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Prediction of relationship between surface area, temperature, storage time and ascorbic acid retention of fresh-cut pineapple using adaptive neuro-fuzzy inference system (ANFIS)

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ABSTRACT

Adaptive neuro-fuzzy inference system (ANFIS) was developed for the prediction of ascorbic acid (AA) retention during storage of fresh-cut pineapple as a function of surface area, storage temperature and time. Our results demonstrate that surface area and temperature are the two most important factors influencing the degradation of AA in fresh-cut pineapple during storage. The AA in fresh-cut pineapple with a high surface area is more easily destroyed than that with a low surface area at the same storage temperature. In addition, the ANFIS model with triangular-shaped membership function (trimf) (RMSE = 7.88%; R^2 = 0.95) provides the best prediction accuracy than models with other membership functions (RMSE = 8.97–10.19%; R^2 = 0.91–0.93). Therefore, the high-surface-area fresh-cut fruit should be stored at a relatively low temperature as compared with the low-surface-area produce. The ANFIS model with trimf is an adequate model for the prediction of AA retention during storage of fresh-cut pineapple.

1. Introduction

Pineapple is one of the most important fruit crops of tropical and subtropical regions (Bartholomew et al., 2002), particularly in the form of processed products. Pineapple is a good source of antioxidants because of high levels of phenolics (Hossain and Rahman, 2011). Pineapple juice has been reported as a preferred choice to dissolve phytobezoars, as it contains bromelain, a proteolytic enzyme (Altinbaş et al., 2014). As a ready-to-eat product, fresh-cut pineapple is attractive to consumers (Rocculi et al., 2009). Fresh-cut pineapple is therefore sold at many supermarkets and food distribution outlets in different shapes (cubes, slices, chunks, and cored whole fruit) (González-Aguilar et al., 2004; Marrero and Kader, 2006). Moreover, minimally processed pineapple has a commercial advantage in terms of reduced weight for transport, as bulky inedible crown and peel tissues are removed (Budu and Joyce, 2003). However, cutting pineapple severely affects its shelf life and nutrition quality because of the exposed wound (Watada and Qi, 1999; Soliva-Fortuny and Martin-Belloso, 2003).

From a nutritional perspective, the extent of ascorbic acid retention is widely adopted as a quality criterion for processed pineapple. It is generally observed that if ascorbic acid is well preserved, the other nutrients are also well retained (Lin et al., 1998). Therefore, determining the effect on ascorbic acid during storage by using accurate models is important for the food processing industries. To date, many researchers have studied the degradation of ascorbic acid in foods during storage and processing using mathematical models, such as kinetic models (Burdurlu et al., 2006; Al-Zubaidy and Khalil, 2007; Zheng and Lu, 2011; Demiray et al., 2013; Kurozawa et al., 2014; Remini et al., 2014), Weibull distribution function (Manso et al., 2001; Oms-Oliu et al., 2009; Zheng and Lu, 2011; Djendoubi Mrad et al., 2012; Jiang et al., 2014) and artificial neural network (Lu et al., 2010; Zheng et al., 2011a,b). The adaptive neural-fuzzy inference system (ANFIS) is a multilayer feed-forward network which combines neural network learning algorithms and fuzzy inference systems to construct input-output mapping (Jang, 1993). The fuzzy logic is generally in 89% agreement with results provided by experts. ANFIS has a high training speed, is the most effective learning algorithm and has a

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simple software compared to other learning techniques (Jang and Sun, 1995). In addition, another advantage of this model is faster convergence and better results when applied without any prior knowledge (Altug et al., 1999). Therefore, ANFIS has been used as a modeling tool in agriculture and food technology, for bruise detection (Zheng et al., 2011a,b), food rheology (Karaman and Kayacier, 2011), food processing (Amiryousefi et al., 2011), prediction of yield (Khoshnevisan et al., 2014a) and various extractions from plants and vegetables (Jhin and Hwang, 2014). However, by taking account of recent research, there is no published data on the prediction of ascorbic acid retention in fresh-cut pineapple during storage using ANFIS as a function of storage temperature, time and surface area.

Therefore, the objectives of this research were (1) to evaluate the effect of surface area on ascorbic acid retention during storage of fresh-cut pineapple, (2) to develop ANFIS model to predict ascorbic acid retention as a function of surface area, storage temperature and time, and (3) to compare the performance derived by the use of ANFIS models with different membership functions for predicting ascorbic acid retention during storage of fresh-cut pineapple.

2. Materials and methods

2.1. Materials

Pineapple fruits (*Ananas comosus* L., cv. Smooth Cayenne) were taken from a local market in Jinghua (Zhejiang, P.R. China) and directly transported to the laboratory within 10 mins at 5 °C. The fruits were sorted and graded on the basis of size, shape and maturity, and those with visible infections and mechanical injuries were rejected.

2.2. Preparation of fresh-cut pineapple

Pineapple fruits were washed in an aqueous solution of 1 g L^{-1} sodium hypochlorite at pH 7.0. After washing, the fruit were hand-peeled and cut into cubes of 1–3 cm in a cooled room (8 ± 1 °C; 80% RH), using a sharp knife. Working area, cutting boards, knives, containers and other utensils and surfaces in contact with the fruit during processing were washed and sanitized with 1 g L^{-1} sodium hypochlorite solution to have a maximum sanitizing effect prior to use. The mass (M) was measured by an MP2000-2 balance (±0.001 g) (Shanghai Balance Instruments, China). The surface area (SS) of pineapple cube was in the range from 2048 to 5389 m^2 kg^{-1}. The SS was determined using the equation:

$$SS = \frac{6 \times l^2}{M} \quad (1)$$

where l and M are the length and the mass of pineapple cubes, respectively.

All cut types were washed with sodium hypochlorite solution for 2 min and rinsed for 1 min in tap water. The excess surface water remaining on the products was absorbed with paper towels and they were placed in polypropylene containers (12 cm × 13 cm × 5 cm). The samples were stored in darkness at 5, 8 and 15 °C, and they were analyzed just before packaging (zero time) and after storage for 1, 2, 3, 4, 5 and 6 d. Three pineapple cubes selected randomly from the product were used for the zero time evaluations and 60 pineapple cubes were randomly selected for storage at different temperatures, resulting in a total of 540 pineapple cubes. For each storage time, 3 pineapple cubes per sample were randomly picked and analyzed.

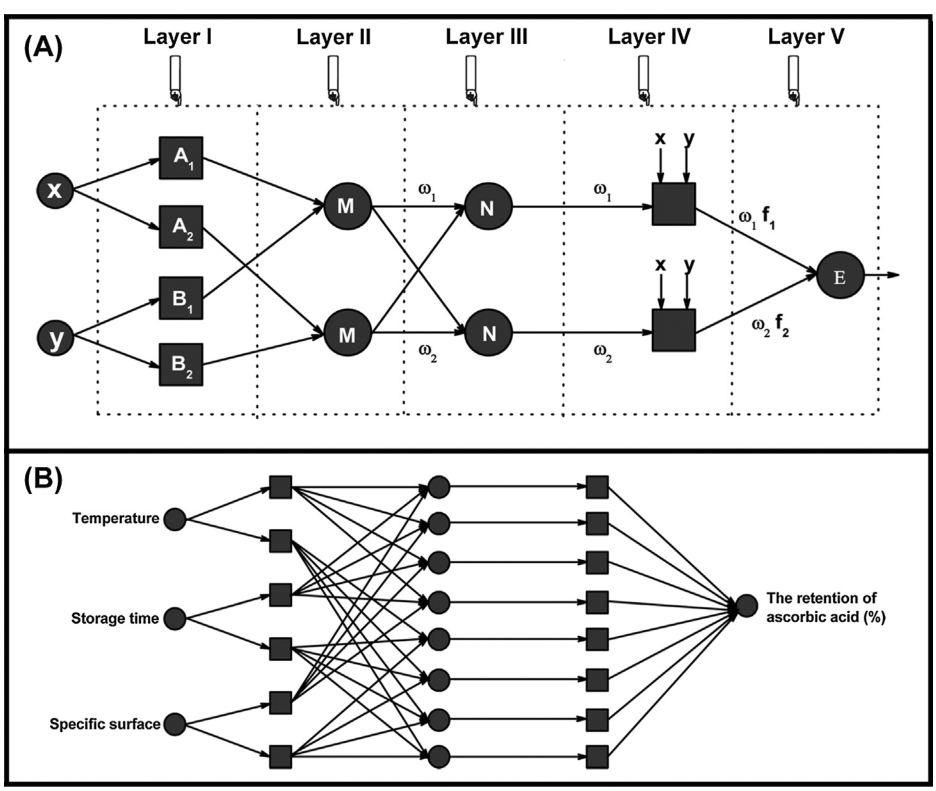

Fig. 1. ANFIS architecture: (A) the first-order Takagi–Sugeno inference system and (B) multiple input single output models consisting of three inputs (temperature, storage time and surface area) and one output (the retention of ascorbic acid) used in this study.

2.3. Determination of ascorbic acid (AA)

The AA content was determined by the standard titrimetric method by titration of filtrate against 2,6-dichlorophenol indophenol (AOAC, 2000). Results of AA content were expressed as milligram ascorbic acid per 100 g fresh weight. The AA content was measured in triplicate.

2.4. ANFIS model

ANFIS uses a feed-forward network to search for fuzzy decision rules that perform well on a given task. The ANFIS architecture of the first-order Takagi–Sugeno inference system is shown in Fig. 1A, where, the ANFIS structure consists of five layers.

As an example, assume that the ANFIS model has two inputs x and y and one output f. For a first order Sugeno fuzzy model, two fuzzy if–then rules are considered:

Rule 1: If x is A_1 and y is B_1; then $f_1 = p_1x + q_1y + r_1$ (2)

Rule 2: If x is A_2 and y is B_2; then $f_2 = p_2x + q_2y + r_2$ (3)

where A_1,A_2 and B_1, B_2 are the fuzzy sets for inputs x and y, respectively, p_1, q_1, r_1 and p_2, q_2, r_2 are the parameters of the output function that are determined during the training process.

The node functions in each layer are described as follows:

Layer I is fuzzification layer. Every node i in this layer is an adaptive node with a node output defined by:

$$O_{1,i} = \mu_{Ai}(x) \quad \text{for}\, i = 1, 2 \tag{4}$$

$$O_{1,i} = \mu_{B_{i-2}}(y) \quad \text{for}\, i = 3, 4 \tag{5}$$

where x (or y) is the input to the node i; μ_{Ai}(or μ_{Bi-2}) is the fuzzy membership function (MF).

Layer II is rule layer. The nodes i in this layer are fixed nodes, labeled M, whose output is the product of all the incoming signals. The output of this layer is given by:

$$O_{2,i} = w_i = \mu_{Ai}(x)\mu_{Bi}(y) \quad \text{for}\, i = 1, 2 \tag{6}$$

Layer III is normalization layer. The ith node of this layer, labeled N, calculates the normalized firing strength as:

$$O_{3,i} = \overline{w_i} = \frac{w_i}{w_1 + w_2} \text{for}\, i = 1, 2 \tag{7}$$

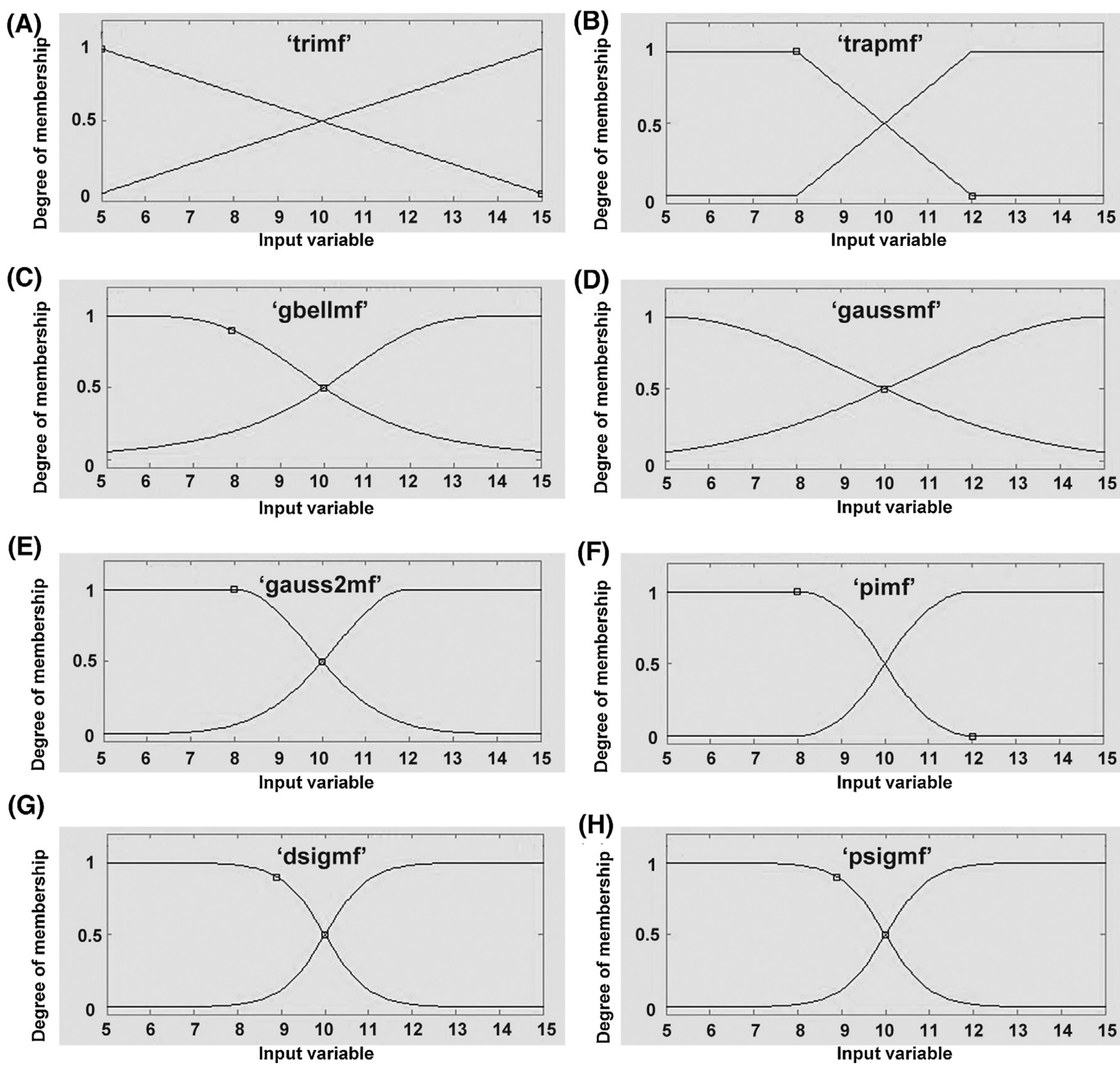

Fig. 2. Membership functions of the ANFIS model: (A) triangle (trimf), (B) trapezoidal (trapmf), (C) generalized bell (gbellmf), (D) Gaussian (gaussmf), (E) two-sided Gaussian (gasuss2mf), (F) Pi curve (pimf), (G) difference between two sigmoidal functions (dsigmf), and (H) product of two sigmoidal functions (psigmf).

Layer IV is the defuzzification layer. Every node i in this layer is an adaptive node with a node function:

$$O_{4,i} = \overline{w_i} f_i = \overline{w_i}(p_i x + q_i y + r_i) \tag{8}$$

where $\{p_i, q_i, r_i\}$ is the parameter set of this node.

Layer V is the output layer. The single node in this layer is a fixed node labeled E, which computes the overall output as the summation of all incoming signals. Overall output is given by:

$$O_{5,i} = \sum_i \overline{w_i} f_i = \frac{\sum_i w_i f_i}{\sum_i w_i} \tag{9}$$

In this study, 70% and 30% of data were selected randomly for training and testing, respectively. Modeling was performed using ANFIS Toolbox in MATLAB (R2010a, the MathWorks Inc., USA) and Sugeno-type fuzzy inference systems were used in the modeling of prediction of the retention of ascorbic acid during storage of fresh-cut pineapple. Two types of methods, grid partition (Jang and Sun 1995) and subtractive fuzzy clustering (Chiu 1994), are generally utilized to classify the input data and make the rules. When there are a few input variables, grid partition is a suitable method for data classification. In this work, therefore, the ANFIS model was constructed using grid partition method. Multiple input single output models consisting of three inputs including storage temperature, time and surface area were developed to predict the retention of ascorbic acid, as shown in Fig. 1B. We use eight different types of input MFs, including triangle (trimf), trapezoidal (trapmf), generalized bell (gbellmf), Gaussian (Gaussmf), two-sided Gaussian (Gasuss2mf), Pi curve (pimf), product of two sigmoidal functions (psigmf), and difference between two sigmoidal functions (dsigmf), as shown in Fig. 2. A linear function was used as output MFs. Recently, the hybrid learning algorithm was employed in ANFIS model to predict wheat grain yield on the basis of energy inputs (Khoshnevisan et al., 2014b). It has been established that the hybrid learning algorithms have better performance compared to the single ones (Jang, 1992, 1993; Polat and Güneş, 2006).

2.5. Selection of optimal prediction model

The prediction performance of the prediction model was compared using root mean squared error (RMSE) and the coefficient of determination (R^2) of the linear regression line between the predicted values from the model and the desired output. The RMSE was calculated as follows:

$$\text{RMSE} = \sqrt{\sum_{i=1}^{N} \left(\frac{k_E - k_P}{N} \right)^2} \tag{10}$$

where N is the total number of data, and the parameter k_P represents the predicted value from the models for a given input while k_E is the desired output (experimental).

In addition, general linear fitting model for analysis was determined using OriginPro software version 7.5.

3. Results and discussion

3.1. Effects of surface area and storage temperature on the AA retention during storage of fresh-cut pineapple

Fig. 3 illustrates contour plots of the AA retention as a function of storage temperature and surface area of fresh-cut pineapple. There is a decrease in the AA retention caused by increase of both temperature and surface area during storage of fresh-cut pineapple. This fact may be due to a higher loss of AA from the smaller pieces with a larger cut surface area. The main problem is that

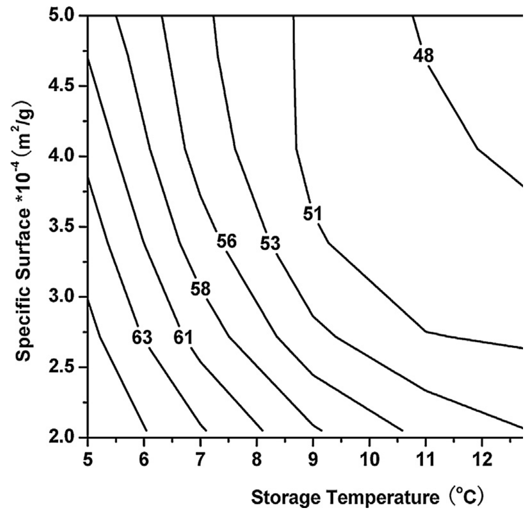

Fig. 3. The contour plots of ascorbic acid retention as a function of storage temperature and surface area of fresh-cut pineapple during storage.

when cells are ruptured by cutting during minimal processing, wound-induced biochemical reactions are initiated that shorten storage life (Watada, 1997; Cantwell and Suslow, 2002). Aguayo et al. (2004) reported that slices senesce quickly and have a shorter shelf-life than wedges because of double the cut area than the wedges. Similar observation was reported by other researchers (del Aguila et al., 2006; Artés-Hernández et al., 2007; Argañosa et al., 2008). In essence, the quality of fresh-cut products as affected by different cut types is determined by the surface area. In addition, AA is known to be thermolabile.

The degradation of AA in fresh-cut pineapple with a high surface area is much faster than the one with a low surface area at the same storage temperature, as shown in Fig. 3. Finnegan and O'Beirne (2015) also recently documented that, in general, the smaller the cut size, the greater the extent of deterioration. To preserve the AA content, therefore, the high-surface-area produce must be stored at a relatively low temperature as compared with the low-surface-area produce. Other studies also point out that temperature control is the most common and important technology to minimize the effect of cutting on fruit and vegetable storage (Brecht, 1995; Cantwell, 1996; Watada et al., 1996; Vigneault et al., 2008; Siddiqui et al., 2011; Rahman et al., 2013).

3.2. ANFIS models for the prediction of AA retention in fresh-cut pineapple as a function of surface area, storage temperature and time

We used 70% of the data to generate the model, and the remaining 30% were used for prediction. In the training phase, the initial ANFIS model was generated by grid partition method, and eight different types of MFs were used for fuzzification of input data. Hybrid learning enables perfection of ANFIS model parameters in each epoch and minimizes error (Jang, 1993; Jang and Sun, 1995).

After the training phase, the ANFIS models were tested against an independent data set. The agreement between the observed experimental and the ANFIS model predicted values at the phases of model development and prediction are presented in Fig. 4. In addition, the values of RMSE and R^2 for training and prediction sets are shown in Table 1. According to Table 1, the RMSE and R^2 values of ANFIS models with different MFs are 7.88% and 0.95 for 'trimf', 10.14 and 0.91 for 'trapmf', 9.13 and 0.93 for 'gbellmf', 8.97 and 0.93 for 'gaussmf', 9.25 and 0.93 for 'gauss2mf', 10.19 and 0.91 for 'pimf', 10.06 and 0.91 for 'dsigmf', and 10.18 and 0.91 for 'psigmf', respectively. The R^2 between observed and predicted values were

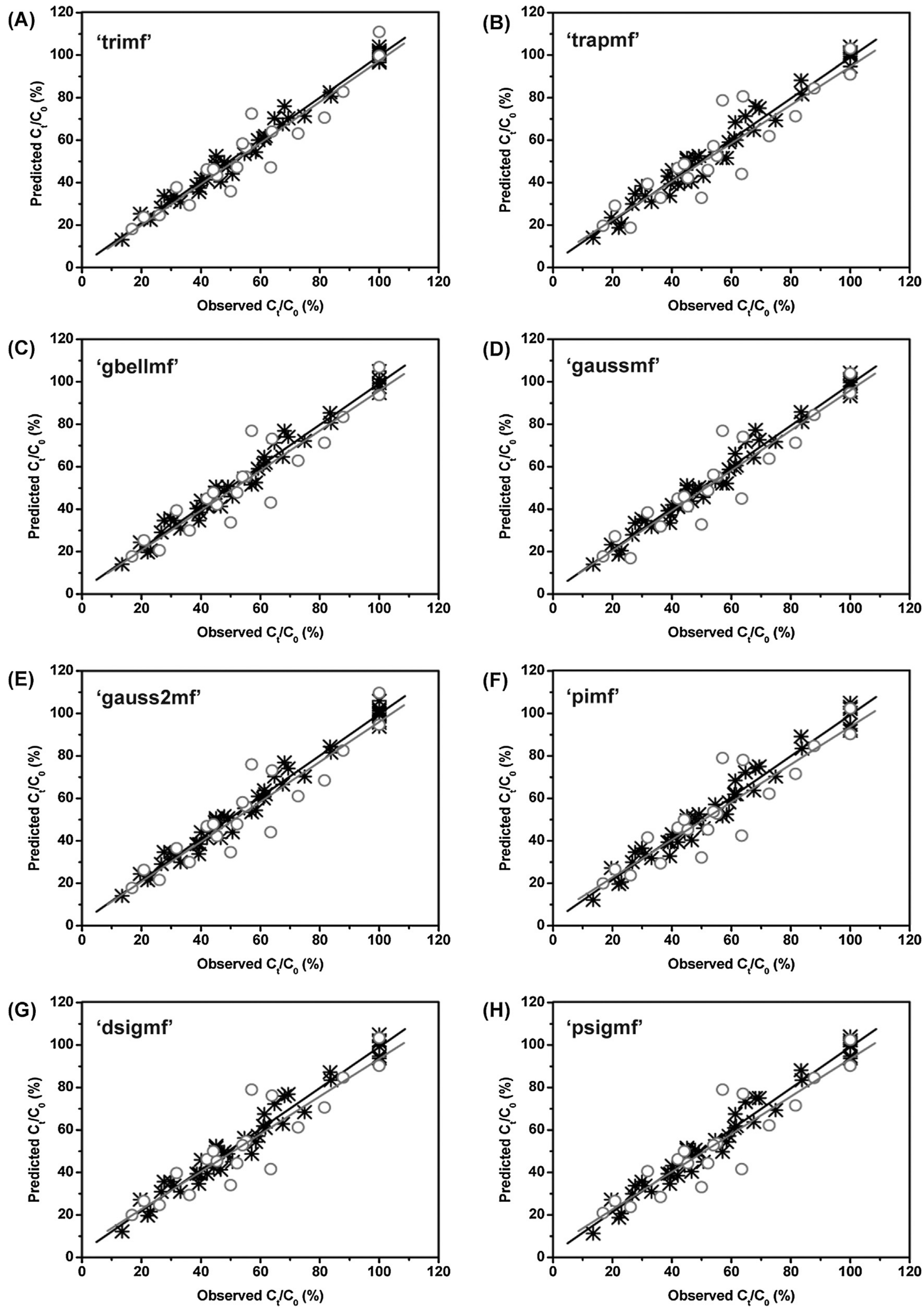

Fig. 4. Correlation between observed and predicted ascorbic acid retention percentage in fresh-cut pineapple during storage performed using the ANFIS models with different membership functions at training (*) and prediction (◯) p hases: (A) 'trimf', (B) 'trapmf', (C) 'gbellmf', (D) 'gaussmf', (E) 'gasuss2mf', (F) 'pimf', (G) 'dsigmf', and (H) 'psigmf'.

greater than 0.91 in all cases. This demonstrates the reliability of ANFIS model for prediction of the AA retention in fresh-cut pineapple during storage. Further, the comparisons reveal that the performance of ANFIS model with 'trimf' is better than that with other MFs (Table 1). Therefore, we recommend using the ANFIS model with 'trimf' for predicting the AA retention in fresh-cut pineapple.

Table 1
The root mean squared error (RMSE) and the coefficient of determination (R^2) for the prediction of the retention of ascorbic acid by ANFIS models with different types of input membership functions at training and prediction phases.

Membership functions	Training phase		Prediction phase	
	RMSE (%)	R^2	RMSE (%)	R^2
trimf	3.29	0.99	7.88	0.95
trapmf	4.61	0.98	10.14	0.91
gbellmf	3.89	0.99	9.13	0.93
gaussmf	3.81	0.99	8.97	0.93
gasuss2mf	3.80	0.99	9.25	0.93
pimf	4.55	0.98	10.19	0.91
dsigmf	4.68	0.98	10.06	0.91
psigmf	4.41	0.98	10.18	0.91

4. Conclusions

Surface area and storage temperature significantly affect the AA retention in fresh-cut pineapple during postharvest storage. The AA loss in the high-surface-area product is much faster than that of the low-surface-area product at the same storage temperature. The R^2 values between observed and predicted using ANFIS model with all MFs were greater than 0.91. Therefore, the ANFIS model can be reliably used to predict AA retention in fresh-cut pineapple as a function of surface area, storage temperature and time. In addition, the ANFIS model with 'trimf' is recommended due to higher prediction performance (RMSE = 7.88%; R^2 = 0.95).

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