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Development of an expert system to determine the measured characteristics of grape fruit stored in cold storage using fuzzy logic

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ABSTRACT

The increase in the production and consumption of grapes in the world has increased the need for research in the field of creating conditions for further preservation of this fruit, and the lack of sensors that can provide accurate information from the production and storage process to control systems for decision-making is obvious and evident. Therefore, this study aimed to determine some characteristics of grape fruit (taste index, pH, firmness, ion leakage, ΔE, number of mold and general acceptance) stored in cold storage in the range of storage time from 0 to 60 days was measured and according to the importance Achieving these characteristics during fruit storage, a model using fuzzy logic was created as an expert system with accuracy (with a correlation coefficient greater than 0.96) and very high speed capable of predicting and determining these product characteristics only by using It was time to save it. This system was able to obtain the value of each of these studied characteristics at any desired storage time in the range of 0 to 60 days with very high accuracy and in a fraction of a second. On the other hand, it was found that with increasing storage time, the amount of taste index, pH, number of molds, ΔE and ionic leakage of the samples increased, but the degree of hardness and overall acceptance decreased.

1. Introduction

The importance of consuming fruits and vegetables is due to the reduction of cancer and the reduction of mortality and heart diseases. Also, consumption of such substances lowers blood pressure and increases resistance to diseases. The existence of cold stores, processing industries and consumer markets absorb a huge part of these products, but due to the lack of sufficient capacity of such industries and centers of consumption and storage and production more than the capacity of the raw material, the statistics of waste increases at this stage [1]. One of the oldest fruits known to mankind is the grape with the scientific name *Vitis vinifera* L., and the cultivation of this fruit began from 6000 to 8000 years ago, but it is still very popular among consumers, so that its production rate ranks fourth among fruit products in the world. According to the Food and Agriculture Organization (FAO), about 23% of the world's grapes are eaten fresh. Fresh grapes have important nutrients for the body that strengthen the immune system and prevent cancer and reduce blood pressure, bad cholesterol and the aging process.. This fruit also contains various vitamins such as vitamins B, C and K and minerals (potassium, calcium and magnesium), antioxidants, plant nutrients including resveratrol, phenols, carotenoids and fibers, and without doubt, eating grapes fresh is the healthiest way to consume this fruit [2, 3, 4]. Grapes are a fruit with low physiological activity and are very sensitive to weight loss and fungal infections, especially *Botrytis cinerea* gray mold, during the post-harvest period. One of the important factors in the chain of food preservation from the time of production to the time of consumption is the use of cold to store horticultural products. The storage life of fruits is strongly influenced by the production conditions in the fields or orchards and their harvest, as well as the temperature and humidity of the warehouse [5, 6]. The increase in the production and consumption of grapes in the world has increased the need for research in the field of creating conditions for further preservation of this fruit. Until today, storage at low temperature is the most widely used technology after harvesting to preserve the quality of fruit and other horticultural products and increase their useful life [7, 8]. However, the duration of keeping grapes at low temperature is limited and the commercial value of this fruit decreases without proper treatments [9, 10]. In the food industry, the lack of sensors that can provide control systems with accurate information from the production process for decision-making is obvious. Since these controls are one of the key and undeniable points in this industry, it is necessary to look for ways to overcome this deficiency and defects in process control and monitoring systems. These control systems should be able to measure the desired characteristics during product production and collect this information and transfer it to the control room [11]. Nasiri et al. (2022) used a fuzzy controller along with the use of neural networks and genetic algorithm to optimize the storage conditions as well as the classification of tomatoes, the results of which showed a high accuracy of 90% of these models in predicting the quality of this product [12]. Zandi et al. (2021) used fuzzy logic and neural-fuzzy adaptive inference system to predict the physical and chemical changes and quality classification of coated lemon during the storage period [13]. Magal Haze et al. (2022) used fuzzy logic to predict the sales period of peaches with the highest quality. This study determined that modeling using fuzzy logic can be used for all fruits to reduce food wastage and waste. And as a result, it leads to the improvement of the social, economic and environmental aspects of society [14]. The aim of this research is to provide a powerful and

practical model to predict some characteristics of grape fruit stored in cold storage with very high accuracy and in a very short time, which can be used to control and manage the different stages of harvesting, transportation, grading, storage, and also, the processing of this product should be used.

2- Materials and methods

2-1- Grape preparation and its storage conditions in cold storage

'Rish Baba' grapes were purchased from Malayer city of Hamadan province and the bunches of grapes were immediately transferred to the laboratory of Malayer university Grape and Raisin Research Institute and were graded based on uniformity in maturity, size, color and absence of fungal infection or signs of physical damage. They were transported at -1°C and 90% relative humidity and were kept under these conditions for 60 days and were taken out of the cold storage at regular intervals (once every 10 days) and then examined.

2-2- Investigated Tests

2-2-1- Taste index (Maturity index)

The taste index of grape fruits was determined according to the method of Farzaneh et al. (2018) and through the ratio of total soluble solids to titratable acidity [1].

2-2-2- Determination of pH

The pH of the samples was determined by measuring the pH of the extracted extract using a pH meter (Atago, England) at a temperature of 20°C [1].

2-2-3- Determining of ion leakage

To measure ion leakage, the method of Sajadian et al. (2019) was used with some changes. In this method, 0.1 g of the sample was mixed with 10 ml of double-distilled water and placed in a hot water bath (Topsonics, Lithuania) at a temperature of 40ºC and it was placed for 30 minutes and its initial electrical conductivity (EC1) was determined by an EC meter (DEC-2 ATAGO, England). Again, the samples were placed in a hot water bath (100°C for 15 minutes) and their secondary electrical conductivity (EC2) was measured, and the ionic leakage rate of the samples was determined from equation 1 [15].

(1)

$$\%\text{Ionic leakage} = \frac{EC_1 - EC_2}{EC_1} \times 100$$

2-2-4- Measuring the firmness of the fruit tissue

To determine the texture firmness of grape samples, a fruit penetrometer (Chinese model) was used with a special cylindrical prop, and the maximum penetration force to create a depth of 10 mm was calculated in terms of newton [16].

2-2-5- Examining the color changes of the samples (ΔE)

To measure the color of the fruit, a color photo was taken of the fruit samples under uniform and appropriate light and at a radiation angle of 45 degrees with a Canon Power shot SX110 IS digital camera with a resolution of 9 megapixels. Then the images were transferred to the computer and using Photoshop 6 software, the amount of L*, a* and b* indices was obtained and the amount of ΔE was calculated from equation 2 [17].

(2)

$$\Delta E = \sqrt{(L_1 - L_0)^2 + (a_1 - a_0)^2 + (b_1 - b_0)^2}$$

2-2-6- Counting the number of molds in the samples

First, 10 grams of each sample was mixed with 90 ml of sterile physiological serum and homogenized, and after preparing

different dilutions, 1 ml of each prepared dilution was transferred to petri dishes containing PDA culture medium and cultured by surface method and at temperature it was incubated at 25°C for 5 days. The samples were prepared in three replicates and only 30-300 colony forming units (cfu/g) were considered [18].

2-2-7- General acceptance of samples

In order to check the overall acceptance of grape samples after the end of the storage time, the taste test and the 5-point hedonic method were used. First, explanations were given about the product's color, shine, texture, taste, appearance, and presence or absence of mold and rot, and grading was done based on very good (score 5) to very bad (score 1). The number of ten panelists was considered in there replications [19].

2-3- Modeling using fuzzy logic

Fuzzy logic tool in MATLAB software was used to simulate, interpolate and increase the data obtained from the storage time of grape fruit in cold storage. Using Mamdani modeling method for inputs and outputs under the fuzzy if-then rule, storage time ratios in certain time intervals based on time selection in 7 levels with the term very very low for time zero (VVL), very low for time 10 days (VL), low for 20 days (L), medium for 30 days (M), high for 40 days (H), very high for 50 days (VH) and very very high for 60 days (VVH) in the Fuzzy logic tool of MATLAB software was simulated.

Seven output variables including taste index, pH, texture firmness, ΔE, mold count, ion leakage and overall acceptance were determined and defined in the same way at 7 levels. Triangular membership functions were used to regulate changes in input variables. A triangular membership function with three parameters {a,b,c} is defined as equation 3. Figure (1) shows the Mamdani model designed for this study [11].

(3)

$$triangle(x;a,b.c) = \begin{cases} 0 & x \le a \\ \frac{x-a}{b-a} & a \le x \le b \\ \frac{c-x}{c-b} & b \le x \le c \\ 0 & c \le x \end{cases}$$

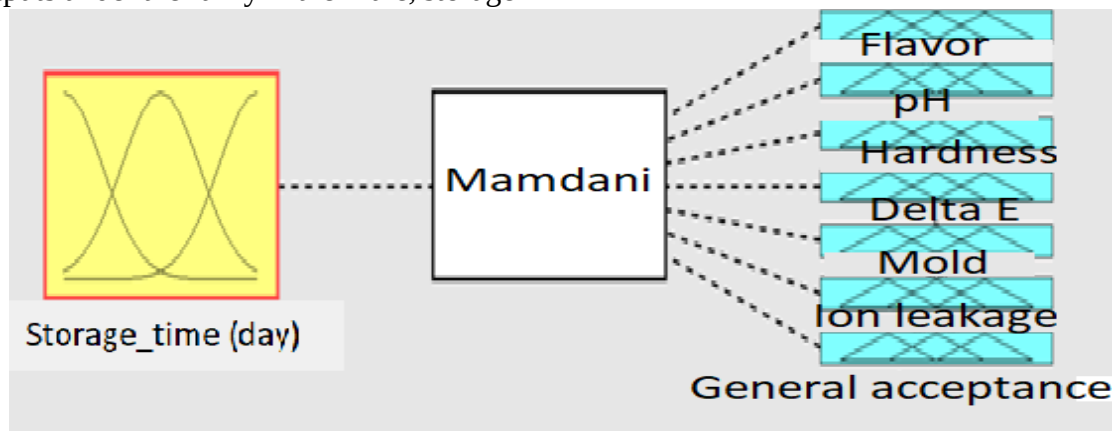


Figure1- The suggested topology of the designed fuzzy logic system in this investigation

Using this temporal classification, 7 fuzzy if-then rules were defined, which are given in relations 4 to 10. Considering that the triangular membership function has been used to model and adjust this system, it is necessary to determine three parameters a, b and c for the input and output variables (according to Equation 3). Determining these values is one of the most important steps in reaching an optimal system to achieve the least error and the most correlation. The values of the parameters used for the membership functions of the input variable are given in Table 1. Also, the graphs of its

membership functions are presented in Figure 2.

4. If (Storage_time(day) is VVL) then (Flavor index is VVL)(pH is VVL)(Hardness is VVH)(E is VVL)(Mold is VVL)(Ion_leakage is VVL)(General_acceptance is VVH)
5. If (Storage_time(day) is VL) then (Flavor index is VL)(pH is VL)(Hardness is VH)(E is VL)(Mold is VL)(Ion_leakage is VL)(General_acceptance is VH)
6. If (Storage_time(day) is L) then (Flavor index is L)(pH is L)(Hardness is H)(E is H)(Mold is L)(Ion_leakage is L)(General_acceptance is H)
7. If (Storage_time(day) is M) then (Flavor index is M)(pH is M)(Hardness is M)(E is M)(Mold is M)(Ion_leakage is M)(General_acceptance is M)
8. If (Storage_time(day) is H) then (Flavor index is H)(pH is H)(Hardness is L)(E is H)(Mold is H)(Ion_leakage is H)(General_acceptance is L)
9. If (Storage_time(day) is VH) then (Flavor index is VH)(pH is VH)(Hardness is VL)(E is VH)(Mold is VH)(Ion_leakage is VH)(General_acceptance is VL)
10. If (Storage_time(day) is VVH) then (Flavor index is VVH)(pH is VVH)(Hardness is VVH)(E is VVH)(Mold is VVH)(Ion_leakage is VVH)(General_acceptance is VVL)

Table1- Triangular membership function parameters for storage time

The title of membership functions	Parameters of membership functions		
	a	b	c
The first membership function	0	0	5
Second membership function	5	10	15
Third membership function	15	20	25
Fourth membership function	25	30	35
Fifth membership function	35	40	45
Sixth membership function	45	50	55
Seventh membership function	55	60	65

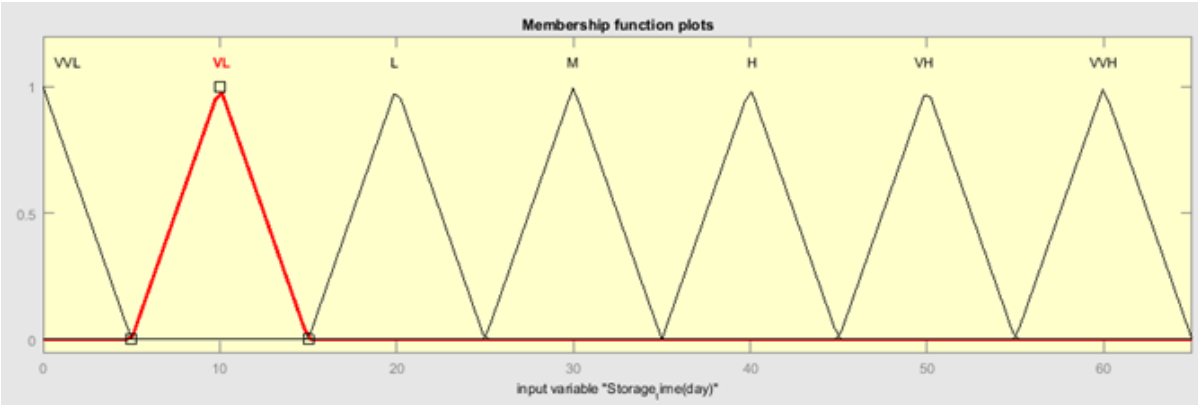


Figure 2- Membership functions of the input variable

3-Results and Discussion

3-1- The effect of storage time on the measured characteristics

The results showed that the taste index of the samples increased with the increase in storage time (Figure 3). The reason for this increase can be attributed to the decrease in acidity and increase in ºBrix of fruits during storage. Khalil et al. (2023) also stated that the ripening index (taste index) of the samples increases with the increase in storage time [20]. In another study in 2016, it was shown that with the increase in storage time, the amount of this index decreases, which was stated to be the reason for this phenomenon of increased acidity and stability of ºBrix during the storage of grapes, which was in conflict with the results of this section [21].

Hosseinpoor et al. (2017) by investigating the effect of hot water treatment and nano packaging on the quality properties of 'Sangelo' nectarine fruit during storage, stated that with the increase in storage time, the taste index of the fruits increases due to the increase in sugar and decrease in titratable acidity, which was in line with the results of this the section [22].

Figure 3b showed that with the increase in storage time, the pH of the samples increased, which can be attributed to the decrease in organic acids and the increase in fruit sugars as a result of respiration. In line with these results, Garcia et al. (2011) also stated that with increasing storage time, the pH of the samples increases [23]. In another study, researchers attributed the increase in pH during grape fruit storage to interactions that lead to fruit senescence and also to the conversion of acids into other substances such as sugars [1]. In line with these results, Ngo et al. (2021) also determined that the pH of the samples increased with the increase in storage time [24]. Ion leakage has been considered as an indicator of membrane damage for indirect measurement of cell membrane integrity and can show the decrease of cell membrane integrity and the occurrence of frost damage in horticultural products [25]. The findings indicated that the ionic leakage of the samples increased with increasing storage time (Figure 3c). Some researchers stated that the activity of more enzymes during storage and tissue destruction is one of the causes of increased ionic leakage of fruits during storage [26]. In line with the findings of this section, Esmaeili et al. (2019) showed by evaluating the effect of harvesting time and the duration of fruit storage in cold storage on some quality characteristics of blueberry fruit that the ion leakage index increases with the increase of storage time [27].

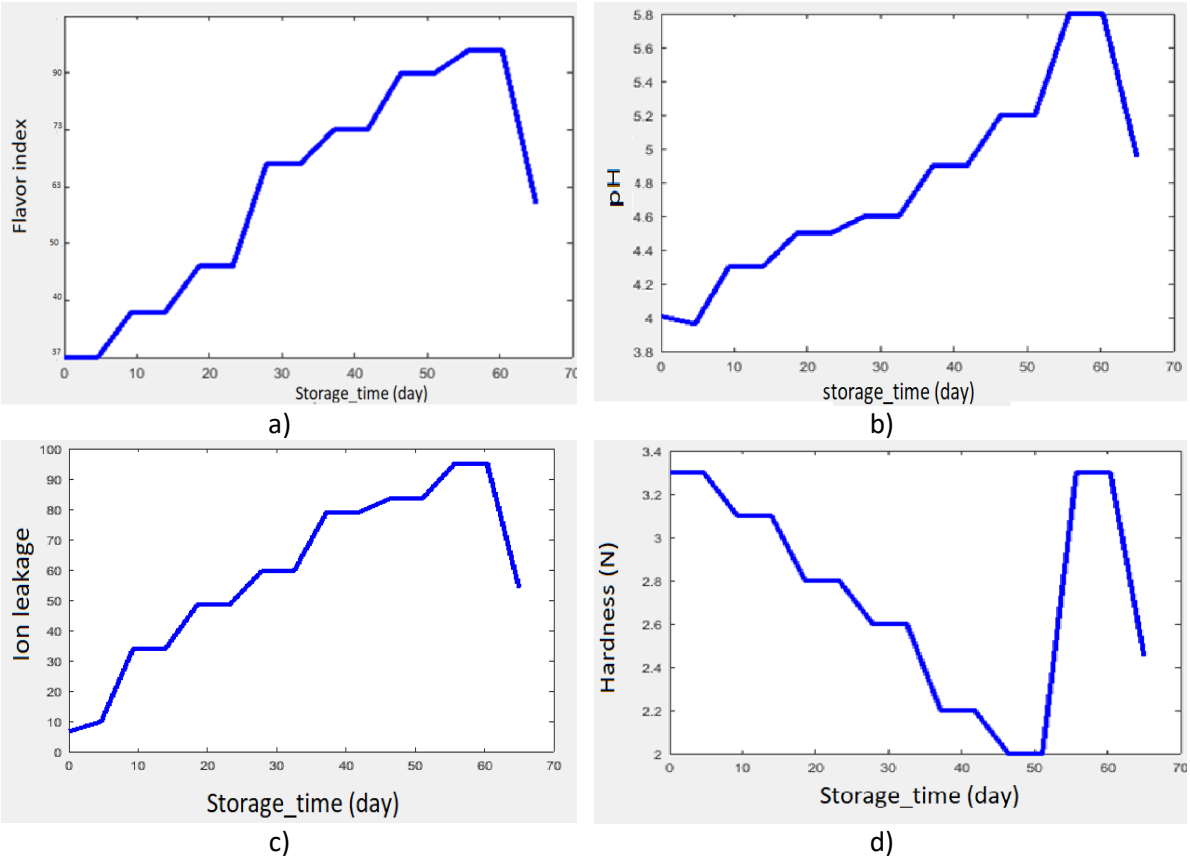
In the examination of the change in the firmness of the grape tissue during the storage period, it can be stated that the firmness of the samples decreased with the increase in the storage time (Figure d3). The phenomenon of softening in fruits during storage begins with the decomposition of the main components of the cell wall and intercellular lamella of the fruit as a result of the activity of enzymes such as polygalacturonase, pectinase and hemicellulose. This phenomenon in grapes is associated with the greatest decrease in hemicellulose and cellulose and to some extent pectin. Decay caused by microorganisms, especially molds, in fruits, including grapes, is directly related to the increase in the phenomenon of fruit softening, which is associated with the production of pectin-degrading enzymes [28, 29].

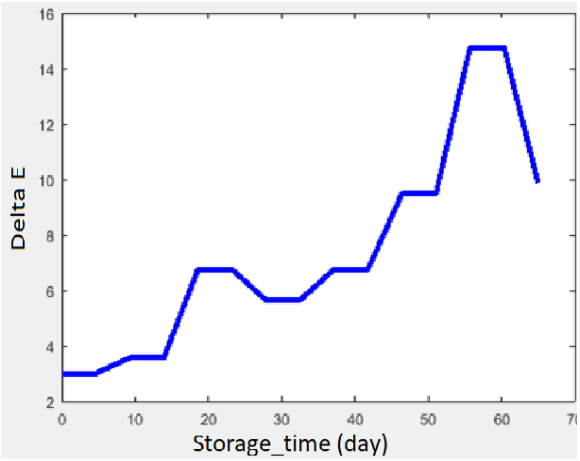
The color of grape skin is considered one of the most important characteristics of grapes to maintain marketability and consumers' desire for this product, the color of grapes usually originates from anthocyanins and flavonoids, which are sensitive to temperature changes and other environmental factors [30]. In the examination of color changes, the increase in refrigeration time caused an increase in color changes (Figure e3). Sadeghipour et al. (2012) also investigated the effect of active edible coatings based on methyl cellulose on the shelf life of tomatoes and stated that color changes increase with time, which was in line with the results of this section [31]. The reason for the increase in color changes over time can be attributed to the revelation of hidden pigments and the softening of the tissue with the gradual decomposition of pectin materials and the reduction of the titratable acidity of the samples.

The results showed that the number of molds in the samples increased with the increase in storage time (Figure f3). Ziaolhagh (2021) investigated the effect of storage time on Shahroud red Fakhri grapes and showed that with the increase of storage time, the number of molds in the

fruits increases, which was in line with the results of this section. These researchers considered the increase in humidity and pH as the causes of the increase in the number of molds in the samples [32]. Eshghi et al. (2022) also investigated the effect of using different polysaccharides on the shelf life of grape fruit and stated that the number of mold and yeast in the samples increased with the increase in storage time due to the increase in simple sugars and decrease in acidity [33].

As the storage time increased, the points obtained for the overall acceptance of the samples decreased (Figure g3). Agha Babaei et al. (2016) by optimizing the formulation of edible coating of methyl cellulose and Shirazi thyme extract on the quality and storage life of grapes, stated that with the increase in storage time, the amount of points given for the overall acceptance of the samples from the eyes of the evaluators decreased due to the shrinkage of these products. Other factors that decrease the sensory scores obtained for general acceptance can be mentioned more moldiness, weight loss, color changes, etc. [34]. Other researchers found the reason for the lower score for overall acceptance with increasing time to be the decrease in tissue stiffness, changes in the color of fruits, and more activity of enzymes [35].





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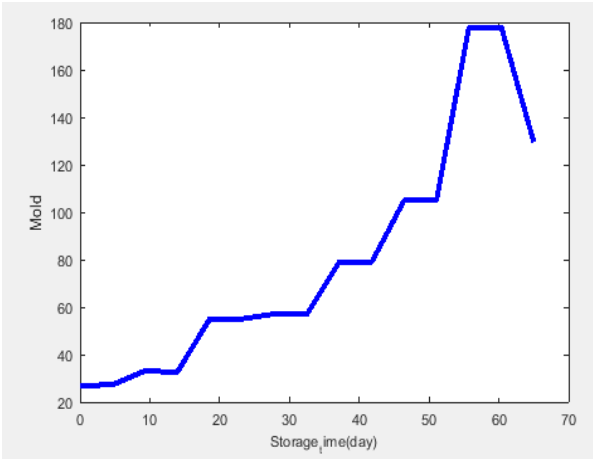

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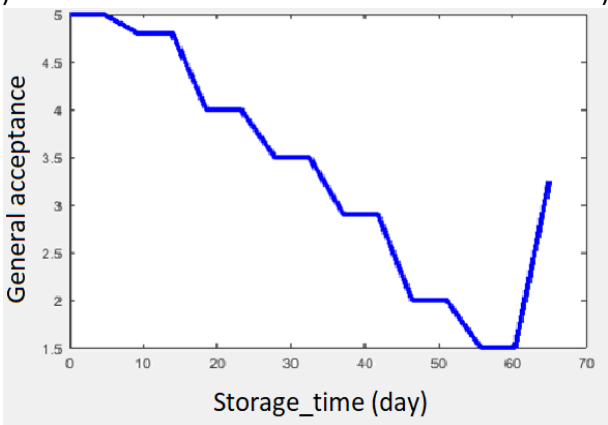


g)

Figure 3- Effect of storage time on a) taste index, b) pH, c) ion leakage, d) hardness, e) ΔE, f) mold number and g) general acceptance

3-2- Evaluation of the accuracy of the fuzzy model

Figure 4 shows the output of the fuzzy system for 25 days of fruit storage. As you can see, each row of the graphs corresponds to a rule and each column corresponds to a variable. The sixth diagram of the second to fifth columns is related to the aggregation of the weighted decisions of the system outputs. In this comprehensive output system, by entering the retention time values, all the output values can be obtained immediately.

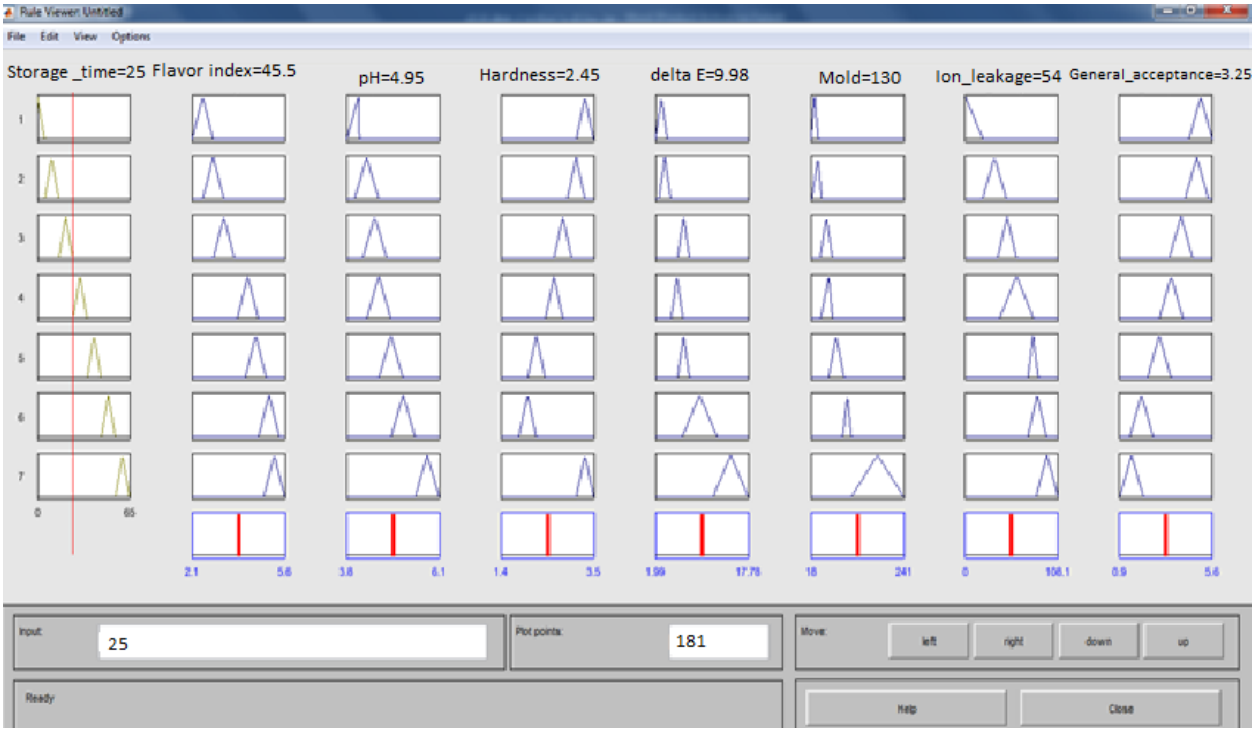
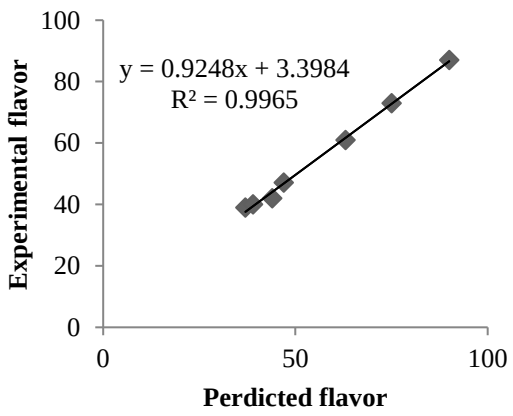
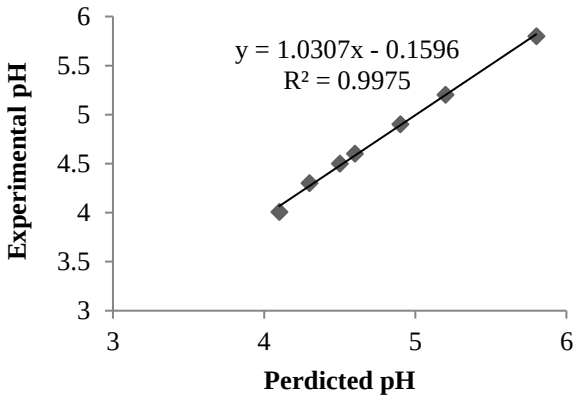


Figure 4- The output of the proposed fuzzy logic system

Also, Figure 5, which shows the high correlation coefficients (more than 0.96) of the values predicted by the fuzzy logic system against the laboratory data for the seven output variables, can be seen as a proof of the high accuracy of this system. On the other hand, it was found that the designed models were the most accurate for predicting the data obtained from general acceptance (with correlation coefficient = 1).



a)



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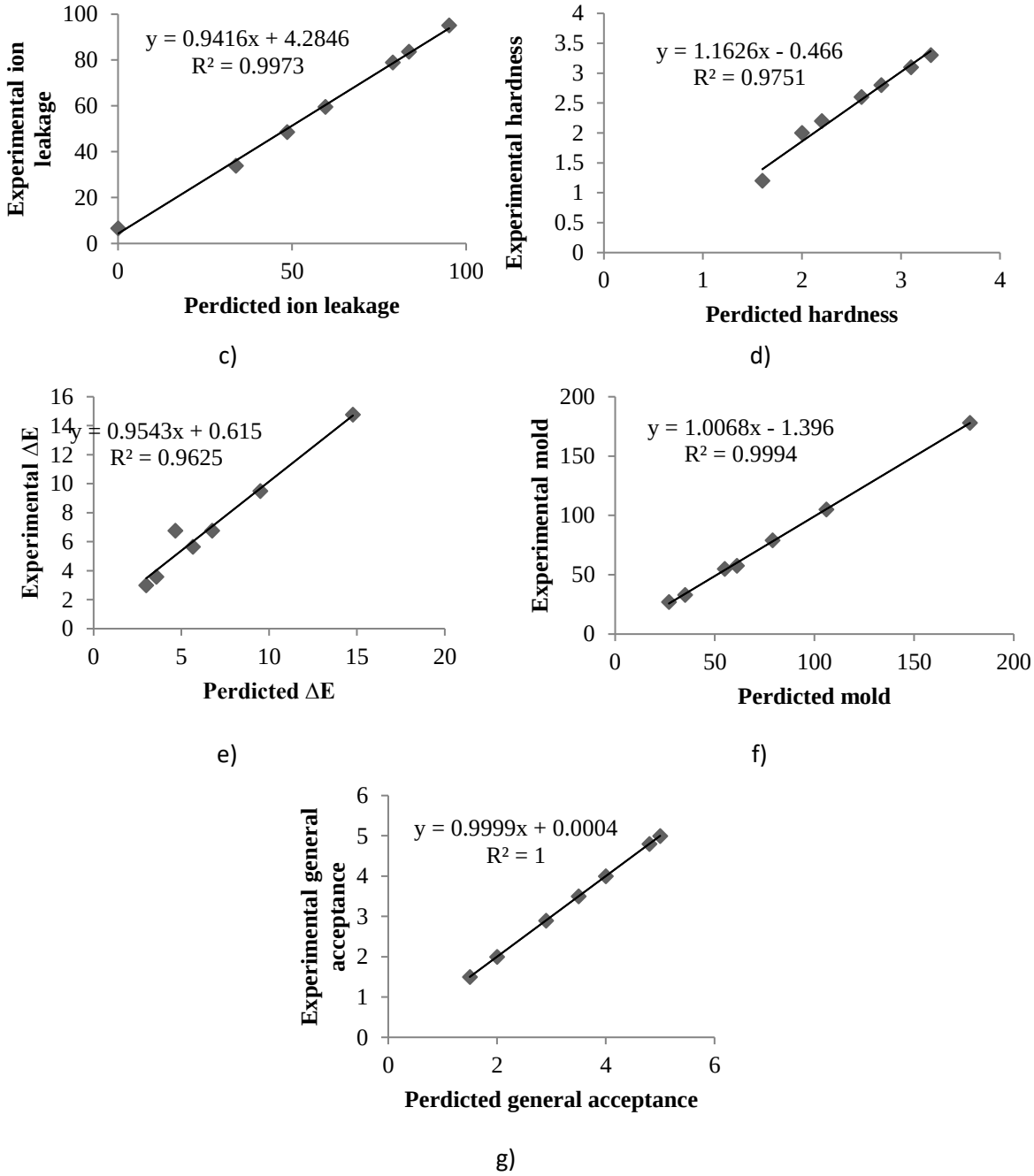

Figure 5- The comparison of laboratory data and amounts predicted by fuzzy logic model for a) taste index, b) pH, c) ion leakage, d) hardness, e) ΔE, f)mold number and g) general acceptance

The main goals in controlling the processes of the food industry can be considered as achieving food safety and health, minimum process, highest quality and minimum costs. To achieve these goals, appropriate equipment, timely detection of errors in the process, and the ability to control the process online are necessary. The inhomogeneity and variability of raw materials and the high rate of increase and decrease in production have limited the appropriate tools for controlling food industry processes. In addition, many processes in the food industry are non-linear and often with diverse time dynamics, which has caused complications in this industry that even in modern computer systems there are problems to automate these processes [11]. Zandi et al. (2021) investigated the application of fuzzy logic and neuro-fuzzy adaptive inference system to predict the

physical and chemical changes and qualitative classification of coated lemon during the storage period, and in this research they used fuzzy logic and with the help of the maximum method. - Mamdani minimum and one of the triangular, Gaussian and trapezoidal membership functions for the quality classification of coated lemon using two algorithms, one with five inputs (tissue hardness, soluble solids, percentage of green color, volume and skin color) and the other with three inputs They used the result of the image (green color percentage, volume and skin color), finally these researchers stated that these models can be used as a non-destructive method in cold storages due to the use of features extracted from the images [13].

4- Conclusion

Considering the importance of the ability to control the storage process of agricultural products and also considering the complexity and unpredictability of the behavior of agricultural products, which has caused this control process with problems, the use of new methods such as fuzzy logic in this field can be very efficient and useful. . In this research, fuzzy logic was used to predict the measured characteristics of grape fruit during storage, and according to the obtained results, this technique can be used to design and create a practical control system to control and manage different stages of harvesting and transportation. , suggested grading, maintenance, storage and processing of this product as well as similar products.

5-References

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ایجاد یک سیستم‌کارشناس برای تعیین ویژگی‌های مورد اندازه‌گیری میوه انگور نگهداری شده در سردخانه با استفاده از منطق فازی

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چکیده

افزایش تولید و مصرف میوه انگور در جهان، نیاز به تحقیقات در زمینه ایجاد شرایطی برای حفظ بیشتر این میوه را افزایش داده است و کمبود سنسورهایی که بتوانند اطلاعات دقیق را از فرایند تولید و نگهداری برای تصمیم‌گیری در اختیار سیستم‌های کنترل قرار دهند، بدیهی و مشهود می‌باشد. لذا این مطالعه با هدف تعیین برخی از ویژگی‌های میوه انگور (شاخص طعم، pH، سفتی، نشت یونی، ΔE، تعداد کپک و پذیرش کلی) نگهداری شده در سردخانه در دامنه زمان نگهداری صفر تا ٦۰ روز اندازه‌گیری شد و با توجه به اهمیت دست‌یابی به این ویژگی‌ها در طول انبارمانی میوه‌ها، مدلی با استفاده از منطق فازی ایجاد گردید که به‌عنوان یک سیستم کارشناس با دقت (با ضریب همبستگی بیشتر از ۰/۹٦) و سرعت بسیار بالا قادر به پیشگویی و تعیین این ویژگی‌های محصول تنها با استفاده از زمان نگهداری آن بود. این سیستم قادر بود، مقادیر هر یک از ویژگی‌های مورد مطالعه را در هر زمان نگهداری دلخواه در محدوده‌ی صفر تا ٦۰ روز با دقت بسیار بالا و در کسری از ثانیه به‌دست آورد. از طرفی مشخص گردید که با افزایش زمان نگهداری میزان شاخص طعم، pH، تعداد کپک‌ها، ΔE و نشت یونی نمونه‌ها افزایش ولی میزان سفتی و پذیرش کلی کاهش یافت.