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Full Research Paper

Classification of *Parus* strawberry fruit by combining image processing techniques and intelligent methods

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Abstract

Nowadays, in modern agriculture, the combination of image processing techniques and intelligent methods has been used to replace humans by smart machine. There is no international or domestic standard classification for *Parus* variety. In this study, an artificial image processing and artificial neural network (ANN) method was used to classify strawberry fruit of *Parus* variety. In the first step, the fruit was divided into 6 classes (ANN outputs) by the expert, and 100 samples were randomly collected from each class. In the next step, the images of the samples were captured and three geometric properties with twelve color properties (as ANN inputs) were extracted. Morphological and color characteristics of the area of the fruit were extracted using the functions defined in Matlab software. Optimum artificial neural network structures (15-18-6) considering root mean squared error (RMSE) and correlation coefficient (R^2) were investigated to classifiy the strawberry samples. Finally, the perceptron neural network with a structure of 6-18-15 was selected with the classification rate of 83.83%. The results obtained by ANN showed that the lowest and highest accuracy was related to small ripe (about 65%) and small raw (about 100%). Based on the accuracy of the results and economic aspects, ANN method is considered a proper method to classify strawberry fruit.

Keywords: Artificial neural network, Image processing, Intelligent methods, Strawberry classification.

Introduction

Strawberry is one of the finest and native fruits with delicious taste which cultivated in moderate region. Due to medicinal and nutritional properties the cultivation of strawberry is increasing (Nezmer *et al.*, 2018). This fruit is a rich source of vitamin C, minerals, and other ingredients which are essential in the body (Samimi and Khodaei, 2011). Typically, usually consumed raw and fresh, but also used in preparation of jellies, jams, ice creams and sweets (Taghavi, 2005). Iran with cultivation land of more than 3900 hectares of strawberries is the twentieth in the world among the countries which produce strawberries. The average yield of strawberries is 14 tons per hectare which has a good growth related to the European countries (FAO, 2017). According to the reports of agricultural organization of Iran, more than 25% of total strawberries production lost during the harvesting until marketing. The amount post-harvest waste of the strawberry fruit is very high due to the use of poor quality processing systems, lack of knowledge and skills in producing and harvesting, inappropriate postharvest mechanisms and activities associated with marketing channels (Salami *et al*., 2010).

Quality is a human concept that incorporates many parameters (Nemzer *et al.*, 2018). The quality of the fruit is defined by various parameters. According to various investigations, data such as color, shape, size and mass they are not sufficient for the consumer to buy a product; they would like to have more information about the fruit that is supposed to be consumed (Voca *et al.*, 2008; Doving and Mago, 2002). For example, in the case of strawberries, the quality is depending on the appearance of the fruit (the intensity and distribution of the color, the shape, size, non-destruction factor), its rigidity and its taste (as measured by the amounts of sugars, organic

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acids, phenolic acids and aromatic compounds). By increasing the content of the acid and increasing the amount of vitamin C, the soluble solids and the sugar of the fruit, the taste will be improved (Mitcham, 1996). Qualitative grading of various agricultural products can be effective in reducing post-harvest damage, maintaining quality and improving their commercial value. Strawberries are no exception to this rule. In recent years, attention has been focused on non-destructive methods for the qualitative grading of agricultural products. One of the common techniques is machine vision technology, which combines image processing techniques and intelligent methods. This technology has advantages over traditional and malicious methods such as no need for expert manpower, more precision, lower cost (Chen et al., 2002), quick response, identifying several indicators simultaneously and non-destructive (Liming and Yanchao, 2010). This technology can help to identify the apparent imperfections of the product during various process (Riquelme *et al.,* 2008), Qualitative Grading (Leemans and Destain, 2004) and the product classification based on shape and size (Abdullah *et al.,* 2006).

Several studies have been carried out on the use of machine vision in grading and classification of agricultural products. In order to cluster the strawberries, a technology of machine vision was used to recognize the number of features including the size (the largest diameter), shape (the edge of the fruit) and color (the a-channel) considering k-means algorithms. The accuracy of the clustering process using this algorithm was about 95%, 90%, 88% for the characteristics of the largest diameter, edge of the fruit and a-channel of color, respectively (Liming and Yanchao, 2010). It was also used to classify the raisin product on four grades: green without tail, black without tail, green with tail and black with tail. The algorithm was based on image processing and intelligent methods. The superior features of the raisin shape and color were selected after segmentation of the images by Otsu method (Otsu, 1979) using the Correlation-based Feature Selection which acts on the basis of the correlation of the selected properties. The classification was also carried out using backup vector machine, decision tree and artificial neural network, which was the most suitable method with accuracy of 96.33% (Mollazade *et al.,* 2012). In another research, almond image processing techniques were classified into three classes as: large, medium and small, based on the image area. After segmentation the images of the specimens, their area was measured. Then the weight of the samples was measured using a balance and it was selected as the basis for class selection with the accuracy of 99.70% (Castelo-Quispe *et al.,* 2013). In a study on the classification of strawberry fruit (not a specified variety) a new method without considering ANN method with accuracy of 0.94-0.97 was performed and the consumed time to define the class of the strawberry was about 0.4-0.55 s for each strawberry (Mar Oo and Zar Aung, 2018). Other methods were also used to grading the strawberry fruit (Feng *et al.,* 2008; Nagata *et al.,* 2000). Moreover other researchers used ANN method for classification of the fruits such as pineapple (Chia *et al.,* 2012), kiwi (Torkashvand *et al.,* 2017) and apple (Singh *et al.,* 2015) based on different parameters.

It was found that the combination of image processing techniques and computational intelligence is a reliable method to classify the agricultural products. Thus, in the present study, the processing techniques and also artificial neural network were used to classify the strawberry of *Parus* variety. Moreover, strawberry classification was carried out using artificial neural network as an input data to the system and several features were identified for this purpose. Also unlike the other studies in producing the images from the samples, the fruit flower bowl was not removed to maintain its quality.

Materials and methods

ANN structure:

An artificial neural network contains three layers including input, output and processing layers. Each layer has a group of nerve cells (neurons) that generally associated with all the neurons of the other layers, except the user limits communication between neurons; but

this is the main point that the neurons in each layer do not correlate with other neurons in the same layer.

For the nervous cell c, we designate the input from the neural cell p to this b_{pc} cell. According to Schmidhuber, 2015 the weight of this input is ω_{pc}, and we designate the sum of the multiplications of inputs with their weights by a_c:

$$a_c = \sum_p \omega_{pc} \times b_{pc} \quad (1)$$

Now, the nonlinear function has to be applied to a_c and the output indicated by b_c.

$$b_c = \theta_c(a_c) \quad (2)$$

Similarly, the output from the nervous cell c enters the n cell named b_{cn} and its weight by ω_{cn}. Now we put all the weights of this neural network into a set called W to learn the weights to the network. Finally, by considering x as input and y as output data, the following equation obtained which must be minimized:

$$Q(W) = \sum_{i=1}^{n} l(h_w(x_i).y_i) \quad (3)$$

For the present study, first strawberry fruit samples were collected from Kurdistan province, Iran. Samples were kept in a lighting enclosure and after cutting fruit, images from the background the characteristics were extracted. Finally, the samples were classified using artificial neural network as shown in algorithm which depicted in Fig. 1.

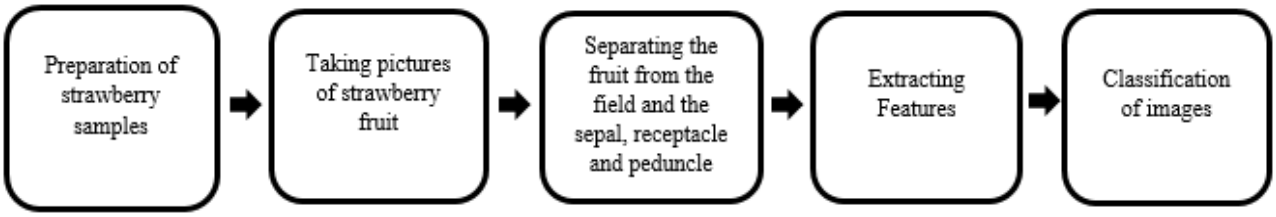

Fig. 1. The main steps of the proposed algorithm to classification

The number of neurons for the hidden layer was determined using the method of trial and error. The hidden layer is important for the ANN modeling process and it is directly affected on the performance of the collector. About 30 times run was performed to define the best structure based on output data and the relative error.

Collection and classification of samples

In Kurdistan province, strawberries are often cultivated in open area and the land under cultivation of *Parus* variety is surpassing other varieties due to the various reasons. Therefore, in the present study, *Parus* strawberry fruit samples were collected from a strawberry farm located in Noshur Sofla, a village of Kamyaran city, Kurdistan province, Iran in Spring 2014. Samples were transferred to the laboratory of agricultural machinery Department, University of Ilam. During the transportation process, no changes in color and texture were observed in the fruit.

Considering the other published papers related to the strawberry classifications, it was found that there was no international or domestic standard for *Parus* variety classification. Therefore, according to the expert's opinion and the characteristics of the size, shape and color, the samples were divided into six classes (Fig. 2). In order to verify the accuracy of the classification, some physical properties (geometric dimensions, mass, volume, apparent and actual density, porosity), mechanical properties (rigidity and bioavailability), and chemical properties (ascorbic acid, acidity, total soluble solids and flavor index) were considered as summarized in Table 1.

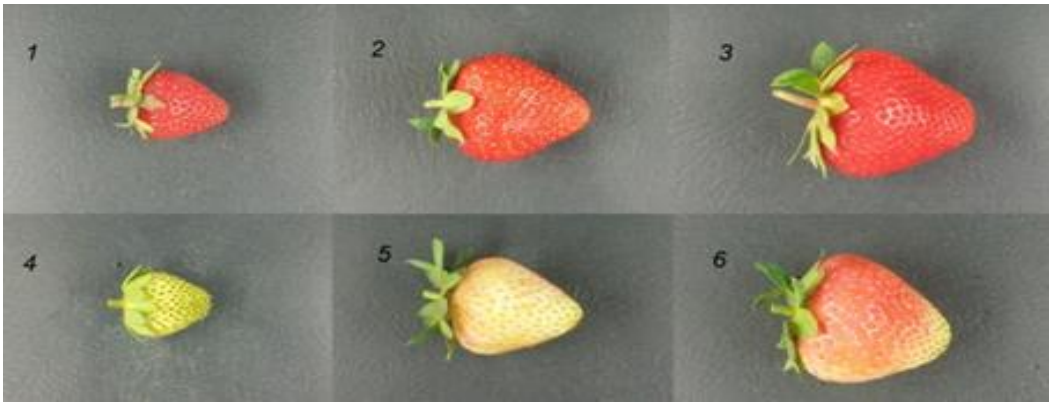

Fig. 2. Different classes of strawberry (Parus variety) used for this research: 1) small ripe, 2) medium ripe, 3) big ripe, 4) small raw, 5) medium raw, 6) big raw.

Table 1. The Strawberry properties

Properties	Class					
	1	2	3	4	5	6
Height (mm)	29.44	36.63	42.48	26.47	33.08	42.07
Mass (gr)	4.925	11.909	21.779	5.471	11.71	21.437
Apparent Density (kg/m^3)	942.367	962.449	970.166	860.592	861.623	881.513
Actual Density (kg/m^3)	561.743	430.873	401.441	498.408	385.318	376.956
Porosity	40.39	55.232	58.621	42.085	55.28	57.238
Rigidity (N/m^2)	10.1	7.8	5.2	28.2	13.7	11.5
Bioavailability (N)	13.7	16.9	29.7	74.5	50.1	35.1
Ascorbic Acid (10^{-5} gr/gr)	39.53	44.06	47.2	7.25	7.2	13.55
Acidity	0.55	0.64	0.67	1.08	1.1	0.99
Total Soluble Solids (%)	8.9	8.6	8.4	4	4.2	5.5
Flavor Index	16.3	13.5	12.6	3.6	3.8	5.5

Images preparation

About 100 images of each class were selected randomly for production of images. To remove environmental noise, an image processing box of 30*30*30 cm^3 was used. Tubular LED bulbs were also used inside the box to provide the best lightning quality and low disturbed noise on images. To eliminate the effect of the noises and the shadows, the black color was selected. To capture images, Samsung Galaxy S II with 8 megapixels (3248×2448 pixels) resolution camera was used which placed at a distance of 30 centimeters above the samples. For lightening D65 as standard value was considered for the process. The box made for the image processing and the lightning illustrated in Fig. 3.

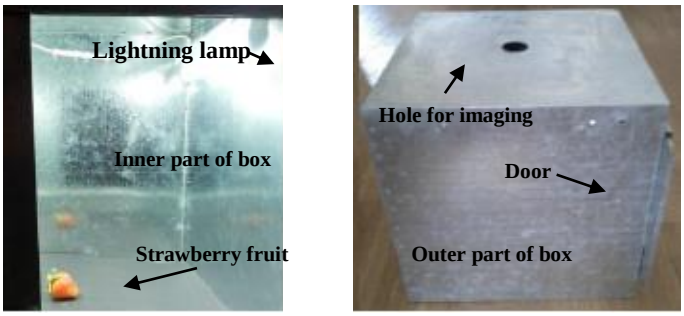

Fig. 3. The image processing box

Images segmentation

Image segmentation is one of the most important parts of image processing method. It is divided into pieces or constructive objects and there are several ways to segment the image. In this research, thresholding method was used using R, G, B color components in RGB color space to separate strawberry fruit from the background and flower bowl. After separating the strawberry fruit from the background and the flower bowl, a morphological operation of the dilatation and wear with a circular structure (using open and closed operators) was used to repair the edges of the strawberry fruit. Fig. 4 shows the various steps undertaken in the image processing (Gonzalez and Wood, 2018).

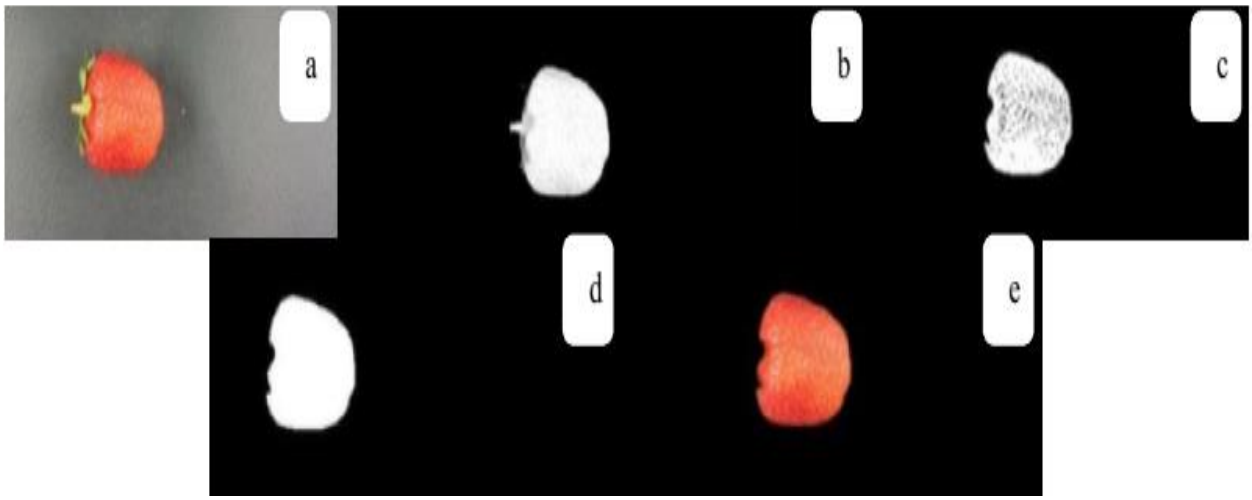

Fig. 4. Image segmentation: a) Sample image in RGB color space, b) Deletion of background, c) Deletion of sepal, receptacle and peduncle, d) Filling the holes and repairing the image border, e) Isolated fruit after segmentation.

To separate the fruit and bowl from the black background, three red, green and blue components were first extracted. A gray image was defined using the difference between the red and blue color components. In this image, the border between the fruit and the bowl with the background was visible. The threshold function with defined value in this boundary was applied to the image and the binary image was obtained with values of 1 for fruit and flower bowl and zero for background. By applying the opening and closing functions and their combination, bumps, troughs and pits were modified. After that by combination of three red, green and blue components of the original image, the color image of the fruit and bowl separated from the background (considering the binary image had zero value) was obtained. To separate the bowl from the fruit the similar steps were taken, except that the linear combination of all three color components was used to obtain the gray image. Morphological and color characteristics of the area were extracted using the functions defined in Matlab (R2012a).

Extraction of fruit features

Many features have been developed on image processing issues. The purpose of extracting image attributes is to describe the image based on some statistical descriptors. The features are categorized into three categories: morphological or geometric characteristics, colors and texture. Each of these features could be used for various applications, including morphological characteristics (diameter, environment, area, shape and volume) used in grading crops, color characteristics used to determine the level of handling, breakdowns and spoilage. The appearance of agricultural products and tissue features are used to determine the level of shrinkage of agricultural products and the recognition of plant diseases. In this study,

fifteen characters, including three morphological characteristics and twelve color characteristics, were used to classify the strawberry fruit of *Parus* (Table 2).

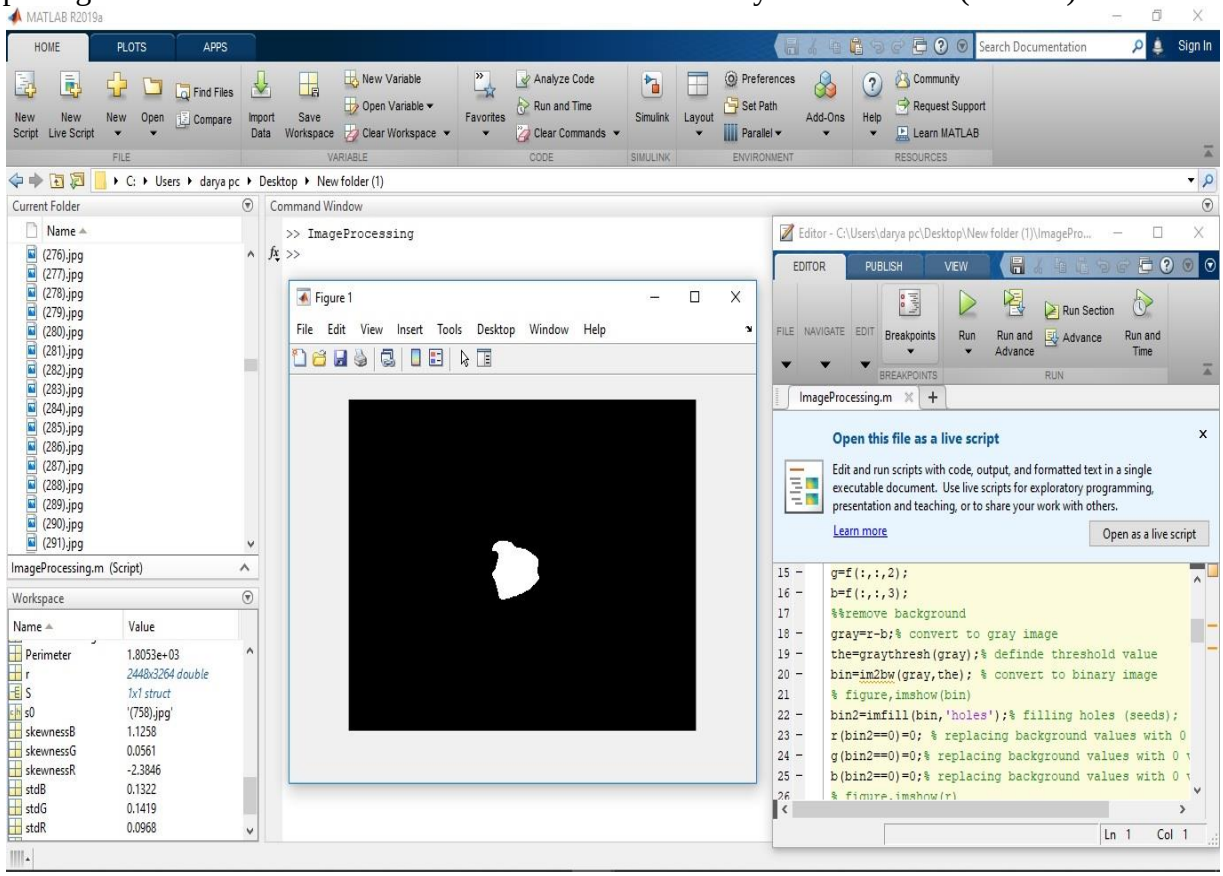

Fig. 5. A plot of Matlab environment applied for image processing of strawberry fruit

Table 2. The Features extracted from the images

Name	Color feature	Name	Apparent feature
F1	MeanR	F13	Area
F2	MeanG	F14	Perimeter
F3	MeanB	F15	AspectRatio
F4	StdR		
F5	StdG		
F6	StdB		
F7	SkewnessR		
F8	SkewnessG		
F9	SkewnessB		
F10	KurtosisR		
F11	KurtosisG		
F12	KurtosisB		

To calculate the morphological characteristics, the images were first converted to the binary images, and then three properties of the area, the environment and the ratio of the main diameter to the mean diameter of the samples were extracted. Due to the distinction between different classes in terms of shape and size, the morphological features were used for

classification process. By examining different color spaces, the RGB color space was chosen because of the difference in color components at different classes. Four statistical descriptors related to the color including: mean, standard, skewness and kurtosis were extracted from strawberry samples. MATLAB software (R2012a) was used to plot the images and extract morphological features of color (Fig. 5).

R, G and B represented red, green, and blue components of the fruit image separated from the background and the bowl, respectively. Other parameters are presented by Eqs. 4-7 as follow

$$\text{Mean} = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad (4)$$

$$\text{Std} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \mu)} \qquad (5)$$

$$\text{Skewness} = \frac{\frac{1}{n}\sum_{i=1}^{n}(x_i-\mu)^3}{\sigma^3} \qquad (6)$$

$$\text{Kurtosis} = \frac{\frac{1}{n}\sum_{i=1}^{n}(x_i-\mu)^4}{\sigma^4} \qquad (7)$$

ANN setting

In order to classify strawberry fruit, the artificial neural networks (ANNs), one of the methods of data mining, was used (Omid *et al*., 2009). Each ANN structure consists of at least three layers of the neuron: 1. Input layer, 2. hidden layer, 3. Output layer. The number of neurons in the input, hidden, and output layers were identified as the number of inputs vector variables, the difficulty and complexity of the classification and the number of output classes, respectively. As shown in Fig. 6, the number of neurons in the input layer is equal to the number of properties extracted from the sample images (15 characteristics), and the number of output layer neurons is also considered equal to the number of grades. The model with the structure of 15-18-6 was concluded as the suitable.

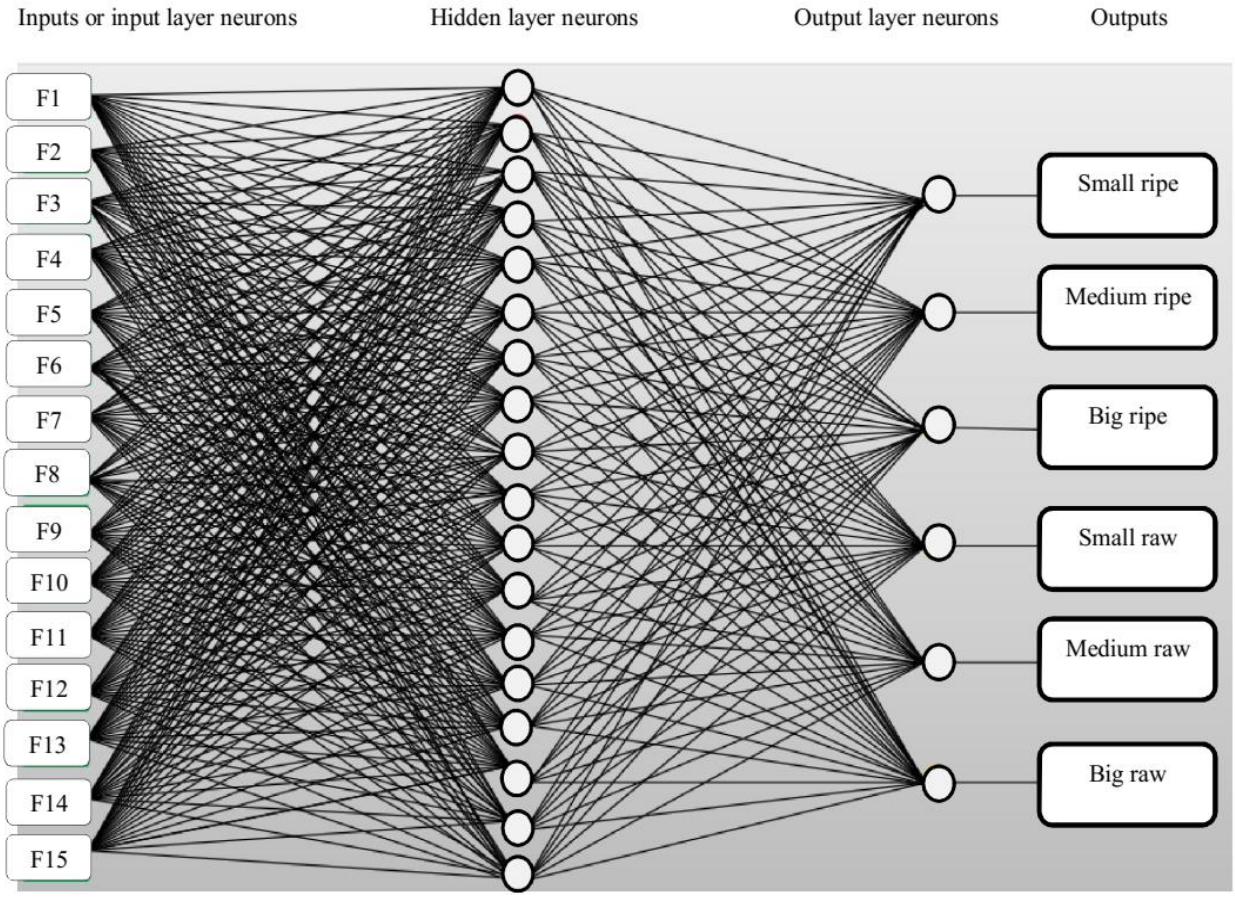

Fig. 6. ANN structure used for classification

It should be noted that there is always a tendency toward the lowest number of layers and neurons in the system. This reduces the size of the network and increases the speed of training which is very important in online studies. Other important factors in ANN design are activity function, training algorithm and number of training rounds. In this study, artificial neural network with multiplayer perceptron structure was used. This structure is appropriate for online structural applications, because there is no need for a timed order for input data and the input neuron activity function is linear. Also, in order to increase the learning speed and solve the complexity of the problem, the linear sigmoid activity function was used in the hidden layer neurons and the output layer. Training was also used bundled with momentum learning algorithm with momentum of 0.7 and learning factor of 0.6. This algorithm is one of the fastest learning algorithms which varies by varying the amount of momentum, changing the learning speed to match the inconsistency or incompatibility of input data, which results in the deletion of data from the learning process. Also in this algorithm, the stop index is the increase in the mean square error (MSE). Six hundred paired vectors were assigned to the network, of which 50% were used for training, 20% for assessment, and 30% for testing. ANN modeling was done in NEUROSOLUTION 5 software.

Evaluation of the results

In order to evaluate the ANN performance in classification of *Parus* strawberry fruit and to select the best structure of statistical indexes, classification rate (CCR (%)), correlation coefficient (r) and root mean square error (RMSE) were used in different training periods (Eqs. 8 and 9):

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x_A - x_p\right)^2} \quad (8)$$

$$r = 1 - \frac{\sum_{i=1}^{n}\left(x_A - x_p\right)^2}{\sum_{i=1}^{n} x_p^2} \quad (9)$$

Results and discussion

Selecting the best ANN structure

After implementing different ANN structures, the best structure was selected based on correlation coefficient (Fig. 7) and root mean square error (Fig. 8). The hidden layer which makes the model predict the class of the samples directly affected on the accuracy of the classification process. Fig. 7 shows that the pattern of the curve plots generated by ANN and the actual data are the same. The values of the correlation coefficient and root mean square error for the number of hidden neurons (2 to 20) and the number of different training periods (100, 300, 500, 750 and 1000 rounds) were investigated. It is clear from Figs. 7 and 8 that with increasing the number of hidden neurons and increasing the number of periods, the correlation coefficient increases as well. But the root mean squared error decreases, among which the single-layer perceptron structure with eighteen neurons in the hidden layer (with function linear sigmoid activity and momentum training algorithm with values of learning coefficient of 0.6 and momentum of 0.7) are less correlated to other structures with a higher correlation coefficient (0.83) and root mean square error (0.20).

ANN strawberry classification

After selecting the best structure of ANN, it was used for classification of strawberry fruit of *Parus* variety in six categories including: small ripe (first class), middle ripe (second class), big ripe (third class), small raw (fourth class), medium raw (fifth class) and big raw (sixth class). Also, in order to verify the network performance, the confusion matrix of the network (Table 3) was calculated and the classification rate (Table 4) was extracted.

The confusion matrix is a square matrix that the number of rows and columns is equal to the number of classes. The elements of the i-th column represent the i-class of the samples which classified by artificial neural network into different classes in the rows. Moreover, the classification rate shows the accuracy of the ANN in classifying the samples in each class.

For example, the i-class classification rate is obtained by dividing the a_{ii} element by the sum of i-class elements. In fact the optimal confusion matrix is the one which the elements in the main diagonal are 100% and the others are 0%. The elements in Table 3 show that the matrix is closer to diagonal matrix.

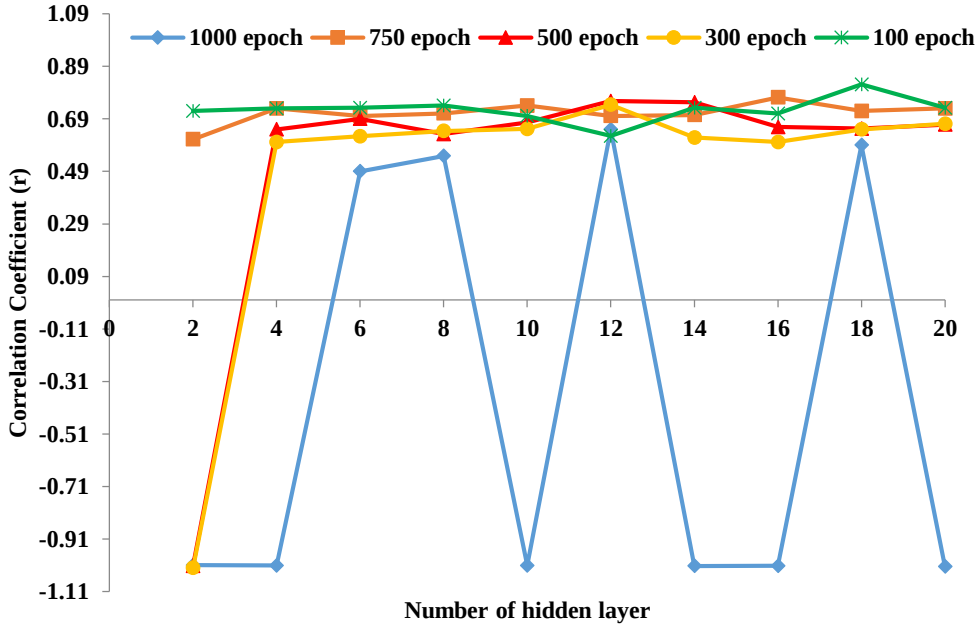

Fig. 7. Variations of Correlation coefficient with the number of hidden layer neurons and number of training courses

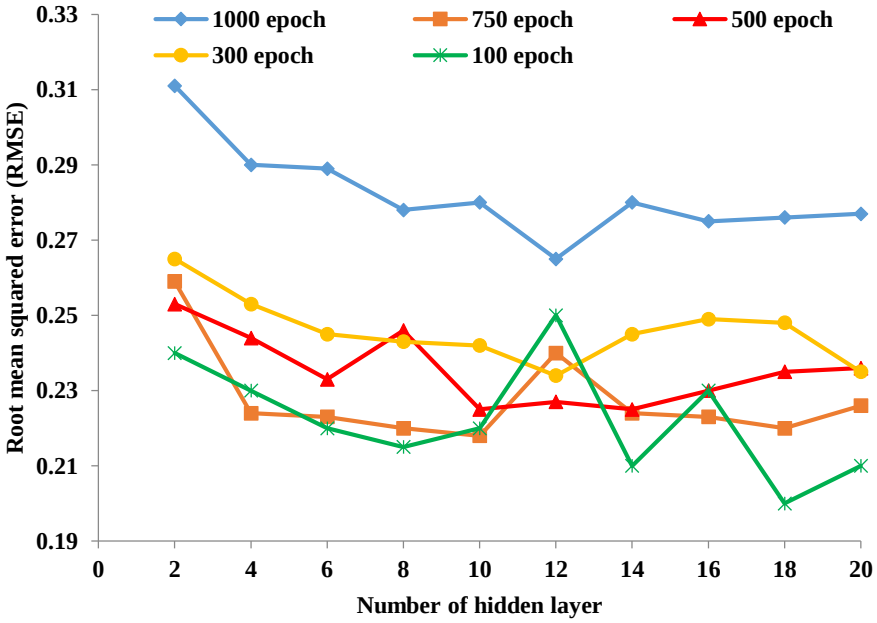

Fig. 8. Variations of RMSE withthe number of hidden layer neurons and number of training courses

Table 3. The confusion matrixof the network based on the number of output classes of ANN to validate the classification process ranged between 0-100%

ANN prediction	Real					
	Small ripe	Medium ripe	Big ripe	Small raw	Medium raw	Big raw
Small ripe	65	4	0	0	0	0
Medium ripe	35	90	12	0	0	2
Big ripe	0	4	81	0	0	13
Small raw	0	0	0	100	8	0
Medium raw	0	0	0	0	84	2
Big raw	0	2	7	0	8	83

Table 4. The classification rate for strawberry fruit

Statistical index	Real					
	Small ripe	Medium ripe	Big ripe	Small raw	Medium raw	Big raw
CCR (%)	65	90	81	100	84	83

The values of classification rate of strawberry fruit (*Parus* variety) are listed in Table 4. Based on the turbulence confusion matrix, the lowest accuracy of the strawberry classification was related to the small class (first class) which was about 65% due to the similarity of this class with the middle class. It can be implied that about 35% of the samples (in the first class) were mistakenly classified in the second class. As shown in Fig. 1, only the morphological features of these two classes can be distinguished, while color-based features do not make any distinction between the mentioned classes. In this study, during preparing the samples, the top section of the strawberries was not separated from the fruit because it has significant impact on maintaining the fruit quality. In the other hand by removing the top section of the fruit the spoilage rate increases. Therefore in image processing operations, to remove the top section even by applying image restoration techniques some parts were lost or eliminated from the texture of the fruit. This leads an error in the calculation of morphological properties which affected on the classification process. Also, a significant number of the first class specimens were located at the boundary between the first and second class, morphologically. The highest precision was related to the small raw class (fourth grade) with the accuracy of 100%. This was due to the entire class distinction with the other classes based on morphological and color characteristics. The accuracy of the classification in the other columns revealed that the classification accuracy was between 80% and 90%. Other researcher's studies on the classification process of fruit reported the same results (Hameed *et al.*, 2018). The factor that may reduce classification accuracy in this study is the lack of standard classification and presence the large number of samples on the boundary between the two classes defined by the expert. Also the large number of classes can be another factor for reducing the accuracy of the network. In this research, the classification rate was about 83.83 %, which shows that the qualitative grading of strawberry of *Parus variety* based on morphological and color characteristics using ANN methods can be very applicable especially in the design of grading and sorting machines. The results obtained by the present study are in agreements with the results obtained for the classification of the strawberry (Nagata *et al.*, 2000; Feng *et al.*, 2008; Liming & Yanchao, 2010; Mar Oo and Zar Aung, 2018).

Comparison between the data obtained experimentally and by the software showed that the time taken to classify the one hundred of strawberries by an expert is about 117 s while for the software it was about 2.5 s. In addition, if the erosion and fatigue factors of the expert are considered, then the classification time is increased. For a farmer maximizing the harvest or post harvest process with low price is considered as the main goal especially for the strawberry which the different conditions such as weather, atmospheric conditions and workers skill directly affecting the yield. Thus based on obtained results of ANN method applied to classification of *Parus* variety, and economic considerations it can be implied that ANN method is a suitable method used for grading strawberry fruit.

Conclusion

One of the main stages of harvesting and post harvesting processes is classification of food materials produced in agricultural sector. *Parus* variety is the popular strawberry planted in the west of Iran, especially Kurdistan province. Artificial neural network as a fast and accurate method mostly used for prediction the phenomenon such as classification. In this study, strawberry of *Parus* variety classified in six classes using image processing techniques and artificial neural network based on expert's opinion. The extracted features were included twelve color properties and three morphological characteristics. The best artificial neural network, was neural network with two-layer perceptron with eighteen neurons in the hidden layer, sigmoid activity function, momentum education algorithm (with momentum values of 0.7 and learning factor of 0.6). The accuracy was about 83.83 %. The results also showed that, using various neural networks and morphological and color characteristics could be more efficient in maintaining the quality of strawberries.

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References

Abdullah, M. Z., Mohamad-Saleh, J. Fathinul-Syahir, A. S., & Mohd-Azemi, B. M. N. (2006). Discrimination and classification of fresh-cut starfruits (*Averrhoa carambola* L.) using automated machine vision system. *Journal of Food Engineering*, 76(4), 506–523.

Castelo-Quispe, S., Banda-Tapia, J. D. Lopez-Paredes, M. N. Barrios-Aranibar, D., & Patino-Escarcina, R. (2013). Optimization of Brazil-Nuts Classification Process through Automation using Colour Spaces in Computer Vision. *International Journal of Computer Information Systems and Industrial Management Applications*. 5, 623-630.

Chen, Y. R., Chao, K., & Kim, M. S. (2002). Machine Vision Technology for Agricultural Applications. *Computers and Electronics in Agriculture*, 36 (2), 173-191.

Chia, K.S., Abdul Rahim, H., Abdul Rahim, R. (2012). Prediction of soluble solids content of pineapple via non-invasive low cost visible and shortwave near infrared spectroscopy and artificial neural network. *Biosystems Engineering*, 113, 158–165.

Doving, A. andF. Mago. (2002). Methods of testing strawberry fruit firmness. Journal of Acta *Agriculture Scandinavica*, 52: 43-51.

FAO. (2017). FAOSTAT Agricultural Statistics Database. Retrieved from http://www.fao.org.

Feng, G., Qixin, C., & Masateru, N. (2008). Fruit detachment and classification method for strawberry harvesting robot. *International Journal of Advanced Robotic Systems*, 5(1), 4.

Gonzalez, R. C., & Wood, R. E. (2018). Digital Image Processing. Pearson publications. New York, United States America.

Leemans, V., & Destain, M. F. (2004). A real-time grading method of apples based on features extracted from defects. *Journal of Food Engineering*, 61, 83-89.

Liming, X., & Yanchao, Z. (2010). Automated strawberry grading system based on image processing. Computers and Electronics in Agriculture. 71, 32-39.

Mar Oo, L,. & Zar Aung, N. (2018). A simple and efficient method for automatic strawberry shape and size estimation and classification. *Biosystems Engineering*.170, 96-107.

Mitcham, B. (1996). Quality assurance for Strawberries: A Case Study. Perishables Handling Newsletter Issue No. 85. Pages 6-9.

Mollazade, K., Omid, M., & Arefi, A. (2012). Comparing data mining classifiers for grading raisins based on visual features. *Computers and Electronics in Agriculture*, 84, 124-131.

Nagata, M., Bato, P. M., Mitarai, M., Qixin, C., & Kitahara, T. (2000). Study on sorting system for strawberry using machine vision (Part 1). *Journal of the Japanese Society of Agricultural Machinery*, 62(1), 100-110.

Nemzer, B., L. Vargas, X. Xia, and H. Feng. (2018). Phytochemical and physical properties of blueberries, tart cherries, strawberries, and cranberries as affected by different drying methods. *Food Chemistry*, 262: 242-250.

Otsu, N. (1979). A threshold selection method from gray-level histograms. IEEE Transactions on Systems, Man, and Cybernetics, 9, 62-66.

Riquelme, M. T., Barreiro, P. Ruiz-Altisent, M., & Valero, C. (2008). Olive classification according to external damage using image analysi. *Journal of Food Engineering*, 87, 371-379.

Salami, P., Ahmadi, H., Keyhani, A., & Sarsaifee, M. (2010). Strawberry post-harvest energy losses in Iran. *Researcher*, 2, 67-73.

Samimi Akhijahani, H. and J. Khodaei. (2011). Some physical properties of strawberry (Kurdistan varity). *World Applied Sciences Journal*, 13 (2): 256-212.

Schmidhuber, J. (2015). Deep learning in neural networks: An overview. *Neural networks*, 61, 85-117.

Singh S.P., Bansal, S., Ahuja, M., Parnami, S. (2015). Classification of apples using neural networks. International Journal of Science, Technology and Management, 4 (1); 1599-1605.

Taghavi, T. (2005). Strawberry production guide: sana publications, Tehran, Iran. (In persian)

Torkashvand, A.M., Ahmadi, A., Layegh Nikravesh, N. (2017). Prediction of kiwifruit frmness using fruit mineral nutrient concentration by artificial neural network (ANN) and multiple linear regressions (MLR). *Journal of Integrative Agriculture*, 16(7): 1634–1644

Voca, S., Dobricevic, N., Dragovic-Uzelac, V., DuralijaDruzic, j., Cmelik, Z., & Babjelic, M.S. (2008). Fruit quality of new early ripening strawberry cultivars in Crotia. *Journal of Food Technology and Biotechnology*. 46, 292-298.

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طبقه بندی توت‌فرنگی رقم پاروس با ترکیب تکنیک پردازش تصویر و روش‌های هوشمند

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چکیده

امروزه در کشاورزی مدرن ترکیبی از تکنیک‌های پردازش تصویر و روش‌های هوشمند برای جایگزینی ماشین‌های هوشمند به‌جای انسان استفاده می‌شود. هیچ استندارد بومی و بین‌المللی برای طبقه‌بندی توت‌فرنگی رقم پاروس وجود ندارد. در این مطالعه از روش پردازش تصویر مصنوعی و شبکه عصبی مصنوعی (ANN) برای طبقه‌بندی میوه توت‌فرنگی رقم پاروس استفاده شده است. در گام اول این میوه توسط یک متخصص به شش کلاس طبقه‌بندی شد (به‌عنوان خروجی ANN) و از هر کلاس ۱۰۰ نمونه به‌طور تصادفی جمع‌آوری گردید. در گام بعد تصاویر نمونه‌ها ضبط شده و سه خصوصیت هندسی با ۱۲ ویژگی رنگ (به‌عنوان ورودی‌های ANN) استخراج گردید. خصوصیات مورفولوژیکی و رنگ سطح میوه با استفاده از توابع تعریف شده در نرم‌افزار Matlab استخراج شد. ساختار شبکه عصبی بهینه (۱۵-۱۸-۶) با توجه به خطای میانگین مربعات (RMSE) و ضریب هبستگی (R^2) برای فرآیند طبقه‌بندی نمونه‌های توت‌فرنگی در نظر گرفته شد. در نهایت شبکه عصبی پرسپترون با ساختار ۱۵-۱۸-۶ با دقت طبقه‌بندی ۸۳/۸۳٪ انتخاب گردید. نتایج به‌دست آمده از ANN نشان داد که کمترین و بیشترین دقت به‌ترتیب به کلاس‌های کمتر رسیده (تقریبا ۶۵٪) و کمتر نارس (تقریبا ۱۰۰٪) مربوط است. با توجه به نتایج و ملاحظات اقتصادی، ANN روش مناسبی برای طبقه‌بندی میوه توت‌فرنگی می‌باشد.

واژه‌های کلیدی: شبکه عصبی مصنوعی، پردازش تصویر، روش‌های هوشمند، طبقه‌بندی توت‌فرنگی.

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Full Research Paper

Effects of some salts on the shelf life of Shahrood Sorkh-e-Fakhri table grapes stored in cold storage

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Abstract

In this study, some preservative solutions were used as an alternative to sulphur fumigation. For this purpose, sodium metabisulfite, calcium chloride, sodium acetate, and sodium carbonate solutions at concentrations of 0.5, 1 and 2 percent were applied. Grapes (Sorkh-e-Fakhri var.) were dipped in different concentrations of each solution for 2 minutes. After dipping, the surface water of grapes was dried by natural air blowing and then, put in conventional baskets and stored at 0.5-1°C at 85-95% RH for 6 months. The percentage of moldiness, soluble solids, reducing sugar, acidity, and pH of the samples were determined after 2, 4, and 6 months of storage. The results of this study showed that the effect of type of preservative used and the storage time, on the percentage of moldiness and pH and acidity of all samples were significant at 1% level. Sodium metabisulfite had the highest inhibitory effect on mold growth. Calcium chloride had the greatest effect on moisture retention. In addition, the highest pH was observed in samples immersed in sodium carbonate solution. In the case of interactions, the effect of type of preservative and storage time on moldiness, moisture content, brix, sugar content, and acidity, and also the type of preservative and its concentration on moldiness and acidity of samples were significant. According to the obtained results, it was shown that the grapes could be stored for 6 months by dipping them in 0.5% sodium metabisulfite for 2 minutes before cold storage.

Keywords: Cold Storage, Preservatives, Shelf Life, SO_2 Replacement, Table Grapes

Introduction

Molding in fruits is due to the growth of microorganisms on their surface as well as physiological damage. Some of these damages can be fully controlled and delayed by proper storage conditions. Among the different methods of storage, the use of cold stores makes the least changes compared to other methods (Jay, 2005; Fatemi, 2007). Various variables, including non-compliance with technical and hygienic issues, can cause adverse changes in the quality and health of stored foods. In Iran, large quantities of fresh grapes are stored in cold stores in late summer and marketed in late fall and winter (Ghodsvali, 2000). Lack of accurate information about the storage conditions of fresh grapes in cold stores can reduce the quality of the product during storage. Fumigation with Sulfur dioxide is often used to disinfect grapes. It inhibits the growth of decay fungi such as *Botrytis*, *Cladosporium* and *Alternaria* (Zomorodi, 2005). For this purpose, the grapes are disinfected in the cold store with sulfur gas several times. Sulfur dioxide gas combines with high moisture content in the cold store and produces sulfuric acid, which is a very strong acid and causes the evaporator tubes to corrode in the cold store. Also, due to high sulfur dioxide gas consumption in most grape cold stores, residual sulfur dioxide levels exceed the permitted level, causing respiratory problems and sensitization in consumers, while also having a nasty odor (Sharayei *et al*., 2004).

Shahrood Fakhri Red Grape has 20% soluble solids, pH of 3.9 and acidity of 0.8 (Sherafatian, 1999). Storage conditions of this grape cultivar in Shahroud are at temperatures usually 0.5 to 1 °C and their relative humidity is 90-94%. Disinfection of the cold store rooms also begins with sulfur before the grape arrives and continues until the end of May of the following year. So that once a week from late September to early January of the same year and from early January to the end of March every two weeks

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and from April to late May every 20 days disinfection is carried out by burning solid sulfur in cold rooms. The amount of sulfur used in the cold rooms is 8.5 kg of solid sulfur for about 400 tons of grapes (Ghodsvali, 2000). Different methods can be used to reduce the adverse effects of sulfur dioxide. These include the use of preservatives, the use of edible coatings, as well as the proper packaging and use of systems that gradually release sulfur gas (Sharayei *et al*., 2004). Chemicals investigated so far include sodium bicarbonate, sodium carbonate, potassium carbonate, calcium chloride, sodium formate, sodium phosphate, ammonium chloride, sodium acetate, potassium chloride, ammonium sulfate, sodium sulfate, ammonium bicarbonate, sodium silicate, sodium metabisulfite and potassium metabisulfite and so on (Nigro *et al*, 2006). Edible coatings include chitosan (Meng et al, 2008), sodium alginate (Miguel *el al*, 2009) and methyl cellulose (Yeol *et al*, 2002). Various salts have been used to control pre-harvest or post-harvest molds in the cold storage. It has been shown that boron in the form of potassium tetraborate prevents growing of the spores and spreading of the *botrytis cinerea* mycelium in grapes kept in the cold store (Qin *et al*, 2010). Youssef and Roberto (2014) used salts such as potassium sulfate, potassium sorbate, potassium bicarbonate, calcium sulfate, and calcium chloride before and after harvesting to control gray mold in grapes and showed that potassium bicarbonate and sorbate potassium were the most effective in controlling gray mold growth. Carvalho et al. (2008) investigated the effect of calcium chloride concentration and storage time on the amount of reducing sugars in grapes. They showed that the 2% concentration of calcium chloride was able to maintain the quality of grapes in the cold store. Doulatibaneh and Zomorodi (2004) studied the effects of calcium chloride spraying on the quality and storage traits (including maintaining firmness, reducing waste and loss of water and shedding berries during storage) of two grape varieties of Rish Baba and Ghezel Uzum. Results showed that spraying 20 days before harvest increased calcium content of the berries. During storage, the amount of brix, pH and percentage of weight loss increased but the acidity decreased. Fungal contamination was the lowest in 1 and 1.5% of calcium chloride. Nigro et al. (2006) examined the effect of 19 different salts on grape mold growth and showed that calcium chloride, potassium carbonate, sodium bicarbonate and sodium carbonate had the most effect.

The use of grapegard sheets containing 10% sodium metabisulfite solution improved the quantitative and qualitative characteristics of grapes (Zomorodi *et al.,* 2005). Ethanol has also been used to prevent mold growth on grapes and it has been shown that the effect of ethanol on mold prevention is even better than that of sulfur (Lurie *et al.*, 2006). Guzev et al. (2008) investigated the effects of sulfur dioxide and ethanol on Aspergillus fungi in grape storage. They showed that the fungus survived in the grapes stored at 20°C for 7 days, but storing at 0°C for one month using SO_2 gas packs reduced the number of fungi completely. Immersion of grape clusters in ethanol solution before cold storage had no effect on *Aspergillus niger* reduction. Spraying 16% ethanol solution containing 1% calcium chloride before harvesting on fresh grapes reduced the development of gray mold. This can reduce the damage caused by decaying clusters from 15% in the control samples to 5% in the samples treated by the above method. In this way, after 6 weeks of storage in the cold store, mold-induced lesions of gray mold were also reduced by 50% compared to untreated control samples (Chervin *et al.*, 2009). Adding 0.5% and 1% potassium sorbate to 10% and 20% ethanol reduced grape mold growth by 10% or less. After 30 days of storage at 1°C, the combination of 20% ethanol with 0.5 or 1% potassium sorbate had the same effect as the effect of SO_2 releasing sheets on reducing mold in grapes (Karabulut *et al*., 2005). By immersing the grape in 30% ethanol solution for 10 seconds at 24 °C, germination of the spores of *Botrytis cinerea* was completely prevented. Soaking the moldy grapes for 3 minutes in 10% ethanol solution at 30, 40, or 50°C reduced the moldiness to 20.7, 6.7 and 1.7

berries/kg after 30 days of storage at 1°C. The treatments used had no significant effect on the appearance of the berries, their cracking, meat browning, taste, weight loss and color of the berries (Karabulut *et al*., 2004).

Gabler et al. (2010) used a combination of chemical and biological fumigation to control post-harvest gray mold decay of grapes. After fumigating the grapes with ozone or SO_2 during the pre-cooling phase, they continuously treated the fruits during storage with the *Muscador albus* fungi, which produces volatiles. The natural appearance of gray mold in grapes kept at 0.5°C for 1 month was 31%, while ozone fumigation reduced it to 9.7% and biofumigation with *Muscador albus* reduced it to 4.4%. The combination of these two methods reduced the rate of gray mold appearance to 3.4%. However, the effect of using this method was less than using SO_2 gas. The use of this gas reduced the appearance of mold to 1.1%.

Pre-harvest chitosan spraying and post-harvest coating with chitosan had a good effect on controlling mold growth on grapes at 0°C and 2°C and significantly prevented weight loss at 20°C (Meng *et al*., 2008). Edible coatings such as methyl cellulose with antimicrobial agents, n-capric acid, isopropyl ester and sodium nitrate were also sprayed to increase the storage life of grapes (Yeol *et al.*, 2002).

In Shahroud/Iran, SO_2 fumigation is conventionally used in all cold stores for storing grapes, which is uncontrolled and usually more than the permitted level. Our innovation is to use GRAS salts to replace fumigation with SO_2. Thus, the aim of this study was to investigate the effect of some of these safe salts for humans that do not have sulfur problems and harmful effects on the shelf life of Shahrood Sorkh-e-Fakhri grapes and to introduce the best method (salt type and concentration) for elimination of sulfur dioxide gas application. Instead of unhealthy grapes with a nasty and harmful odor of sulfur, the grapes are offered to consumers with good quality and health in the fall and winter seasons.

Materials and Methods

According to the study performed by Ghodsvali (2000), if the grapes are harvested at full maturity, their shelf life will be longer. This time for Sorkh-e-Fakhri grapes in the Shahroud area is in late October. Therefore, in this study, first, the grapes of Sorkh-e-Fakhri cultivar were harvested at full maturity at the end of October and transferred to a cool, shady environment to reduce their initial temperature. During this time, the moisture content, average weight of the berries, soluble solids or brix, reducing sugar percentage, acidity and pH of the samples were measured (Table 1) and then 10 to 15 clusters were placed in each plastic basket.

Table 1. Grape characteristics after harvesting

Reducing sugar (%)	Moisture content (%)	Acidity (%)	pH	Brix (%)	Mean weight of berries (g)
15	78.18	0.48	4.29	20.4	5.41

Experimental treatments consisted of four permitted salts (sodium carbonate, calcium chloride, sodium acetate and sodium metabisulfite) in three concentrations (0.5, 1 and 2%) and total in 12 treatments. Each treatment was applied in three replications. The grapes were immersed in each solution for 2 minutes. The samples were then air-dried in the garden at about 30°C for one hour. One sample was immersed in distilled water as a control. The samples were then stored in a refrigerator at 0.5-1°C and 90-95% relative humidity for 6 months. Each month various tests including mold percentage, average weight of berries, soluble solids content, sugar content, acidity and pH of samples were measured and recorded. After leaving the fridge, the samples were kept in the laboratory for one day and then their mold level was assessed. The results were analyzed using a completely randomized factorial design with three replications and the means were compared by Duncan's test.

To measure mold percentage, the number of decayed and moldy berries in each basket was

counted and the percentage of moldiness was determined by dividing the number of molded berries by the total number of studied berries (Sherafatian, 1999).

To measure soluble solids, after extraction of grape extract for experiments, two drops of extract were poured onto a manual refractometer (Atago, Tokyo, Japan) and the percent of soluble solids (Brix) was read from the apparatus.

Sugar content was measured by Fehling method and according to Iranian National Standard for Grape juice No. 2685 (ISIRI, 2007). 25 grams of the sample was transferred to a 100 ml graduated balloon containing 2 mL of saturated lead acetate and a small amount of activated carbon. It was made to volume with distilled water and then filtered. 5 mL of Fehling's "A" and 5 mL of Fehling's "B" was added to 250 ml flask. After adding a few drops of methylene blue and about 20 mL of distilled water, the solution was heated to boiling. The filtered solution was then poured into the burette and gently added to the boiling solution to fade blue to give a brick red color. Regarding the volume of solute consumed, the percentage of reducing sugars was calculated from equation 1:

$$n = \frac{F \times 100 \times 100}{V \times 25} \quad (1)$$

Where, n, is the reducing sugar (percent), F is the Fehling factor and V, is the consumed volume of the Fehling solution for titration.

To measure the acidity, 10 g (m) of grape juice was diluted with 50 mL of distilled water and titrated in the presence of phenolphthalein indicator with 0.1N sodium hydroxide until a pale pink appearance (V). Then the acidity percent was calculated based on tartaric acid from the equation 2 (Doulatibaneh and Zomorodi, 2004).

$$Acidity = \frac{V \times 0.075 \times 100}{m} \quad (2)$$

The Metrohm pH meter was used to measure the pH of the juice extracted from the grapes.

To measure the moisture, about 5 grams of each sample was weighed and completely shredded on a plate, then dried at 70°C for 6 hours to reach constant weight. The plate was weighed again and moisture content was obtained by weight difference from equation 3:

$$Moisture\ Content = \frac{X_1 - X_2}{M} \times 100 \quad (3)$$

Where X_2 is the sample weight and the plate after drying, X_1 is the sample weight and the plate before drying and M is the sample weight.

Results and Discussion

According to the analysis of variance (Table 2), it was observed that the effect of type of salt used and storage time on mold percentage, pH and acidity of all samples were significant at 1% level.

Table 2- Analysis of variance of the effect of different treatments on the studied characteristics

Source Deviation	Mean Squares						
	Acidity	Reducing sugar	Brix	pH	Moisture content	Sample weight	Moldiness
type of salt(A)	0.015**	0.929	0.973	0.028**	0.599*	0.37	45.90**
Salt concentration (B)	0.006	0.639	7.746	0.014	0.171	0.001	0.28
A× B	0.009**	0.189	2.99	0.006	0.284	0.234	0.827**
storage time (C)	0.024**	16.453**	9.156	0.077**	0.049	0.969	43.21**
A× C	0.007*	1.269*	8.5*	0.006	0.405*	0.448	2.923**
B× C	0.006	0.434	3.39	0.002	0.237	0.127	0.432
A× B ×C	0.005*	0.227	3.8	0.008	0.36*	0.189	0.193
Error	0.003	0.519	4.04	0.005	0.185	0.329	0.247

** Significant at 1% level, * significant at 5% level

Interaction effects of salt type and storage time on moldiness, moisture content, brix, sugar content and acidity, as well as salt type and concentration on moldiness and acidity of

samples were also significant. The significant effect of storage time on the sugar content of the samples is due to the change in the moisture content of the samples during storage, thereby increasing the sugar concentration. As can be seen from Table 2, the effect of the concentrations used in this study on any of the examined traits was not significant. of course, if higher concentrations were used, this effect could be significant, but at concentrations higher than 2%, the salts used would precipitate on the berries and make their appearance undesirable.

As seen in Figure 1, sodium metabisulfite had the highest inhibitory effect on mold growth and had the lowest molding on samples treated with this salt due to the presence of sulfur in it. The storage time had a significant effect on the molding rate as well, so that the molding after six months was significantly higher than the four months storage (Fig. 1).

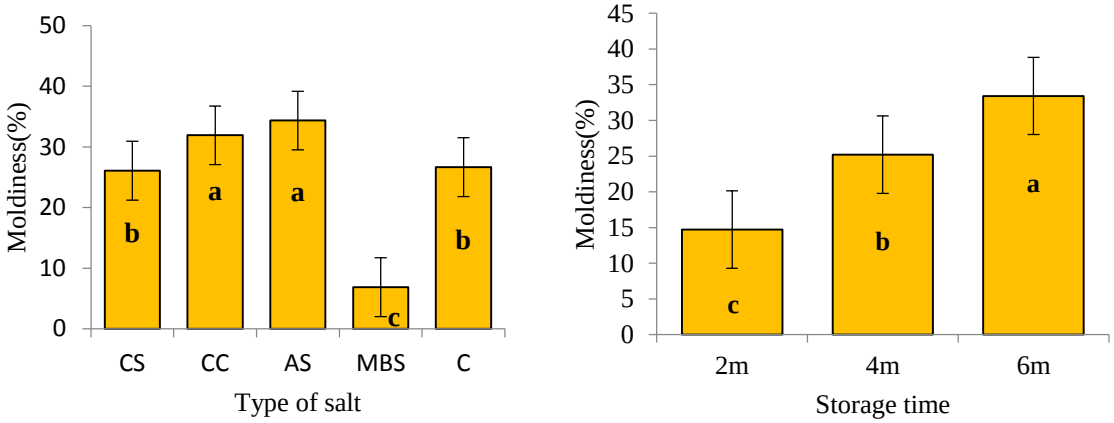

Fig 1. The effect of salt type (left) and storage time (right) on the moldiness of the grape samples; CS=sodium carbonate; CC= calcium chloride; AS= sodium acetate; MBS=sodium metabisulfite; C=control; m=month

The interaction between the type of salt and its concentration as shown in Fig. 2 was the lowest for the different concentrations of sodium metabisulfite and the highest for the different concentrations of sodium acetate and 2% calcium chloride. It can be seen from Fig. 2 that the inhibitory effect of sodium metabisulfite is even greater after six months than the effect of other substances

.

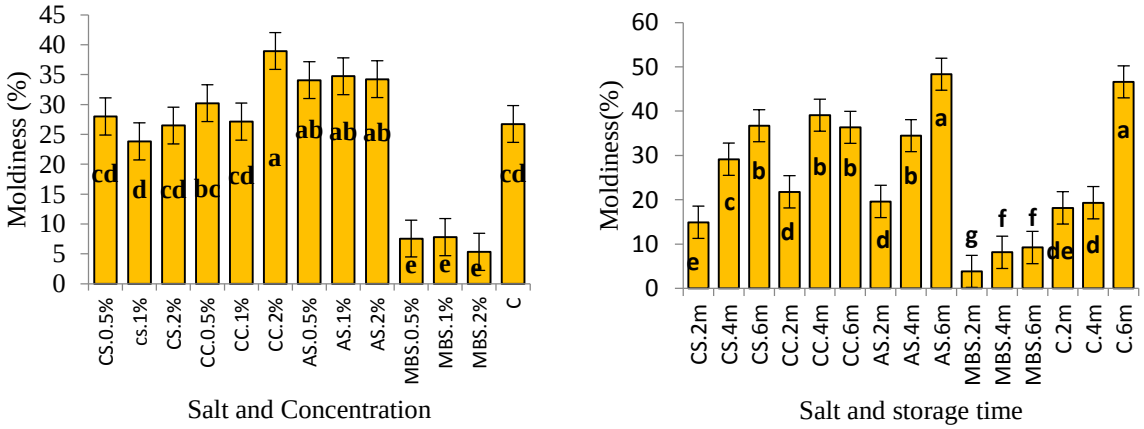

Fig 2. The mutual effect of the salt type and concentration (left) and salt type and storage time (right) on the moldiness of the grape samples; CS=sodium carbonate; CC= calcium chloride; AS= sodium acetate; MBS=sodium metabisulfite; C=control, m=month

Regarding the effect of salt on moisture content of the samples, it was observed that all the materials used had better preservation of the moisture content of the samples compared to the control samples, which calcium chloride had the greatest effect in this regard. The interaction between salt type and storage time also showed that calcium chloride retained more moisture than other materials (Figure 3).

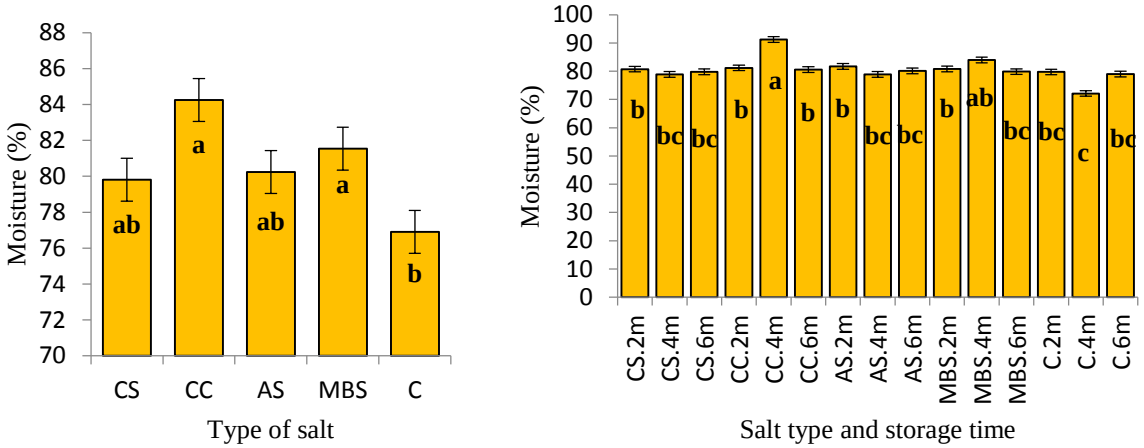

Fig 3. The effect of the salt type (left) and the mutual effect of salt type and storage time (right) on the moisture content of the grape samples; CS=sodium carbonate; CC= calcium chloride; AS= sodium acetate; MBS=sodium metabisulfite; C=control; m=month

According to Fig. 4, the highest pH was for samples immersed in sodium carbonate solution, because sodium carbonate was more alkaline than the other salts used, and even the pH of the samples treated was higher than that of the control sample. There was no significant difference between the other treatments.

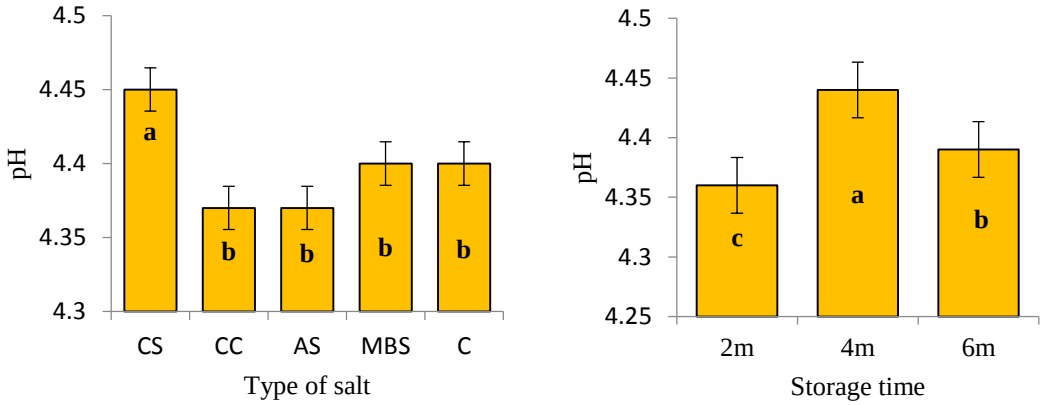

Fig 4. The effect of salt type (left) and storage time (right) on the pH of the grape samples; CS=sodium carbonate; CC= calcium chloride; AS= sodium acetate; MBS=sodium metabisulfite; C=control, m=month

The aim of the current study was to select effective salts to increase the shelf life of Shahrood Sorkh-e-Fakhri grapes. The different salts used had different effects on the mold content of the samples and other shelf-life characteristics. All salts used were effective at different concentrations. Sodium acetate did not have any effect on the reduction of moldiness and even increased moldiness in comparison with the control. This effect is probably due to the fact that these salts provide more nutrients to the mold or provide better environmental conditions for growth (Nigro *et al*., 2006). Other salts at all concentrations

reduced the amount of moldiness that was most affected by sodium metabisulfite and then sodium carbonate. Nigro et al. (2006) showed that the use of salts such as sodium acetate and sodium phosphate increased the growth of *Botrytis cinerea* on small grape clusters. In the case of calcium carbonate, they also showed that using this compound in vitro and in the culture medium did not prevent the growth of *Botrytis cinerea*, but if used for fresh grapes, it inhibits mold growth. This is due to specific biochemical interactions between salt and grape tissue. Sharayei et al. (2004) also mentioned the inhibitory effect of metabisulfite in their research. Chervin et al. (2009) also prevented the development of gray mold rot on grapes during 6 weeks of storage by using ethanol solution containing calcium chloride. Nigro et al. (2006) also showed that the inhibitory effect of calcium chloride was less than other salts such as sodium carbonate and sodium bicarbonate. They obtained the minimum inhibitory concentrations of salts against *Botrytis cinerea* as greater than 2% for sodium acetate and calcium chloride, 0.25% for sodium carbonate and 0.5% for sodium sulfate.

In the current study, it was found that the salts used had no effect on the pH of the samples except sodium carbonate. Sodium carbonate increases the pH due to the alkaline conditions it creates, which may be a reason for the lower salt content to prevent molding. Increasing the storage time from 2 months to 4 months increased the pH value initially, probably because of the increased salt concentration led to the decrease in moisture content. However, by increasing the storage time from 4 months to 6 months the pH value decreased due to the increased contamination of grapes with molds and the effect of molds on the decomposition of alkaline salts. Nigro et al. (2006) showed that pH alone cannot explain the inhibitory effect of salts. Ca^{2+} ions can easily penetrate the fruit epidermis (Schonher, 2000). The mechanism by which calcium increases plant tissue resistance to mold has not been established yet. Most of the calcium that penetrates into the plant tissue accumulates in the middle layer of the cell wall and thereby forms ionic bridges between and inside the pectic polysaccharides that harden the cell wall. The formation of calcium junctions between pectic polysaccharides makes the cell wall more resistant to the hydrolytic enzymes produced by molds (Tobias *et al*., 1993). Various researchers have shown that carbonates and bicarbonates are effective in preventing spore growth, elongation of mold hyphae, and producing pectin-degrading enzymes in many molds (Hervieux *et al.*, 2002; Mills *et al*., 2004; Smilanick *et al.*, 2005). In the current study, it was observed that the storage time was significant on the examined traits, including the percent of grape moldiness. Sharayei et al. (2004) also showed in their research on Kolahdari and Kaj Angor grape cultivars that the effect of the storage time of the grapes treated with sodium metabisulfite was significant on all quantitative and qualitative traits except grape acidity. They also showed that different concentrations of sodium metabisulfite were effective in decaying grapes and recommended 10% sodium metabisulfite concentration for storage of grapes in cold stores. In the current study, it was found that the highest moisture content was in the samples treated with sodium metabisulfite and calcium chloride. Calcium chloride inhibits moisture excretion by affecting fruit texture and hardening it (Schonher, 2000) and sulfur dioxide gas emitted by sodium metabisulfite prevents respiratory and transpiration reactions and prevents loss of product moisture (Sharayei *et al*., 2004). Pretel et al (2006) also showed that the rate of weight loss and moisture loss in grapes treated with gradual release of SO_2 was lower than that control.

Conclusion

According to the results of the experiments and the fact that the most important factor in this study was the number of moldy grapes during storage, to store the grapes in the cold store, it is recommended to immerse them in a 0.5% sodium metabisulfite solution for about 2 minutes before transferring them into the cold store rooms. This allows the grapes to be easily stored for up to 6 months. To replace sulfur

dioxide, other researches recommending to consider the possibility of using ozone generators in grape cold stores. In addition, it is recommended to consider the use of other harmless chemicals and in different concentrations or combinations of two or more, to investigate the possibility of spraying grape clusters with harmless antifungal chemicals such as calcium chloride, potassium carbonate, potassium bicarbonate, etc. before harvesting and its effect on increasing the shelf life of grapes.

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References

Carvalho, G., L. Lima, J. Silva, H. Siqueira and E. Morais. 2008. Calcium chloride concentrations and storage time on reducing sugar contents of grape cv red globe (*Vitis vinifera* L). *Ciencia e agrotecnologia*, 32(3), 894-899.

Chervin, S., D. Lavigne, and P. Westercamp. 2009. Reduction of gray mold development in table grapes by preharvest sprays with ethanol and calcium chloride. *Postharvest Biology and Technology*, 54, 115–117

Doulatibaneh, H. and S. Zomorodi. 2004. The Effects of Spraying $CaCl_2$ Solution on Quality and Storage Traits of Two Rishbaba and Ghezel Ozum Cultivars of grapes. West Azarbaijan Agricultural and Natural Resources Research Center, AREEO, Urmia, Iran. *Research final report* No. 83/821.

Fatemi, H. 2007. Principles of food preservation technology. Sahami Enteshar Ltd.

Gabler, F., J. Mercier, J.I. Jiménez and J.L. Smilanick, 2010. Integration of continuous biofumigation with Muscodor albus with pre-cooling fumigation with ozone or sulfur dioxide to control postharvest gray mold of table grapes. *Postharvest Biology and Technology*, 55, 78–84

Ghodsvali, A. 2000. Evaluating the effect of harvest time on the storability of Shahroud Sorkhe Fakhri variety grape in the cols store. Golestan Agricultural and Natural Resources Research and Education Center, AREEO, Gorgan, Iran. *Research final report* No. 79/740.

Guzev, L., A. Danshin, T. Zahavi, A. Ovadia, and A. Lichter. 2008. The effects of cold storage of table grapes, sulphur dioxide and ethanol on species of black Aspergillus producing ochratoxin A. *International Journal of Food Science and Technology*, 43, 1187–1194

Hervieux, V., E.S. Yaganza, J. Arul and R.J. Tweddell. 2002. Effect of organic and inorganic salts on the development of Helminthosporium solani, the causal agent of potato silver scurf. *Plant Dis*., 86, 1014–1018.

Iran National Organization of Standardization. 2007. Fruit juices – Test methods. 2685.

Jay, J.M., M. J. Loessner and D. A. Golden. 2005. Modern food microbiology, Mortazavi, S. A., Ziaolhagh, H., Mashhad, Ferdowsi university of Mashhad Publication.

Karabulut, O., F. Gabler, M. Mansour and J.L. Smilanick. 2004. Postharvest ethanol and hot water treatments of table grapes to control gray mold. *Postharvest Biology and Technology*, 34, 169–177

Karabulut, O., G. Romanazzi, J.L. Smilanick and A. Lichter. 2005. Postharvest ethanol and potassium sorbate treatments of table grapes to control gray mold. *Postharvest Biology and Technology*, 37,129–134

Lurie, S., E. Pesis, O. Gadiyeva, O. Feygenberg, R. Ben-Arie, T. Kaplunov, Y. Zutahy and A. Lichter. 2006. Modified ethanol atmosphere to control decay of table grapes during storage. *Postharvest Biology and Technology*, 42, 222–227

Meng, X., B. Li, J. Liu and S. Tian. 2008. Physiological responses and quality attributes of table grape fruit to chitosan preharvest spray and postharvest coating during storage. *Food Chemistry*, 106, 501–508

Miguel A., J. Dias, S. Albertini, and M. Spoto. 2009. Postharvest of grape envolved with films of sodium alginate and cold storage. *Ciencia e tecnologia de alimentos*, 29 (2), 277-282

Mills, A.A.S., H.W. Platt and R.A.R. Hurta. 2004. Effect of salt compounds on mycelial growth, sporulation and spore germination of various potato pathogens. *Postharvest Biology and Technology*, 34, 341–350.

Nigro F., L. Schena, A. Ligorio, I. Pentimone, A. Ippolito and M. Salerno. 2006. Control of table grape storage rots by pre-harvest applications of salts. *Postharvest Biology and Technology*, 42,142–149

Pretel, M.T., M.C. Martínez-Madrid, J.R. Martínez, J.C. Carreño and F. Romojaro. 2006. Prolonged storage of "Aledo" table grapes in a slightly CO_2 enriched atmosphere in combination with generators of SO2. *LWT - Food Science Technology*, 39(10),1109–1116.

Qin, G., Y. Zong, Q. Chen, D. Hua and S. Tian. 2010. Inhibitory effect of boron against Botrytis cinerea on table grapes and its possible mechanisms of action. *International Journal of Food Microbiology*, 138(1-2), 145-150.

Schonherr, J. 2000. Calcium chloride penetrates plant cuticles via aqueous pores. Planta 212, 112–118.

Sharayei, P., Shahbake, M.A. and Mokhtarian, A. 2004. Investigation the Effect of Grapeguard on Quality and Controlling Fungal Contamination of Grape in Cold Storage. *Journal of Agricultural Engineering Research*. 5(20):1-16.

Sherafatian, D. 1999. Method of storing grapes in cold stores. Agriculture Ministry. Deputy of Horticultural Services. No.22090.

Smilanick, J.L., Mansour, M.F., Margosan, D.A., Mlikota Gabler, F., Goodwine, W.R. 2005. Influence of pH and NaHCO3 on effectiveness of imazalil to inhibit germination of Penicillium digitatum and to control postharvest green mold on citrus fruit. *Plant Dis*., 89, 640–648.

Tobias, R.B., Conway, W.S., Sams, C.F., Gross, K.C., Whitaker, B.E. (1993). Cell wall composition of calcium-treated apples inoculated with Botrytis cinerea. *Phytochemistry*, 32, 35–39.

Yeol, K., H. Ryun, C. Jeong, K. Yong and K. Hwan. 2002. Study on the extending storage life of grape by applying edible coating materials. *Agricultural Chemistry and Biotechnology*, 45(4), 207-211

Youssef, K. and S.R. Roberto. 2014. Applications of salt solutions before and after harvest affect the quality and incidence of postharvest gray mold of 'Italia'table grapes. *Postharvest Biology and Technology*, 87, 95-102.

Zomorrodi, S. 2005. Storage, processing, and quality control of grapes. *Agricultural research and Education Organization Ltd*. Tehran

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نشریه پژوهشهای علوم و صنایع غذایی ایران
جلد ۱۶، شماره ۶، بهمن- اسفند ۱۳۹۹، ص. ۱۱۰-۱۰۱

اثر برخی از نمک‌ها در افزایش زمان نگهداری انگور سرخ فخری شاهرود در سردخانه

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چکیده

به‌منظور افزایش زمان ماندگاری انگور سرخ فخری و جلوگیری از کپک‌زدگی آن در سردخانه، خوشه‌های انگور در محلول‌های نگهدارنده غوطه‌ور شدند. برای این منظور محلول‌های متابی‌سولفیت سدیم، کلرید کلسیم، استات سدیم و کربنات سدیم با غلظت‌های مختلف ۰/۵، ۱ و ۲ درصد تهیه شد و انگورها پس از قرار گرفتن در سبدهای مناسب، در شرایط دمای حدود ۰/۵ تا ۱ درجه‌ی سانتی‌گراد و رطوبت نسبی ۸۵ تا ۹۵ درصد در سردخانه به مدت ۶ ماه نگهداری شدند. هر دو ماه یک‌بار درصد کپک‌زدگی، مواد جامد محلول، درصد قند، اسیدیته و pH نمونه‌ها بررسی شد. نتایج این پژوهش نشان داد که اثر نوع ماده استفاده شده و زمان نگهداری بر درصد پوسیدگی و مقدار pH و اسیدیته‌ی تمام نمونه‌ها در سطح ۱٪ معنی‌دار می‌باشد. متابی‌سولفیت سدیم بیشترین اثر بازدارندگی را بر کپک‌ها داشت. همچنین، از میان نمک‌های مورد استفاده کلرید کلسیم بیشترین اثر را در حفظ رطوبت نشان داد. بیشترین مقدار pH نیز در نمونه‌هایی به‌دست آمد که در محلول کربنات سدیم غوطه‌ور شده بودند. در مورد اثرات متقابل نیز اثر نوع ماده و زمان نگهداری بر میزان پوسیدگی، مقدارررطوبت، بریکس، درصد قند و اسیدیته و همچنین نوع ماده و غلظت آن بر میزان پوسیدگی و اسیدیته‌ی نمونه‌ها معنی‌دار می‌باشد. با توجه به نتایج و داده‌های حاصل از تجزیه و تحلیل آماری شرایط مناسب برای نگهداری انگور در سردخانه، غوطه‌وری آن‌ها به مدت حدود ۲ دقیقه در محلول ۰/۵ درصد متابی‌سولفیت سدیم قبل از سردخانه‌گذاری می‌باشد. با این کار می‌توان انگور را به راحتی تا ۶ ماه نگهداری کرد.

واژه‌های کلیدی: انگور سرخ فخری، جایگزین گوگرد، سردخانه، نگهدارنده‌ها، زمان ماندگاری

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Full Research Paper

Using several fruit and vegetable juices as substrates for producing non-dairy probiotic beverages

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Abstract

Probiotics are living microorganisms that provide beneficial effects when they are eaten with food. The probiotic dairy products raise the risks associated with increased cholesterol and lactose intolerance. In this research, fruit and vegetable juices of apple, banana, carrot and tomato were used as substrates for producing probiotic beverages and the viability of two LABs of *L. acidophilus* and *L. plantarum* in these products was investigated. Fruit and vegetable juices were inoculated with bacterial suspensions to obtain a concentration of 10^5 CFU/ml for each LAB. Samples were incubated at 37°C for 72 hours and at 24-hour intervals, pH levels and viable cell count in products were determined based on CFU/ml. Fermented products were transferred to the refrigerator and the viability of LABs was determined at 4°C for 4 weeks. The results show that, in all products, the pH decreased over time, so that there was a significant difference between the two examined bacteria during the experiment ($P<0.05$). Both LABs were able to grow well in products and to ferment the fruit and vegetable juices properly implying that all the beverages were able to provide suitable conditions for the growth of two strains of LABs. *L. plantarum* showed a higher viability in cold storage at 4°C. In general, considering the high growth rate of these bacteria in the products and pH reduction and their viability during cold storage at 4°C, fruit and vegetable juices of apple, banana, carrot and tomato can be a good substrate for producing non-dairy probiotic beverages.

Keywords: Viability, Cold storage, Fermented Fruit and Vegetable Juices, *L. acidophilus, L. plantarum*

Introduction

Fermentation of food is a desirable process in the food industry, and microorganisms and their enzymes play an important role in this field. Fermentation improves the flavor and taste of foods; increases the shelf-life of foods and enhances the nutritional value of products (Karovicova and Kohajdova, 2003).

Food enrichment with probiotics has been considered as one of the methods of producing fermentation products. Probiotics are living microorganisms that provide beneficial effects for the host if they are eaten with food in adequate amount. Some of the most important health effects of adding probiotics to foods include improving digestive system function (Vasudha and Mishra, 2013), preventing diarrhea (Fuller *et al*., 2008), reducing constipation (Ouwehand *et al*., 2002), improving the lactose digestion (Li *et al*., 2012), reducing serum cholesterol levels (Pereira *et al*., 2002), diminishing the inflammatory bowel disease (Fooks *et al*., 2002), decreasing the risk of colon cancer (Rafter, 2004), enhancing both innate and acquired immunity in the immune system (Fuller *et al*., 2008), decreasing the risk of recurrent urogenital tract infection (Dani *et al*., 2002), inhibiting *Helicobacter pylori* infection (Hamilton-Miller *et al*., 2003), and preventing allergies (Delcenserie *et al.*, 2010).

To provide these health effects, probiotic bacteria should be presented alive in foods, and their concentrations be high enough in the food. The viability of probiotic organisms under difficult conditions, such as low pH of foods and against gastrointestinal enzymes, is one of the most important concerns in the processes and production of probiotic foods. In this regard, the final number of probiotic bacteria must be at least 10^6 - 10^7 CFU/ml or g at the time of food consumption, in order to be

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suitable for providing health (Vasudha and Mishra, 2013; Shaikh Uzma *et al.*, 2018).

The use of different species of probiotic bacteria for producing dairy products has become popular since the late 1970s, and nowadays, dairy products are the most popular probiotic products. Milk products have high cholesterol content, and the increasing population of people with high cholesterol level is regarded as one of the most important food concerns in the modern era. So, consumers prefer more vegetarian diets with lower cholesterol levels. Besides, lactose intolerance in some people is another problem associated with consuming the dairy products (Vasudha and Mishra, 2013).

Therefore, among the foods suitable for adding probiotics, there have been a great demand for non-dairy probiotic products due to a number of reasons; such as milk lactose intolerance in some individuals and high levels of cholesterol in dairy products. Since fruits and vegetables contain beneficial substances such as minerals, antioxidants, dietary fiber and vitamins and are free of sensitizing ingredients present in milk, they can be good substrates for producing non-dairy probiotic beverages (Carlos *et al*., 2007; Nematollahi *et al*., 2013). More than 90% of probiotic foods contain Lactobacillus and Bifidobacterium species (Perricone *et al.*, 2015). Meanwhile, several strains of *L. plantarum* and *L. acidophilus* were used as probiotics in fruit substrates due to their tolerance to acidic conditions (Peres *et al.*, 2012).

High intake of carotenoid-rich fruits and vegetables are associated with a reduced risk of various cancers, including colon cancer. A study conducted on individuals consuming carrot and tomato juices indicated that a diet rich in carotenoids, especially high-dose b-carotene and lycopene, can modify luminal processes relevant to colon carcinogenesis (Schnabele *et al.*, 2008).

The present study aimed at using fruit and vegetable juices of apple, banana, carrot and tomato as substrates for producing non-dairy probiotic beverages by two lactic acid bacteria (LAB) of *L. acidophilus* and *L. plantarum*.

Materials and methods

Bacterial Strains

The strains of the tested LABs were *Lactobacillus acidophilus* (PTCC[1] 1643) and *Lactobacillus plantarum* (PTCC 1745). They were purchased from the Iranian Research Organization for Science and Technology (IROST) in a lyophilized form. Then, they were recovered in MRS[2] broth medium (Merck, Germany) for 24 h at 37°C in an anaerobic jar in the microbiology laboratory of the Azadshahr branch, Islamic Azad University. MRS broth medium supplemented with 20% glycerol was used to store standard strains at -20°C (Pakbin et al., 2014; Yoon et al., 2005).

Fermentation of fruit and vegetable juices by LABs

Fruits and vegetables, including banana, apple, carrot, and tomato were bought from the local market and then were juiced with a juicer (Hitachi, Japan). Fruit and vegetable juices were pasteurized at 80°C for 5 minutes. Then they were transferred to sterile tubes (25×200 mm) and were inoculated with bacterial suspensions of *L. acidophilus* and *L. plantarum*, so that suspensions containing 10^5 CFU/ml of each of the bacteria in the fruit and vegetable juices were obtained. For this purpose, first turbidity equal to 0.5 McFarland $=1.5\times10^8$ CFU/ml was prepared from each acid lactic bacteria. Then, by adding this bacterial suspension to the samples, fruit and vegetable juices containing 10^5 CFU/ml of each of the bacteria were obtained.

Fermentation of fruit and vegetable juices was performed at incubator of 37°C for 72 hours and the number of LABs per ml of fruit and vegetable juice based on colony forming unit (CFU/ml) was determined by serial dilution and pour plate culture method in MRS agar at intervals of 24 hours and they were incubated at 37°C for 72 hours in an anaerobic jar (Pakbin *et al*., 2014; Yoon *et al*., 2005; Sivudu *et al*., 2014). The number of bacteria per ml of fruit and vegetable juices was

1 Persian Type Culture Collection
2 Man, Rogosa and Sharpe

determined based on colony forming unit (CFU/ml) (Pakbin *et al.*, 2014; Yoon *et al.*, 2005; Sivudu *et al.*, 2014).

The viability of LABs in fermented fruit and vegetable juices at 4°C

After 72 hours of fermentation, the fermented fruit and vegetable juices were stored at 4°C for 4 weeks and samples were taken at weekly intervals, and the viability of *L. acidophilus* and *L. plantarum* in fermented fruit and vegetable juices was determined and expressed as colony forming units (CFU/ml) (Pakbin *et al.*, 2014; Sivudu *et al.*, 2014; Yoon *et al.*, 2005).

Measuring pH

During fermentation and at 24-hour intervals, pH of each sample of fermented fruit and vegetable juices was measured with a pH meter (WTW, Inolab 720, Germany). Calibration was carried out using KCL solutions at pH 7, 10 and 4.

Statistical Analysis

All experiments were performed in triplicate and the mean values were reported. The Significant differences ($P< 0.05$) between means were determined by Duncan`s multiple range test.

Results and discussion

pH Changes During Fermentation in Fruit and Vegetable Juices

The results of pH changes during the fermentation process in fruit and vegetable juices, inoculated with *L. acidophilus* and *L. plantarum* are presented in Figures 1 and 2, respectively.

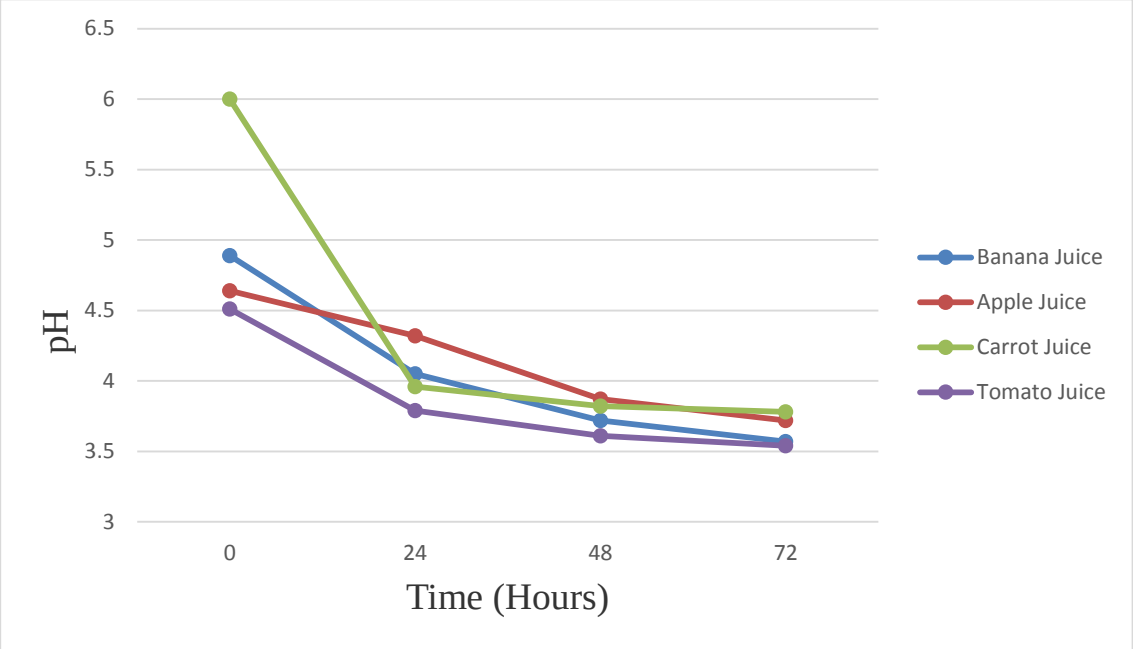

Fig. 1. Changes in pH During Fermentation by *L. acidophilus* in Fruit and Vegetable juices

In all products inoculated with these two bacteria, the pH decreased over time. However, there was a significant difference between the two bacteria during all days of the experiment ($P<0.05$). The trend of pH change in the fermented fruit and vegetable juices has been also observed in other studies (Yoon *et al.*, 2004, 2005, 2006; Kaur *et al.*, 2016; Kohajdova *et al.*, 2006) which is justifiable due to the production of lactic acid by *L. acidophilus* and *L. plantarum*. Among the fermented products, the process of reducing the pH of carrot juice from 6 to 3.78 and 3.74 for *L. acidophilus* and *L. plantarum*, respectively, was significant in the present research (Figure. 1 and 2).

In the study of Ayaseh et al. (2017) in order to produce probiotic carrot juice with *Lactococcus lactis*, the pH of fermented carrot juice decreased from 6.63 at the time of inoculation to 3.62 after 24 h.

Yoon et al. (2005) conducted a study on the fermentation of beet juice by different lactic acid bacteria. They found that *L. acidophilus* and *L. plantarum* produced more lactic acid than other species, and pH of fermented beet juice decreased from 6 to less than 4.5 after 48 hours incubation at 30°C.

Kohajdova et al. (2006) also tested different varieties of vegetables, including cabbage, tomatoes, pumpkin and courgette for preparing probiotic vegetable juices during lactic acid fermentation. From the point of view of lactic acid production and pH reduction, during the fermentation process, in all vegetable juices, the pH reduction was reported to be between 6.15- 6.5 to 3.35- 3.8 and all products were considered as suitable substrates for lactic acid fermentation by *L. plantarum* were introduced. Studies have shown that during lactic acid fermentation, the pH levels of vegetable and fruit juices decreased from about 6-6.5 to 3.8-4.5. Certainly, the rapid reduction of pH in the initial stages of fermentation to obtain a high quality product is of great importance and it may be considered as an advantage. Because in an environment with low acidity, lactic acid fermentation is inhibited by bacteria producing butyric acid (Viander *et al*., 2003; Holzapfel, 2002, Kohajdova *et al*., 2006).

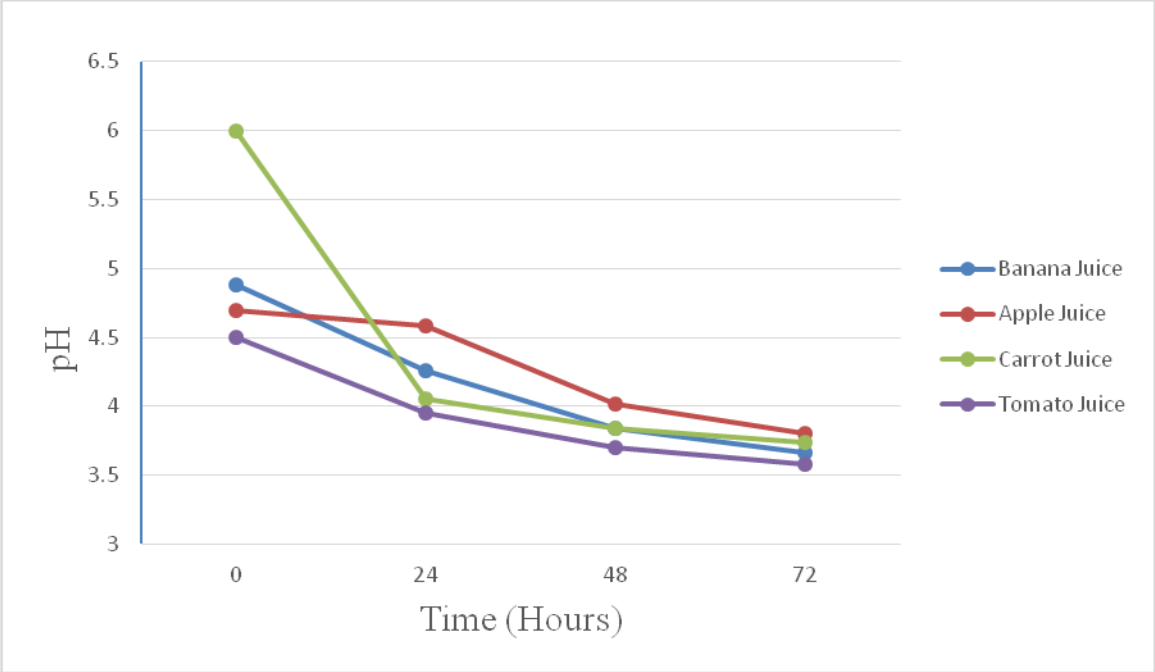

Fig. 2. Changes in pH During Fermentation by *L. plantarum* in Fruit and Vegetable juices

Growth kinetics of *L. acidophilus* and *L. plantarum* during fermentation of fruit and vegetable juices

The growth kinetics of *L. acidophilus* and *L. plantarum* during the fermentation of fruit and vegetable juices are shown in Figures 3 and 4, respectively.

The results showed that both of these LABs were able to grow well in the fruit and vegetable juices without any additives and to ferment the fruit and vegetable juices appropriately. So that the log of *L. acidophilus* count in products, which were prepared from 4.07– 4.23 CFU/ml at the beginning of fermentation (Time= 0), increased to 11.6–12.68 CFU/ml on the third day (Figure 3). This increase was also observed for *L. plantarum* in the prepared products from 3.56– 3.77 CFU/ml

at the beginning of fermentation to 10.46–11.63 CFU/ml on the third day (Figure 4). This indicated that all the prepared products (fruit and vegetable juices) were able to provide the proper conditions (acidic pH, and nutrients) for the growth of these two lactic acid bacteria. Tuorila and Cardello also reported that fruit and vegetable juices could be a good environment for probiotic growth (Tuorila and Cardello, 2002)..

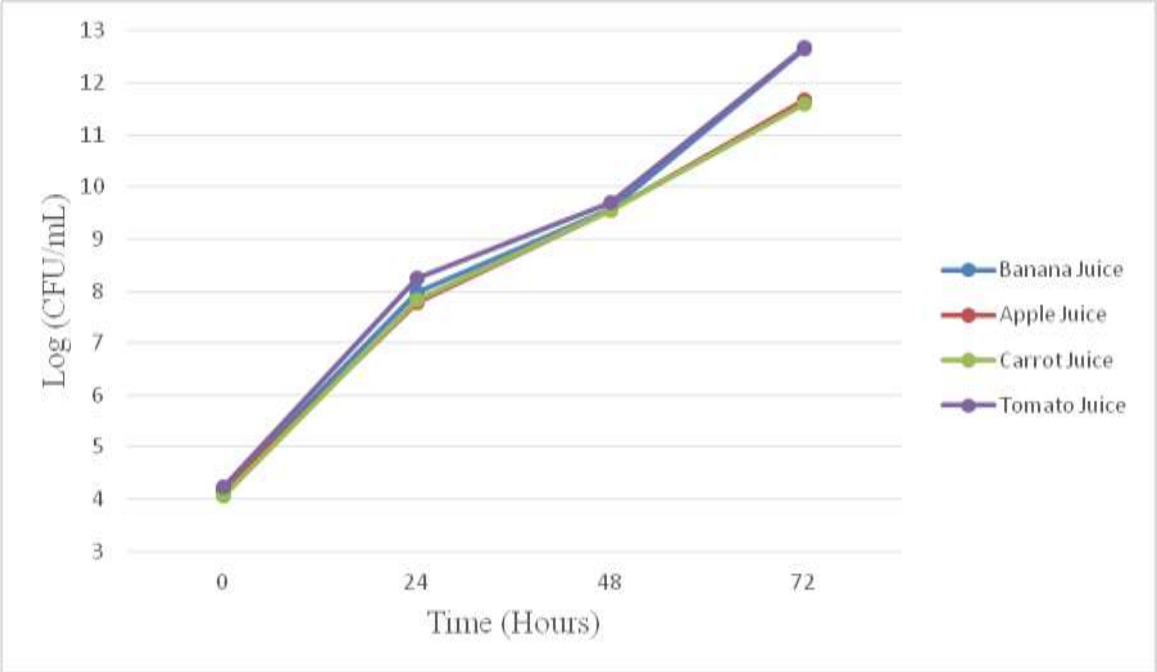

Fig. 3. Growth Kinetics of *L. acidophilus* During Fermentation of Fruit and Vegetable juices

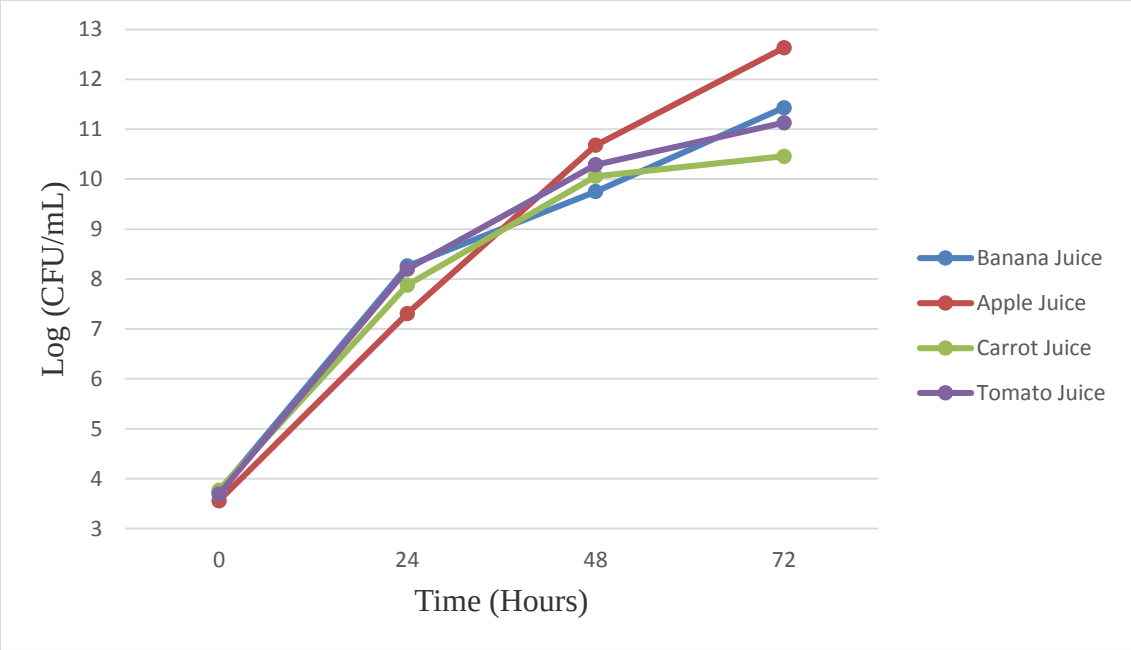

Fig. 4. Growth Kinetics of *L. plantarum* During Fermentation of Fruit and Vegetable Juices

Yoon et al. (2005) also investigated the fermentation of beet juice by lactic acid bacteria and proposed *L. acidophilus* and *L. plantarum* as probiotic candidates. Wheat and barley extract have also been reported as suitable environments for the growth of *L. acidophilus* and *L. plantarum* (Charalampopoulos *et al.*, 2003).

As it can be seen, among the tested products, tomato juice had the lowest initial pH level (Figure 1) and the results of the growth kinetics of *L. acidophilus* in this product also showed that the highest bacterial growth rate (Viable counts) was related to the tomato juice among all tested products (Figure 3). It could be justified due to the acidophilic nature of *L. acidophilus* (Peres *et al.*, 2012). These cases, along with the proper viability of this bacterium in tomato juice in cold storage conditions (Figure 5.) suggested that tomato juice was the best substrate among the products tested for the growth of *L. acidophilus* and the preparation of a non-dairy probiotic beverage. The probiotic suitability of this bacterium in tomato juice has also been reported in other studies (Kaur *et al.*, 2016; Yoon *et al.*, 2004)

Effect of Cold Storage on the Viability of Lactic Cultures in Fermented Fruits and Vegetables Juice at 4°C

In order to obtain the health benefits of the product, the presence of a large number of live probiotic bacteria in the final product is of great importance. In this regard, the number of probiotic bacteria surviving in the food at the time of consumption, must be at least 10^6 to 10^7 CFU/ml or g to be useful in providing health benefits (Vasudha and Mishra, 2013; Shaikh Uzma *et al.*, 2018).

The comparison of the viability of the two tested LABs in the prepared products and the process of reducing the number of *L. acidophilus* and *L. plantarum* during 4 weeks of cold storage at 4°C are shown in Figures 5 and 6, respectively. As it can be seen, *L. plantarum* presented higher viability during cold storage at 4°C than *L. acidophilus*.

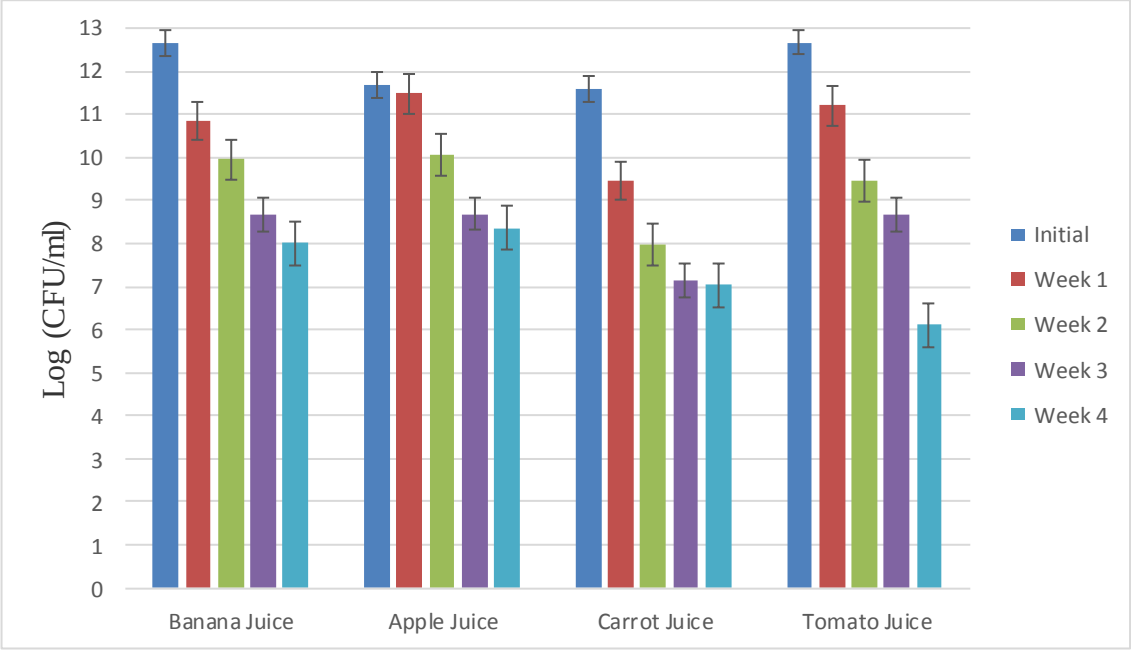

Fig. 5. Viability of *L. acidophilus* in Fermented Fruit and Vegetable Juices in 4°C

Accordingly, the log of *L. plantarum* count in products prepared at the initial of the cold storage was within the range of 10.46 - 12.63 CFU/ml and this number decreased to 8.11 - 9.23 CFU/ml at the end of the fourth week of storage at 4°C (Figure 6.). While, the log of

the number of *L. acidophilus* at the beginning of the cold storage in fruit and vegetable juices was within the range of 11.6– 12.68 and this number decreased to 6.1– 8.37 at the end of the fourth week (Figure 5).

The lower viability of *L. acidophilus* compared to *L. plantarum* in cold storage conditions has also been reported in other studies (Yoon *et al*., 2004 and 2005; Mousavi *et al*., 2011; Claude and Gardner, 2008).

Moreover, Yoon et al. (2004) evaluated the fermentation of beet juice and tomato juice by 4 lactic acid bacteria, which showed the less viability of *L. acidophilus* during storage at 4°C compared to *L. plantarum*, *L. casei* and *L. delbrueckii*. *L. plantarum* that showed the highest viability at cold storage among the four lactic acid bacteria tested. Mantzourani et al. (2019) also considered the possibility of using *L. plantarum* as a probiotic in pomegranate juice, and they evaluated the viability of this bacterium at cold storage at 4°C. Mousavi et al. (2011) conducted a study on the fermentation of pomegranate juice by *L. plantarum*, *L. paracasei*, *L. delbrueckii* and *L. acidophilus* and they showed that *L. plantarum* and *L. delbrueckii* created better conditions compared to the other two strains in terms of growth in pomegranate juice and the reduced pH and viability at 4°C. Claude and Gardner also reported sensitivity of *L. acidophilus* among 10 species of lactobacillus in 10 varieties of fruit juices mixed with milk components during 80 days of storage at 4°C (Claude and Gardner, 2008).

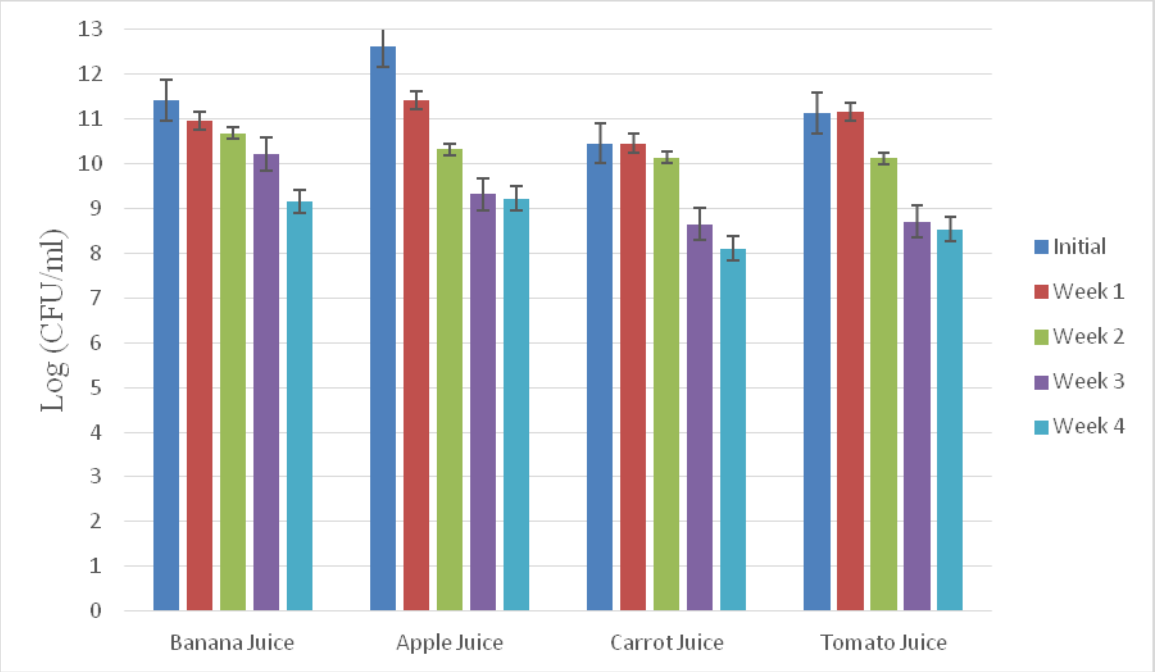

Fig. 6. Viability of *L. plantarum* in Fermented Fruit and Vegetable Juices in 4°C

The reason for the sensitivity to cold storage conditions may be due to the inability of the bacteria to survive in low pH stress conditions and high acidity of the products at low temperature (4°C) (Mousavi *et al*., 2011). Sheehan et al. (2007) reported that low pH of fruit juices within the range of 2.5 to 3.7 led to the sensitivity of bacteria to stress conditions such as cold. Claude and Gardner also showed that the viability of probiotics increased in cold storage at 4°C by increasing the pH of fruit juices from 3.8 to 4.2 (Claude and Gardner, 2008). Several factors could affect probiotic viability and survival in fruit and vegetable juices. The most important of these factors include intrinsic food parameters such as acidity, pH, oxygen, water activity, the presence of salt, sugar and chemical or

microbial preservatives such as hydrogen peroxide and bacteriocins. Also processing parameters such as incubation temperature, cooling rate and storage methods and finally microbiological factors, the most important of which are type of probiotic strains, compatibility of strains and inoculation rate (Tripathi and Giri, 2014).

Among all these factors, pH is the most important factor in the viability of probiotics in fruit juice. Fruit juices are naturally high in organic acids with low pH. It is assumed that acidic environment and the intrinsic antimicrobial activity of accumulated organic acids together affect probiotic bacteria. Among probiotics, lactobacilli generally found to be more resistant and survive in fruit juices with pH ranging from 4.3 to 3.7, while bifidobacteria are less acid tolerant; even pH 4.6 is unfavorable for their survival (Tripathi and Giri, 2014). In general, pH exerts a detrimental effect, but protein and dietary fiber could protect cells from acidic stress (Perricone *et al.*, 2015).

Although the pH is a drawback for probiotic survival in fruit and vegetable juices, Ranadheera et al. (2015) assumed that the incorporation of lactic acid bacteria into fruit juices with low pH may enhance the resistance of bacteria to subsequent stressful acidic conditions in the gastrointestinal tract.

Conclusion

Overall, the results of this study showed that banana, apple, carrot and tomato juice can provide the raw materials needed for growth of *L. acidophilus* and *L. plantarum* and due to the proper growth of these lactic acid bacteria in these products and decreased pH and the viability of these two bacteria in these products of plant origin in cold storage at 4°C, banana, apple, carrot and tomato juices can be suitable substrates for producing the non-dairy probiotic products.

References

Ayaseh, A., Taban, H., & Yari Khosroshahi, A. 2017. Production of probiotic carrot juice with using of Lactococcus lactis. *Journal of Food Research*, 27 (4), 183-191.

Carlos, K., Ferrai, B. & Faculdades, C. 2007. Functional food and physical activities in health promotion of again people. *Maturitas*, 58, 327-339.

Charalampopoulos, D., Pandiella, S.S. & Webb, C. 2003. Evaluation of the effect of malt, wheat and barley extracts on the viability of potentially probiotic lactic acid bacteria under acidic conditions. *International Journal of Food Microbiology*, 82, 133–141.

Claude, P. & Gardner, J. 2008. Effect of Storage in a Fruit Drink on Subsequent Survival of probiotic lactobacilli to gastro, international stresses. *Food Research International*, 41, 539-543.

Dani, C., Biadaioli, R., Bertini, G., Martelli, E. & Rubaltelli, F.F. 2002. Probiotics Feeding in Prevention of Urinary Tract Infection, Bacterial Sepsis and Necrotizing Enterocolitis in Preterm Infants. *Biology of the Neonate*, 82, 103–108.

Delcenserie, V., Martel, D., Lamoureux, M., Amiot, J., Boutin, Y. & Roy, D. 2010. Immunomodulatory Effects of Probiotics in the Intestinal Tract. *Current Issues in Molecular Biology*, 10, 37-54.

Fooks, L.J. & Gibson, G.R. 2002. Probiotics as modulators of the gut flora. *British Journal of Nutrition*, 88, 39-49.

Fuller, R., Perdigon, G. & Rastall, R.A. 2008. The Health Benefits of Probiotics and Prebiotics, Gut Flora, *Nutrition, Immunity and Health*, 46-58.

Hamilton-Miller, J.M.T. 2003. The role of probiotics in the treatment and prevention of Helicobacter pylori infection. *International Journal of Antimicrobial Agents*, 22 (4), 366-366.

Holzapfel, W.H. 2000. Appropriate starter culture technologies for small-scale fermentation in developing countries. *International Journal of Food Microbiology*, 75, 197-212.

Karovicova, J. & Kohajdova, Z. 2003. Lactic acid–fermented vegetable Juices Palatable and whole some foods. *Chemical Papers*, 59 (2), 143-148.

Kaur, S., Kaur, HP. & Grover, J. 2016. Fermentation of Tomato juice by Probiotic Lactic acid bacteria. *International Journal of Advances in Pharmacy*. *Biology and Chemistry*, 5 (2), 212-219.

Kohajdova, Z., Karovicova, J. & Greifova, M. 2006. Lactic acid fermentation of some vegetable juices. *Journal of Food and Nutrition Research*, 45 (3), 115-119.

Li, J., Zhang, W., Wang, C., Yu, Q., Dai, R. & Pei, X. 2012. *Lactococcus lactis* expressing food-grade β-galactosidase alleviates lactose intolerance symptoms in post-weaning Balb/c mice. *Applied Microbiology and Biotechnology*, 96 (6), 1499-1506

Mantzourani, I., Kazakos, S., Terpou, A., Alexopoulos, A., Bezirtzoglou, E., Bekatorou, A. & Plessas, S. 2019. Potential of the Probiotic *Lactobacillus Plantarum* ATCC 14917 Strain to Produce Functional Fermented Pomegranate Juice. *Foods*, 8 (4), 1-13.

Mousavi, Z.E., Mousavi, S.M., Razavi, S.H., Emam-Djomeh, Z. & Kiani, H. 2011. Fermentation of pomegranate juice by probiotic lactic acid bacteria. *World Journal of Microbiology and Biotechnology*, 27, 123–128.

Nematollahi, A., Sohrabvandi, S., Mortazavin Farsani, A.M. & Berarnejad Bariki, I. 2013. Application of fruit and vegetable for the production of non-dairy-based probiotic Drink. *Iranian Journal of Nutrition Sciences & Food Technology*, 7 (4), 73-81

Ouwehand, A.C., Lagström, H., Suomalainen, T. & Salminen, S. 2002. Effect of Probiotics on Constipation, Fecal Azoreductase Activity and Fecal Mucin Content in the Elderly. *Annals of Nutrition and Metabolism*, 46, 3-4.

Pakbin, B., Razavi, H., Mahmoudi, R. & Gajarbeygi, P. 2014. Producing Probiotic Peach Juice. *Biotechnology and Health Sciences*, 1 (3), 1-5.

Pereira, D.I.A. & Gibson G.R. 2002. Effects of Consumption of Probiotics and Prebiotics on Serum Lipid Levels in Humans. *Critical Reviews in Biochemistry and Molecular Biology*, 37 (4), 259-281.

Peres, C.M., Peres, C., Hernández-Mendoza, A. & Malcata, F.X. 2012. Review on fermented plant materials as carriers and sources of potentially probiotic lactic acid bacteria-With an emphasis on table olives. *Trends Food Science and Technology*, 26, 31–42.

Perricone, M., Bevilacqua, A., Altieri, C., Sinigaglia, M. & Corbo, M.R. 2015. Challenges for the Production of Probiotic Fruit Juices. *Beverages*, 1, 95-103.

Rafter, J. 2004. The effects of probiotics on colon cancer development. *Nutrition Research Reviews*, 17, 277–284.

Ranadheera, C.S., Prasanna, P.H.P. & Vidanarachchi, J.K. 2014. Fruit juice as probiotic carriers. In Fruit Juices: Types, Nutritional Composition and Health Benefits, 1st ed.; Elder, K.E., Ed.; Nova Science Publishers: Hauppauge, NY, USA, pp. 1–19.

Schnabele, K., Briviba, K., Bub, A., Roster, S., Pool-Zobel, B.L. & Rechkemmer G.L. 2008. Effects of Carrot and Tomato Juice Consumption on Faecal Markers Relevant to Colon Carcinogenesis in Humans. *British Journal of Nutrition*, 99, 606-613.

Shaikh Uzma, A., Deshpande, H.W. & Kulkarni, D.B. 2018. A review on probiotic beverages prepared using vegetables. *International Journal of Chemical Studies*, 6 (5), 61-65.

Sheehan, V.M., Ross, P. & Fitzgerald, G.F. 2007. Assessing the acid tolerance and the technological robustness of probiotic cultures for fortification in fruit juices. *Innovative Food Science Emerging Technologies*, 8, 279–284.

Sivudu, S.N., Umamahesh, K. & Reddy, O.V.S. 2014. A Comparative study on Probiotication of mixed Watermelon and Tomato juice by using Probiotic strains of Lactobacilli. *International Journal of Current Microbiology and Applied Sciences*, 3 (11), 977-984.

Tripathi, M.K. & Giri, S.K. 2014. Probiotic functional foods: Survival of probiotics during processing and storage. *Journal of Functional Foods*, 9, 225-241.

Tuorila, H. & Gardello, A.V. 2002. Consumer response to an off flavour in juice in the presence of specific health claims. *Food Quality and Preference*, 13, 561–569.

Vasudha, S. & Mishra, H.N. 2013. Non dairy probiotic beverages. *International Food Research Journal*, 20(1), 7-15.

Viander, B., Maki, M. & Palva, A. 2003. Impact of low salt concentration, salt quality on natural large scale sauerkraut fermentation. *Food Microbiology*, 20, 391-395.

Yoon, K.Y., Woodams, E.E. & Hang, Y.D. 2005. Fermentation of beet juice by beneficial lactic acid bacteria. *Lebensm Wiss Technology*, 37, 73-75.

Yoon, K.Y., Woodams, E.E. & Hang, Y.D. 2004. Probiotication of tomato juice by Lactic Acid Bacteria. *Journal of Microbiology*, 42 (4), 315-318.

Yoon, K.Y., Woodams, E.E. & Hang, Y.D. 2006. Production of probiotic cabbage juice by lactic acid bacteria. *Bioresource Technology*, 97, 1427–1430.

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جلد ۱۶، شماره ۶، بهمن- اسفند ۱۳۹۹، ص. ۱۲۱-۱۱۱

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استفاده از چند آب‌میوه و سبزی به‌عنوان محیط پایه برای تولید نوشیدنی‌های پروبیوتیک غیرلبنی

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تاریخ دریافت: ۱۳۹۸/۰۹/۱۴
تاریخ پذیرش: ۱۳۹۸/۱۲/۱۴

چکیده

فراورده‌های پروبیوتیک لبنی خطر افزایش کلسترول و عدم تحمل لاکتوز را مطرح می‌سازند. در این تحقیق از آب‌میوه‌ها و سبزی‌های سیب، موز، هویج و گوجه به‌عنوان محیط پایه برای تولید نوشیدنی‌های پروبیوتیک استفاده شد و قابلیت زنده‌مانی دو باکتری اسید لاکتیک *لاکتوباسیلوس اسیدوفیلوس* و *لاکتوباسیلوس پلانتاروم* در این محصولات مورد بررسی قرار گرفت. آب‌میوه‌ها و سبزی‌ها با سوسپانسیون‌های باکتریایی تلقیح شدند به‌طوری که سوسپانسیون حاوی 10^5 CFU/ml از هریک از باکتری‌ها در آب‌میوه‌ها و سبزی‌ها حاصل شد. نمونه‌ها به مدت ۷۲ ساعت در ۳۷ درجه سانتی‌گراد گرمخانه‌گذاری شدند و در فاصله‌های ۲۴ ساعته، pH و تعداد باکتری در هر میلی‌لیتر از آب میوه و سبزی براساس واحد تشکیل‌دهنده کلنی (CFU/ml) تعیین شد. محصولات تخمیر شده به یخچال منتقل شده و زنده‌مانی باکتری‌های اسید لاکتیک طی چهار هفته در ۴ درجه سانتی‌گراد مورد بررسی قرار گرفت. نتایج نشان داد که در همه محصولات تلقیح شده با این دو باکتری، میزان pH با گذشت زمان کاهش یافت به‌طوریکه تفاوت ایجاد شده در همه روزها بین دو باکتری مورد مطالعه، معنی‌دار بود ($P<0/05$). هر دو باکتری اسید لاکتیک توانستند در محصولات تولید شده بدون هر گونه افزودنی به‌خوبی رشد نمایند و به‌طور مناسبی آب‌میوه‌ها و سبزی‌های مورد آزمون را تخمیر نمایند. *لاکتوباسیلوس پلانتاروم* زنده‌مانی بیشتر را در ۴ درجه سانتی‌گراد نشان داد. به‌طور کلی با توجه به رشد مناسب این باکتری‌های اسید لاکتیک در محصولات مذکور و کاهش pH و زنده‌مانی آنها در شرایط نگهداری در ۴ درجه سانتی‌گراد، آب‌میوه‌های موز و سیب و آب سبزی‌های هویج و گوجه‌فرنگی می‌توانند سوبسترای مناسبی برای تولید محصولات پروبیوتیک غیرلبنی باشند.

واژه‌های کلیدی: زنده‌مانی، نگهداری در سرما، آب‌میوه و سبزی تخمیری، *لاکتوباسیلوس اسیدوفیلوس*، *لاکتوباسیلوس پلانتاروم*

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Full Research Paper

Production of a probiotic camel milk enriched with pomegranate peel powder

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Abstract

In this study, the probiotic bacterium *Lactobacillus acidophilus* with different percentages of pomegranate peel powder (0, 0.5, 1, 1.5, and 2%) were used to produce a functional camel milk-based beverage. The physicochemical, antioxidant and sensory properties of the resulting drinks were evaluated. The results showed that enrichment of milk with pomegranate peel powder improved the survival of probiotic bacteria from 6.95 to 7.35 Log CFU/ml. Addition of pomegranate peel to beverages increased their antioxidant activity from 7 to 85.33, 9.13 to 93.66 and 0.126 to 0.435 as measured by DPPH free radical scavenging, $ABTS^{+}$ free radical scavenging and reduction potency tests, respectively. Rheological studies also showed that the addition of pomegranate peel powder to beverages increased their viscosity from 5.65 to 21.5 mPa. Adding pomegranate peel powder to beverages also changed the color factors (L*, a* and b*) so that increasing the level of pomegranate peel powder increased the red and yellow color in the samples. Also, the results of the sensory evaluation, including taste, appearance, smell and general acceptance indicated that the produced beverages were well-liked by consumers. However, the results of sensory evaluation showed that adding high percentages of pomegranate peel powder to beverages could reduce the sensory acceptance of the final product.

Keywords: Dairy Products, Functional Food, Lactobacillus, Milk, Prebiotics.

Introduction

Camel milk, which is consumed fresh or sour, plays an essential role in the nutrition of desert people. Camel milk is comparable to cow's milk in terms of functional, health and technological characteristics (Salami *et al.*, 2008; Moslehishad *et al.*, 2013). Many health benefits have been reported for camel's milk, such as anti-diabetic, cholesterol-lowering, antihypertensive, antioxidant, and anti-cancer effects. It has also been reported that the allergic effects of camel's milk are much less than those of cow's milk because camel's milk lacks beta-lactoglobulin, an allergenic protein (Shori *et al.*, 2012; Hajian *et al.*, 2020). Due to the importance and numerous benefits of camel milk, the production of functional products based on camel milk recently has received much attention (Solanki and Hati, 2018). Probiotics are living microorganisms that provide therapeutic effect in the digestive tract of living organisms, especially the large intestine. Their benefits include prevention of gastrointestinal disorders, increased immune system, anti-cancer properties, lowering blood cholesterol, improving joint diseases, production of a wide range of enzymes, antimicrobial effects and modification and improvement of lactose metabolism (Saljooghi *et al.*, 2017; El Hatami *et al.*, 2018).

Pomegranate is a fruit that is native to Iran and possesses numerous health properties (Moghadam *et al.*, 2020). This fruit is rich in bioactive compounds such as ELI tannins and anthocyanins. Due to its high nutritional value, pomegranate is considered as a nutraceutical, and today it has attracted much attention from researchers (Sorrenti *et al.*, 2019). Hence, various parts of pomegranate such as fruit juice and extract are widely used as health products (Dogahe *et al.*, 2015). One of the by-products of pomegranate processing is its skin, which is discarded without use or used as animal feed. Pomegranate peel is rich in antioxidant compounds and has antimicrobial properties. Pomegranate peel contains various phenolic

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compounds such as ellagic acid, lignins, catechins, epicatechins and tannins (Ali *et al.*, 2019; Moghadam *et al.*, 2020). Therefore, it has been reported that it can be used in the formulation of dairy products.

Currently, foods containing probiotics are recognized as one of the best functional food products, and their health benefits can even be doubled by enrichment with other compounds (Debon *et al.*, 2010). Many authors have studied different characteristics of probiotic cow's milk (El Hatmi *et al.*, 2018), camel milk (Saljooghi *et al.*, 2017; Mahmoudi, *et al*, 2019), bio-doogh (Ziaolhagh and Jalali, 2017), camel yogurt (Ladjevardi, *et al*., 2016), and yogurt (Ibrahim *et al.*, 2020).

In this study, we aimed to produce a probiotic drink from camel milk by using *Lactobacillus acidophilus*. We used pomegranate peel powder to add to its functional properties.

Materials and Methods

All experiments were performed in the fall and winter of 2019.Camel milk was collected from camel farms in Shahroud city (Taroud village), Iran. All milk samples were transported to the Food Laboratory of Shahroud, University of Medical Sciences at a temperature of 4°C during transport. Milk fat was separated by the method described by Salami et al. (2010) to prepare skimmed milk. First, milk was poured into 250 ml Falcons and then was centrifuged for 20 minutes at 6000 g. Subsequently, the lipid phase was separated from the milk as a supernatant. *L. acidophilus* was obtained as a dry powder from Christin Hansen, Denmark. Then a suitable amount of it was dissolved in 50 ml of sterilized skimmed milk (121°C for 15 minutes) and activated at 42°C for 15 minutes before use. Pomegranate peel powder was purchased from a local market, Shahroud, Iran. 2,2-diphenyl-1-picrylhydrazyl (DPPH) and 2, 2'-Azino-Bis-3-Ethylbenzothiazoline-6-Sulfonic Acid (ABTS) were purchased from Sigma-Aldrich USA. Other materials used in this study were purchased from Merck Germany or Sigma Aldrich, USA and all of them were analysis grade.

Production of beverage samples

Thirteen g of skim milk powder was dissolved in 100 g of distilled water (w/w) and different percentages of pomegranate peel powder (0, 0.5, 1 and 1.5 w / w) were added to it. The activated strain of *L. acidophilus* was then added to the samples in sufficient quantities to obtain an initial cfu/ml of 10^9. After inoculation, the samples were transferred to a hot water bath so that pH could be measured and recorded. All samples were fermented at 42°C until they reached a pH of 4.5, and then the samples were transferred to the refrigerator for three weeks to perform various experiments on them.

Determining the viability of probiotic bacteria

One ml of beverage samples was added to 9 ml of 0.1 ml sterile peptone water and diluted accordingly. The bacteria were cultured in MRS medium, the pH of which had previously been raised to 5.4 with acetic acid. It was then incubated at 37°C for 48 hours. After incubation, the bacteria were counted (Batista *et al.*, 2017).

Evaluation of antioxidant activity

In the present study, the antioxidant activity of the beverages was evaluated by three different methods, including DPPH free radical scavenging method, $ABTS^+$ free radical scavenging and reducing power during storage, which will be explained below.

Free radical scavenging of DPPH

The ability of the samples to inhibit DPPH free radicals was measured by the method described by Tapal and Tiku (2012) with some changes. For this purpose, first, an ethanolic solution of DPPH with a concentration of 0.1 mM was prepared. Then 200 µl of the sample or distilled water as the control sample was added to 2 ml of DPPH solution. After this step, the samples were kept in the dark place for 30 minutes and then centrifuged for 10 minutes at 8000 rpm. Finally, the absorbance of the

samples at 517 nm was determined using a spectrophotometer, and the percentage of free radical scavenging was calculated using the equation (1).

$$Inhibition\ percent = \frac{A_{conrol} - A_{sample}}{A_{control}} \quad (1)$$

Where $A_{control}$ is the absorption of the control sample and A_{sample} is the absorption of the sample.

$ABTS^+$ free radical scavenging

The ability of the samples to inhibit $ABTS^+$ free radicals was determined by mixing 7.4 mM $ABTS^+$ in phosphate buffer with 2.6 mM potassium persulfate. This solution was stored at room temperature for 18 hours before use. The solution was then diluted with distilled water to an absorbance of 0.7 at 734 nm. Then 200 microliters of beverage or distilled water (as control samples) were mixed with 2 ml of $ABTS^+$ solution and their adsorption was read at 734 nm. Finally, the percentage of free radical scavenging ABTS was determined using the following formula (Mohammadian *et al.*, 2020).

$$ABTS\ radical\ scavenging\ activity(\%) = \frac{A_{control} - A_{sample}}{A_{control}} \quad (2)$$

Where $A_{control}$ is the absorption of the control sample and A_{sample} is the absorption of the sample.

Reducing power

The reducing power of the samples was also used to evaluate the antioxidant activity of different samples (Tapal and Tiku, 2012). For this purpose, 0.1 ml of beverage samples were mixed with 2.5 ml of 0.2 M phosphate buffer at pH 6.6 and 2.5 ml of potassium ferric cyanide (0.1%) for 20 minutes and heated at 50°C. Then 2.5 ml of 10% trichloroacetic acid was added to the samples, and after mixing, they were centrifuged at 1500 g for 10 minutes. Then 2.5 ml of the supernatant was mixed with 2.5 ml of distilled water and 0.5 ml of $FeCl_3$ (0.1%), and after 10 minutes, their adsorption at 700 nm was read using a spectrophotometer. Higher absorption indicates higher antioxidant activity.

Viscosity

After 3 weeks of storage, the apparent viscosity of different beverage samples was determined using a rotary viscometer (Model LV-DV3T, Brookfield Engineering Inc., USA) equipped with a SC4-18 spindle at 25°C. For this purpose, 20 ml of each beverage sample was poured into the viscometer cup, and its viscosity was recorded.

Color indices

Colorimetryof beverage samples containing different percentages of pomegranate peel powder was performed using a Hunterlab device (Minolta colorimeter, CR-300, Japan). Components L* (brightness, 0-100), a* (green/red, from -60 to +60) and b* (blue/yellow, from -60 to +60) were recorded (Moghadam *et al.*, 2020).

Sensory evaluation

Sensory characteristics of beverage samples, including taste, odor, appearance and overall acceptance were measured based on a 5-point hedonic method. For this purpose, panelists consisting of 30 untrained people received samples randomly without knowing the type of sample. This test was performed by panelists based on 5-point hedonic test and its scoring was very bad= 1, bad= 2, average= 3, good= 4 and very good= 5 (Saljooghi *et al.*, 2017).

Statistical analysis

This research was carried out in a completely random design. Also, data analysis was performed by one-way analysis of variance (one-way ANOVA) and comparison of mean data with at least three replications by Duncan's multi-range method at 5% probability level using SPSS software version 19.

Results and Discussion

Survival of *l. Acidophilus*

Survival of *L. acidophilus* in a functional camel milk drink containing different concentrations of pomegranate peel powder is shown in Table 1. Significant changes in

bacterial viability were observed in each treatment during 21 days of storage so that the final bacterial population at the end of the storage period in all treatments was less than the first day. Therefore, the survival of *L. acidophilus* in fermented camel milk drink generally decreased during the storage period in all samples. Decreased biological activity of this probiotic bacterium during storage can be due to the low pH of fermented products, which is one of the most important factors in reducing the viability of probiotics. Another reason for the decrease in the viability of probiotic bacteria in fermented beverages can be due to the shock of environmental stress, after inoculation (Nagpal *et al.*, 2012).

The results of this study also showed that the reduction in bacterial viability in samples containing pomegranate peel powder was less than the control sample. In fact, at the end of the storage period, the survival of bacteria in the sample containing pomegranate peel powder was higher, and with increasing the percentage of pomegranate peel powder, more survival was observed. The number of probiotic bacteria in the samples containing pomegranate peel powder was in the standard range (minimum 10^7 cfu/ml). Therefore, it can be said that some compounds in pomegranate peel, such as phenolic compounds, led to increase the survival of probiotic bacteria. In line with the results of this study, other researchers have suggested that adding pomegranate peel extract to a fermented milk drink improves the survival of probiotic bacteria (Al-Hindi and Abd El Ghani, 2020). Other researchers have also suggested that probiotic bacteria, such as *L. acidophilus* can break down tannic acid in pomegranate peel and generate energy from it, which can improve their survival (Ibrahim and Awad, 2020).

Table 1. Comparison of viability (Log cfu/ml) of probiotics in different treatments during storage.

Pomegranate peel powder (%)	Time (day)			
	0	**7**	**14**	**21**
0	9.00 ± 0.00^{a}	8.15 ± 0.07^{b}	7.65 ± 0.00^{a}	6.95 ± 0.21^{a}
0.5	9.00 ± 0.00^{a}	8.20 ± 0.14^{b}	7.70 ± 0.07^{a}	7.00 ± 0.14^{a}
1	9.00 ± 0.00^{a}	8.30 ± 0.14^{ab}	7.75 ± 0.07^{a}	7.15 ± 0.21^{a}
1.5	9.00 ± 0.00^{a}	8.50 ± 0.00^{a}	7.80 ± 0.07^{a}	7.20 ± 0.14^{a}
2	9.00 ± 0.00^{a}	8.55 ± 0.07^{a}	7.95 ± 0.14^{a}	7.35 ± 0.21^{a}

Different superscript letters in each column indicate a statistically significant difference ($p < 0.05$).

Antioxidant properties of beverages

In the present study, three methods were used to evaluate the antioxidant activity of beverage samples during storage. These methods include the percentage of free radical scavenging DPPH, the percentage of free radical scavenging ABTS and also the reducing power test. In all three methods, a larger number indicates greater antioxidant activity. The results are shown in Tables 2, 3 and 4, respectively. As can be seen in these tables, with increasing the percentage of pomegranate peel in beverage formulations, their antioxidant activity has also increased significantly. In all three methods, the lowest antioxidant activity was related to the control sample without pomegranate peel, and the highest antioxidant activity was related to the sample containing 2% of pomegranate peel powder. This increase in antioxidant activity due to the increase in the percentage of pomegranate peel in the beverage formulation might be as a result of the presence of antioxidant compounds in pomegranate peel that have a high ability to inhibit free radicals. The most important of these antioxidants are phenolic compounds in pomegranate peel, the most important of which are catechins, punicalin, gallic acid and ellagic acid (Smaoui *et al.*, 2019). In line with the results of the present study, other researchers have shown that the addition of pomegranate peel powder to yoghurt has significantly inhibited free radicals of $ABTS^{+}$ and DPPH (Kennas *et al.*, 2020). The researchers also claimed that the increase in antioxidant activity due to the addition of pomegranate peel powder is due to the phenolic

contents. These compounds are natural antioxidants in pomegranate peel.

Table 2. The percentage of free radical scavenging DPPH during storage time in different samples.

Pomegranate peel powder (%)	Time (day)			
	0	7	14	21
0	5.20±0.26^{e}	5.33±0.46^{e}	6.26±0.20^{e}	7.00±0.30^{e}
0.5	57.16±0.76^{d}	62.00±2.00^{d}	64.66±1.52^{d}	69.66±1.52^{d}
1	61.16±1.25^{c}	66.33±1.30^{c}	73.16±1.04^{c}	73.66±1.54^{c}
1.5	65.66±2.08^{b}	70.83±1.04^{b}	75.83±1.04^{b}	78.93±0.90^{b}
2	74.83±1.60^{a}	79.16±1.04^{z}	83.50±1.32^{a}	85.33±2.51^{a}

Different superscript letters in each column indicate a statistically significant difference ($p < 0.05$).

Besides, the results showed that the antioxidant activity of beverage samples during storage was significantly increased, which could be due to the occurrence of fermentation by the existing probiotic bacteria. Fermentation has increased the antioxidant activity of the samples. Increased antioxidant activity due to fermentation can be due to the increase in free phenol content in the samples during the fermentation process as well as the enzymatic activity of bacteria in the beverage (Vuong *et al.*, 2006). In fact, during fermentation, phenolic amino acids and phenolic peptides appear to be formed from proteins in milk, which have good antioxidant activity. Previous studies have also shown that the presence of amino acids such as tyrosine (phenolic group), methionine, histidine (imidazole group), tryptophan (indole group), cysteine and proline in camel milk casein may be related to the antioxidant properties during fermentation (Korhonen and Pihlanto, 2006).

Table 3. Investigation of the percentage of $ABTS^{+}$ free radical scavenging during storage time in different samples.

Pomegranate peel powder (%)	Time (day)			
	0	7	14	21
0	6.60±0.55^{e}	7.13±0.32^{e}	8.03±0.15^{e}	9.13±0.32^{e}
0.5	66.00±1.00^{d}	68.66±1.52^{d}	71.33±1.52^{d}	73.66±1.42^{d}
1	71.33±1.52^{c}	75.00±1.00^{c}	78.00±2.00^{c}	82.16±1.25^{c}
1.5	76.16±1.60^{b}	79.16±0.76^{b}	83.66±1.53^{b}	88.33±1.04^{b}
2	85.00±2.00^{a}	89.66±1.50^{a}	91.33±1.56^{a}	93.66±1.52^{a}

Different superscript letters in each column indicate a statistically significant difference ($p < 0.05$).

Table 4. Reduction power (absorption at 700 nm) during storage time in different samples.

Pomegranate peel powder (%)	Time (day)			
	0	7	14	21
0	0.092±0.010^{d}	0.108±0.004^{e}	0.117±0.002^{e}	0.126±0.007^{e}
0.5	0.255±0.007^{c}	0.269±0.002^{d}	0.306±0.006^{d}	0.317±0.002^{d}
1	0.285±0.007^{b}	0.300±0.002^{c}	0.326±0.006^{c}	0.342±0.004^{c}
1.5	0.306±0.008^{b}	0.329±0.012^{b}	0.344±0.005^{b}	0.353±0.002^{b}
2	0.390±0.006^{a}	0.403±0.002^{a}	0.423±0.004^{a}	0.435±0.005^{a}

Different superscript letters in each column indicate a statistically significant difference ($p < 0.05$).

Color factors and viscosity

Color is one of the important characteristics of food products that affect their desirability. Therefore, in the present study, the color factors of beverages, including L*, a* and b* were evaluated, and the results are shown in Table 5. Therefore, in the present study, the color factors of beverages, including L*, a* and b* were evaluated. The results showed that with increasing the percentage of pomegranate peel

in beverages, the lightness or L * of the samples decreased, but the factors a* and b* increased. These results indicate that the increase in pomegranate peel in the drink has led to increase the turbidity, yellowness, and also redness in the samples. This increase in color can be due to the presence of some anthocyanin pigments in pomegranate peel. In line with these results, other researchers showed that increasing the amount of pomegranate peel powder in mung bean protein-based edible films decreased the transparency and also increased the redness and yellowness of the samples (Moghadam *et al*., 2020). In another study, researchers showed that enriching yogurt with pomegranate peel powder altered the color factors of the final product, and therefore pomegranate peel could also be used as a coloring agent in food formulations (Kennas *et al.*, 2020). Other researchers have suggested that enriching chicken broth with pomegranate peel powder reduced the brightness of the samples, which could be due to the dullness of the pomegranate peel (Shrama and Yadav, 2020).

Another important factor in food products is their rheological properties. Therefore, in the present study, the viscosity of beverage samples was examined in the presence of different percentages of pomegranate peel. The results showed that with increasing the amount of pomegranate peel in the formulation, the viscosity of the samples were also increased, which could be due to the presence of some hydrocolloids and polysaccharides, such as pectin in pomegranate peel, which has the property of increasing viscosity (Yang *et al*., 2018). The pectin in pomegranate peel can cause the accumulation of proteins in camel's milk, such as casein and whey proteins, through electrostatic bonding, which can increase the viscosity of the product (Al-Hindi and Abd El Ghani, 2020). In line with these results, the researchers showed that the addition of pomegranate peel powder to yogurt increased the viscosity.

Table 5. Color factors and viscosity of different samples after 3 weeks of storage.

Pomegranate peel powder (%)	L*	a*	b*	Viscosity (mPa)
0	36.57 ± 1.52^{a}	1.17 ± 0.03^{d}	3.48 ± 0.52^{c}	5.65 ± 0.21^{d}
0.5	35.21 ± 0.28^{ab}	1.77 ± 0.10^{d}	4.47 ± 0.41^{c}	7.85 ± 0.49^{d}
1	34.48 ± 0.54^{bc}	3.43 ± 0.16^{c}	5.24 ± 0.32^{c}	11.00 ± 1.41^{c}
1.5	33.70 ± 0.28^{bc}	6.77 ± 0.46^{b}	8.91 ± 1.01^{b}	16.45 ± 1.34^{b}
2	33.10 ± 0.42^{c}	9.00 ± 0.34^{a}	11.62 ± 0.79^{a}	21.50 ± 0.70^{a}

Different superscript letters in each column indicate a statistically significant difference ($p < 0.05$).

Sensory properties

One of the most important characteristics of food products is their sensory properties, which have a great impact on the consumer. Therefore, the sensory characteristics of the produced beverage, including taste, appearance, smell, and general acceptance were evaluated. As shown in Table 6, in all sensory properties, the highest score is related to the control sample without pomegranate peel and the sample with 0.5% of pomegranate peel powder. Therefore, these results showed that adding 0.5% of pomegranate peel powder to the drink did not have side effect on sensory properties. While with increasing the percentage of pomegranate peel powder in the formulation (one per cent and above), the sensory evaluation score decreased slightly. This indicates that the drink containing high percentages of pomegranate peel powder has not been very desirable to consumers. In line with the results of the present study, other researchers who enriched muffin cakes with pomegranate peel powder also stated that cakes containing pomegranate peel powder had lower sensory scores compared to the control sample (Topkaya and Isik, 2019). Another study showed that the enrichment of fermented dairy beverages with pomegranate peel extract and probiotic lactic acid bacteria did not make a significant difference in their sensory properties (Al-Hindi and Abd El Ghani, 2020). Therefore,

the results of the present study have shown that the by-products of the juice industry, such as pomegranate peel, which are considered as waste, can be effectively used to produce useful products.

Table 6. The score of sensory characteristics of different samples after 3 weeks of storage.

Pomegranate peel powder (%)	score			
	Taste	Appearance	Smell	Total acceptance
0	5.00±0.00^{a}	5.00±0.00^{a}	5.00±0.00^{a}	5.00±0.00^{a}
0.5	5.00±0.00^{a}	5.00±0.00^{a}	5.00±0.00^{a}	5.00±0.00^{a}
1	4.80±0.44^{ab}	5.00±0.00^{a}	4.60±0.54^{ab}	4.80±0.44^{a}
1.5	4.40±0.54^{bc}	4.60±0.54^{ab}	4.20±0.44^{b}	4.40±0.54^{ab}
2	4.00±0.00^{c}	4.20±0.44^{b}	3.60±0.54^{c}	4.00±0.70^{b}

Different superscript letters in each column indicate a statistically significant difference ($p < 0.05$).

Conclusion

In the present study, the probiotic bacterium *L. acidophilus*, along with different percentages of pomegranate peel powder as a substance rich in bioactive compounds were used to produce a beneficial health drink based on camel milk. The results showed that the use of pomegranate peel powder improved the survival of probiotics. The results also showed that the enrichment of the drink with different percentages of pomegranate peel powder caused a change in viscosity as well as the color factors of the final product. Fermentation, as well as the use of pomegranate peel powder, improved the antioxidant properties of the beverages produced. Pomegranate peel powder is also a rich combination of bioactive compounds with high antioxidant properties that can be used to improve the antioxidant properties of food products. Also, the results of the sensory evaluation showed that the produced drinks had good desirability in terms of aroma, taste, appearance, smell and general acceptance among consumers. In general, the results of the present study showed that camel milk could be a suitable environment for the growth of probiotics and by using a suitable percentage of pomegranate peel powder a beneficial camel milk drink with desirable biochemical properties along with an increase in antioxidant activity could be produced.

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References

Al-Hindi, R.R., and Abd El Ghani, S. 2020. Production of functional fermented milk beverages supplemented with pomegranate peel extract and probiotic lactic acid bacteria. *J. Food Qual.*, 2020: 4710273.

Ali, A., Chen, Y., Liu, H., Yu, L., Baloch, Z., Khalid, S. and Chen, L. 2019. Starch-based antimicrobial films functionalized by pomegranate peel. *Int. J. Biol. Macromol.*, 129: 1120-1126.

Batista, A.L.D., Silva, R., Cappato, L.P., Ferreira, M.V.S., Nascimento, K.O., Schmiele, M. and Pimentel, T.C. 2017. Developing a synbiotic fermented milk using probiotic bacteria and organic green banana flour. *J. Funct. Foods*, 38: 242-250.

Debon, J., Prudencio, E.S. and Petrus, J.C.C. (2010). Rheological and physico-chemical characterization of prebiotic microfiltered fermented milk. *J. Food Eng.*, 99(2): 128-135.

Dogahe, M.K., Towfighi, A., Khosravi-Darani, K., Dadgar, M., Mortazavian, A.M. and Ahmadi, N. 2013. Influence of pomegranate peel on viability of probiotic bacteria in pomegranate juice. *Iranian J. Nutri. Sci. & Food Technol.*, 7(5): 17-23.

El Hatmi, H., Jrad, Z., Oussaief, O., Nasri, W., Sbissi, I., Khorchani, T. and Canabady-Rochelle, L.L. 2018. Fermentation of dromedary camel (*Camelus dromedarius*) milk by *Enterococcus faecium*, *Streptococcus macedonicus* as a potential alternative of fermented cow milk. *LWT - Food Sci. and Tech.,* 90: 373-380.

Hajian, N., Salami, M., Mohammadian, M., Moghadam, M. and Emam-Djomeh, Z. 2020. Production of low-fat camel milk functional ice creams fortified with camel milk casein and its antioxidant hydrolysates. *Appl. Food Biotechnol.,* 7(2): 95-102.

Ibrahim, A., Awad, S. and El-Sayed, M. 2020. Impact of pomegranate peel as prebiotic in bio-yoghurt. *Br. Food J.,* 122(9): 2911-2926.

Kennas, A., Amellal-Chibane, H., Kessal, F. and Halladj, F. 2020. Effect of pomegranate peel and honey fortification on physicochemical, physical, microbiological and antioxidant properties of yoghurt powder. *J. Saudi Soc. Agric. Sci.,* 19(1): 99-108.

Korhonen, H. and Pihlanto, A. 2006. Bioactive peptides: production and functionality. *Int. Dairy J.,* 16(9): 945-960.

Ladjevardi, Z.S., Yarmand, M., Emam-Djomeh, Z., Niasari-Naslaji, A. 2016. Physicochemical properties and viability of probiotic bacteria of functional synbiotic camel yogurt affected by oat β-glucan during storage. *J. Agr. Sci. Tech.* 18(5):1233-1246.

Mahmoudi, M., Khomeiri, M., Saeidi, M., Kashaninejad, M., Davoodi, H. 2019. Study of Potential Probiotic Properties of Lactic Acid Bacteria Isolated from Raw and Traditional Fermented Camel Milk. *J. Agr. Sci. Tech.,* 21(5):1161-1172.

Moghadam, M., Salami, M., Mohammadian, M., Khodadadi, M. and Emam-Djomeh, Z. 2020. Development of antioxidant edible films based on mung bean protein enriched with pomegranate peel. *Food Hydrocolloids,* 104: 105735.

Mohammadian, M., Moghaddam, A.D., Sharifan, A., Dabaghi, P. and Hadi, S. 2020. Nanocomplexes of whey protein fibrillar aggregates and quercetin as novel multi-functional biopolymeric ingredients: interaction, chemical structure, and bio-functionality. *J. Iran. Chem. Soc.,* 17: 2481-2492.

Moslehishad, M., Mirdamadi, S., Ehsani, M.R., Ezzatpanah, H. and Moosavi-Movahedi, A.A. 2013. The proteolytic activity of selected lactic acid bacteria in fermenting cow's and camel's milk and the resultant sensory characteristics of the products. *Int. J. Dairy Technol.,* 66(2): 279-285.

Nagpal, R., Kumar, A., Kumar, M., Behare, P.V., Jain, S. and Yadav, H. 2012. Probiotics, their health benefits and applications for developing healthier foods: a review. *FEMS Microbiol. Lett.,* 334(1): 1-15.

Salami, M., Moosavi-Movahedi, A.A., Ehsani, M.R., Yousefi, R., Haertle, T., Chobert, J.M. and Pourtakdoost , S. 2010. Improvement of the antimicrobial and antioxidant activities of camel and bovine whey proteins by limited proteolysis. *J. Agric. Food Chem.,* 58(6): 3297-3302.

Salami, M., Yousefi, R., Ehsani, M.R., Dalgalarrondo, M., Chobert, J.M., Haertle, T. *et al*. 2008. Kinetic characterization of hydrolysis of camel and bovine milk proteins by pancreatic enzymes. *Int. Dairy J.,* 18(12): 1097-1102.

Saljooghi, S., Mansouri-Najand, L., Ebrahimnejad, H., Doostan, F. and Askari, N. 2017. Microbiological, biochemical and organoleptic properties of fermented-probiotic drink produced from camel milk. *Veterinary Research Forum,* 8(4): 313.

Sharma, P. and Yadav, S. 2020. Effect of Incorporation of Pomegranate Peel and Bagasse Powder and Their Extracts on Quality Characteristics of Chicken Meat Patties. *Food Sci. Animal Res.,* 40(3): 388.

Shori, A.B. 2012 Comparative study of chemical composition, isolation and identification of micro-flora in traditional fermented camel milk products: Gariss, Suusac, and Shubat. *J. Saudi Soc. Agric. Sci.,* 11(2): 79-88.

Smaoui, S., Hlima, H.B., Mtibaa, A.C., Fourati, M. *et al*. 2019. Pomegranate peel as phenolic compounds source: Advanced analytical strategies and practical use in meat products. *Meat Sci.*, 158: 107914.

Solanki, D. and Hati, S. 2018. Fermented camel milk: A Review on its bio-functional properties. *Emirates J. Food and Agric.*, 30(4): 268-274.

Sorrenti, V., Randazzo, C.L., Caggia, C., Ballistreri, G., Romeo, F.V., Fabroni, S. and Vanella, L. (2019). Beneficial effects of pomegranate peel extract and probiotics on pre-adipocyte differentiation. *Frontiers in Microbiology*, 10: 660.

Tapal, A., and Tiku, P. 2012. Complexation of curcumin with soy protein isolate and its implications on solubility and stability of curcumin. *Food Chem.*, 130(4): 960-965.

Topkaya, C. and Isik, F. 2019. Effects of pomegranate peel supplementation on chemical, physical, and nutritional properties of muffin cakes. *J. Food Process. Preserv.*, 43(6): 13868.

Vuong, T., Martin, L. and Matar, C. 2006. Antioxidant activity of fermented berry juices and their effects on nitric oxide and tumor necrosis factor-alpha production in macrophages 264.7 gamma no (–) cell line. *J. Food Biochem.*, 30(3): 249-268.

Yang, X., Nisar, T., Hou, Y., Gou, X., Sun, L. and Guo, Y. 2018. Pomegranate peel pectin can be used as an effective emulsifier. *Food Hydrocolloids*, 85: 30-38.

Ziaolhagh, S.H. and Jalali, H. 2017. Physicochemical properties and survivability of probiotics in bio-doogh containing wild thyme essence and xanthan gum. *Int. Food Res. J.*, 24(4): 1805-1810.

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تولید شیر شتر پروبیوتیک غنی‌سازی شده با پودر پوست انار

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چکیده

در این مطالعه، از باکتری پروبیوتیک *Lactobacillus acidophilus* با درصدهای مختلف پودر پوست انار (صفر، ۰/۵، ۱ ، ۱/۵ و ۲ درصد) برای تولید یک نوشیدنی فراسودمند مبتنی بر شیر شتر استفاده شد. خصوصیات فیزیکوشیمیایی، آنتی‌اکسیدانی و حسی نوشیدنی‌های حاصل ارزیابی شد. نتایج نشان داد که غنی‌سازی شیر با پودر پوست انار باعث بهبود بقای باکتری‌های پروبیوتیک از ۶/۹۵ به ۷/۳۵ Log CFU/ml می‌شود. با افزودن پوست انار به نوشیدنی‌ها، فعالیت آنتی‌اکسیدانی آن‌ها در روش مهار رادیکال‌های آزاد DPPH، مهار رادیکال‌های آزاد ABTS و قدرت احیاکنندگی، به‌ترتیب از ۷ به ۸۵/۳۳، ۹/۱۳ به ۹۳/۶۶ و ۰/۱۲۶ به ۰/۴۳۵ افزایش یافت. مطالعات رئولوژیکی نشان داد که افزودن پودر پوست انار به نوشیدنی‌ها باعث افزایش ویسکوزیته آن‌ها از ۵/۶۵ به ۲۱/۵ mPa می‌شود. افزودن پودر پوست انار همچنین باعث تغییر عوامل رنگ (L*، a* و b*) شد و افزایش پودر پوست انار رنگ قرمز و زرد در نمونه‌ها را افزایش داد. همچنین، نتایج ارزیابی حسی، از جمله طعم، ظاهر، بو و پذیرش کلی نشان داد که نوشیدنی‌های تولید شده مورد پسند مصرف‌کنندگان قرار گرفته‌اند. با این حال، نتایج ارزیابی حسی نشان داد که افزودن درصد بالای پودر پوست انار به نوشیدنی‌ها می‌تواند میزان پذیرش حسی محصول نهایی را کاهش دهد.

واژه‌های کلیدی: پروبیوتیک، پری‌بیوتیک، شیر، غذاهای فراسودمند، فراورده‌های لبنی، لاکتوباسیلوس

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Full Research Paper

Simulation of fuzzy temperature controller during infrared dry blanching and dehydration of apple slices by intermittent heating method

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Abstract

In this study, fuzzy temperature controller was designed using stepwise heating during the infrared irradiation of apple with intermittent heating method. For this purpose, the dry blanching process and dehydration of apple slices were examined at three temperatures of 70, 75 and 80°C based on inactivity of polyphenol oxidase enzyme (PPO) as blanching speed index and vitamin C preservation as maintaining quality index. The samples were removed from the infrared dryer in 2- minute intervals to separate the time required for the dry blanching process and dehydration of apple slices. For all temperatures, the heating process was continued until no sign of color change stemming from catechol reagent (adequacy of blanching). Finally, the fuzzy controller of the temperature with the feedback loop was designed, simulated, and implemented by comparing two first and second order transfer functions in MATLAB software. Simulation efficiency was examined using the indices of integral squared error (ISE), integral absolute error (IAE), integral time-weighted absolute error (ITAE) and steady state error (e_{ss}). These parameters must be close to zero. The results revealed that the temperature of 80°C and time of 15 minutes were appropriate for blanching operation and the temperature of 70°C was appropriate for dehydration. The simulation results confirmed that the higher order of the transfer function led to a faster response, but an increase in oscillations and reduction in the stability were not appropriate. For the first-order transfer function, the values of efficiency indices, including (ISE), (IAE) and (ITAE) were calculated to be 0.760, 0.821 and 0.589, respectively, of the second-order transfer function. The simulation indicated the reliability of the fuzzy control model and showed an acceptable computational efficiency, since the fuzzy rule test during simulation showed high sensitivity to maintain steady state error (e_{ss}) close to zero.

Keywords: Infrared, Apple, Intermittent heating, Fuzzy controller, Simulation.

Introduction

In recent years, a significant increase in production volume has led to extensive effort to develop controller and automation systems in the food industry, and for this purpose, computer controllers are considered (Odetunji & Kehinde, 2005). The control of food processes due to the heterogeneity in the food product, the lack of accurate sensors to record key variables of the process, the sensitivity of the qualitative characteristics and the interaction of the control variables is relatively difficult. In the control of food processes, the main goal is food safety, high quality, minimal processing, high efficiency with minimal cost, and finally reduced cost (Mittal, 1996; Linko & Linko, 1998). The energy consumed during the process is very important from the point of view of engineering and economics. For consumers, the health, appearance, and sensory characteristics of the final product are very important. Thus, the main goal of a control system is to maintain maximum nutrient and safety of the product while optimizing energy consumption (Rywotycki, 2002).

Nowadays, the use of infrared heating for the drying of food due to its high productivity (between 80 and 90%) has gained popularity (Jaturonglumlert and Kiatsiriroat, 2010). One of the modern processes in the food industry is simultaneous infrared dry-blanching and dehydration (SIRDBD) of fruits and vegetables, which increase the quality of the final product

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and reduce environmental contamination (Zhu *et al*., 2010). Dried fruits and vegetables have been considered as a snack or as ready-to-eat products (Velickova *et al.*, 2014). In this regard, apples play an important role in the fruit basket of consumers. In addition to improving shelf-life, dried apple is also used in producing other products such as baby food (Doymaz, 2010).

Infrared heating is feasible in two continuous and intermittent methods. During continuous heating, the intensity of the radiation is kept constant and the high intensity of the radiation can lead to adverse changes in the color of the product. The use of intermittent heating is a solution to prevent undesirable quality changes during irradiation. In this method, the surface temperature of the product is kept constant. Thus, the advantage of the intermittent state is to save energy and improve the quality of the final product (Zhu and Pan, 2009). One advantage of infrared heating technology in the food industry is that its equipment has the capability of compression and automation with a high degree of control based on process parameters. The fast response time (low thermal inertia) makes the control of the infrared thermal processes easy and fast (Jun *et al.*, 2010).

The performance of many thermal processing operations for food products is strongly dependent on human control and monitoring. Some process control variables are unclear subjective and cannot be expressed merely as numerical data. However, human perceptions can be used in the form of fuzzy techniques presenting experimental data and then used to apply the control measures (Brown *et al*., 2001). The fuzzy logic tool is a mathematical method used to examine the phenomena, providing a structure with human reasoning capability. In fact, this tool provides the capability to express the probability of occurrence of a phenomenon verbally (such as high, low, moderate, and often). It provides diagnostic power in modeling. This method uses the theory of probabilities to explain the occurrence of a phenomenon. Thus, it can be a form of probabilistic modeling used in many engineering areas (Liu & Li, 2005).

Fuzzy logic has high popularity in achieving design and simulation of process control systems, especially in the food processing industry (Lao *et al.*, 2012). This method has provided an appropriate tool to deal with the uncertainties in food processes (Trystram, 2012). Fuzzy control is performed with this goal that it closes more to human thinking and education practices. This leads to automatic control of the process in the form of qualitative expressions such as low temperature, high rate of error other outputs in computer systems (Rywotycki, 2002). In fact, the main characteristic of fuzzy systems is that they are capable to provide the behavior of complex systems in the form of expressive formulations (Birle *et al.*, 2013).

Most of the fuzzy studies published in the food industry focused on controlling the process (Perrot *et al*., 2006). The process of dry-blanching and dehydration with infrared irradiation has not been investigated so far in the form of fuzzy modeling and the design of an automatic temperature controller. Non-linear models have been examined only in other drying methods and infrared heating control related to other products has been examined. For example, Brown et al. (2001) developed a fuzzy controller for the process of roasting wheat seeds with an infrared beam. Control rules were written using observations of the experiment and interviews with system operators. The results showed that in all experiments, the fuzzy controller could act as an operator and react quickly and predictably to process conditions. Some studies have also been conducted on control measures for drying in other thermal methods. Menlik et al. (2010) examined the behavior of apple slices under the effect of the freeze drying process using artificial neural network. Li et al. (2010) examined the control of drying the carrot slices in the microwave using fuzzy logic. Their results revealed that the quality of carrots was not greatly damaged by the fuzzy control strategy and the loss of time and energy was prevented. Cuccurullo et al. (2012) developed a microwave system for drying apple slices with temperature online control. The control system

using infrared thermography was used to control the temperature by detecting the maximum instantaneous temperature among several product slices rather than one cut. In the latest studies, Sturm et al. (2014) studied the impact of two different control strategies, such as constant air temperature and constant product temperature on the quality and behavior of apple drying by the air displacement method. Vega et al. (2016) simulated the process of drying apple slices by hot air using feedback control system of the surface temperature. The results of these investigations revealed that the active application of product temperature control can prevent the product from overheating and thus prevent its degradation. Based on Luz et al. (2010) and Guillaume and Charnomordic (2001) in the feedback system, through comparing outputs and inputs and using their differences as a control tool, the pre-determined relationship between output and input is always maintained. If such systems operate without human intervention, it would be called as automatic control system.

In this study, infrared irradiation operation was programmed using an intermittent heating method through software for automatic temperature control and fuzzy control. For this purpose, in the first step, the optimum temperature for each operation of blanching and dehydration of apple product was determined separately based on a nutritional quality index (vitamin C) and the time needed to deactivate the polyphenol oxidase enzyme (PPO). Then, the appropriate timetable to change the temperature was determined. In the second step, the fuzzy controller was developed for controlling the temperature in blanching and dehydration, and its performance was simulated in the simulation environment (SIMULINK). This automation was performed for using the appropriate temperature for blanching and dehydration with the aim of improving the heating process, reducing the adverse qualitative effects, and finally increasing the process speed.

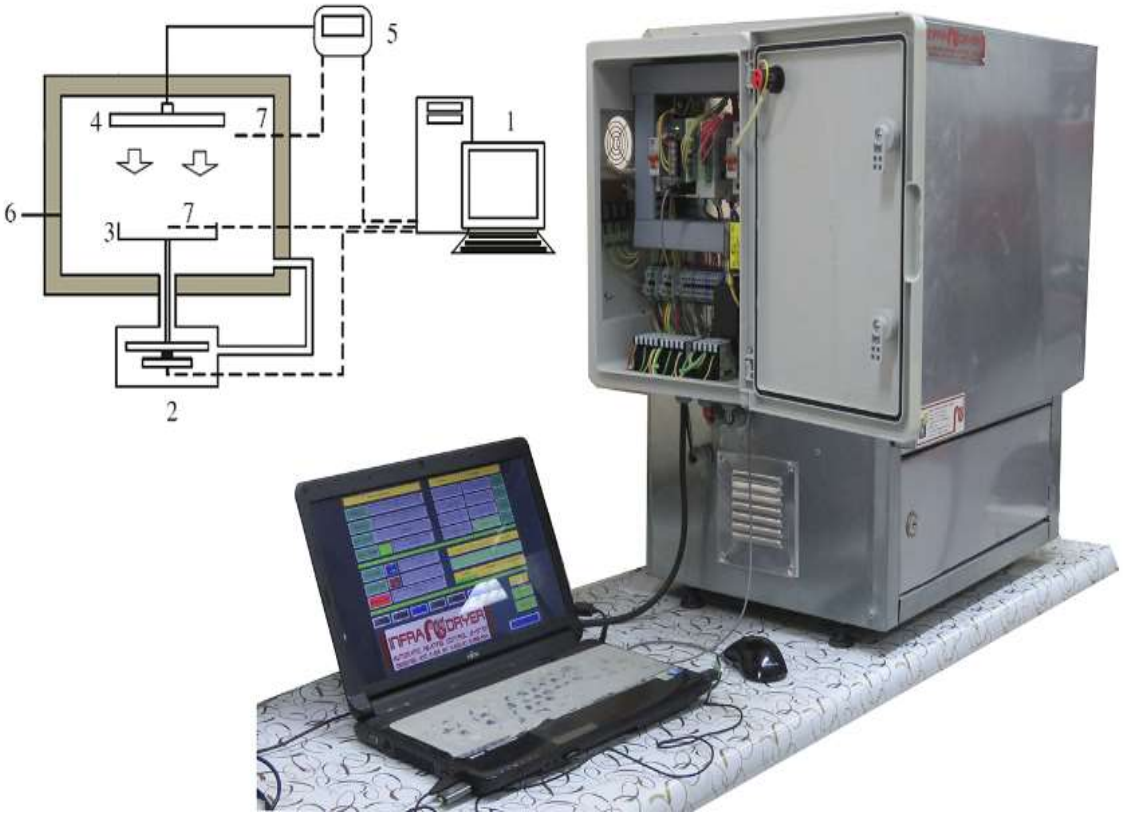

Fig. 1. Infrared drying system and its accessories, (1) computer (2) balance (3) specimen tray (4) infrared ceramic radiator (5) programmable logic controller (6) drying chamber (7) thermocouples

Materials and Methods

Preparation of Apple Slices

The apple (*Golden Delicious* variety) was kept at 0± 1°C and relative humidity of 90-95% (Acevedo *et al.*, 2008). After peeling the specimens, they were prepared in three sizes as slices with thicknesses of 5, 9 and 13 mm and 20 mm in diameter. The average of moisture content for apples was measured by the oven (Binder FD53) at 103° C for 24 hours and it was equal to 84± 1% based on the wet weight (AOAC, 2000).

Infrared heating equipment

Figure 1 shows the components of the automatic drying system (Liu *et al.*, 2014). This system can monitor the weight and control the temperature during irradiation. The surface temperature of the specimen in the drying chamber is continuously controlled using the K type thermocouple and the programmable logic controller (PLC). For testing, intermittent irradiation, operation was performed at three constant surface temperatures equal to 70, 75, 80°C.

Process monitoring

Figure 2 shows different sections designed by the ADP 6.6.1 software manufactured by Beijer Company, Sweden. These sections include the temperature setting and monitoring page, weight recording and power setting (Figure 2 a) and the settings designed to perform the stepwise process of temperature (Figure 2 b). SoftPanel 6.6.1 software was used to run the designed program. Based on Octavia et al. (2014), the automatic temperature control system can be run over time using the user panel (Figure 2 b).

Fig. 2. Different sections designed by ADP software, temperature, power and weight setting and monitoring (a), settings for a stepwise process at different temperatures (b)

Product quality characteristics

A) Enzymatic Activity Investigation (Speed or Adequacy of blanching)

To evaluate the enzymatic activity of polyphenol oxidase (PPO) and its effect on the product color, apple slices were removed from the infrared dryer in 2- minute intervals. Then, according to the method proposed by Lee et al (2002), 1 ml of catechol reagent was sprayed on the sample surface and the sample was

immediately kept at 25°C (ambient temperature) for 15 minutes. To prepare a 0.1 molar catechol solution, 1.1011 gram catechol powder was dissolved in 100 ml distilled water in an Erlenmeyer container to obtain the given concentration level. As can be seen in Figure 3, the enzymatic activity is intensified in the presence of catechol precursor and its effect is manifested in the form of browning. The heating process was continued till the time no sign of color change stemming from catechol reagent addition on sample was observable. Consequently, the sample's color transformation was also scanned and image acquisition was performed. Flatbed scanner (HP Scanjet G2710), made in USA, was used according to the method of Romani et al (2009). The images featured a 300 dpi quality and were saved in TIFF-24 bit format. Color analysis of the obtained images was carried out in color spaces L*a*b* by the use of "color space convertor" plugin in ImageJ software, version 1.6.0.

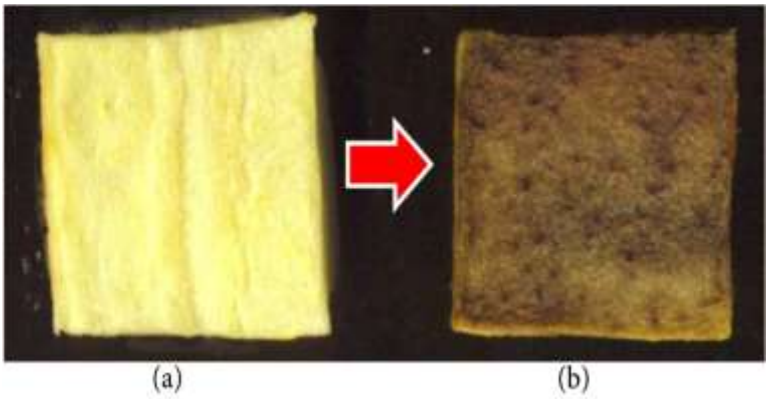

Fig. 3. Enzymatic activity investigation, (a) Apple slice (5 mm) heated using 70°C for 30 min. (b) intensification of enzymatic activity and sample's change of color as a result of catechol reagent spray and the sample's final color after 15 min at 25°C.

The browning index (BI) of the sample was calculated corresponding to the method proposed by Maskan (2001) based on equation (1) before making use of catechol reagent (BI_0) and in the presence of catechol precursor (BI_c). The variable "x" given in the equation is calculated based on equation (2). The differential of the browning index ($\Delta BI = BI_c - BI_0$) was computed as the enzymatic activity residual. Finally, the time required for the enzyme degradation until attaining a zero residual between the browning index ($\Delta BI=0$) was taken into account.

$$BI = \frac{\left[100(x-0.31)\right]}{0.17} \quad (1)$$

$$x = \frac{(a+1.75L)}{(5.645L+a-3.012b)} \quad (2)$$

B) Vitamin C content (maintaining quality index)

Vitamin C content determination of the processed sample and degradation modeling was carried out similar to the method of Timoumi et al. (2007) based on the titration by 2, 6-Dichlorophenol-Indophenol (DCPIP). The model can be defined as stated in equation (3). In this equation, C denotes Vitamin C content and k is the degradation kinetic constant (min^{-1}).

$$Ln\left(\frac{C}{C_0}\right) = -kt \quad (3)$$

Controller system design with the feedback loop

The fuzzy controller was designed as a classical feedback control technique following the method of Aguilar et al. (2012). As shown in Figure (4), by considering the set temperature (r), the error (e), command (u), and output (y),

one fuzzy controller with a feedback loop as considered.

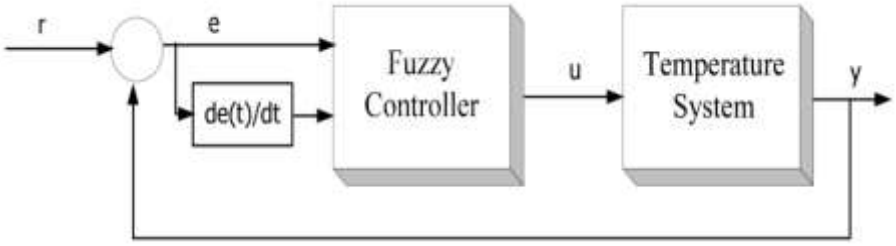

Fig. 4. The block diagram of fuzzy temperature controller with feedback loop (Aguilar *et al.*, 2012)

In the controlling operation of the temperature, two parameters as error (e) and the error variations (de) are important for control function and so the control decisions were made based on the results derived from equation (4). Based on Sharma (2011), the goal of designing a controller is to achieve zero-level error ($e \rightarrow 0$) with the time tendency to infinity ($t \rightarrow \infty$). The error variations (de) can also be calculated based on equation (5). In the fuzzy controller, error (e) and error variations (de) were used as inputs. The output command variations (du) from the controller were considered as output and can be calculated using equation (6)

$$e(t) = r(t) - y(t) \quad (4)$$

$$de = e(t) - e(t-1) \quad (5)$$

$$du = u(t) - u(t-1) \quad (6)$$

Fuzzy temperature controller design (FLC)

A) Membership function

To set the histogram of membership functions, the triangular membership function (trimf) as the simplest function was considered for inputs and outputs. This function has three different locational points of a, b, and c, whose variations are shown in Figure 5, and can be calculated by Equation 7 as proposed by Sivanandam et al. (2007) and Singh et al. (2012). Figure 6 shows the setting of membership functions for inputs (Figure 6a) and output (Figure 6b) in the fuzzy temperature controller

$$f(x;a,b,c) = \begin{cases} 0 & x < a \\ \frac{x-a}{b-a} & a \le x < b \\ \frac{c-x}{c-b} & b \le x \le c \\ 0 & c < x \end{cases} \quad (7)$$

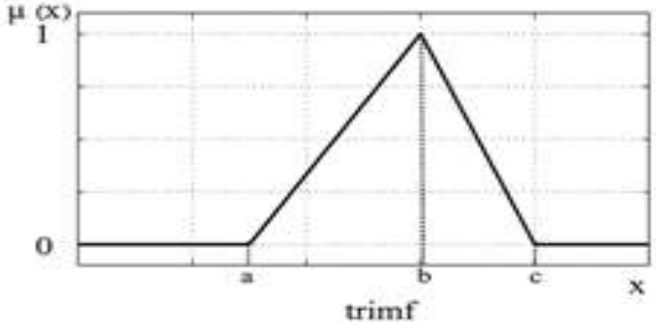

Fig. 5.Triangular polynomial membership function

B. Description of Linguistic variables

The linguistic description of the fuzzy system variables is presented in Table 1, based on the results of (4) and (5).

Figure 7 shows the temperature control system based on error and error variations in different modes. Different modes in this Figure include: a). The error in the form of LN and

error variations in the form of LP indicate that the temperature is much higher than the considered level and the error rate is increasing b) error in the form of SN and error variations in the form of SP indicate that the temperature is somewhat higher than the set value and is decreasing to reach the considered level, c) the error in the form of zero and the error variations in the form of SN indicate that the temperature is very close to the considered temperature but it is increasing d) the error in the form of zero and the error variations in the form of SP indicate that the temperature is very close to the considered temperature but it is decreasing e) The error in the form of SP and the error variations in the form of SP indicate that the temperature is lower than the considered level and is more decreasing f) The error in the form of LP and error variations in the form of LN indicate the temperature is much lower than the considered level, but it is increasing

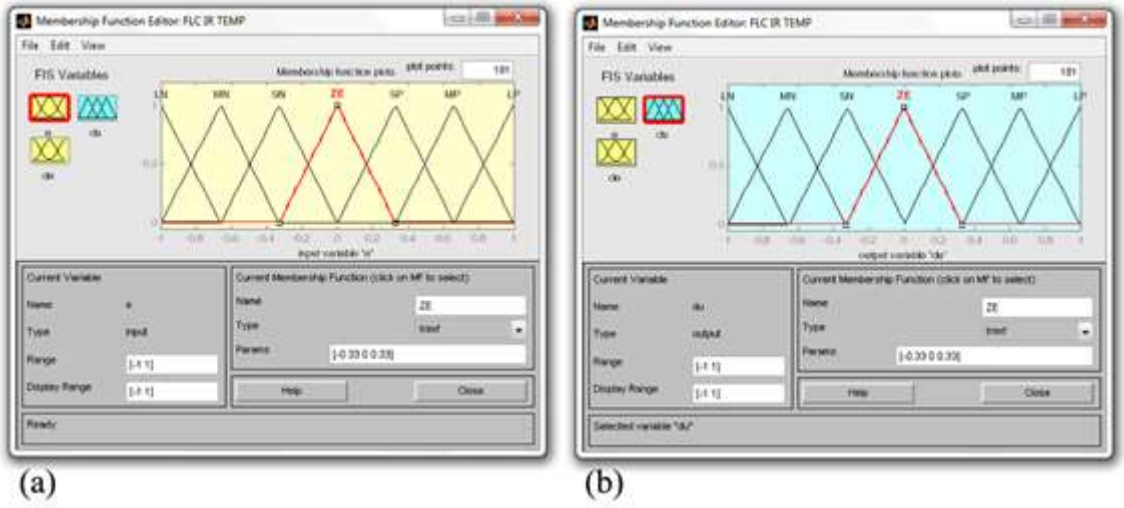

Fig. 6. Histogram of membership functions for the error input (e) and the error variations (de) (a) and the output command difference (du) (b)

Table 1- Error Linguistic scale (e), error variations (de), and output command variations (du) in temperature setting

Row	Symbol	Term
1	LN	Large Negative
2	MN	Medium Negative
3	SN	Small Negative
4	ZE	Zero
5	SP	Small Positive
6	MP	Medium Positive
7	LP	Large Positive

C) The setting of rules for fuzzy control

A set of fuzzy rules was considered verbally for system temperature control as equation model 8 in the editor of the fuzzy rule setting. These rules were considered in such a way that process temperature to remain slightly lower and close to the set temperature, and then, the heat is fed slowly to correct the error. The matrix of rules for the 49 possible rules is shown in Table 2. Figure 8 illustrates the three-dimensional diagram derived from the rules of the temperature controller of fuzzy model.

$$If\ e(t)\ is\ LP\ and\ de(t)\ is\ SP,\ then\ du(t)\ is\ LP. \quad (8)$$

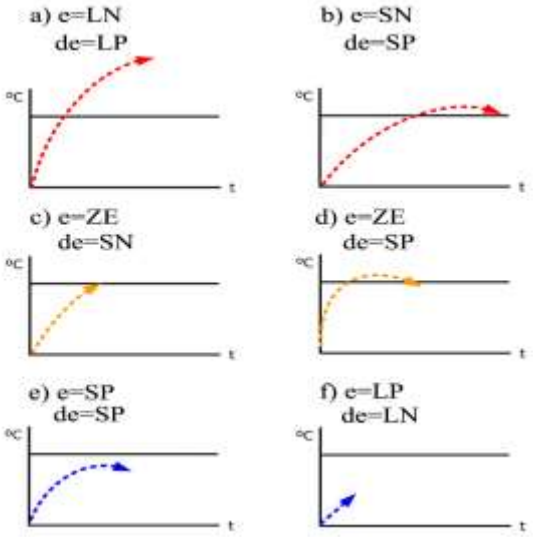

Fig.7. Temperature setting system in different modes for error (e) and error variations (de)

Table 2- Matrix of writing rule for temperature control

	de						
e	**LN**	**MN**	**SN**	**ZE**	**SP**	**MP**	**LP**
LP	LN	LN	LN	LP	LP	LP	LP
MP	LN	LN	LN	MP	LP	LP	LP
SP	LN	LN	LN	SP	MP	LP	LP
ZE	LN	LN	LN	ZE	SP	MP	LP
SN	LN	LN	LN	SN	ZE	SP	MP
MN	LN	LN	LN	MN	SN	ZE	SP
LN	LN	LN	LN	LN	MN	SN	ZE

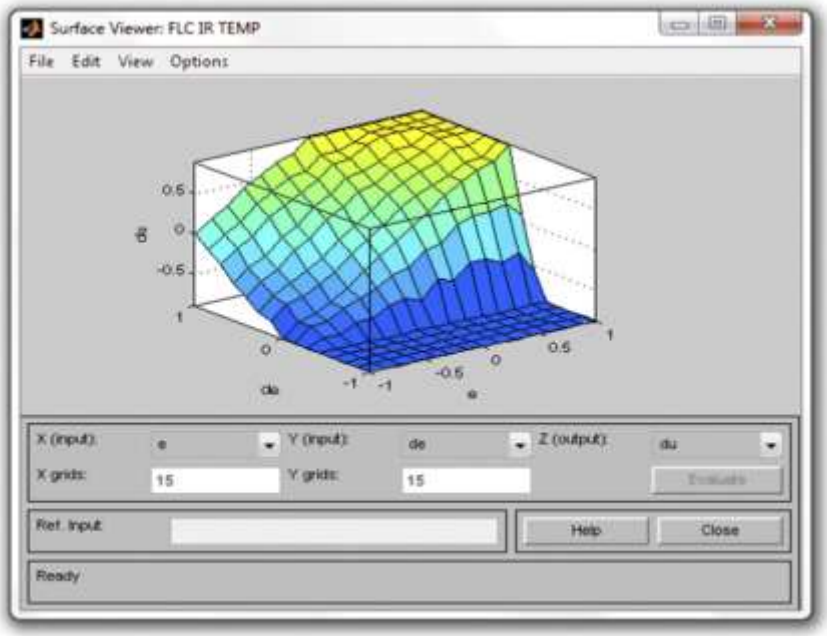

Fig. 8. The three-dimensional diagram of error (e), error variation (de) and command difference (du) based on fuzzy rules

Simulation and implementation of fuzzy temperature controller

The simulation was performed in the SIMULINK environment in MATLAB software. The output of the controller system was recorded dynamically based on two transfer functions. According to Berk et al. (2010), the first-order transfer function was considered as equation 9 and the second-order transfer function was considered as equation 10. These two functions were compared with each other. In these equations, S is the operator. The parameters of this simulation are listed in Table 3.

$$G(s) = \frac{1.2}{10s + 1} \quad (9)$$

$$G(s) = \frac{1}{25s^2 + 5s + 1} \quad (10)$$

Table 3- Simulation model parameters

Simulation parameter	value
Solver	ode45
RelTol	1e-3
Refine	1
MaxOrder	5
ZeroCross	on

The fuzzy controller was simulated and implemented following the final model shown in Figure 9 by testing the first-order and zero-order functions. Figure 10 shows the structure of the fuzzy controller model in the simulation.

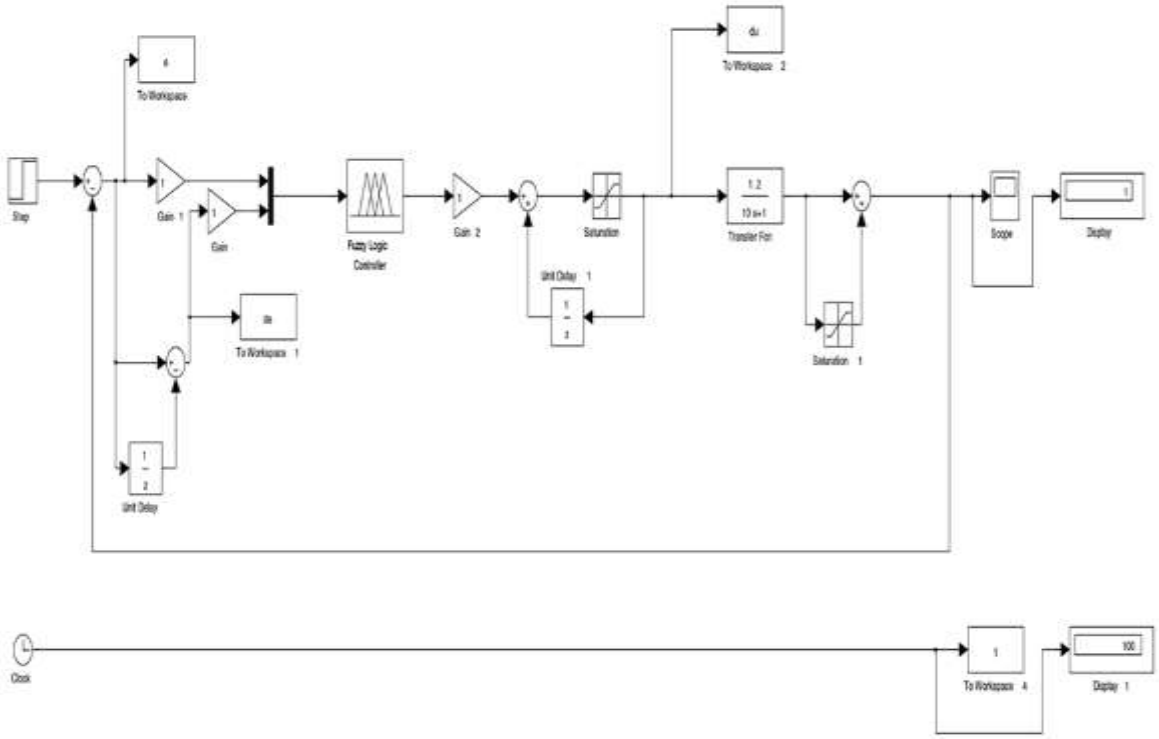

Fig.9. Block diagram of closed loop simulated model for the implementation of fuzzy temperature controller

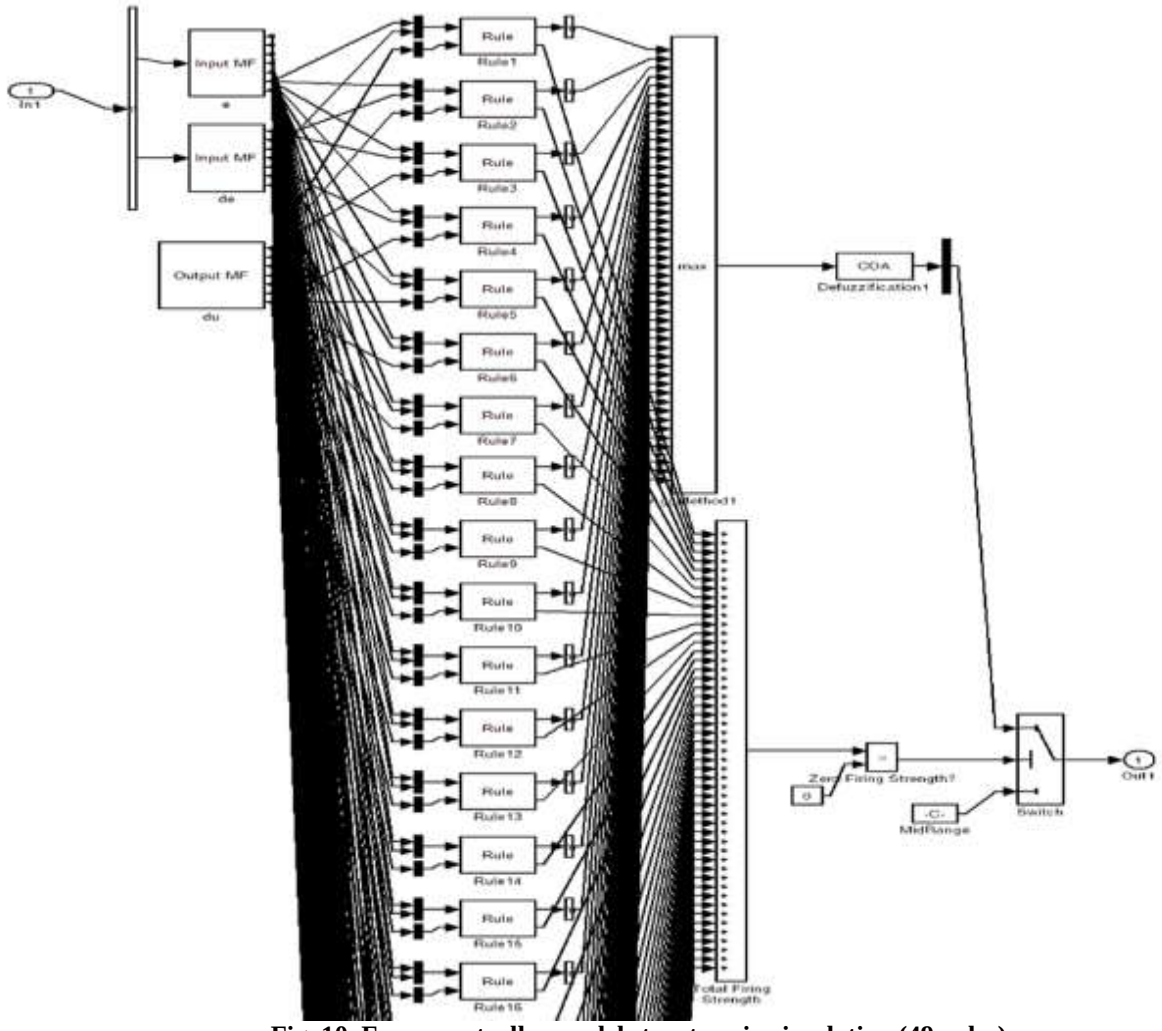

Fig. 10. Fuzzy controller model structure in simulation (49 rules)

Simulation efficiency

According to Pirrello et al. (2001), the controller efficiency was examined using Integral Squared Error (ISE) obtained by equation (11), Integral Absolute Error (IAE) by equation (12), and Integral Time-weighted Absolute Error (ITAE) by equation (13). Also, based on Vaishnav and Khan (2007), steady state error (ess) was also evaluated and compared for two transfer functions.

$$ISE = \int_0^\infty e^2 dt \tag{11}$$

$$IAE = \int_0^\infty |e| dt \tag{12}$$

$$ITAE = \int_0^\infty t\,|e| dt \tag{13}$$

Results and discussion

Blanching time and vitamin degradation

A) The time required for Blanching

Figure 11 demonstrates the mean comparisons of the time required for enzyme inactivation of apple slices in various thicknesses and various temperatures studied ($P<0.05$). As can be seen, the time required for polyphenol oxidase is significantly decreased with the increase in temperature or reduction in thickness. In line with this, Zhu et al. (2010) expressed that enzyme inactivation takes place faster generally in IR radiation on thinner slices and/or in higher surface temperatures. As

reported by Lin et al. (2009), the increase in thickness causes a reduction in the uniform distribution of temperature inside the product. Many of the researchers have reported rapid heating rates and temperature as factors influencing the enzyme inactivation (MacDonald & Schaschke, 2000; Bingol *et al*., 2012; Jeevitha *et al*., 2013; Bingol *et al.*, 2014 and Guiamba *et al.*, 2015).

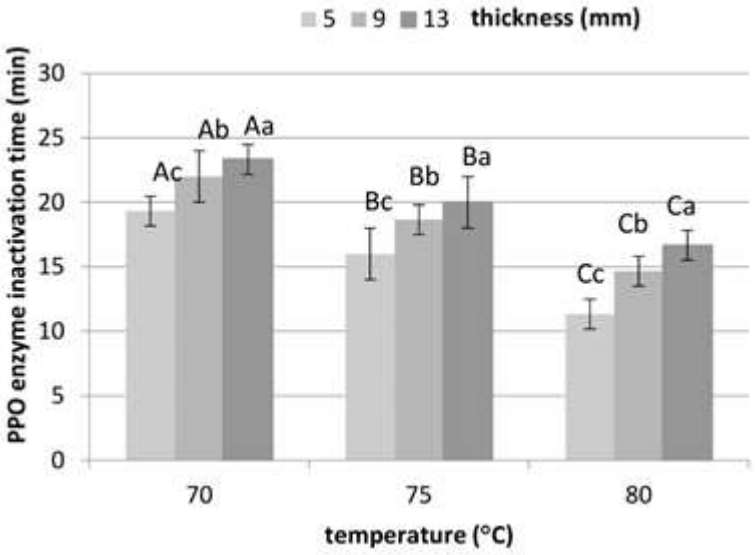

Fig. 11. Statistical comparison of the time required for polyphenol oxidase inactivation in various treatments, the capital letters are comparisons between various temperatures and the small letters are comparisons between various thicknesses (P<0.05)

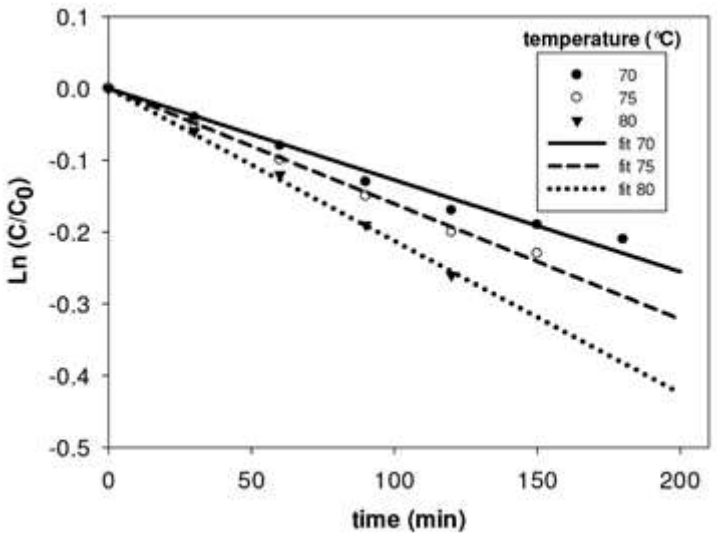

Fig. 12. Vitamin C degradation kinetic model fit estimation in various radiation temperatures for a thickness of 5mm

B) Vitamin C degradation

Figure 12 shows the diagram of kinetic model fit estimations for ascorbic acid degradation in various temperatures (thickness= 5mm). Table 4 summarizes the model's fit estimations on the empirical data in various treatments along with the statistical comparison of the degradation kinetic constants (k). In terms of the kinetic constant (k), the difference between the studied temperatures

(70, 75, and 80°C) was statistically significant (P<0.05) and the vitamin degradation kinetic constant (k) was found elevated with the increase in temperature. Joshi et al. (2011) reported that the use of Vitamin C, for its protection against polyphenols oxidation, as the major reason behind ascorbic acid oxidation under high temperature conditions. In the present study, the vitamin content of the sample was found almost similar in shorter times at various temperatures (Figure 12-in 30 minutes). Thus, the use of high temperature and short time (HTST), meanwhile accelerating the enzyme degradation and annihilation of oxidative enzymes can be appropriate in preserving the product quality. Therefore, it was found that the proper thickness for quickly blanching and the lower dependency of vitamin degradation to temperature was the thickness of 5 mm. These results are in compliance with what was found by Uddin *et al*., 2001; Chua *et al*., 2003; Timoumi *et al*., 2007; Wu *et al*., 2010; Kaya *et al.,* 2010; and, Mrad *et al*., 2012.

Table 4. Vitamin C degradation model fit estimations over the experimental data obtained from various treatments

Thickness	Temperature (°C)	k (min^{-1})	Adj.R^2	RMSE
5	70	-0.001275^{Ca}	0.9758	0.01237
	75	-0.001606^{Ba}	0.9944	0.006606
	80	-0.002122^{Aa}	0.9977	0.004916
9	70	-0.001152^{Cb}	0.9981	0.005043
	75	-0.001533^{Bb}	0.9953	0.008689
	80	-0.00196^{Ab}	0.9933	0.01191
13	70	-0.0011^{Cb}	0.9967	0.007898
	75	-0.00149^{Bb}	0.9953	0.0105
	80	-0.001900^{Ab}	0.989	0.01757

*Capital letters denote the comparisons between the test temperatures and the small letters denote the comparisons between the slices' thicknesses; similar letters denote the absence of significant difference (P<0.05)

Temperature separation for blanching and dehydration

The appropriate temperature for blanching operation was evaluated 80°C. For dehydration operation, the temperature of 70°C was evaluated to be more appropriate than 75°C. In this regard, Zhu et al. (2010) observed significantly higher enzyme transfer rates at 80°C during infrared radiation. They considered the most appropriate temperature at 75°C and a thickness of 5 mm. Table 5 shows the appropriate time classification for each step of the process and the changing pattern of radiation temperature based on the maximum time required for blanching. Thus, the undesired quality effects can be prevented by the gradual reduction of the surface temperature during irradiation. Also, blanching speed would be increased by high temperature heating in a short time (HTST). Nowak and Lewicki (2004) had argued that the effect of infrared energy on apple slices is increased when the water was removed from the product during heating. Thus, a reduction in surface temperature can have the desired effect in this regard.

Table 5- Appropriate time and temperature separation for each blanching and dehydration operation

Time (min)	0-15	15-30	30-45	45-60	60-75
Main process	blanching	Blanching-dehydration	dehydration	dehydration	dehydration
Temperature (°C)	80	75	70	70	70

Response analysis in simulation

Figure 13 shows the step response diagram in simulation. As seen, the first-order transfer function (Figure 13a) caused a more desired response than the second order transfer function (Figure 13b). In fact, increasing the order of the

transfer function caused an increase in the response speed. However, this was done by increasing the cost of oscillations and reducing the stability, which is not desirable. In the output response of the simulation model, recorded by the first-order transfer function, there is almost no overshoot and the time to achieve steady state is 20.55 seconds. In output response derived from second-order transfer function, to achieve steady state after 37 seconds is possible, and the sharp drop of response is seen after achieving the response value equal to one. In this regard, Coeyman and Bowles (1996) stated that the fuzzy temperature controller reduces the rate of overshoot to the minimum level.

Ahuja and Kumar (2014) reported that the use of the fuzzy controller in the form of closed loop showed a zero percent of overshoot, in fact, had better performance than high-power control systems. Shakya et al. (2014) also reported that the fuzzy controller has a very small overshoot and has a faster response than other control methods. They stated that oscillatory responses can damage the system and the proper fuzzy controller does not show this dangerous oscillation during the unsteady period. Al Gizi et al. (2014) also stated that the appropriate fuzzy controller achieved a set point with a very small oscillation, which this oscillation is due to the initial speed of the system response.

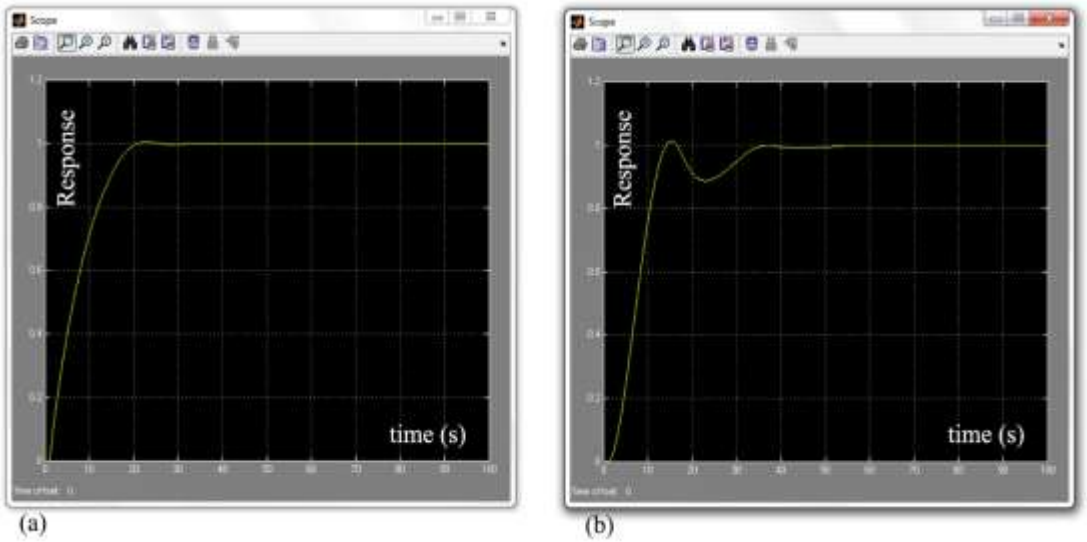

Fig. 13. Step response diagram for the simulated model by recording the output by the first-order transfer function (a) and the second-order transfer function (b)

Figure 14 shows the diagram of error (e) versus the response time for the first order transfer function and the second order transfer function. As seen, the first order function leads to faster achieving the zero error level in steady form. While the second order function leads to achieving the zero level earlier, but this state is not steady. Pirrello et al. (2001) observed a similar error process for the fuzzy controller of the rotatory drying process. Figure 15 shows the diagram of error variations (de) during the response time. The first order transfer function reduces the error variations to zero with more regular oscillations. Thus, based on Figure (16), the first-order transfer function would lead to achieve steady level of the command difference (du) faster.

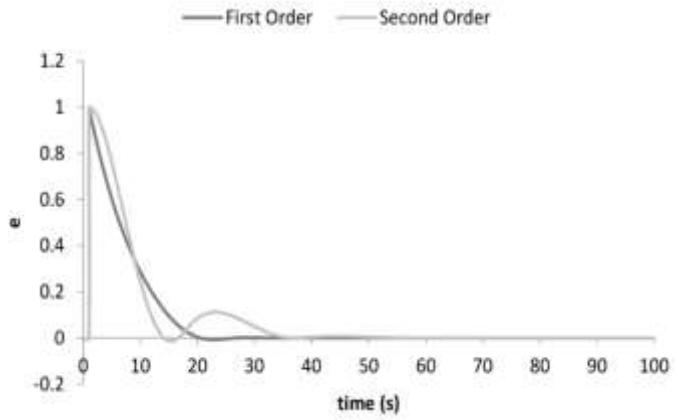

Fig. 14. Diagram of error (e) versus response time for first order transfer function and second order transfer function

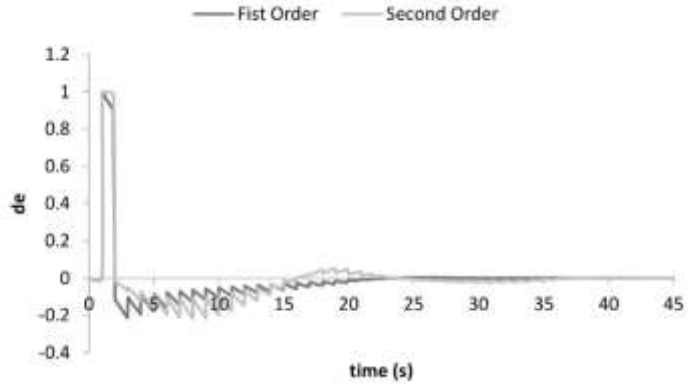

Fig. 15. Diagram of error variations (de) during response time for first order transfer function and second order transfer function

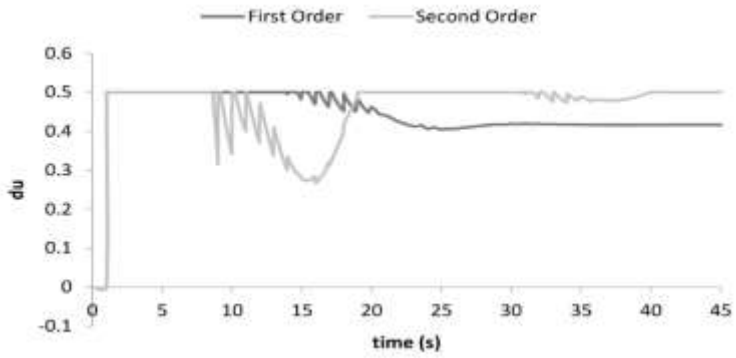

Fig. 16. Diagram of command difference (du) during the response time for the first order transfer function and the second order transfer function

Efficiency of simulation

Table 6 illustrates the simulation evaluation indices with the first order transfer function and the second order transfer function. In general, the first order transfer function has a desired state compared to the second order transfer model. The index of (ISE) for the first order transfer function was 0.760 times than that of the second-order transfer function. Alghannam (2012) considered the index of (IAE) appropriate to evaluate the computer simulation efficiency, which for the first-order transfer; it

was seen 0.821 times than that of the second-order function. According to the ITAE index, it can be seen that in the long term implementation of controller, the error rate of the model simulated with the first order transfer function is 0.589 of the error resulting from the second-order transfer function. According to Al Gizi et al. (2014), the simulation results indicate the validity of the fuzzy model, since fuzzy rules test shows high sensitivity to system error to achieve the zero error level. The proposed model also provides acceptable computational efficiency to maintain a system steady state error close to zero. In this regard, the steady state error (e_{ss}) of the first order function is closer to zero.

Table 6- Analysis of the efficiency of the simulated controller model with the output of different transfer functions

Transfer function	Simulation evaluation index			
	ISE	IAE	ITAE	e_{ss}
First order	3.718	6.485	39.944	-7.78×10^{-12}
second order	4.891	7.898	67.805	3.19×10^{-7}

Conclusion

In this study, the appropriate temperatures for infrared irradiation with intermittent heating method were separated based on the qualitative changes of apple slices in terms of deactivation of polyphenol oxidase (PPO) enzyme and vitamin C degradation. Accordingly, the temperature of 80°C was selected for blanching operation, and then, dehydration at 70°C was considered appropriate. The fuzzy temperature controller was set at target temperature to reduce the overshoot and it was implemented in the simulation environment. The results of the simulation with the first order transfer function confirmed the fuzzy rules, since they cause to achieve zero steady state error (ess). The application of fuzzy temperature controller in the irradiation with intermittent heating can be used as smart processing system in the food industry.

References

Acevedo, N. C., Briones, V., Buera, P., & Aguilera, J. M. (2008). Microstructure affects the rate of chemical, physical and color changes during storage of dried apple discs. *Journal of Food Engineering*, 85(2), 222-231.

Aguilar, R., Muñoz, V., & Callero, Y. (2012). Control application using fuzzy logic: Design of a fuzzy temperature controller. *Fuzzy Inference System-Theory and Applications*: InTech.

Ahuja, R. K., & Kumar, R. (2014). Design and Simulation of Fuzzy Logic Controller based Switched-Mode Power Supply. International *Journal of Electrical Engineering*, 2(5), 16-21.

Al Gizi, A. J., Mustafa, M., & Jebur, H. H. (2014). A novel design of high-sensitive fuzzy PID controller. *Applied Soft Computing*, 24, 794-805.

Alghannam, A. R. O. (2012). Design of a Simple Fuzzy Logic Control for Food Processing. Trends in Vital *Food and Control Engineering*: InTech.

AOAC. (2000). Official methods of analysis. 17th ed., Association of Official Analytical Chemists. Washington, DC, Unites States.

Berk, P., Rakun, J., Vindis, P., Stajnko, D., & Lakota, M. (2010). Temperature loop structure with fuzzy and classical controllers. *DAAAM International scientific book*, 117-128.

Birle, S., Hussein, M., & Becker, T. (2013). Fuzzy logic control and soft sensing applications in food and beverage processes. *Food Control*, 29(1), 254-269.

Brown, R., Rothwell, T., & Davidson, V. (2001). A fuzzy controller for infrared roasting of cereal grain. Canadian *Biosystems Engineering*, 43, 3.9-3.16.

Chua, K., Mujumdar, A., & Chou, S. (2003). Intermittent drying of bioproducts—an overview. *Bioresource Technology*, 90(3), 285-295.

Coeyman, B., & Bowles, J. (1996). Fuzzy logic applied to reboiler temperature control. Paper presented at the Fuzzy Systems, 1996, Proceedings of the Fifth IEEE International Conference on.

Cuccurullo, G., Giordano, L., Albanese, D., Cinquanta, L., & Di Matteo, M. (2012). Infrared thermography assisted control for apples microwave drying. *Journal of Food Engineering*, 112(4), 319-325.

Doymaz, İ. (2010). Effect of citric acid and blanching pre-treatments on drying and rehydration of Amasya red apples. *Food and Bioproducts Processing*, 88(2), 124-132.

Guillaume, S., & Charnomordic, B. (2001). Knowledge discovery for control purposes in food industry databases. *Fuzzy Sets and Systems*, 122(3), 487-497.

Jaturonglumlert, S., & Kiatsiriroat, T. (2010). Heat and mass transfer in combined convective and far-infrared drying of fruit leather. *Journal of Food Engineering*, 100(2), 254-260.

Jun, S., Krishnamurthy, K., Irudayaraj, J., and Demirci, A. (2010). Fundamentals and Theory of Infrared Radiation. In: Pan, Z., and Atungulu, G. G. (Eds.), Infrared Heating for Food and Agricultural Processing, CRC Press, pp. 1-18.

Kaya, A., Aydın, O., & Kolaylı, S. (2010). Effect of different drying conditions on the vitamin C (ascorbic acid) content of Hayward kiwifruits (*Actinidia deliciosa* Planch). *Food and Bioproducts Processing*, 88(2), 165-173.

Lao, S., Choy, K. L., Ho, G. T., Yam, R. C., Tsim, Y., & Poon, T. (2012). Achieving quality assurance functionality in the food industry using a hybrid case-based reasoning and fuzzy logic approach. *Expert Systems with Applications*, 39(5), 5251-5261.

Lee, M.-K., Kim, Y.-M., Kim, N.-Y., Kim, G.-N., Kim, S.-H., Bang, K.-S., & Park, I. (2002). Prevention of browning in potato with a heat-treated onion extract. Bioscience, *Biotechnology, and Biochemistry*, 66(4), 856-858.

Li, Z., Raghavan, G. V., & Wang, N. (2010). Carrot volatiles monitoring and control in microwave drying. *LWT-Food Science and Technology*, 43(2), 291-297.

Linko, S., & Linko, P. (1998). Developments in monitoring and control of food processes. *Food and Bioproducts Processing*, 76(3), 127-137.

Liu, Y., Zhu, W., Luo, L., Li, X., & Yu, H. (2014). A mathematical model for vacuum far-infrared drying of potato slices. *Drying Technology*, 32(2), 180-189.

Liu, Z., & Li, H.-X. (2005). A probabilistic fuzzy logic system for modeling and control. IEEE *Transactions on Fuzzy Systems*, 13(6), 848-859.

Luz, G. R., dos Santos Conceição, W. A., de Matos Jorge, L. M., Paraíso, P. R., & Andrade, C. M. G. (2010). Dynamic modeling and control of soybean meal drying in a direct rotary dryer. *Food and Bioproducts Processing*, 88(2), 90-98.

Maskan, M. (2001). Kinetics of colour change of kiwifruits during hot air and microwave drying. *Journal of Food Engineering*, 48(2), 169-175.

Menlik, T., Özdemir, M. B., & Kirmaci, V. (2010). Determination of freeze-drying behaviors of apples by artificial neural network. Expert Systems with Applications, 37(12), 7669-7677.

Mittal, G. S. (1996). Process controls in the food industry: Problems and solutions. *Food science and technology, Marcel Dekker*, Inc., 1-12.

Mrad, N. D., Boudhrioua, N., Kechaou, N., Courtois, F., & Bonazzi, C. (2012). Influence of air drying temperature on kinetics, physicochemical properties, total phenolic content and ascorbic acid of pears. *Food and Bioproducts Processing*, 90(3), 433-441.

Nowak, D., & Lewicki, P. P. (2004). Infrared drying of apple slices. *Innovative Food Science & Emerging Technologies*, 5(3), 353-360.

Octavia, N., Maung, M. M., & Tun, H. M. (2014). Performance Evaluation of Fuzzy Logic Controller in Water Bath Temperature Control System. International Journal of Science, *Engineering and Technology Research*, 3(6), 1623-1629.

Odetunji, O. A., & Kehinde, O. O. (2005). Computer simulation of fuzzy control system for gari fermentation plant. *Journal of Food Engineering*, 68(2), 197-207.

Perrot, N., Ioannou, I., Allais, I., Curt, C., Hossenlopp, J., & Trystram, G. (2006). Fuzzy concepts applied to food product quality control: A review. *Fuzzy Sets and Systems*, 157(9), 1145-1154.

Pirrello, L., Yliniemi, L., & Leiviskä, K. (2001). Development of a Fuzzy Logic Controller for a Rotary Dryer with Self-Tuning of Scaling Factor: University of Oulu.

Romani, S., Rocculi, P., Mendoza, F., & Dalla Rosa, M. (2009). Image characterization of potato chip appearance during frying. *Journal of Food Engineering*, 93(4), 487-494.

Rywotycki, R. (2002). The effect of fat temperature on heat energy consumption during frying of food. *Journal of Food Engineering*, 54(3), 257-261.

Shakya, R., Rajanwal, K., Patel, S., & Dinkar, S. (2014). Design and Simulation of PD, PID and Fuzzy Logic Controller for Industrial Application. *International Journal of Information and Computation Technology*, 4(4), 363-368.

Sharma, D. (2011). Designing and modeling fuzzy control Systems. *International Journal of Computer Applications*, 16(1), 46-53.

Singh, K., Mishra, A., & Mishra, H. (2012). Fuzzy analysis of sensory attributes of bread prepared from millet-based composite flours. *LWT-Food Science and Technology*, 48(2), 276-282.

Sivanandam, S., Sumathi, S., & Deepa, S. (2007). Introduction to fuzzy logic using MATLAB (Vol. 1): Springer.

Sturm, B., Vega, A.-M. N., & Hofacker, W. C. (2014). Influence of process control strategies on drying kinetics, colour and shrinkage of air dried apples. *Applied Thermal Engineering*, 62(2), 455-460.

Timoumi, S., Mihoubi, D., & Zagrouba, F. (2007). Shrinkage, vitamin C degradation and aroma losses during infra-red drying of apple slices. *LWT- Food Science and Technology*, 40(9), 1648-1654.

Trystram, G. (2012). Modelling of food and food processes. Journal of Food Engineering, 110(2), 269-277.

Uddin, M., Hawlader, M., & Zhou, L. (2001). Kinetics of ascorbic acid degradation in dried kiwifruits during storage. *Drying Technology*, 19(2), 437-446.

Vaishnav, S., & Khan, Z. (2007). Design and performance of PID and fuzzy logic controller with smaller rule set for higher order system. Paper presented at the Proceedings of the World Congress on Engineering and Computer Science.

Vega, A.-M. N., Sturm, B., & Hofacker, W. (2016). Simulation of the convective drying process with automatic control of surface temperature. *Journal of Food Engineering*, 170, 16-23.

Velickova, E., Winkelhausen, E., & Kuzmanova, S. (2014). Physical and sensory properties of ready to eat apple chips produced by osmo-convective drying. *Journal of food science and technology*, 51(12), 3691-3701.

Wu, G.-C., Zhang, M., Mujumdar, A. S., & Wang, R. (2010). Effect of calcium ion and microwave power on structural and quality changes in drying of apple slices. *Drying Technology*, 28(4), 517-522.

Zhu, Y., & Pan, Z. (2009). Processing and quality characteristics of apple slices under simultaneous infrared dry-blanching and dehydration with continuous heating. *Journal of Food Engineering*, 90(4), 441-452. doi:http://dx.doi.org/10.1016/j.jfoodeng.2008.07.015

Zhu, Y., Pan, Z., McHugh, T. H., & Barrett, D. M. (2010). Processing and quality characteristics of apple slices processed under simultaneous infrared dry-blanching and dehydration with intermittent heating. *Journal of Food Engineering*, 97(1), 8-16.

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شبیه‌سازی کنترل‌کننده فازی دما طی فرآیند بلانچینگ خشک و آبزدایی مادون قرمز برش‌های سیب با روش حرارت‌دهی متناوب

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چکیده

در این مطالعه، حرارت‌دهی مرحله‌ای و کنترل‌کننده فازی دما طی پرتودهی مادون قرمز سیب با روش حرارت‌دهی متناوب طراحی شد. بدین منظور، فرآیند بلانچینگ خشک و آبزدایی همزمان برش‌های سیب در سه دمای ۷۰، ۷۵ و ۸۰ درجه سانتی‌گراد براساس غیرفعال‌سازی آنزیم پلی‌فنل اکسیداز یا PPO (شاخص سرعت بلانچینگ) و حفظ ویتامین C (شاخص ثبات کیفیت) مطالعه شد. نمونه‌ها از خشک‌کن مادون قرمز با فاصله زمانی ۲ دقیقه به‌منظور جداسازی اختصاصی زمان بلانچینگ خشک و آبزدایی برش‌های سیب، خارج شدند. برای تمامی دماها، فرآیند حرارتی تا زمان عدم تغییرات رنگ ناشی از معرف کاتکول ادامه یافت (کفایت بلانچینگ). در نهایت، کنترل‌کننده فازی دما با حلقه پسخور با مقایسه دو تابع انتقال مرتبه یک و مرتبه دو در نرم‌افزار MATLAB طراحی، شبیه‌سازی و اجرا گردید. کارایی شبیه‌سازی با استفاده از شاخص‌های انتگرال مربع خطا (ISE)، انتگرال قدر مطلق خطا (IAE) و انتگرال قدرمطلق خطا در زمان (ITAE) و خطای شرایط پایا (e_{ss}) بررسی شد. این پارامترها بایستی به صفر نزدیک باشند. نتایج نشان داد که دمای ۸۰ درجه سانتی‌گراد به مدت ۱۵ دقیقه برای عملیات بلانچینگ و دمای ۷۰ درجه سانتی‌گراد برای عملیات آبزدایی مناسب بود. نتایج شبیه‌سازی تایید کرد که مرتبه بالاتر تابع انتقال موجب پاسخ سریع‌تر شد، اما افزایش نوسانات و کاهش پایداری مطلوب نبود. برای تابع انتقال مرتبه یک، شاخص‌های کارایی شامل (ISE)، (IAE) و (ITAE) به‌ترتیب ۰/۷۶۰، ۰/۸۲۱ و ۰/۵۸۹ برابر تابع انتقال مرتبه دو محاسبه شد. شبیه‌سازی نشان‌دهنده اعتبار مدل کنترل فازی بود و کارایی محاسباتی قابل قبولی نشان داد؛ زیرا آزمون قوانین فازی طی شبیه‌سازی حساسیت بالایی به حفظ خطای پایای (e_{ss}) نزدیک به صفر نشان داد.

واژه‌های کلیدی: مادون قرمز، سیب، حرارت‌دهی متناوب، کنترل‌کننده فازی، شبیه‌سازی.

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Full Research Paper

An integrated Fuzzy AHP-TOPSIS approach toward optimization of food formulation: case study bread

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Abstract

In this study, the fuzzy hierarchical analysis (FAHP) and TOPSIS methods was used to select the best formulations of gluten-free baguette contain modified quinoa flour (QM). For this purpose, two criteria, namely physical and chemical properties (with sub-criteria of texture, taste, flavor, color, porosity, moisture, ash and mineral content, fiber content and antioxidant activity) were used to evaluate the best formulation of gluten-free of baguette. Incorporating QM from 0 to 15% increased moisture content, fiber content, hardness, antioxidant activity, a* value, Fe^{+2} and Ca^{+2} content and decreased L* and b* values. Results of FAHP-TOPSIS method showed the chemical properties have a relatively higher importance compared to the physical properties of the product and the highest importance degree of product quality evaluation is for fiber content and antioxidant activity with a final weight of 0.271 and 0.239, respectively. Also, from the experts' point of view and based on the sub-criteria, baguette containing 10% QM with a proximity index of 0.871 was selected as the best formulation.

Keywords: Modified quinoa; bread; FAHP-TOPSIS; Physicochemical properties.

Introduction

The demand for gluten-free products with different flavors and formulations has growing by increasing the number of patients with celiac disease. As demand increases, the production of gluten-free product as an alternative to wheat flour should be increased (Lynch, Coffey, & Arendt, 2018). Rice is one of the most important grains, which is used to provide a gluten-free diet for patients with celiac. Rice is colorless and has unique nutrition facts such as a low amount of sodium, protein, fat, fiber, and a high amount of carbohydrate, as well as desirable taste and high digestibility. However, in rice-based products compared to wheat-based ones, the technical quality is low due to lack of protein in the viscoelastic gluten network, thereby causing quality problems such as low volume and weak texture (Yano *et al.*, 2017). One of the best approaches to enrich and improve the characteristics of bread is to use different alternative fiber sources such as pseudocereal buckwheat, quinoa, and amaranth (Alvarez-Jubete *et al.*, 2010; Sandr *et al.*, 2017; Sciarini *et al.*, 2017; Stojceska & Ainsworth, 2008).

Quinoa (*Chenopodium quinoa Willd*) is one of the important agricultural products containing high protein and dietary fiber. Besides, quinoa is rich in various minerals and the amount of potassium, calcium, phosphorus, magnesium, and iron is higher than other cereals (Ebrahimzadeh *et al.*, 2015; Elgeti *et al.*, 2014; Iglesias-Puig *et al.*, 2015; Stikic *et al.*, 2012). Typically, non-treated flours are used in bread formulation. It is possible to enhance the functional properties of flour for use in the formulation of gluten-free products through physical treatments such as dry and wet heat treatments (Miranda *et al.*, 2010; Motta *et al.*, 2019; Rocchetti *et al.*, 2017). Among these methods, heat-moisture treatment is a cost-effective method for physical modification of flour (Rocchetti *et al.*, 2017; Xiao *et al.*, 2017).

Considering the dependency of food formulation on physical and chemical

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parameters, selecting the best formula among several formulations is a multi-criteria decision. The hierarchical analysis method is understandable because of its simple structure (Noshad *et al*., 2018). However, since this method needs pairwise comparison among chooses to form a decision matrix, the calculations take a long time and the accuracy is low. Besides, in the TOPSIS method, the ranking is done by ideal positive and negative responses. It should be noted that the comparison between criteria and choices is not certain and it is best to use vocabulary and phrases. Hence, the theory of fuzzy sets is used to achieve realistic results. This theory is a step for closing the certainty in classical mathematics problems and uncertainty in the real world (Behzadian *et al*., 2012; Ligus & Peternek, 2018; Sakthivel *et al*., 2018; Yang *et al*., 2013).

Therefore, this study aimed to investigate the effect of modified quinoa flour on the physicochemical properties of gluten-free baguette. Also, for the first time in this study, the combination of two methods of fuzzy hierarchical analysis (FAHP) and TOPSIS was used to select the best formulation of gluten-free baguette containing treated quinoa flour.

Material and Methods

Preparation of Modified quinoa flour

Red quinoa seed, rice flour, yeast, salt sugar and oil were purchased from the local market. Red quinoa seed was hydrothermally processed in boiling water for 20 min. Then, they were dried at 50°C and milled.

The preparation of bread dough

Rice flour (85- 100%), modified quinoa flour (0- 15%, QM0, QM5, QM10, QM15), dry yeast (1%), salt (1%), sugar (1%), and bread improver (0.4%) were mixed in the agitators (Spiral model, Thailand) and the required water was added to the mixture. The dough was stirred at 150 rpm for 10 min and after six min, 1% oil was added to dough. After preparing the dough, the primary fermentation was carried out for 30 min at ambient temperature (25℃), and then the dough was divided into 250 grams' pieces. After the dividing operation, they were placed at ambient temperature for 8- 10 min to allow the middle fermentation time to pass. After completing this step and forming the dough, the final fermentation was performed for 45 min in an oven at 45℃ under saturated vapor. Finally, the baking operation was carried out in hot air (ZuccihelliForni, Italy) at 260℃ for 13 min. After cooling, each sample was packaged in polyethylene bags and stored at ambient temperature for assessing the quantitative and qualitative characterization.

Chemical components analysis

Flour moisture and protein content, the ash of bread and flour, and the fiber of bread samples were determined according to AACC 44-16, AACC 46-12, AACC 08-01, and AOAC 199-43 standards respectively (Freund & Kim, 2006; Pourmasoumi, et al., 2018; Ziska, Morris, & Goins, 2004).

Minerals content

The minerals of bread and flour samples including iron and calcium were measured using an atomic absorption device (Analytic Jena model, Germany, Model ContrAA300) (Anjum, Ali, & Chaudhry, 1991).

Texture

The bread hardness was measured based on AACC 74-09 standard using a texture analyzer (TA-XT-PLUS mode, Micro stable system, UK) with probe diameter (36 mm), 0.25 mm/s speed and 50% penetration depth (Gåmbaro *et al*., 2002).

Color

The color of samples was measured using the Konica Minolta colorimeter (CR-400 model, Japan).

Antioxidant activity

The sample was defatted by 1:1 v/v ratio (Chloroform/ Petroleum ether) and dried in an oven at 40℃. Then, 1 gr of the defatted and dry sample was mixed with methanol and then centrifuged at 2000 rpm for 15 min. Subsequently, 0.1μL of the supernatant was mixed with 3.9 μL DPPH methanol solution.

After incubation in the oven for 30 min, the absorbance of the sample was measured at 517 nm (Gåmbaro *et al*., 2002).

Choice of the best formula

First, the effective criteria for selecting the best type of product were identified by expert opinions and snowball technique, which included four chemicals and five physical properties. Each factor has sub-factor; the sub-criteria of chemical properties consisted of moisture content, ash, fiber, and antioxidant activity. Also, the sub-criteria of physical properties included texture, flavor, color, porosity, and flavor.

Concept of fuzzy AHP

Definition 1. Let $A\epsilon\ G(R)$ be called a triangular fuzzy number if its membership function $\mu_A(x) = R \rightarrow [0,1]$ be equal to (Eq.1):

(1)

$$\mu_A(x) = \begin{cases} \dfrac{x}{m-l} - \dfrac{l}{m-l}, & x\epsilon[l,m] \\ \dfrac{x}{m-u} - \dfrac{u}{m-u}, & x\epsilon[m,u] \\ 0, & otherwise \end{cases}$$

R shows the set of real numbers and *G(R)* is all fuzzy sets. Where, Lower, modal, and upper value of a triangular fuzzy number can be defined by *l*, *m* and *u*, respectively.

Definition 2. Operating rules of triangular fuzzy numbers are as follows:

1. $A= (l_1, m_1, u_1)$ *and* $B= (l_2, m_2, u_2)$; $A\pm B= (l_1\pm l_2, m_1\pm m_2, u_1\pm u_2)$.

2. $A= (l_1, m_1, u_1)$ *and* $B= (l_2, m_2, u_2)$; $A.B\approx (l_1l_2, m_1m_2, u_1u_2)$.

3. (α, α, α), $\alpha \epsilon R>0$ *and* $A= (l_1, m_1, u_1)$; $\alpha.A= (\alpha\ l_1, \alpha\ m_1, \alpha\ u_1)$.

4. $A= (l_1, m_1, u_1)$; $A^{-1}\approx(1/u_1, 1/m_1, 1/u_1)$.

Fuzzy AHP extent analysis methodology

The weights of criteria were evaluated according to the method of extent analysis which was presented by (Chang, 1992). This method includes the following steps:

1. The first step of the fuzzy AHP method is the evaluation of pairwise comparison (a_{ij}) of criteria and sub-criteria in a hierarchy framework by experts. For example, criterion i strongly prefers the criterion j: then $a_{ij}= (3, 4, 4.5)$ (Table 1). If the strong importance of element j over element i is confirmed, then the pairwise comparison scale can be denoted by $a_{ij}= (1/4.5, 1/4, 1/3)$.

Table 1. Linguistic variables and triangular fuzzy numbers

Linguistic variables	Description	Fuzzy number
$\tilde{1}$	Equally preferred	(1, 1, 1)
$\tilde{2}$	Equally to moderately preferred	(1, 1.5, 1.5)
$\tilde{3}$	Moderately preferred	(1, 2, 2)
$\tilde{4}$	Moderately to strongly preferred	(3, 3.5, 4)
$\tilde{5}$	Strongly preferred	(3, 4, 4.5)
$\tilde{6}$	Strongly to very strongly preferred	(3, 4.5, 5)
$\tilde{7}$	Very strongly preferred	(5, 5.5, 6)
$\tilde{8}$	Very strongly to extremely preferred	(5, 6, 7)
$\tilde{9}$	Extremely preferred	(5, 7, 9)

2. M_{gi}^1, M_{gi}^2, …, M_{gi}^3 are defined as values of extent analysis of *i-th* object for *m* goals. Therefore, the value of the fuzzy synthetic extent for *i-th* object is (Eq.2):

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} \quad (2)$$

Where, M_{gi}^{j} *(j=1, 2,…, m)* are triangular fuzzy numbers.

3. The degree of possibility $M_1 \geq M_2$ calculates as follows (Eq.3):

$$V(M_1 \geq M_2) = sup_{x \geq y}\left[min\left(\mu_{M_1}(x), \mu_{M_2}(y)\right)\right] \quad (3)$$

Since M_1 (l_1, m_1, u_1) and M_2 (l_2, m_2, u_2) are convex fuzzy numbers, we have (Eq.4):

$$V(M_1 \geq M_2) = \begin{cases} 1, & if\ m_1 \geq m_2 \\ 0, & if\ u_1 \leq l_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & otherwise \end{cases} \quad (4)$$

Where, $\frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}$ is an intersection point between membership functions of M_1 and M_2 (μ_{M_1}, μ_{M_2}). This point is indicated in fig. 1 (Yang *et al.*, 2013).

Degree of possibility for convex fuzzy number was calculated as follows:

$$V\left(M \geq M_1, M_2, \ldots, M_k\right) = V\left[\left(M \geq M_1\right) and \ldots and \left(M \geq M_k\right)\right] = \min V\left(M \geq M_1\right),\ i = 1,2,\ldots,k$$

If $d'(A_i) = min\ V(S_i \geq S_k) k = 1,2,\ldots,n;\ k \neq i$, then the importance of weight vector is (Eq.5):

$$W' = \left(d'(A_1), d'(A_2), \ldots\ldots, d'(A_i)\right)^T \quad (5)$$

Where A_i (i=1,2,…,n) are n criteria or sub-criteria.

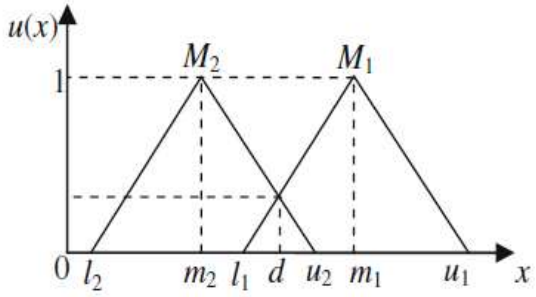

Fig 1. Membership functions of M_1 and M_2

The accurate importance of weight vector is obtained by normalization (Eq.6):

$$W = \frac{\acute{W}}{\sum_1^i \acute{W}} = \mathrm{W} = \left(d(A_1), d(A_2), \ldots\ldots, d(A_2)\right)^T \quad (6)$$

Where W is a non-fuzzy number.

Consistency Index

Pairwise comparison matrix is divided into two matrixes (Eq.7)

$$A^m = [a_{ijm}]$$
$$A^g = \sqrt{a_{iju}.a_{ijl}} \quad (7)$$

Where A^m and A^g are modal and compilation (compilation of upper and lower values) matrixes.

Then, the weight vector of matrixes calculate as follows (Eq.8):

$$w_i^m = \frac{1}{n}\sum_{j=1}^{n} \frac{a_{ijm}}{\sum_{i=1}^{n} a_{ijm}} \quad (8)$$

$$w_i^g = \frac{1}{n}\sum_{j=1}^{n} \frac{\sqrt{a_{iju}.a_{ijl}}}{\sum_{i=1}^{n} \sqrt{a_{iju}.a_{ijl}}}$$

Maximum eigenvalues of matrixes are given by (Eq.9):

$$\lambda_{\max}^m = \frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{n} a_{ijm}\left(\frac{w_j^m}{w_i^m}\right) \quad (9)$$

$$\lambda_{\max}^g = \frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{n} \sqrt{a_{iju}.a_{ijl}}\left(\frac{w_j^g}{w_i^g}\right)$$

Finally, the Consistency Index (CI) of matrixes be defined as (Eq.10):

$$CI^m = \frac{(\lambda_{\max}^m - n)}{(n-1)} \quad (10)$$

$$CI^g = \frac{(\lambda_{max}^g - n)}{(n-1)}$$

And Consistency Rate (CR) calculates as follows (Eq.11):

$$CR^g = \frac{CI^g}{RI^g} \quad (11)$$

$$CR^m = \frac{CI^m}{RI^m}$$

Where RI^m and RI^g are random indexes (Table. 2). The Pairwise comparison matrix is consistent if both of the rates be less than 0.1.

Table 2. Random index

Size matrix	2	3	4	5	6	7	8
RI^m	0	0.4890	0.7937	1.0720	1.1996	1.2874	1.3410
RI^g	0	0.1796	0.2627	0.3597	0.3818	0.4090	0.4164

Topsis

The TOPSIS ranks alternatives according to the calculated distance from the positive ideal and negative ideal solutions (Ebrahimzadeh *et al.*, 2015). The first step is to normalize the performance matrix (Eq.12):

$$r_{ij} = \frac{x_{ij}}{(\sum_{i=1}^{n} {x_{ij}}^2)^{0.5}} \quad (12)$$

Where, x_{ij} and r_{ij} are data of un-normal and normal performance matrix, respectively. With the weights obtained by the FAHP method, the weighted normalization performance matrix is calculated as follows (Eq.13):

$$V = r.diag(W) \quad (13)$$

Where diag(w) is a diagonal matrix where the diagonal elements are the weights of criteria. Then, the positive ideal solution (A+) and the negative ideal solution (A−) can be defined and the distance of each alternative from A+ and A− can be calculated as follows (Eq.14):

$$S_i^+ = (\sum_{j=1}^{m} (V_{ij} - V_j^+)^2)^{0.5} \qquad i = 1,2,\dots,n \quad (14)$$

$$S_i^- = (\sum_{j=1}^{m} (V_{ij} - V_j^-)^2)^{0.5} \qquad i = 1,2,\dots,n$$

Where, I and j show criteria and alternatives, respectively.

Finally, Closed Index (*CI*) can be calculated as follows (Eq.15):

$$CI = \frac{S_i^-}{S_i^+ + S_i^-} \quad (15)$$

Statistical analysis

The experiments were conducted in a completely randomized design with the factorial arrangement. Duncan's multiple range test to provide significance levels ($p<0.05$) for the difference between data and analysis of variance (ANOVA) using SPSS16 to interpret the results were utilized. At least three replicates were performed for each experiment.

Results and discussion

Component analysis

The results of analyzing the chemical compounds of rice and modified quinoa (QM) flour are as follows:

Rice flour contains moisture (8.9 ± 0.87 %,), protein (8.53 ± 0.94 %), ash (0.7± 0.1 %), and crude fiber (2.4± 0.87 %), while modified quinoa flour has moisture (7.1 ± 1.1 %), protein (7.4 ± 1.8 %), ash (1.7 ± 0.2 %), and crude fiber (2.7 ± 0.87 %).

Moisture content

Table 3 shows the variance analysis values of the effect of adding a different levels of QM flour and storage time on the moisture content of samples. As seen, the storage time and adding QM flour have significant effect on produced samples ($P<0.05$). According to the results, the moisture content of all treatments was reduced at storage time, while adding QM on the primary formulation of baguette led to an

increase of moisture content of samples. QM flour can increase the moisture content of the final product because of high fiber content and having hydroxyl groups in their structure and the ability to bond with water molecules. Yangilar), reported that blanching results in degradation of starch granules, consequently a higher interaction of starch with water. Using two different soluble (Inulin) and insoluble (Oat fibers) as an alternative for rice flour in gluten-free cake showed no significant difference in terms of moisture content(Yangilar, 2013).

Fiber content

Given the Table 3, addition the QM flour in the formulation, led to increase the fiber in gluten-free baguette so that the max and min fiber content was for a sample with 15% QM flour and the control sample respectively. Iglesias et alreported that by adding whole quinoa flour to bread, the crude fiber content was increased(Iglesias-Puig *et al.*, 2015). Moreover, comparing 4 different types of cereal such as quinoa, wheat, barley, and corn indicated that the amount of crude fiber in quinoa is higher than others. Therefore, it is possible to consider quinoa as a rich source of fiber(Alvarez-Jubete *et al.*, 2010).

Hardness

The evaluation of adding QM flour to the formulation of baguette showed that adding QM flour led to the increasing of hardness due to the reduction in gas retention in samples. An increase in the hardness of cereal products by adding fibers was also reported in many other studies (Ebrahimzadeh *et al.*, 2015; Elgeti *et al.*, 2014; Sciarini *et al.*, 2017). It should be noted that the hardness of the sample texture was increased by storage time.

Color

Evaluation of adding QM flour to baguette formulation demonstrated that it led to reducing L* and b* values compared to the control sample, the color of the sample became red, and the amount of a* value was increased. The reason for increasing the redness of samples containing QM flour was its natural reddish-brown color. It seems that because of high lysine amino acid in quinoa and its role in the Maillard reaction, the browning reaction was intensified and the color of the crust bread became darker. Ebrahimzadeh et al. (2015) showed that by increasing the quinoa in bread, L* and b* values were reduced and a* value was increased, which is in agreement with the results of the present study.

Antioxidant activity

The results of analysis of variance (table 3) demonstrated that adding treated QM flour had a significant effect ($P<0.05$) on antioxidant activity, while storage time had no significant effect ($P<0.05$). As treated QM flour in bread formulation increased, the antioxidant activity increased so that the maxi and min antioxidant activity was for bread with 15% treated QM flour and control sample, respectively. Quinoa has more polyphenols and tocopherols compared to wheat and barley, and the amount of Quercetin and Kaempferol was 36 and 40.2 µmol/100gr, respectively (Alvarez-Jubete *et al.*, 2010).

Ash and minerals content

Table 3 illustrates that adding QM flour has a significant effect ($P<0.05$) on the ash content of samples. According to the results, an increase in QM flour in formulation led to increasing ash content of gluten-free baguette. Moreover, by increasing QM flour content in the formulation, Fe^{+2} and $Ca^{+2}$was increased from 0.7 to 125.47± 3.1mg/100g and from 17.1 ±0.97 to 25.12 mg/100g, respectively (Table 4). Iglesias et al. conducted a study on whole quinoa flour and indicated that an increase in quinoa flour content caused an increase in ash and mineral content(Iglesias-Puig *et al.*, 2015)

Table 3. Effect of QM flour and storage time physicochemical properties of bread

Source	DF	Moisture content	Ash	Fiber content	Hardness	L* value	a* value	b* value	Antioxidant activity
Storage time (A)	2	22.82**	0.003^{ns}	0.077^{ns}	3.84**	13.1**	3.7**	0.75**	6.56^{ns}
Quinoa (B)	3	98.49**	1.51**	79.17**	39.61**	46.05**	0.73*	0.38**	82.4**
A×B	6	30.02**	0.007^{ns}	0.16^{ns}	28.53**	8.1^{ns}	0.29^{ns}	0.04^{ns}	97.1^{ns}
Error	12	8.24	0.033	0.47	0.49	7.59	0.54	0.24	14.47
R^2		93.77	97.82	99.41	98.91	89.86	89.57	83.1	98.29
R^2-Adj		88.06	95.82	98.87	97.9	80.57	80.1	70.1	96.73

*Significant at P < 0.05; ** significant at P < 0.01; ns, non-significant.

.Table 4. Effect of QM flour on $Fe^{+2}$and Ca^{+2} content of bread

Criteria	Chemical properties	Physical properties
Chemical properties	(1,1,1)	(0.811,1.07,1.316)
Physical properties	(0.76, 0.935, 1.233)	(1,1,1)

Similar letters in rows denote the absence of significantly different ($p<0.05$).

Fuzzy AHP- TOPSIS method (FAHP)

To analyze the final products and select the best one, the relative weight of criteria and sub-criteria was calculated using the FAHP method. The weight of the calculated relative importance is reliable when the answers of the experts are consistent with the pair-wise comparisons of the criteria and sub-criteria. For this purpose, certainty opinions of the experts are converted to the fuzzy scale and aggregate fuzzy pairwise matrices comparisons were calculated through the geometric mean of these opinions and the consistency rates concerning these comments (Tables 5, 6 and 7). The results indicated that consistency rates of calculations to compare the sub-criteria of chemical and physical properties were less than 0.1. Hence, the responses of experts were consistent and reliable. To compare two criteria of physical and chemical properties, it is not necessary to calculate the consistent rate of responses, because the inconsistent responses are done when there are more than two criteria for comparison.

Table 5. Aggregate fuzzy pairwise matrices comparisons of criteria

	Quinoa Flour	Control	5QM	10QM	15QM
Fe^{+2} (mg/100g)	6.7 ± 0.47^{a}	0.7 ± 0.1^{d}	3.2 ± 0.87^{c}	5.13 ± 0.74^{b}	5.87 ± 0.97^{b}
Ca^{+2} (mg/100g)	148.7 ± 2.74^{a}	17.1 ± 0.97^{d}	88.45 ± 1.42^{c}	122.2 ± 2.74^{b}	125.47 ± 3.1^{b}

Table 6. Aggregate fuzzy pairwise matrices comparisons sub-criteria of chemical properties

Criteria	Texture	Flavor	Color	Porosity	Taste
Texture	(1,1,1)	(1.384,1.931, 2.213)	(0.917,1.27, 1.384)	(2.258,3.189, 3.43)	(0.917,1.27 ,1.384)
Flavor	(0.452,0.518, 0.722)	(1,1,1)	(0.653,0.687, 1.052)	(1,1.555,1.55)	(0.653,0.65 3,1)
Color	(0.722,0.788, 1.09)	(0.951,1.456, 1.532)	(1,1,1)	(1.51,2.296, 2.414)	(0.951, 1.09,1.147)
Porosity	(0.292,0.314, 0.443)	(0.643,0.643,1)	(0.414,0.436, 0.662)	(1,1,1)	(0.518, 0.518, 1)
Flavor	(0.722,0.788, 1.09)	(1,1.532,1.532)	(0.872,0.917, 1.052)	(1,1.929, 1.929)	(1,1,1)
Compatibility rates	$CR_m = 0.002$		$CR_g = 0.02$		

Table 7. Aggregate fuzzy pairwise matrices comparisons sub-criteria of physical properties

Criteria	Relative weights of criterion	Sub-criteria	Relative weights	Final weight	Rank
Chemical properties	0.569	Moisture content	0.07	0.04	7
		Ash content	0.034	0.019	8
		Fiber content	0.477	0.271	1
		Antioxidant activity	0.419	0.239	2
Physical properties	0.431	Texture	0.339	0.146	3
		Flavor	0.13	0.056	6
		Color	0.259	0.11	4
		Porosity	0.034	0.015	9
		Taste	0.238	0.103	5

After the consistency test, the weight of the relative importance of the criteria and sub-criteria is calculated to select the best product. Fig. (2.A) shows that the chemical properties have a relatively higher importance compared to the physical properties of the product. Comparing the weight of relative importance of sub-criteria of chemical properties indicated that two criteria namely fiber and antioxidant properties of the product have the maximum relative importance (Fig. 2 (B)).

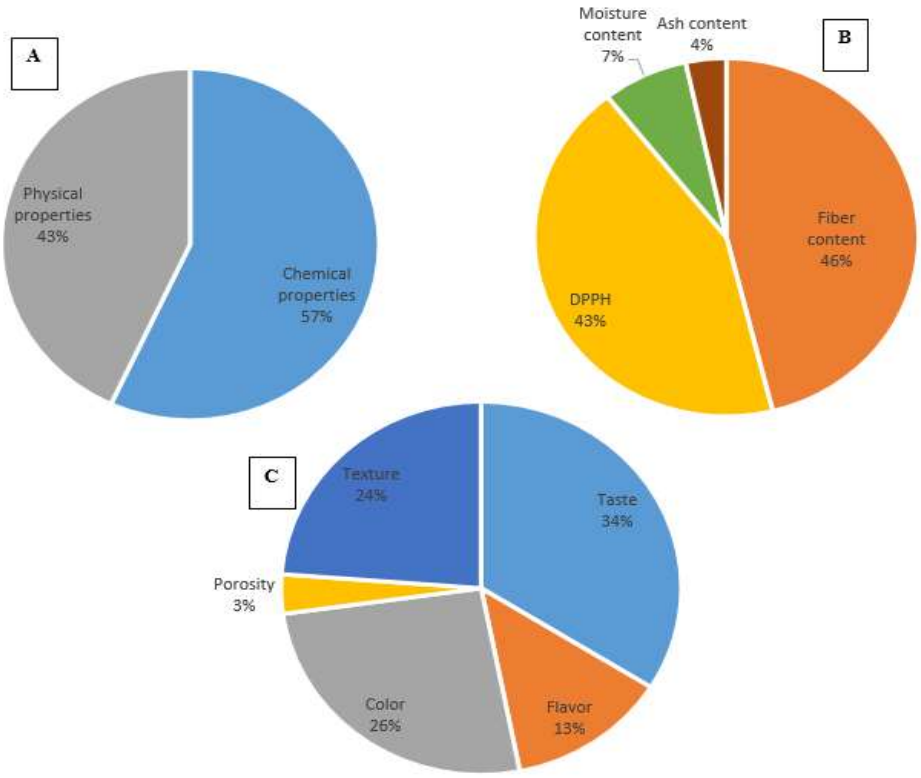

Fig. 2. Weight relative importance of criteria (A), sub-criteria of chemical properties (B), sub-criteria of physical properties (C)

Also, in quality evaluation of the product, the relative importance of two criteria such as moisture content and ash has no significant differences. As seen in Fig.2 (C), according to

expert opinions, the greatest importance of the sub-criteria of physical properties in evaluating the quality of the product respectively is for texture, color, taste, and flavor, and the porosity of the product has lower relative importance compared to other criteria. The computational weights of the sub-criteria are local weight. Nevertheless, to evaluate and rank these sub-criteria, it is necessary to calculate their overall weight. At this stage, the final weights (overall) of the sub-criteria were calculated by multiplying the relative weight of the calculated sub-criteria by the weight of the relevant criterion to that sub-criterion (Table 8). The results demonstrated that the highest importance degree of product quality evaluation is for fiber and antioxidant activity with an overall weight of 0.271 and 0.239, respectively. This conclusion suggests that from the perspective of food industry experts, these two properties should be evaluated in selecting the best type of product. Furthermore, the overall weight of the three sub-criteria of porosity, moisture content, and ash content is estimated to be less than 0.05, which indicates the lower importance of these properties compared to other chemical and physical properties in selecting the best product from the point of view of food industry experts.

Table 8. The weight of the relevant criterion to that sub-criterion

Criteria	Relative weights of criterion	Sub-criteria	Relative weights	Final weight	Rank
Chemical properties	0.569	Moisture content	0.07	0.04	7
		Ash content	0.034	0.019	8
		Fiber content	0.477	0.271	1
		Antioxidant activity	0.419	0.239	2
Physical properties	0.431	Texture	0.339	0.146	3
		Flavor	0.13	0.056	6
		Color	0.259	0.11	4
		Porosity	0.034	0.015	9
		Taste	0.238	0.103	5

Table 9. The normalized aggregate score

	QM0 (Product A)	QM5 (Product B)	QM10 (Product C)	QM15 (Product D)	Ideal solution (A+)	Anti-ideal solution (A-)
Moisture content	0.023	0.02	0.02	0.015	0.023	0.015
Ash content	0.006	0.009	0.012	0.01	0.012	0.006
Fiber content	0.061	0.101	0.162	0.183	0.183	0.061
Antioxidant activity	0.063	0.111	0.142	0.142	0.142	0.063
Texture	0.053	0.063	0.095	0.074	0.095	0.053
Flavor	0.025	0.021	0.034	0.03	0.034	0.021
Color	0.056	0.056	0.063	0.048	0.063	0.048
Porosity	0.005	0.006	0.009	0.009	0.009	0.005
Flavor	0.047	0.041	0.061	0.054	0.061	0.041

After calculating the weight of the importance of the sub-criteria, the best product among four different products was selected using the TOPSIS method. For this purpose, the performance matrix of each product was extracted by assigning a score of 1 to 10 to that product by the various sub-criteria. Then, the aggregate performance matrix of experts' opinions was estimated through geometric meaning and normalized. Subsequently, the normalized aggregate scores of experts multiplied by the weight of the overall importance of the sub-criteria, the normalized aggregate score was calculated, and an ideal

and an anti-ideal alternative was constructed in proportion to the matrix (Table 9). Finally, the closed index of each product was calculated using its distance from the ideal and anti-ideal products (Fig. 3). From the experts' point of view and based on the sub-criteria, product C with a closed index of 0.871 was selected as the best product. Moreover, product D with 0.836 closed index had the appropriate quality and with a less difference with the product C was placed in second place. However, product A with a closed index of 0.086 was identified as the worst product based on experts' perspectives and obtained sub-criteria. Therefore, the producer can use a combination of FAHP and TOPSIS methods to evaluate the quality of the final product and choose the best one.

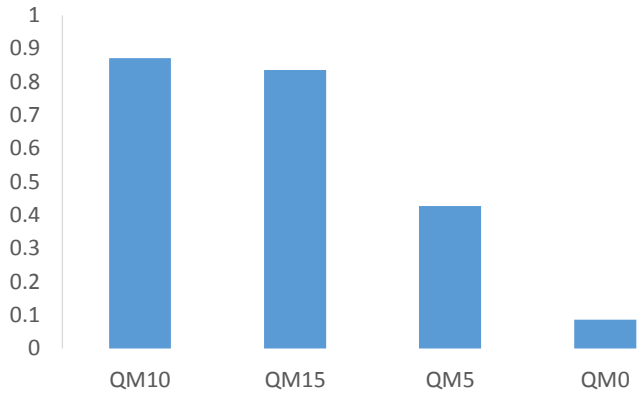

Fig. 3. Proximity index of products

Conclusion

Regarding the dependency of food formulation on physical and chemical parameters, selecting the best formula among several formulations is a multi-criteria decision. In this study, FAHP and TOPSIS methods were used to choose the best formula for gluten-free baguette. Based on physicochemical properties, results of the FAHP-TOPSIS method showed that the baguette containing 10% QM was the best formula compared to other products. The results indicated that the FAHP-TOPSIS method can be used as a novel method for choosing the best formulation of bakery products.

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References

Alvarez-Jubete, L., Arendt, E., & Gallagher, E. (2010). Nutritive value of pseudocereals and their increasing use as functional gluten-free ingredients. *Trends in Food Science & Technology, 21*(2), 106-113.

Alvarez-Jubete, L., Wijngaard, H., Arendt, E., & Gallagher, E. (2010). Polyphenol composition and in vitro antioxidant activity of amaranth, quinoa buckwheat and wheat as affected by sprouting and baking. *Food chemistry, 119*(2), 770-778.

Anjum, F. M., Ali, A., & Chaudhry, N. M. (1991). Fatty acids, mineral composition ond functional (bread and chapati) properties of high protein and high lysine barley lines. *Journal of the Science of Food and Agriculture, 55*(4), 511-519.

Behzadian, M., Otaghsara, S. K., Yazdani, M., & Ignatius, J. (2012). A state-of the-art survey of TOPSIS applications. *Expert Systems with applications, 39*(17), 13051-13069.

Chang, D.-Y. (1992). Extent analysis and synthetic decision. *Optimization techniques and applications*, *1*(1), 352-355.

Ebrahimzadeh, A., Yarmand, M., & Sepahvand, N. (2015). Evaluation of the properties of the chemical, physical and rheological bread enriched with quinoa flour. *Master's Thesis. Islamic Azad university, Quds unit. pp*, 54-56.

Elgeti, D., Nordlohne, S. D., Föste, M., Besl, M., Linden, M. H., Heinz, V., Jekle, M., & Becker, T. (2014). Volume and texture improvement of gluten-free bread using quinoa white flour. *Journal of Cereal Science*, *59*(1), 41-47.

Freund, W., & Kim, M. (2006). 12 Determining the Baking Quality of Wheat and Rye Flour.

Gåmbaro, A., Varela, P., Gimenez, A., Aldrovandi, A., Fiszman, S., & Hough, G. (2002). Textural quality of white pan bread by sensory and instrumental measurements. *Journal of texture studies*, *33*(5), 401-413.

Iglesias-Puig, E., Monedero, V., & Haros, M. (2015). Bread with whole quinoa flour and bifidobacterial phytases increases dietary mineral intake and bioavailability. *LWT-Food Science and Technology*, *60*(1), 71-77.

Ligus, M., & Peternek, P. (2018). Determination of most suitable low-emission energy technologies development in Poland using integrated fuzzy AHP-TOPSIS method. *Energy Procedia*, *153*, 101-106.

Lynch, K. M., Coffey, A., & Arendt, E. K. (2018). Exopolysaccharide producing lactic acid bacteria: Their techno-functional role and potential application in gluten-free bread products. *Food Research International*, *110*, 52-61.

Miranda, M., Vega-Gálvez, A., López, J., Parada, G., Sanders, M., Aranda, M., Uribe, E., & Di Scala, K. (2010). Impact of air-drying temperature on nutritional properties, total phenolic content and antioxidant capacity of quinoa seeds (Chenopodium quinoa Willd.). *Industrial Crops and Products*, *32*(3), 258-263.

Motta, C., Castanheira, I., Gonzales, G. B., Delgado, I., Torres, D., Santos, M., & Matos, A. S. (2019). Impact of cooking methods and malting on amino acids content in amaranth, buckwheat and quinoa. *Journal of Food Composition and Analysis*, *76*, 58-65.

Noshad, M., Savari, M., & Roueita, G. (2018). A hybrid AHP-TOPSIS method for prospectively modeling of ultrasound-assisted osmotic dehydration of strawberry. *Journal of Food Process Engineering*, *41*(8), e12928.

Pourmasoumi, M., Ghiasvand, R., Darvishi, L., Hadi, A., Bahreini, N., & Keshavarzpour, Z. (2018). Comparison and assessment of flixweed and fig effects on irritable bowel syndrome with predominant constipation: A single-blind randomized clinical trial. *EXPLORE*.

Rocchetti, G., Lucini, L., Chiodelli, G., Giuberti, G., Montesano, D., Masoero, F., & Trevisan, M. (2017). Impact of boiling on free and bound phenolic profile and antioxidant activity of commercial gluten-free pasta. *Food Research International*, *100*, 69-77.

Sakthivel, G., Saravanakumar, D., & Muthuramalingam, T. (2018). Application of failure mode and effect analysis in manufacturing industry-an integrated approach with FAHP-fuzzy TOPSIS and FAHP-fuzzy VIKOR. *International Journal of Productivity and Quality Management*, *24*(3), 398-423.

Sandri, L. T., Santos, F. G., Fratelli, C., & Capriles, V. D. (2017). Development of gluten-free bread formulations containing whole chia flour with acceptable sensory properties. *Food science & nutrition*, *5*(5), 1021-1028.

Sciarini, L. S., Bustos, M., Vignola, M. B., Paesani, C., Salinas, C., & Perez, G. T. (2017). A study on fibre addition to gluten free bread: its effects on bread quality and in vitro digestibility. *Journal of food science and technology*, *54*(1), 244-252.

Stikic, R., Glamoclija, D., Demin, M., Vucelic-Radovic, B., Jovanovic, Z., Milojkovic-Opsenica, D., Jacobsen, S.-E., & Milovanovic, M. (2012). Agronomical and nutritional evaluation of quinoa

seeds (*Chenopodium quinoa Willd*.) as an ingredient in bread formulations. *Journal of Cereal Science, 55*(2), 132-138.

Stojceska, V., & Ainsworth, P. (2008). The effect of different enzymes on the quality of high-fibre enriched brewer's spent grain breads. *Food chemistry, 110*(4), 865-872.

Xiao, Y., Liu, H., Wei, T., Shen, J., & Wang, M. (2017). Differences in physicochemical properties and in vitro digestibility between tartary buckwheat flour and starch modified by heat-moisture treatment. *LWT-Food Science and Technology, 86*, 285-292.

Yang, X.-l., Ding, J.-h., & Hou, H. (2013). Application of a triangular fuzzy AHP approach for flood risk evaluation and response measures analysis. *Natural hazards, 68*(2), 657-674.

Yangilar, F. (2013). The application of dietary fibre in food industry: structural features, effects on health and definition, obtaining and analysis of dietary fibre: a review. *Journal of Food and Nutrition Research, 1*(3), 13-23.

Yano, H., Fukui, A., Kajiwara, K., Kobayashi, I., Yoza, K.-i., Satake, A., & Villeneuve, M. (2017). Development of gluten-free rice bread: Pickering stabilization as a possible batter-swelling mechanism. *LWT-Food Science and Technology, 79*, 632-639.

Ziska, L., Morris, C., & Goins, E. (2004). Quantitative and qualitative evaluation of selected wheat varieties released since 1903 to increasing atmospheric carbon dioxide: can yield sensitivity to carbon dioxide be a factor in wheat performance, *Global Change Biology, 10*(10), 1810-1819.

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جلد ۱۶، شماره ۶، بهمن- اسفند ۱۳۹۹، ص. ۱۶۳-۱۵۱

استفاده از روش تحلیل سلسله مراتبی (AHP) فازی و تاپسیس (TOPSIS) در بهینه‌یابی فرمولاسیون مواد غذایی: مورد مطالعاتی نان

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چکیده

در این پژوهش، اثر افزودن آرد کینوا اصلاح شده (QM) بر ویژگی‌های فیزیکوشیمیایی نان باگت بدون گلوتن مورد ارزیابی قرار گرفت. همچنین برای انتخاب بهترین فرمولاسیون نان باگت بدون گلوتن از روش تحلیل سلسله مراتبی فازی (FAHP) و TOPSIS استفاده شد. برای این منظور از دو معیار، ویژگی‌های فیزیکی (با زیر معیارهای بافت، طعم، بو، رنگ و تخلخل) و ویژگی‌های شیمیایی (با زیر معیارهای محتوی رطوبتی، خاکستر و مقدار مواد معدنی، مقدار فیبر و خواص آنتی‌اکسیدانی) برای ارزیابی بهترین فرمولاسیون نان باگت بدون گلوتن استفاده شد. بر اساس نتایج به‌دست آمده، با افزایش مقدار QM از صفر تا ۱۵ درصد، مقدار رطوبت، سفتی، فعالیت آنتی‌اکسیدانی، شاخص رنگی a*، مقادیر آهن و کلسیم در نان افزایش یافت. در حالی که با افزایش مقدار QM، مقادیر شاخص‌های رنگی b* و L* نمونه‌ها کاهش یافت. نتایج روش FAHP-TOPSIS نشان داد، ویژگی‌های شیمیایی نسبت به ویژگی‌های فیزیکی از اهمیت نسبی بالاتری برخودار بودند و بالاترین درجه اهمیت برای ارزیابی کیفیت نان مربوط به محتوای فیبر و میزان فعالیت آنتی‌اکسیدانی، به‌ترتیب با وزن نهایی ۰/۲۷۱ و ۰/۲۳۹ بود. همچنین بر اساس نتایج به‌دست آمده، نان باگت بدون گلوتن حاوی ۱۰ درصد آرد کینوا اصلاح شده با شاخص ۰/۸۷۱ به‌عنوان بهترین فرمولاسیون انتخاب شد.

واژه‌های کلیدی: کینوا اصلاح شده، نان، روش FAHP-TOPSIS، ویژگی‌های فیزیکوشیمیایی.

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