evolution. They have a high ability to find an optimal value (global optimal value or at least near global one) of a complex objective function, without falling into local optima (Bahramparvar *et al.*, 2014; Salehi *et al.*, 2017).
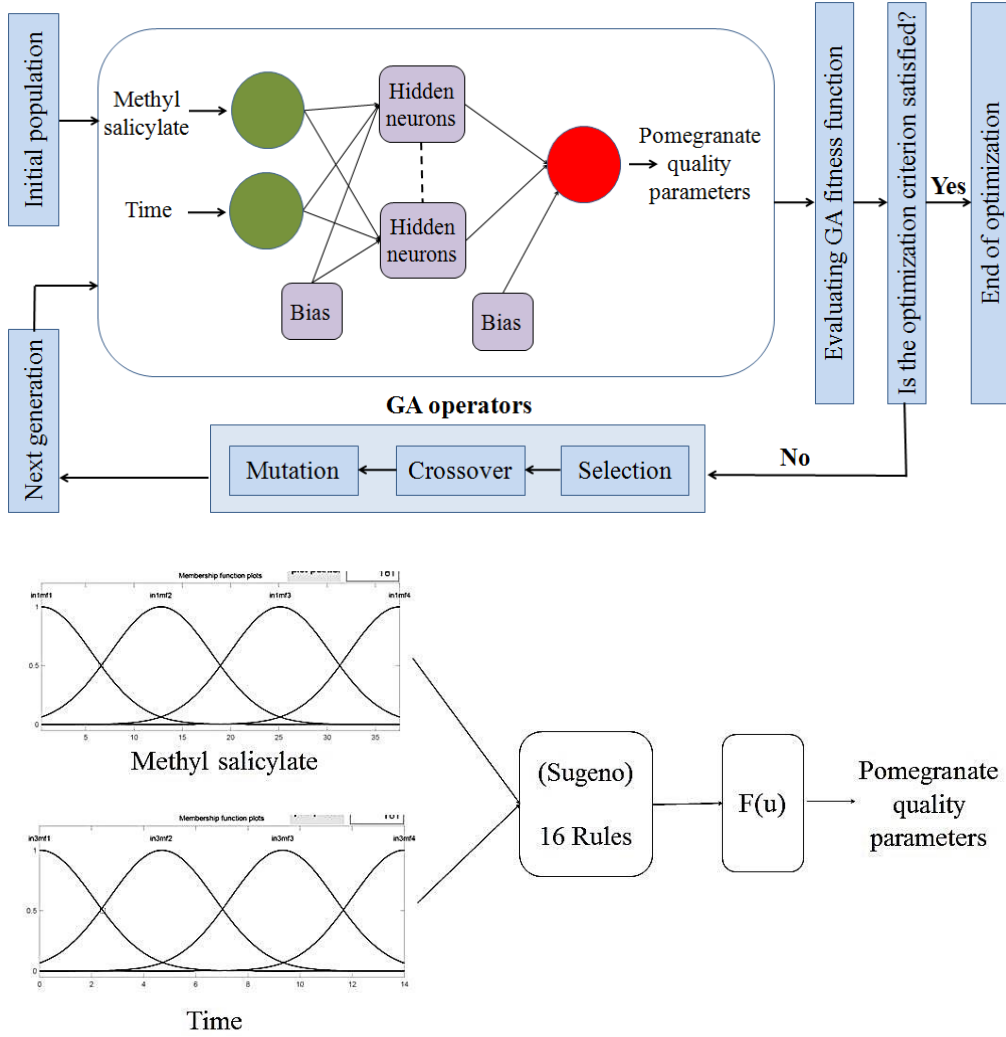
**Fig. 1.** GA-ANN and ANFIS architectures for prediction of pomegranate fruit quality parameters.

In the hidden and output layers, the net input ($x_j$) to node j is of the form:

$$X_j = \sum_{i=1}^{n} W_{ij} y_i + b_j \qquad (1)$$

Where $y_i$ are the inputs, $w_{ij}$ are the weights associated with each input/node connection, n is the number of nodes and $b_j$ is the bias associated with node j. Additionally, bias is an extra input added to neurons (Bahramparvar *et al.*, 2014). A sigmoid activation function (Eq. 2) was chosen to use as the transfer function in the hidden and output layers.

$$f(x) = \frac{1}{1 + e^{-x}} \qquad (2)$$

In present study, 63 data were collected from experiments and then all data were randomly divided into 3 partitions: training (50%), validating (20%), and testing data (30%). The testing data was used for estimating the performance of the trained network on new data, which never was seen by the network during the training (unseen data). The probabilities of the crossover and mutation operators were adjusted at 0.9 and 0.01, respectively.

Also, a sensitivity analysis was conducted to provide a measure of the relative importance among the inputs of the neural network model and to illustrate how the model output varied in response to variation of an input (Salehi & Razavi, 2012). The

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Neurosolution soft ware (6.01, Neuro Dimension, USA) was used for designing the GA-ANN model.

*- ANFIS Model*

The determination of MF parameters and fuzzy rules is not easy for more complex problems. ANFIS structure gives an easy way to generate the MFs and fuzzy rules for Sugeno-type fuzzy inference systems(Salehi & Razavi, 2016). For premise parameters that define MFs, ANFIS employs gradient descent back-propagation neural networks to fine-tune them. A hybrid training method was used as the training method of the ANFIS (Salehi & Razavi, 2016). ANFIS modeling was started by obtaining a data set (input-output data points). The data order was first randomized and then all data were separated into three partitions. 50, 20 and 30 percent of total data was used to training, validating and testing (unseen data) the network, respectively. Each input/output pair contained2 inputs (MeSA concentration and time) and one output (quality parameters of pomegranate)(Figure 1). The number of MFs assigned to each input variable is chosen by trial and error. The ANFIS toolbox of Matlab 7.6 was used to obtain the results, and to build an ANFIS model for predicting the quality parameters of pomegranate.

**Results and Discussion**
*- Pomegranate quality parameters*

Treated fruits with MeSA had lower chilling injury index than control fruits during storage period (Table 1). Similar behavior was observed with respect to electrolyte leakage that is the MeSA application reduced increment rate of the electrolyte leakage occurred in control fruits over storage independently of the applied dose. Chilling injury as a disorder limits the distribution and storage of sensitive fruits with tropical and subtropical background, such as pomegranate, and causes extensive postharvest quality losses. The values of titratable acidity at harvest ($0.30\pm0.01$ g $100g^{-1}$ FW) decreased significantly along storage, the final levels being $\approx0.24$ g $100g^{-1}$ FW with no significant differences due to treatments.

In control fruits the total phenolics content of arils increased from the initial levels of $233\pm8$ to $284\pm3$ mg $100g^{-1}$ at the end of the experiment. The enhancement of total phenolics was slightly higher for 0.1 MeSA than 0.01 mM concentration. Hydrophilic antioxidant activity (H-TAA) was higher than lipophilic antioxidant activity (L-TAA) with values at harvest of $82\pm6$ and $16\pm1$ mg 100 $g^{-1}$, respectively, and for both fractions a net decrease was obtained until the end of the storage period in control arils. During storage total anthocyanins also increased, both in control and treated fruits, although MeSA induced increase (without significant differences among applied doses) was observed from the first sampling date, and was generally maintained over the storage period.

MeSA activate defense mechanisms of plants in response to several abiotic stresses including Chilling injury induced by low temperature. Treatment with MeSA was effective in reducing the development of Chilling injury symptoms in loquat (Meng *et al.*, 2009), peach (Cao *et al.*, 2010) and sweet cherry (Giménez *et al.*, 2016). Similar effects were observed in acetyl salicylate (ASA) treated pomegranate fruits. The ASA treatments, similar to MeSA, were effective in maintaining higher nutritional contents (sugars and organic acids) and bioactive compounds (total phenolics and anthocyanins) and total antioxidant activity, in both hydrophilic and lipophilic fractions. Therefore MeSA has a potential application in post-harvest treatments for alleviating chilling injuries and maintaining fruit quality of pomegranate. Beneficial health effects of fruits based on the content of several phytochemical and bioactive compounds with high antioxidant activity led us to

maintain fruits during storage with lowest quality loss, disorders incidence and chilling symptoms by application of some natural products such as MeSA(Valero & Serrano, 2010).

- *GA-ANN Results*

GA-ANN model was developed for estimation of quality parameters of pomegranate. In this study, ANN with 2–25 neurons was trained using GA to find the optimal network configuration. It was found that GA-ANN with 20 neuronsin one hidden layer could predict quality parameters of pomegranate with high correlation coefficient (r=0.89). Table 2 illustrates the

weights and bias values of optimized network, which could be applied in a computer program for estimation of quality parameters of pomegranate. The prediction efficiency of the GA-ANN model for unseen data was presented in Table 3. The overall agreement between GA-ANN predictions and experimental data was also significant (r=0.89). For example, the calculated correlation coefficient value for estimation of weight loss shows high correlation between predicted and experimental values (Figure 2). The results showed that an acceptable agreement between the predicted and experimental data can be achieved using GA–ANN model.

**Table 1.** Effects of MeSA on pomegranate fruit quality and physiological parameters during postharvest storage

| Time (days) | MeSA concentration (mM) | Weight loss (%) | pH | Titratable acidity (%) | Chilling injury index | Ion leakage (%) | Ethylene (µl/kg/hr) | Respiration | Polyphenols (mg pyrogallol eq. 100g$^{-1}$) | Anthocyanins (mg Cy-3-glue eq.100g$^{-1}$) | Total antioxidant activity (H-TAA mg 100 g$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  | 0.0 | 0.0±0.0 | 5.6±0.2 | 0.3±0.01 | 0.0±0.00 | 22.3±1.4 | 0.10±0.01 | 20.5±1.0 | 492.9±75.9 | 59.0±21.7 | 97.9±9.8 |
| **0** | 0.01 | 0.0±0.0 | 5.6±0.2 | 0.3±0.01 | 0.0±0.00 | 22.3±1.4 | 0.10±0.01 | 20.5±1.0 | 492.9±75.9 | 59.0±21.7 | 97.9±9.8 |
|  | 0.1 | 0.0±0.0 | 5.6±0.2 | 0.3±0.01 | 0.0±0.00 | 22.3±1.4 | 0.10±0.01 | 20.5±1.0 | 492.9±75.9 | 59.0±21.7 | 97.9±9.8 |
|  | 0.0 | 21.3±0.0 | 4.6±0.0 | 0.3±0.00 | 0.2±0.00 | 32.4±0.3 | 0.15±0.00 | 30.6±0.0 | 499.4±0.0 | 82.2±0.0 | 102.4±0.0 |
| **14** | 0.01 | 11.0±1.5 | 4.7±0.2 | 0.3±0.02 | 0.2±0.03 | 42.9±4.1 | 0.13±0.02 | 22.9±1.1 | 481.0±13.4 | 113.5±12.1 | 97.5±3.3 |
|  | 0.1 | 9.3±1.0 | 4.7±0.2 | 0.3±0.02 | 0.1±0.05 | 46.6±5.1 | 0.10±0.04 | 17.1±1.4 | 479.8±56.4 | 105.2±7.1 | 95.0±9.6 |
|  | 0.0 | 10.3±1.3 | 4.5±0.1 | 0.3±0.00 | 0.2±0.00 | 39.8±4.5 | 0.12±0.01 | 25.5±1.6 | 531.6±12.7 | 115.1±6.5 | 111.0±1.6 |
| **28** | 0.01 | 9.6±0.7 | 4.6±0.2 | 0.3±0.01 | 0.1±0.03 | 38.7±2.0 | 0.13±0.03 | 27.5±1.4 | 520.3±45.4 | 100.9±21.1 | 92.2±7.9 |
|  | 0.1 | 10.7±1.2 | 4.6±0.1 | 0.3±0.01 | 0.2±0.06 | 36.6±3.2 | 0.10±0.01 | 28.6±2.3 | 538.9±66.2 | 125.8±6.7 | 97.6±5.6 |
|  | 0.0 | 14.7±0.1 | 4.7±0.2 | 0.3±0.01 | 0.3±0.05 | 46.7±1.5 | 0.11±0.03 | 25.3±0.8 | 525.7±0.4 | 64.1±3.6 | 86.4±2.7 |
| **42** | 0.01 | 13.3±2.4 | 4.9±0.3 | 0.3±0.01 | 0.2±0.12 | 45.1±5.5 | 0.14±0.03 | 30.3±0.9 | 534.4±50.7 | 116.0±10.8 | 89.9±5.5 |
|  | 0.1 | 13.1±1.3 | 4.6±0.4 | 0.3±0.02 | 0.2±0.08 | 44.9±4.0 | 0.18±0.09 | 34.1±5.2 | 510.5±38.7 | 107.2±3.9 | 94.2±6.4 |
|  | 0.0 | 16.4±1.4 | 4.5±0.0 | 0.3±0.01 | 0.2±0.00 | 50.9±4.4 | 0.17±0.02 | 30.5±3.3 | 453.0±23.8 | 84.3±9.9 | 103.0±3.8 |
| **56** | 0.01 | 15.4±0.9 | 4.9±0.2 | 0.3±0.00 | 0.2±0.08 | 51.5±3.1 | 0.18±0.01 | 25.6±2.0 | 547.8±24.7 | 118.8±32.1 | 113.2±14.6 |
|  | 0.1 | 17.4±1.2 | 5.1±0.1 | 0.3±0.01 | 0.1±0.03 | 59.3±4.9 | 0.12±0.02 | 25.6±3.0 | 562.5±38.7 | 122.4±15.1 | 105.4±11.1 |
|  | 0.0 | 19.4±2.8 | 4.8±0.0 | 0.3±0.01 | 0.3±0.08 | 65.0±1.5 | 0.13±0.02 | 35.5±5.4 | 518.1±40.8 | 107.5±7.2 | 75.1±4.1 |
| **70** | 0.01 | 22.1±6.3 | 5.1±0.4 | 0.3±0.01 | 0.1±0.08 | 56.6±6.0 | 0.18±0.06 | 36.4±2.4 | 583.5±28.0 | 98.9±8.5 | 129.9±10.9 |
|  | 0.1 | 20.0±2.6 | 4.9±0.5 | 0.3±0.02 | 0.2±0.08 | 53.5±0.4 | 0.09±0.03 | 32.7±2.3 | 653.4±46.7 | 105.1±19.9 | 112.7±6.4 |
|  | 0.0 | 18.9±0.1 | 4.5±0.1 | 0.2±0.00 | 0.3±0.08 | 62.2±0.1 | 0.16±0.01 | 32.2±2.9 | 663.5±7.7 | 109.7±3.9 | 86.0±1.3 |
| **84** | 0.01 | 21.9±0.8 | 4.6±0.2 | 0.2±0.01 | 0.1±0.08 | 55.7±6.1 | 0.15±0.06 | 32.2±10.1 | 666.9±37.3 | 116.9±12.5 | 131.3±0.5 |
|  | 0.1 | 22.8±1.6 | 5.0±0.5 | 0.2±0.02 | 0.1±0.06 | 52.6±0.4 | 0.17±0.03 | 28.5±6.3 | 698.7±39.5 | 134.6±12.3 | 130.6±5.7 |
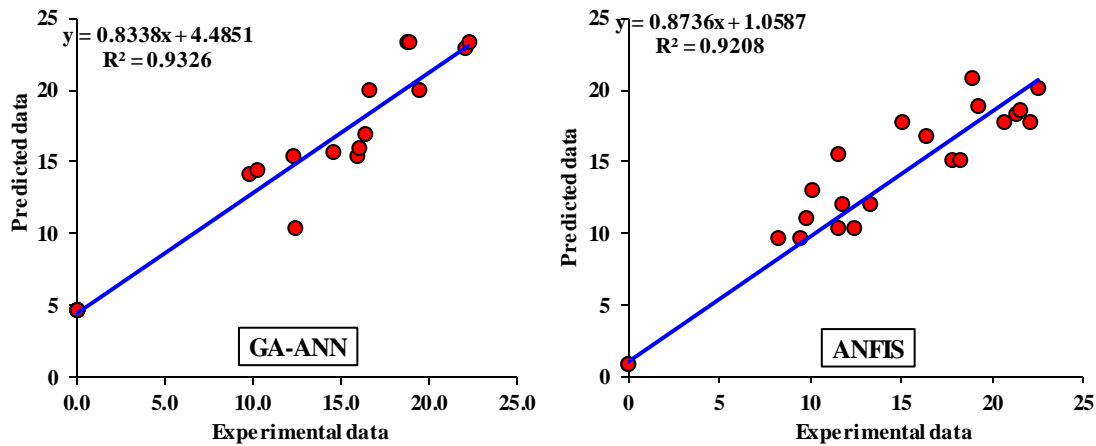
**Fig. 2.** Experimental versus predicted values of weight loss using GA−ANN and ANFIS models for the test data set.

**Table 2.** The weights and bias values of optimized GA-ANN model for prediction of MeSA effects on pomegranate fruit quality

| Hidden neurons | Bias | Input neurons | | Output neurons | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MeSA | Time | Weight loss (%) | pH | Titratable acidity (%) | Chilling injury index | Ion leakage (%) | Ethylene (µl/kg·hr) | Respiration | Polyphenols (mg pyrogallol eq.100g⁻¹) | Anthocyanins (mg Cy-3-glue eq.100g⁻¹) | Total antioxidant activity (H-TAA mg 100 g⁻¹) |
| 1 | 0.003 | 0.376 | -0.873 | 1.571 | 1.257 | 1.049 | 1.123 | 0.148 | -1.235 | -0.109 | -0.095 | -0.447 | -0.713 |
| 2 | 0.115 | 0.571 | 1.631 | 0.238 | 2.248 | 0.474 | 0.211 | 0.088 | -3.325 | 0.451 | 0.267 | -0.792 | -1.383 |
| 3 | 0.204 | -1.152 | -0.872 | 1.197 | 2.511 | 1.439 | -0.445 | -1.609 | 0.365 | 0.337 | 0.227 | -0.325 | -0.414 |
| 4 | 0.564 | -1.333 | 0.121 | 1.133 | 0.344 | 1.542 14. | -0.199 | 0.188 | -0.713 | 0.518 | -1.195 | -0.798 | 0.312 |
| 5 | 0.489 | 0.148 | 1.049 | 1.145 | 0.832 | 1.29 | -0.19 | 0.583 | 0.429 | -0.229 | -0.002 | 0.348 | -0.325 |
| 6 | -0.276 | 0.088 | 0.474 | 1.341 | -0.099 | 1.672 | -0.543 | 1.180 | 1.571 | 0.506 | -0.567 | 1.123 | 0.148 |
| 7 | -0.462 | -1.609 | 1.439 | -0.856 | 0.492 | -1.213 | -0.196 | 1.514 | 0.238 | 2.248 | 0.474 | 0.211 | 0.088 |
| 8 | -0.159 | 0.188 | 1.542 14. | 0.846 | -0.147 | -1.537 | 0.207 | 0.912 | 1.197 | 2.511 | 1.439 | -0.445 | -1.609 |
| 9 | 1.069 | -0.547 | 0.319 | 1.065 | 0.239 | -2.134 | 0.246 | -0.345 | 1.133 | 0.344 | 1.542 14. | -0.199 | 0.188 |
| 10 | 0.856 | 0.248 | 0.838 | 2.671 | -0.087 | 0.459 | 0.268 | 1.968 | 1.145 | 0.832 | 1.29 | -0.19 | 0.583 |
| 11 | 1.219 | -1.235 | 1.985 | 1.127 | 0.736 | 0.793 | -0.131 | -0.73 | 1.341 | -0.099 | 1.672 | -0.543 | 1.180 |
| 12 | 0.167 | -3.325 | 0.986 | 1.325 | 0.685 | 1.180 | 1.180 | 0.459 | -0.856 | 0.492 | -1.213 | -0.196 | 1.514 |
| 13 | -2.272 | 0.365 | 1.325 | 2.356 | -1.658 | 1.514 | 1.514 | 0.793 | 0.846 | -0.147 | -1.537 | 0.207 | 0.912 |
| 14 | 1.114 | -1.125 | 0.365 | -1.362 | 0.658 | 0.912 | 0.912 | -0.289 | 1.065 | 0.239 | -2.134 | 0.246 | -0.345 |
| 15 | 3.089 | 0.315 | 1.236 | 1.365 | 2.325 | -0.345 | -1.365 | 0.895 | 2.671 | -0.087 | 0.459 | 0.268 | 1.968 |
| 16 | 0.324 | 1.571 | 1.257 | 0.225 | 1.365 | 0.986 | 1.325 | 0.685 | 1.127 | 0.736 | 0.793 | -0.131 | -0.713 |
| 17 | 0.231 | 0.238 | 2.248 | -0.985 | -1.356 | 1.325 | 2.356 | 0.9959 | 0.200 | 0.429 | -0.289 | -0.072 | 0.429 |
| 18 | 1.909 | 1.197 | 2.511 | 0.050 | 0.626 | -2.556 | 7.645 | -0.6431 | -0.536 | 0.181 | 0.536 | -0.547 | 0.319 |
| 19 | -0.664 | 1.133 | 0.344 | 1.514 | -0.856 | 1.236 | 1.365 | -0.0652 | 0.192 | 0.099 | 0.149 | 0.248 | 0.838 |
| 20 | 1.157 | -0.567 | 1.123 | 0.148 | 0.365 | 0.325 | 0.225 | 0.4535 | 1.566 | -0.039 | 0.538 | 0.932 | 0.213 |
| Bias | | | | -0.209 | 0.543 | 0.073 | -0.405 | 0.183 | 0.133 | -0.457 | -0.792 | -0.408 | -0.636 |

**Table 3.** Performance of optimized GA-ANN and ANFIS models for prediction of MeSA effects on pomegranate fruit quality

| Model | Performance | Weight loss (%) | pH | Titratable acidity (%) | Chilling injury index | Ion leakage (%) | Ethylene (µl/kg·hr) | Respiration | Polyphenols (mg pyrogallol eq.100g⁻¹) | Anthocyanins (mg Cy-3-glue eq.100g⁻¹) | Total antioxidant activity (H-TAA mg 100 g⁻¹) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| GA-ANN (2/20/10) | Normalized Mean squared error | 0.18 | 0.25 | 0.52 | 0.51 | 0.17 | 0.19 | 0.15 | 0.39 | 0.14 | 0.12 |
| | Mean absolute error | 2.81 | 0.27 | 0.02 | 0.07 | 5.15 | 0.02 | 2.95 | 35.91 | 17.50 | 13.76 |
| | correlation coefficient (r) | 0.97 | 0.88 | 0.83 | 0.82 | 0.92 | 0.88 | 0.93 | 0.80 | 0.92 | 0.93 |
| ANFIS | Normalized Mean squared error | 0.14 | 0.46 | 0.24 | 0.29 | 0.20 | 0.18 | 0.25 | 0.42 | 0.22 | 0.41 |
| | Mean absolute error | 2.17 | 0.21 | 0.02 | 0.05 | 4.43 | 0.03 | 3.68 | 38.48 | 20.00 | 9.13 |
| | correlation coefficient (r) | 0.95 | 0.82 | 0.84 | 0.86 | 0.90 | 0.82 | 0.92 | 0.87 | 0.87 | 0.85 |

Sensitivity analysis was also tested in order to study the sensitiveness of neural network models toward different inputs (Figure 3). Among the input variables, storage timewas the most sensitive factor for prediction of MeSA effects on of pomegranate fruit quality attributes during storage by the selectedGA-ANN.ANN and hyperspectral techniques were used to modeling quality changes in avocados during storage at different temperatures by Maftoonazad *et al.* (2011). Multi-layer ANNs were used in two ways to develop models for predicting quality parameters during storage. The optimal configuration of neural network model was obtained by varying the different model parameters. The results indicated ANN models to be accurate and versatile and they predicted the quality changes in avocado fruits better than the conventional regression models; furthermore, the storage time–temperature-based ANN models were better than the hyperspectra-based ANN models.

Feed-forward back-propagation ANN models were developed by ElMasry *et al.* (2009) to investigate the ability of hyper-spectral imaging and ANN techniques for the detection of chilling injury in red apples. They reported that classification accuracy of above 90% was obtained with the use of selected five optimal wave lengths. Neural network modeling was used to predict shelf life of greenhouse lettuce by Lin and Block (2009). Using such 2-stage neural network models, an $R^2$ of 0.61 could be achieved for predicting remaining shelf life. This study indicated that neural network modeling has potential for cold chain quality control and shelf life prediction.

*- ANFIS Results*

The ANFIS network parameters, such as the type and number of MF and epochs, have been varied to obtain the best results in terms of model validation. ANFIS architecture used in this study is shown in Figure 1. The final ANFIS architecture for predicting the quality parameters of pomegranate, with four Gaussians type MFs for each input (2 inputs) and linear MF for output, and constructed 16 rules resulted high accurate prediction. The performance of optimized ANFIS for prediction MeSA effects on of pomegranate fruit quality was reported in table 3.It can be seen that the ANFIS model was well-trained to modeling methyl salicylate effects on pomegranate quality during postharvest storage (r=0.87).

In Figure 2 the weight loss values versus ANFIS predictions for test data (unseen data) points are shown. It can be seen that the system was well-trained to model the weight loss (r=0.95). In summary a lower number of input parameters were needed for the ANFIS model, improving the speed and
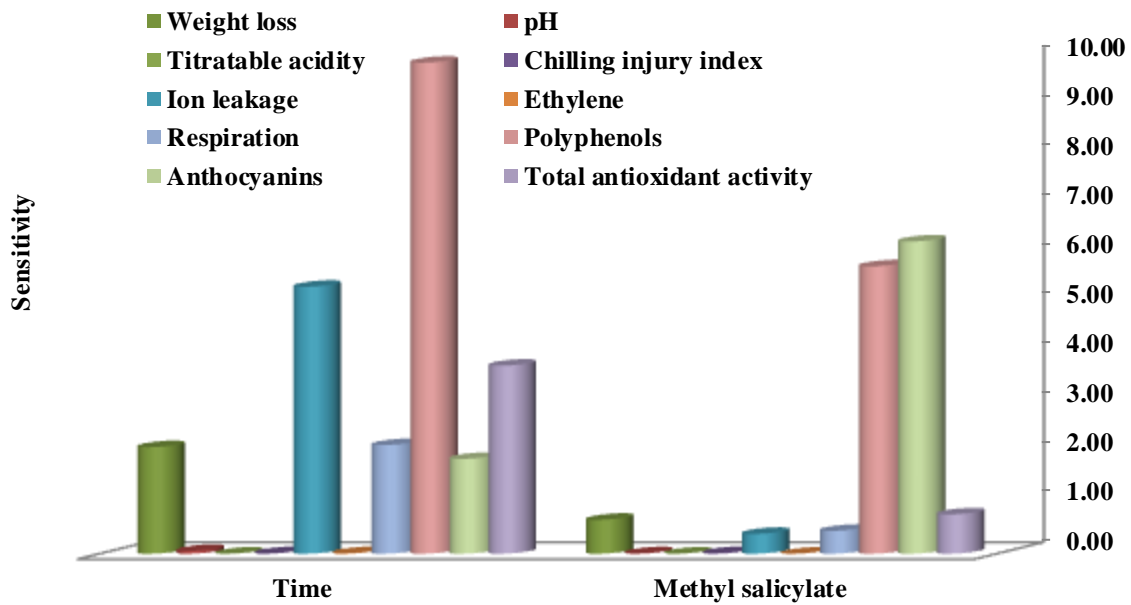
**Fig. 3.** Sensitivity analysis of optimized GA-ANN (2/20/10) for prediction of MeSA effects on pomegranate fruit quality attributes during storage.

ease of prediction. May *et al.* (2011) developed 2 fuzzy logic controllers to reduce the operational times and cooling energy generation for air-conditioning purposes of some buildings. Simulation results showed promising results in achieving optimal operations of the chilling system. Wali *et al.* (2013) developed a fuzzy logic controller in Lab view environment to automatically and continuously adjust the applied power of a microwave reactor system. The fuzzy logic controller tracked the reactor desired temperature precisely with minimal overshoot and a fast warm-up phase. Disturbance in the form of varying flow rate in the process input was well rejected by the controller. Gomez-Melendez *et al.* (2011) developed a fuzzy greenhouse fertigation control system based on a field programmable gate array. The results were confirmed well experimentally and the controller found to be extendable to control greenhouses of other crops that have different nutritional needs.

**Conclusion**

The results suggest that MeSA has potential postharvest application for reducing chilling injury index, maintaining quality and improving the health benefits of pomegranate fruit consumption by increasing the antioxidant capacity. In addition, treatment of pomegranate with MeSA increased bioactive compounds and antioxidant activity.

The application of GA-ANN and ANFIS to simulation of MeSA effects on of pomegranate fruit quality attributes during storage was investigated to predict the pomegranate quality parameters (output) versus MeSA concentration and storage time (inputs). It was found that GA-ANN with 1 hidden layer comprising 20 neurons gives the best fitting with the experimental data, which made it possible to predict quality parameters (weight loss, pH, titratable acidity, chilling injury index, ion leakage, ethylene, respiration, polyphenols, anthocyanins, and total antioxidant activity) with acceptable correlation coefficient (0.89). It was also found that ANFIS models with four Gaussian type MFs (gussmf) for all input variables and linear for output gives the best fitting with the experimental data,

which made it possible to predicted quality parameters with high correlation coefficient(0.87). The results indicated that both GA-ANN and ANFIS models can give good prediction for quality parameters of pomegranate.

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