Performance of Fuzzy Logic Model to Foresee of Ground Pistachio Nut Isotherm

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Abstract

Introduction: One of the most popular nuts in Iran is Pistachio (*Pistachia vera* L.). This nut is used as a food additive due to its high and uniquenutritional properties. Postharvest operations such as handling, cleaning, packaging and storing conditions have considerable effects on sensory attributes, the nutraceutical benefits, and shelf-life. Therefore, this research aims to predict the EMC of ground pistachio nut (GPN) undergoing 20ºC storage based on two key criteria [i.e. T and ERH= (a_w×100)] and application of the intelligent system of fuzzy logic.

Materials and Methods: The fuzzy logic model (FLM) was used to foresee of the EMCs (ads. /des.) behavior of GPN. First, the data obtained for EMC were run in MATLAB software & the fuzzy logic package was applied for EMC modeling of GPN. The variables were divided into two groups: inlet including storage temperature and water activity (a_w) and outlet is EMCs. Next, effective verbal variables were defined for both dependent and independent variables.

Results: The FLM could predict EMCs (ads. /des.) of GPN with an R^2 value equal to 0.9959 and 0.9869, respectively

Conclusions: Totally, the obtained results of present study are operational by workstations of GPN producer & theirplants to control the shelflife.

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1. Introduction

The most important horticultural products in Iran is pistachio. Production of pistachio nut in Iran, USA and Turkey (as three major producing countries) in 2018 were 551307 (~38% of Global production or GP), 447700 (~31% of GP) and 240000 (~17% of GP) MT, respectively (1, 2). Since a major portion of Iran's pistachio production is exported, this crop has a major role for providing foreign income for our country. Because of important role of pistachio in our economy, finding the most suitable preservation & storage conditions (to protect its quality criteria) is vital (3).

Water activity (a_w) of pistachio plays an essential role in acceleration of physiochemical changes (such as decolorization), biochemical reactions (e.g. browning & fat oxidation) & microbiological growth. (a_w) is highly related to the moisture content (MC) or amount of available water and temperature (T) of pistachio undergoing different postharvest stages such as drying, storage & packaging (3).

Various study has been performed to show the influence of a_w, MC&T on pistachio deterioration. Recently, Tavakolipour *et al.* (4) studied lipid oxidation kinetics of GPN at different temperature (15-40^{o}C) & RH (11-87%) & reported that the kinetic modeling follow zero-order model. They indicated that the greatest activation energy (Ea) needed to oxidize fattyacid (FA) of GPN acceded up to 50kJ/mol at a RH=33%. They also reported that these processes are endothermic ($\Delta H^{++}>0$) & non-spontaneous ($\Delta G^{++}>0$). Furthermore, Tavakolipour and Mokhtarian (5) developed a new approach to calculate GPN hysteresis via the goodness analytical equation of isotherm curve based on definite-integration-method (DIM). The maximum hysteresis is involved to the multilayers of section with $0.2<a_w<0.6$. In fact, the said hysteresis accord to the capillary condensation region of pistachio and it decreases with increasing temperature. Furthermore, Tavakolipour (6) stated that the suitable *T*, *RH* for bulk-storage of pistachio nuts respectively were 0-10°C and 65-70% or keeping at> 10°C (e.g. 15°C) &<32%. At these conditions the monolayer MC of pistachio had the shortest changes in its lipid quality factors. Staudt *et al*. (7) used DIM approach for forecasting isotherms curve at various *T* via the (Brunauer–Emmett–Teller model) BET model. Moreover, Zomorodian *et al*. (8) applied 13 models to find the goodness-fit for canola seed and demonstrated that Halsey-model had high correlation to predict the isotherm-curve.

Recently, extensive studies have been published for using of intelligent systems [Genetic-algorithm (GA), ANN, fuzzylogic-system (FLS) & suchlike] to predict of process factors and food quality attributes during the operation time. For instance, for instance, Mokhtarian and Garmakhany (9) predicted the ultrasound osmotic dehydration properties [solid gain (SG) &

water loss (WL)] of courgetti (summer squash or a kind of zucchini) by ANN. The ANN outcomes illustrated that, *tanh* activation function (with 46-nodes in 1^{th} & 2^{nd} HL) was chosen the topology could predict SG & WL of courgetti with an R^2 value equal to 0.938 and 0.985, respectively. Ghodsvali *et al*. (10) predicted the biophysical properties of barley malt including 1000-kernel weight (R^2=0.783), ρ_k (R^2=0.767) & terminal velocity (R^2=0.991) using ANN (as more accurate model with 8-nodes). Tavakolipour and Mokhtarian (11) estimated EMC of GPN through ANN&GA approaches. The results showed, the GA had higher accuracy to modeling of EMC (R^2=0.9996). Tavakolipour and Mokhtarian (12) developed the perceptron neural network (PNN) model for predicting moistureratio (MR) of pistachio nut via convective air dryer and the goodness outlets was achieved when they used PNN with 7 nodes in 1^{th} & 2^{nd} HL(R^2=0.994). Lertworasirikul and Saetan (13) applied the ANN model to osmotic parameters (SG&WL) prediction of kaffirlime peel. Madadlou*et al*. (14) predicted casein protein size using RSM coupled with the ANN method (RSM-ANN). Goni *et al*. (15) used the ANN model as an intelligent tool for predicting freezing & thawing times.

On the other hand, several researchers have used FLS in various area of food technology, e.g. applying of the FLS approach for predicting drying kinetics (16), evaluation of sensory properties (17, 18), water activity (19), water quality (20) and deep-fat frying parameters (21). Nevertheless, few studies have been done on the application of intelligent tools (especially fuzzy logic) in modeling isotherm of food and agricultural products.

Generally, according to notes mentioned above, this research aims to evaluate the possibility of FLS use for predicting (ads./des.) MC of GPN to monitor storage conditions momentarily.

2. Materials and Methods

2.1. Materials

Fresh pistachio nut (Kerman variety) was bought from a fruiterer in Sabzevar. The pistachio nuts should be dried from about 40%MCWB to safe storage moisture of <~7%MCWB (22). The pistachionuts dried to ~4<MCWB(%)<~6 are adopted beside those dried to ~6<MCWB(%)<~11 (because of higher in favorable [such as crispness & sweetness] and lower in unfavorable [such as bitterness & rancidity] organoleptic-quality indicators) (22, 23). The GPN was produced by weighting ten gram of pistachio kernels crushed in a home mill (Black & Decker, London) for 30s (the mean particle size=250µm). According to Tavakolipour and Mokhtarian (5, 11), different saturated salt solutions was employed to got steady state (constant) relative humidity.

2.2. Quantifying of equilibrium moisture content (EMC)

Static gravimetric method was used to measuring sorptionisotherm of GPN at different temperature (15, 25, 35 & 40ºC). In order to obtained different a_w of GPN (ranger from 0.11 to 0.88), eight saturated salt solutions (SSS) were prepared (24). After transferring 150 mL of each SSS into separate glass containers, their grids were suspended. About two grams sample of GPN was weighed separately and placed on grids in the containers, which were then tightly closed, and kept in convective ovens at different air temperatures for equilibration. The required time to reach equilibrium moisture content for sample of GPN was close to 18 day. Equilibration was achieved when the changes in MC (D.B.) did not exceed 0.1%, and it was <0.001 (g/[g.DM]) for three consecutive weighting at 3-day intervals (25). A vacuum oven (T=70ºC & P=150 mbar) was used for 6h to compute the MC of each GPN sample (26). For the (ads.) process, the GPN samples were placed in suspended petridish in containers having silica gel. Again, the same protocol was re-done to reach the equilibrium moisture content. Desorption isotherms were obtained on the dried GPN in a glass container over distilled water. At high levels of a_w (greater than0.7), a little amount of toluene (C_7H_8) was placed in a capillary tube fixed to the inner wall of different containers to inhibit microbial spoilage of the GPN samples (27).

2.3. Fuzzy logicsystem(FLS)

For collecting the required-data for simulating of the empirical EMCs (ads./des.) data, GPN was stored at various T&a_w. The actual numbers of storage temperature(T) and water activity (a_w) were chosen as the inlets of the FLS. As well, the EMCs data (ads./des.) of GPN was adopted as the desired outlets. Three stages were take place in the FLS. Firstly, FLS alter the set of inlet sorption-isotherm data into fuzzy inlet via different isotherm-functions(fuzzification). Secondly, IF-THEN rules & Mamdani implication method (MIN) were applied to covert the fuzzy inlet data to the fuzzy outlet data and Thirdly, the fuzzy outlet data (got by the inference engine derived from this system) are converted again into an actual number of EMCs (ads./des.) via the same defuzzification functions (see Fig. 1). The package of fuzzy logic of MATLAB (2010b, 7.11.0.584) was applied to modeling of GPN isotherm data (16).

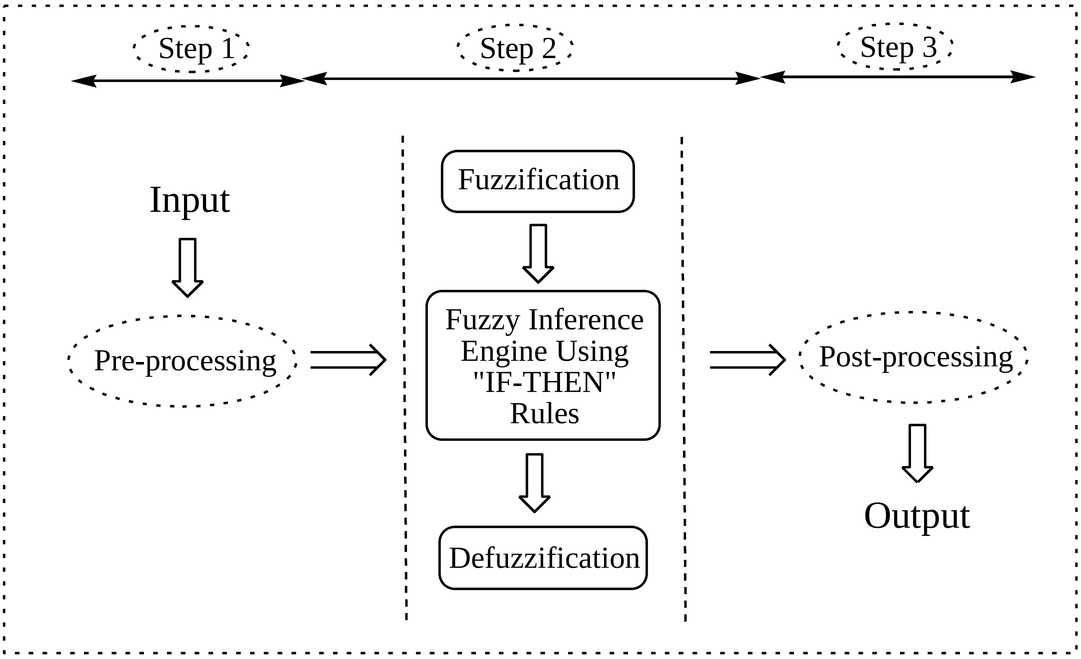


Fig. 1- Schematic structure of the fuzzy inference engine (FEE) to predict EMC of GPN

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{N} (X_{per,i} - X_{exp,i})^2}{\sum_{i=1}^{N} (X_{mean} - X_{per,i})^2} \right] \quad (1)$$

$$P(\%) = \frac{100}{N} \sum_{i=1}^{N} \left| X_{per,i} - X_{exp,i} \right| \quad (2)$$

Where $X_{exp,i}$ & $X_{per,i}$ are the actual and predicted values of X, X_{mean} is the mean predicted value and N is the total number of data (16).

3. Results

Simulation of ground pistachio nut EMCs (ads./des.) of was done using the “Mamdani”-approach. By this arrangement the FR’s were defined between inlet (T&a_w) and outlet (EMCs) variables. Moreover, the TRIMF was employed in the fuzzification of variables. Totally, 32IF-THEN rules with the “AND” operator was obtained for GPN isotherm; some of these rules are given in Table 2.

Table 1- The verbal variables along with MF in the fuzzification of sorption isotherm of GPN

Variable	Membership function	Range	Symbol
		Triangular (TRIMF)	
AirTemperature(AT)	Low	[15, 15, 25]	AT_1
	Medium	[15, 25, 35]	AT_2
	Little high	[25, 35, 40]	AT_3
	High	[35, 40, 40]	AT_4
Water activity (a_w)	Excessively low	[0, 0.11, 0.15]	WA_1
	Very low	[0.09, 0.23, 0.25]	WA_2
	lLow	[0.15,0.32,0.35]	WA_3
	Negativemedium	[0.25,0.44,0.46]	WA_4
	IMedium	[0.46,0.53,0.6]	WA_5
	High	[0.6,0.65,0.7]	WA_6
	Veryhigh	[0.7,0.75,0.85]	WA_7
	Excessively high	[0.75,0.85, 1]	WA_8
EMC (adsorption)	Excessively low	[0, 1, 1.3]	$EMC_{Ads.1}$
	Very low	[1, 1.5, 1.7]	$EMC_{Ads.2}$
	Little low	[1.5, 2, 2.2]	$EMC_{Ads.3}$
	Low	[2.2, 2.5, 3]	$EMC_{Ads.4}$
	Very negative medium	[2.5, 3, 3.4]	$EMC_{Ads.5}$
	Negative medium	[3, 3.4, 4]	$EMC_{Ads.6}$
	Medium	[3.5, 4.2, 5]	$EMC_{Ads.7}$
	Positive medium	[4.4, 5.2, 5.6]	$EMC_{Ads.8}$
	Very positive medium	[5.2, 5.4, 5.6]	$EMC_{Ads.9}$
	Little high	[5.2, 7.1, 7.3]	$EMC_{Ads.10}$
	High	[6, 7.3, 7.5]	$EMC_{Ads.11}$
	Very high	[7.3, 8.2, 8.4]	$EMC_{Ads.12}$
	Excessively high	[7.5, 8.5, 9]	$EMC_{Ads.13}$
EMC (desorption)	Excessively low	[0, 1.1, 1.3]	$EMC_{Des.1}$
	Very low	[1.1, 1.45, 1.9]	$EMC_{Des.2}$
	Little low	[1.5, 2, 2.3]	$EMC_{Des.3}$
	Low	[2, 2.3, 3]	$EMC_{Des.4}$
	Very negative medium	[2.3, 3, 3.4]	$EMC_{Des.5}$
	Negative medium	[3, 3.6, 3.8]	$EMC_{Des.6}$
	Medium	[3.8, 4, 4.8]	$EMC_{Des.7}$
	Positive medium	[4, 4.8, 5.4]	$EMC_{Des.8}$
	Very positive medium	[4.9, 5.35, 5.9]	$EMC_{Des.9}$
	a bit high	[5.2, 5.7, 6.8]	$EMC_{Des.10}$
	Little high	[5.9, 7.25, 7.5]	$EMC_{Des.11}$
	High	[6.8, 7.9, 8.4]	$EMC_{Des.12}$
	Very high	[8, 8.5, 9.2]	$EMC_{Des.13}$
	Excessively high	[8.5, 9.2, 9.8]	$EMC_{Des.14}$

Table 2 -The FR to modeling of GPN sorption isotherm

Rule No.		a_w		Air Temperature		EMC		
						adsorption		desorption
1	if	WA_1	and	AT_1	then	$EMC_{Ads.3}$	and	$EMC_{Des.3}$
2	if	WA_5	and	AT_1	then	$EMC_{Ads.7}$	and	$EMC_{Des.8}$
3	if	WA_4	and	AT_2	then	$EMC_{Ads.4}$	and	$EMC_{Des.6}$
4	if	WA_6	and	AT_2	then	$EMC_{Ads.8}$	and	$EMC_{Des.9}$
5	if	WA_4	and	AT_3	then	$EMC_{Ads.4}$	and	$EMC_{Des.5}$
6	if	WA_6	and	AT_3	then	$EMC_{Ads.8}$	and	$EMC_{Des.9}$
7	if	WA_8	and	AT_3	then	$EMC_{Ads.13}$	and	$EMC_{Des.13}$
8	if	WA_5	and	AT_4	then	$EMC_{Ads.5}$	and	$EMC_{Des.6}$
9	if	WA_1	and	AT_2	then	$EMC_{Ads.2}$	and	$EMC_{Des.2}$
10	if	WA_8	and	AT_2	then	$EMC_{Ads.13}$	and	$EMC_{Des.13}$
11	if	WA_7	and	AT_4	then	$EMC_{Ads.11}$	and	$EMC_{Des.11}$
12	if	WA_1	and	AT_4	then	$EMC_{Ads.1}$	and	$EMC_{Des.1}$
13	if	WA_1	and	AT_3	then	$EMC_{Ads.1}$	and	$EMC_{Des.2}$
14	if	WA_6	and	AT_1	then	$EMC_{Ads.9}$	and	$EMC_{Des.10}$
15	if	WA_3	and	AT_1	then	$EMC_{Ads.2}$	and	$EMC_{Des.3}$
16	if	WA_2	and	AT_1	then	$EMC_{Ads.4}$	and	$EMC_{Des.4}$
17	if	WA_2	and	AT_2	then	$EMC_{Ads.2}$	and	$EMC_{Des.2}$
18	if	WA_3	and	AT_2	then	$EMC_{Ads.2}$	and	$EMC_{Des.2}$
19	if	WA_2	and	AT_3	then	$EMC_{Ads.2}$	and	$EMC_{Des.1}$
20	if	WA_3	and	AT_3	then	$EMC_{Ads.1}$	and	$EMC_{Des.2}$
21	if	WA_2	and	AT_4	then	$EMC_{Ads.1}$	and	$EMC_{Des.1}$
22	if	WA_3	and	AT_4	then	$EMC_{Ads.2}$	and	$EMC_{Des.2}$
23	if	WA_7	and	AT_1	then	$EMC_{Ads.11}$	and	$EMC_{Des.12}$
24	if	WA_4	and	AT_4	then	$EMC_{Ads.3}$	and	$EMC_{Des.5}$
25	if	WA_4	and	AT_1	then	$EMC_{Ads.6}$	and	$EMC_{Des.7}$
26	if	WA_8	and	AT_1	then	$EMC_{Ads.13}$	and	$EMC_{Des.14}$
27	if	WA_5	and	AT_2	then	$EMC_{Ads.5}$	and	$EMC_{Des.6}$
28	if	WA_7	and	AT_2	then	$EMC_{Ads.11}$	and	$EMC_{Des.12}$
29	if	WA_5	and	AT_3	then	$EMC_{Ads.5}$	and	$EMC_{Des.6}$
30	if	WA_7	and	AT_3	then	$EMC_{Ads.11}$	and	$EMC_{Des.11}$
31	if	WA_8	and	AT_4	then	$EMC_{Ads.13}$	and	$EMC_{Des.13}$
32	if	WA_6	and	AT_4	then	$EMC_{Ads.8}$	and	$EMC_{Des.9}$

Specifications of the FLS (MAMDANI type) are given as follows:

- Decision method for AND/OR fuzzy logic system operators respectively are "MIN" & "MAX".
- Implication and Aggregation method, respectively are: "MIN" & "MAX".
- Defuzzification: 'CENTROID (center of gravity).

The outlet performance of the fuzzy expert engine program and fuzzy sets after defuzzification for EMCs (ads. /des.) of GPN are summarized in Table 3.

Table 3- Summary of fuzzy result to predict ground pistachio nut EMCs (ads. & des.)

Inlet Parameters		EMC (%D.B.)			
Temp.(ºC)	a_w	Adsorption		Desorption	
		Experimental result	Fuzzy result	Experimental result	Fuzzy result
15	0.11	2	1.9	2.2	2.07
15	0.23	2.1	2.11	2.3	2.26
15	0.32	2.4	2.36	3	2.92
15	0.44	3.4	3.47	3.8	4.2
15	0.53	4.2	4.23	4.8	4.73
15	0.65	5.4	5.4	5.9	5.9
15	0.75	7.3	6.93	7.9	7.7
15	0.85	8.4	8.33	9.2	9.17
25	0.11	1.3	1.4	1.5	1.48
25	0.23	1.4	1.6	1.6	1.66
25	0.32	1.7	1.88	2.2	2.21
25	0.44	2.5	2.57	3.5	3.47
25	0.53	3.2	2.97	4	3.47
25	0.65	5.1	5.07	5.4	5.38
25	0.75	7.2	6.93	7.4	7.7
25	0.85	8.4	8.33	8.5	8.57
35	0.11	1.1	0.822	1.3	1.48
35	0.23	1.4	1.4	1.3	1.14
35	0.32	1.5	1.25	2	2.11
35	0.44	2.3	2.57	3.1	2.9
35	0.53	3	2.97	3.7	3.47
35	0.65	5	5.07	5.3	5.38
35	0.75	7	6.93	7.2	6.88
35	0.85	8.3	8.33	8.4	8.57
40	0.11	1	0.822	1.1	0.887
40	0.23	1.2	0.922	1.3	1.14
40	0.32	1.4	1.57	1.9	2.11
40	0.44	2.2	1.9	3	2.9
40	0.53	3	2.97	3.4	3.47
40	0.65	4.9	5.07	5.1	5.38
40	0.75	7	6.93	7.2	6.88
40	0.85	8.2	8.33	8.4	8.57

Three dimensions (3D) plot of the relations between inlet and outlet variables of GPN sorption isotherm (with 32IF-THEN rules) are given in Figures 2 and 3. With a glance at Figures 2 and 3, it can vividly be perceived that EMCs (ads./des.) increased and decreased with increasing the water activity (a_w) and increasing storage air temperature (T), respectively.

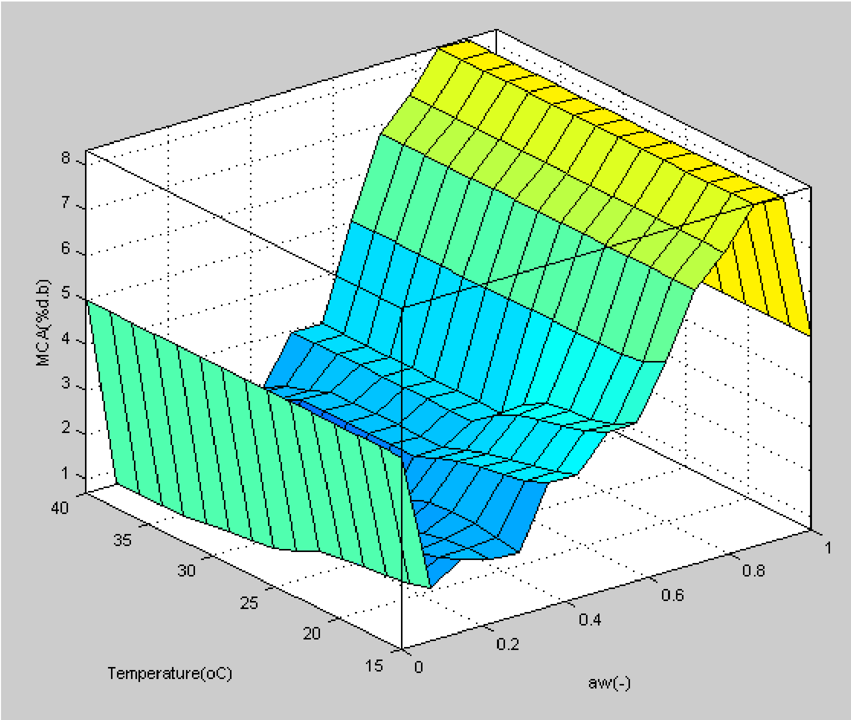


Fig. 2- The 3-dimensions plot for the interaction influence of (T) & (a_w) on GPN's AMC via the FLS

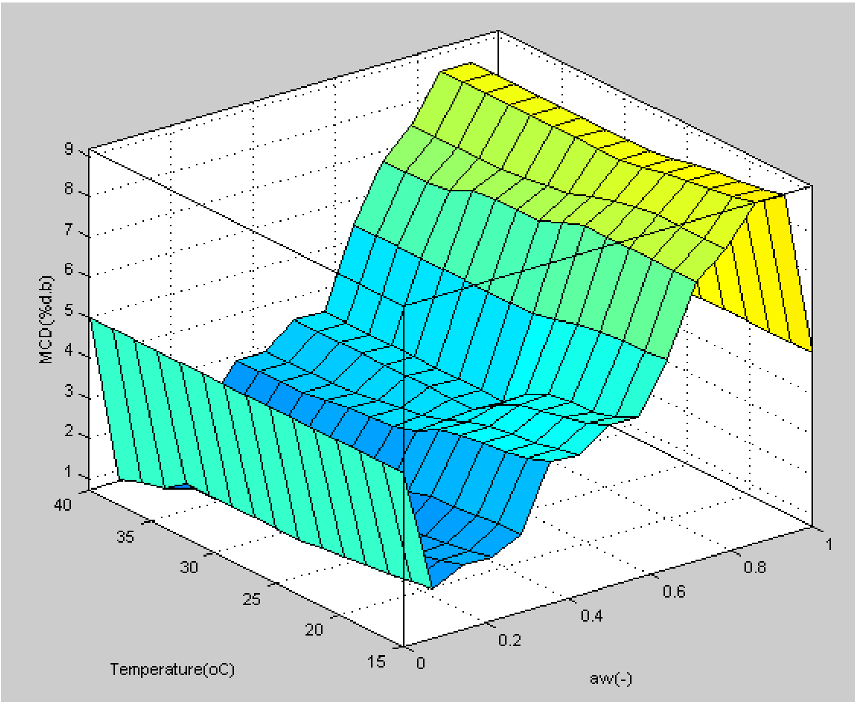


Fig. 3- The 3-dimensions plot for the interaction influence of (T) & (a_w) on GPN's DMC via the FLS

The FR used in developing the FEE to predict ground pistachio nut EMCs (ads./des.) are shown in Fig 4. This figure indeed confirms the recognized results of Table 2, presented for predicting the outlet variables according to defined MF (see Table 1). For example, if the values of inlet variables of *T* and a_w are 25°C and 0.8, respectively, then corresponding EMCs (ads. & des.) values become 7.59 (%D.B) and 8.04 (%D.B), respectively belongings to verbal variables of “VERY HIGH” ($EMC_{Ads.12}$) and “HIGH” ($EMC_{Des.12}$).

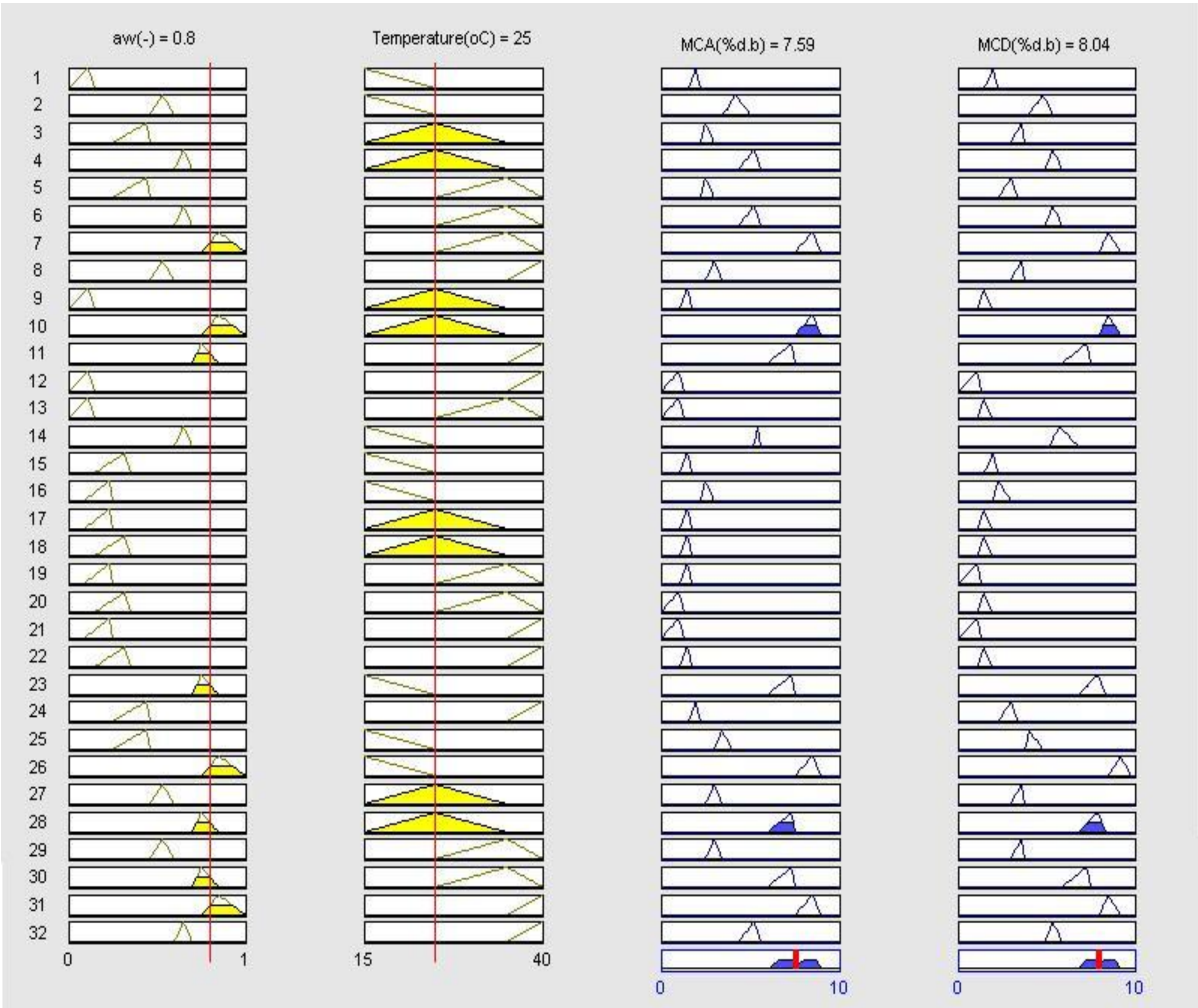
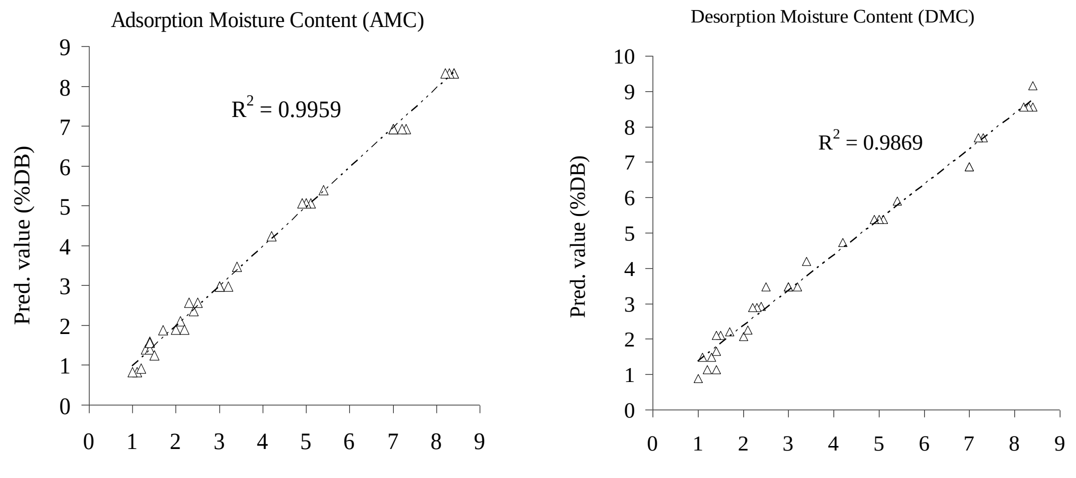


Fig. 4- Different rules used in developing the FM to predict EMC of GPN

The evaluation of performing the FLS model was made via two important statistic standards, specificallyR^2 and P(%). The outcome showed, the FL model had a potential to foresee the EMCs (ads./des.) of GPN with R^2 & P (%) values equal (0.9959 & 13.01) and (0.9869 & 40.63), respectively (see Figure 5).

The plot of pred. vs. actual values of EMCs (ads./des.) is given in Fig 5. As seen, strong correlation (R^2>0.9869) of those data displayed high level of accuracy for FLS choosing to foresee ground pistachio nut EMCs (ads./des.).



(a) (b)

Fig. 5- Pred. (dotted line) & actual values (triangle sign) of the FLS for adsorption moisture conten (AMC) and desorption moisture content (DMC) of GPN.

4. Discussion

The RH of heated air has a major role in storage time of GPN (ground pistachio nuts). Once ambient air is exposed to moisty GPN, a vapor-pressure evenness is created between the water present in GPN and the RH of the surrounding air. The moisture content remains in GPN under such conditions is called EMC. The EMC usually reduces with a rise in temperature depending on changing of RH existing in contacting air. Water activity (a_w) in GPN is defined as the relation between their vapor pressures with the contacting air media, when it is held in a completely undisturbed situation. At evenness conditions the $a_w$of GPN is alike to the RH of contacting air (i.e. a_w=0.01×ERH). The interactions rateof food-water with the surrounding air is determined by its MC & a_w. Meanwhile, the protein, starch, &high molecular-weight polymers in food and agricultural products (such as GPN) create higher EMC than soluble solids, crystalline salts, and sugars (28). Arslan-Tontul (29) evaluated the EMC of whole chia seed. He found that the EMC content of whole chia seed decreased by increasing storage temperature. Tavakolipour and Mokhtarian (5) investigated the EMC of GPN and claimed that a_w and$T$ had positive influence ($p<0.05$) on its EMC. They also showed the maximum EMC (ads.) was attained at (a_w) equal to 0.85 and loading temperature of 15°C (or 25°C), and its EMC reduced with increasing storage temperature at constant (a_w). The minimum EMC was gained at low water activity (a_w= 0.11) and loading temperature of 40°C.

Figure 5 which shows, plot of projected values vs. tested data of EMCs (ads./des.). As can be seen, strong correlation (R^2>0.9869) of those data displayed high level of accuracy for selecting of FLS model to foresee EMCs (ads./des.) of GPN. Tavakolipour *et al*. (16) applied two novel optimization models (FLS & ANN) for smartening of drying kinetics of zucchini slices (especially prediction of moisture ratio or MR). Eventually, evaluation of these results discovered that ANN model had greater accuracy than EEOF to predict MR of dried zucchini. Al-Mahasneh *et al*. (19) modeled roastedwheat MSI via both FLS and Nonliner regression (NLR) models. They illustrated that the FLS had a goodness fit than NLR. Since the R^2, RMSE, E% and SSE of FLS and NLR respectively were ”0.99 & 0.97”, ”0.01 & 0.0038”, ”1.01 & 5.9” and ”0.0008 & 0.009”, the FLS technique was superior and provided a better fit than NLR procedure.

5. Conclusion

The FLS is used to study momentarily monitoring of ground pistachio nuts EMCs (ads./des.) during the storage period. The results reveal that FLS can be provided as a strong arbitration system for monitoring EMCs than the conventional modeling approach including the regression model. Although the resulting regression model is a simple mathematical relationship, it can show EMCs variation as a water activity function and air temperature. In other words, it cannot display the relationship between inlet and outlet variables of GPN undergoing the long-storage period. This study showed that the FLS and other intelligent systems can be introduced as acceptable controlling machines for monitoring EMCs of GPN and similar agricultural products. Since the interaction of water activity and *T* of determine MC of GPN with good approximation, it is possible to predict the allowable storage time and possibly shelf life of GPN at different conditions of packaging or storing. Determining the allowable storage of GPN, will assist us to use the most appropriate methods for processing, packaging and storage of this valuable product. On the other hand, controlling water activity and temperature will save our time and energy for suitable preservation and producing high quality pistachio.

Conflict of interest

The authors of present researches declare that there is no conflict of interest.

References

1- Tavakolipour H, Kalbasi-Ashtari A, Mokhtarian M. Effects of coating pistachio kernels with mixtures of whey protein and selected herbal plant extracts on growth inhibition of *Aspergillus flavus* and prevention of aflatoxin during storage. J Food Saf. **2019**; 40:*e12711*.

2- FAO. FAO Stat Database. Available from http://faostat.fao.org; **2018**.

3- Tavakolipour H, Kalbasi-Ashtari A. Estimation of moisture sorption isotherms in Kerman pistachio nuts. Int J Food Eng. **2008**; 31:*564-82*.

4- Tavakolipour H, Mokhtarian M, Kalbasi-Ashtari A. Lipid oxidation kinetics of pistachio powder during different storage conditions. J Food Proc Eng. **2017**; 40:*e12423*.

5- Tavakolipour H, Mokhtarian M. New approach to the calculation of pistachio powder hysteresis. Int Agrophys. **2016**; 30:*245-51*.

6- Tavakolipour H. Postharvest operations of pistachio nuts. Int J Food Sci Technol. **2013**; 52(2):*1124-1130*.

7- Staudt P.B, Kechinski C.P, Tessaro I.C, Marczak L.D.F, Soares R, De P, Cardozo, N.S.M. A new method for predicting sorption isotherms at different temperatures using the BET model. J Food Eng. **2013**; 114:*139-145*.

8- Zomorodian A, Kavoosi Z, Momenzadeh L. Determination of EMC isotherms and appropriate mathematical models for canola. J Food Bioprod Proc. **2011**; 89:*407-13*.

9- Mokhtarian M, Garmakhany A. Production of ultrasound osmotic dehydration properties of courgette by ANN. Quality Assurance Saf Crops Foods. **2017**; 9(2):*161-69*.

10- Ghodsvali A.R, Farzaneh V, Bakhshabadi H, Zare Z, Karami Z, Mokhtarian M, Carvalho I.S. Screening of the aerodynamic and biophysical properties of barley malt. Int Agrophys. **2016**; 30:*457-64*.

11- Tavakolipour H, Mokhtarian M. Estimation of equilibrium moisture content of pistachio powder through the ANN and GA approaches. Int J Food Eng. **2014**; 10(4): *747-55*.

12- Tavakolipour H, Mokhtarian M. Neural network approaches for prediction of pistachio drying kinetics. Int J Food Eng. **2012**; 8(3): *Article 42*.

13- Lertworasirikul S, Saetan S. Artificial neural network modeling of mass transfer during osmotic dehydration of kaffir lime peel. J Food Eng. **2010**; 98:*214-23*.

14- Madadlou A, Emam-Djomeh Z, Ebrahimzadeh Mousavi M, Ehsani MR, Javanmard M, Sheehan D. Response surface optimization of an artificial neural network for predicting the size of re-assembled casein micelles. J Comput Electronics Agric. **2009**; 68:*216-21*.

15- Goni SM, Oddone S, Segura JA, Mascheroni RH, Salvadori VO. Prediction of foods freezing and thawing times: Artificial neural networks and genetic algorithm approach. J Food Eng. **2008**; 84:*164-78*.

16- Tavakolipour H, Mokhtarian M, Kalbasi-Ashtari A. Intelligent monitoring of zucchini drying process based on fuzzy expert engine and ANN. J Food Proc Eng. **2014**; 37: *474-81*.

17- Mukhopadhyay S, Majumdar GC, Goswami, TK, Mishra HN. Fuzzy logic (similarity analysis) approach for sensory evaluation of chhana podo. LWT-Food Sci Technol. **2013**; 53:*204-10*.

18- Singh K.P, Mishra A, Mishra H.N. Fuzzy analysis of sensory attributes of bread prepared from millet-based composite flours. LWT-Food Sci Technol. **2012**; 48:*276-82*.

19- Al-Mahasneh MA, Bani Amer MM, Rababah TM. Modeling moisture sorption isotherms in roasted green wheat using least square regression and neural-fuzzy techniques. J Food Bioprod Proc. **2012**; 90:*165-70*.

20- Gharibi H, Hossein Mahvi A, Nabizadeh R, Arabalibeik H, Yunesian,M, Sowlat MHA. Novel approach in water quality assessment based on fuzzy logic. J Environ Manage. **2012**; 112:*87-95*.

21- Amiryousefi MR, Mohebbi M, Khodaiyan F, Asadi S. An empowered adaptive neuro-fuzzy inference system using self-organizing map clustering to predict mass transfer kinetics in deep-fat frying of ostrich meat plates. J Comput Electronics Agric. **2011**; 76:*89-95*.

22- Mokhtarian M, Tavakolipour H, Kalbasi-Ashtari A. Effects of solar drying along with air recycling system on physicochemical and sensory properties of dehydrated pistachio nuts. LWT-Food Sci Technol. **2017**; 75: *202-09*.

23- Kader AA, Heintz CM, Labavitch JM, Rae HL. Studies related to the description and evaluation of pistachio nut quality. J American Society Hortic Sci. **1982**; 107(5):*812-16*.

24- Rahman SM. Food Properties Handbook, pp. 23-46, CRC Press, Boca Raton, FL; **1995**.

25- Biquet B, Labuza TP. Evaluation of the moisture permeability characteristics of chocolate fills as an edible moisture barrier. J Food Sci. **1988**; 53(4):*989-97*.

26- AOAC. Official Methods of Analysis of the Association of Official Analytical Chemists, 15th Ed, Association of Official Analytical Chemists, Washington, DC; **1990**.

27- Labuza TP. Moisture Sorption: Practical Aspects of Isotherm Measurement and Use, American Association of Cereal Chemists, St. Paul, MN; **1984**.

28- Heldman DR, Lund D.B. Handbook of Food Engineering. CRC Press, New York; **2007**.

29- Arslan-Tontul S. Moisture sorption isotherm, isosteric heat and adsorption surface area of whole chia seeds. LWT-Food Sci Technol. **2019**; https://doi.org/10.1016/j.lwt.2019.108859.