Representing the human experts judgment on quality indices of white rice

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Abstract: In the present study, a grading system based on fuzzy logic was developed to simulate the behavior of an expert in the evaluation and classification of physical properties of rice grains for pricing the product. Based on two desired quality indices in this study and the input linguistic variables of fuzzy grading system, 250 samples were prepared with different quality conditions which include all the possible states for the rice grains. Lighting and imaging were carried out from each 250 samples of rice products in the same condition. Image processing algorithm was conducted to extract geometric features and light intensity of grains and also fuzzy product pricing model was developed in MATLAB software. Fuzzy inference system was designed with the help of fuzzy toolkit. The input variables of the fuzzy system designed in this study were degree of milling (DOM) and percent of broken kernels (PBK) that were obtained as a real numbers of an image processing algorithm. In total, 25 rules of If-Then were formulated with considering the number of inputs' fuzzy sets. Fuzzy inputs for degree of milling and the percentage of broken kernels were five membership functions of very low, low, medium, high and very high that were selected based on the evaluations conducted from quality of rice production within the rice field factories in north of the country. The results of pricing through fuzzy logic indicated good overall matching with results of product pricing by an expert (overall accuracy of 92%).

Keywords: rice, image processing, broken kernels, degree of milling, pricing, fuzzy logic

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1 Introduction

Among grain products, rice with scientific name of Oryza Sativa L. is considered the world's most important food as a dietary product strategic and it is cultivated in a wide area of the world's agricultural lands after wheat due to the essential need of humans to consume it. Rice cultivation in the world and its production in terms of quality and quantity is important. According to Food and Agriculture Organization of the United Nations in 2010, the world's rice production was 672 million tons which have been produced in 114 rice growing countries of the world (FAOFOODS, 2004). Gilan province is considered as one of the most important rice-producing provinces in the country, the province produces more than 30% of the country's rice. The characteristics of rice cultivation in Gilan province is the diversity of cultivars cultivated by rice producers. One of the problems about rice is sharp price fluctuations and its traditional marketing system which often creates irreparable damage for rice producers. Thus, providing a method for rice pricing based on its physical characteristics in a way that price of this product to be same in the whole country can help producers and consumers of this product. One of the important aspects of distinguishing rice plant compared to other cereals is qualitative and economic importance or marketability of this product. Unlike the other grain products, healthy and completeness of the grains are important about rice. One of the basic criteria in the production of rice is amount of grains that were obtained in the conversion process as a

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complete and not broken form. This index strongly affects the economic value of rice, as the economic value of healthy grains is almost twice the broken grains in various stages of production (Siebenmorgen et al., 1998).

Typically, two major indicators including degree of milling and broken grains percent are raised to determine the quality of rice grains among the manufacturers and producers of grains. Investigating these criteria is mainly done visually and empirically in factories by workers of conversion lines. That is, a person evaluates the quality of product by looking at output product samples of conversion machines and reviewing the above-mentioned indexes depending on his skill and experience of working with rice production systems in factories and exerts the required changes in the conversion system if necessary. Traditional methods of sensory evaluation are widely used in determining the quality of food, but these methods are time consuming and expensive. Also, human physical conditions like fatigue or psychological conditions can affect the end result. These factors motivate the development of alternative methods that evaluate the key characteristics of product in shorter time with more accuracy. One of the methods used is the machine vision method that the image features can be extracted with the help of the method and carried out the classification or quality assessment of the product according to it (Gonzales and Wintz, 1987). Many studies have shown that image processing technique has been successfully used for grading process of agricultural production (Lleó et al., 2011; MakkySoni, 2013). Given that rice allocated the bulk of the country agriculture to itself, but there is still no an appropriate grading process in the country to improve the quality of grading for this product; therefore, image processing and fuzzy logic are ideas that can be used for automatic grading of agricultural products with high quality and precision. Now, a lot of separation and grading systems of agricultural products are done by human based on human judgments(Winter et al., 1996). Manual fruit grading causes fatigue and eye strain and also causes problems in the quality of fruits' grading which results from differential diagnosis of individuals (Gonzales and Wintz, 1987). While this is continuously done in the vision system during the very long time; in other words, it can guarantee that the entire timeframe is used for reviewing the products (Bato et al., 1999). The benefits of reviewing and grading of automatic separation systems such as machine vision systems have been proven for separating many product as an alternative to the traditional separation method (Bato et al., 1999).

Image processing is an effective and non-destructive tool of technology for preparation and analysis of image from a real scene via computer to acquire information or control a process. An obvious example of image processing applications is the food industry. Image characteristics can be extracted by using the image processing, and it is used to detect and identify the quality of products. Researchers have used the apparent color of the fruit as maturation index to classify the product in numerous reports (Blasco et al., 2009; Nogales-Bueno et al., 2014; Pedreschi et al., 2006). Pabamalie et al extracted both events and colored features matrix from images of different cultivars of rice and carried out the classification by using a neural network. The result of this study was precision between 68% and 94% for the four different cultivars of rice (Pabamalie and Premaratne, 2011). Liu et al provided a method for the classification of six cultivars of paddy rice by using color and shape properties. In this paper, seven colorful features and forty morphological features have been extracted from each type of paddy rice, 17 features have been introduced as superior characteristics by using the correlation between features. The precision of this method has been reported 88.3% (Liu et al., 2005). (Verma, 2010) used the morphological features derived from images of rice grains including perimeter, area, length, compression and elongation to classify rice grains by using MLP neural network. He reported that machine vision system used is able to classify rice grains in normal, cracked, plaster, broken and damaged classes with accuracy of 90%-95%.

Because of benefits such as reduced labor costs, higher accuracy, providing proven results in different conditions, the use of machine vision method has been quickly replaced by manual methods (Jelinski et al., 2007). Dehrouyeh developed a system based on machine vision and fuzzy logic for automatic grading of eggs. Information on the various qualitative parameters of eggs including size, crack on the shell, breakage, degree of dirt and blood spots was calculated by using image processing algorithm and placed at the disposal of a fuzzy controller. Fuzzy controller, in which an inference system based on the expert opinion had been used, calculated the final grade of eggs according to data from the images and moved a controller channel by programmable logic controller proportional to the recognized grade. Results obtained of his research showed that the developed system can properly grade the eggs with precision 95.4%. He also reported that the overall time of implementing the control process from the moment of announcing the product grade by the separation algorithm to moment of full stop of grading channel was equal to 1.87 seconds in average (Dehrouyeh et al., 2010). Omid used the acoustics method and fuzzy logic to develop a grading system of pistachio. In his study, the decision tree was used in order to develop the rules. The results showed that the developed system has capability to accurately diagnose of product with the accuracy of 95.27% (Omid, 2011). Kavdir and Guyer used the fuzzy logic for grading apples as offline. They had graded apples in terms of indicators such as color, external defects, shape, weight and size (Kavdir and Guyer, 2004). Soft computing is a new computational method that brings together the salient abilities of human mind for reasoning and learning in uncertain and imprecise environment. Study of previous research shows that methods based on fuzzy logic have the ability to simulate human behavior in uncertain decision making about the diagnosis and determining the quality of food products. Given that broken grains percent and color of rice grain determine the quality and rice prices for each cultivar, but a little diversity of prices is available for buying any cultivars. The aim of this study is to grade the rice according to attributes such as color and size and then, a reasonable price to be considered with regard to product quality by designing a grading system based on fuzzy logic to simulate the behavior of an expert in the evaluation and classification of physical properties of rice grains. In this case, the buyer can select his desired product according to taste and purchasing power, and this leads to attracting the customers satisfaction.

2 Materials and methods

2.1 Samples preparation

Considering the primary reviews conducted in rice processing plants in north of the country, it was found that human experts used five linguistic variables "very low", "low", "medium", "high" and " very high " to judge on both quality indices used in this study i.e. (broken grains percent and degree of milling). As a result, due to the combination of these variables for both indices i.e. degree of milling and broken grains percent, 250 samples with different quality conditions which include all possible qualitative modes for the rice grains were prepared. Rice moisture was measured by using a digital moisture meter (GMK model 303 RS, Korea) that was determined for the examined samples of 11%-13.5%. In order to prepare the samples, 5 kg brown rice of Hashemi cultivar which is the common and local cultivar of rice in the north of Iran was initially prepared. The samples were converted into white rice using a laboratory rice whitener (SATAKE, Model JNMS15, Japan). To achieve the desired degrees of milling, duration of whitening was changed by laboratory whitener. Then, samples' degree of milling was measured using a digital milling meter device (KM, Model C-100, Japan) used in the Rice Research Institute of Iran. After preparation of the samples with different degrees of milling, samples related to each degree of milling were divided into five sections so that five different levels of broken grains were obtained for each degree of milling level. For this purpose, at first the broken grains in the milled samples were completely isolated from the sound grains using a laboratory rotary sieve (SATAKE, Model TRG 5A, Japan) with a groove size of 3 mm and . The range of broken grains obtained from the results of evaluations conducted in rice mills in north of the country. Five different positions were created in terms of broken grains in the samples. After preparing 250 samples with different quality conditions, samples were labeled and referred to different rice field factories in Gilan province to evaluate and determine the ratings by skilled experts. The process of quality assessment was performed by people who work with the rice processing machines through filling a questionnaire which was prepared for this purpose. After collecting the questionnaire forms and via averaging the opinions of experts, 25 product samples were graded.

2.2 Imaging

Images were captured from each 250 sample products in the same illumination condition. A digital camera (Canon power Shot SX520 HS, Japan) was used with a resolution of 16 megapixels to obtain images of rice grains. A cube-shaped chamber was used for imaging that its inside was completely black. Also, two rod-shaped fluorescent lamps with a power of 18 watts, optical gain 38 lmw -1, coefficient of color resolution 67 CRI and life of 5000 h were installed on both sides of the box and in the near box roof. There was also a hole in the middle of the roof on which the camera lens was placed. Thus, imaging was done without any interference of light from outside. The height of camera in the compartment was 20 cm. A schematic of the imaging system is shown in Figure 1.

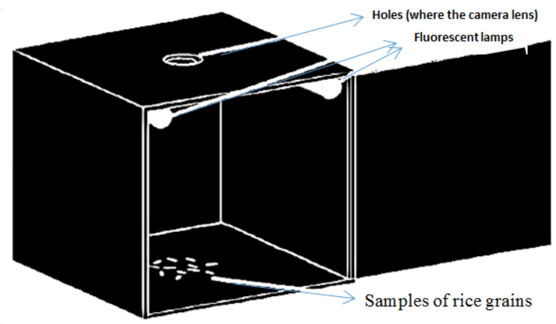


Figure 1 A schematic of the box used for imaging

2.3 Image processing of grains

The captured images were transferred to a computer. In the next step, for the improvement of images quality, rice image was separated from background and its color and size was measured using MATLAB software and image processing methods.

Each image processing algorithm included functions and operators that extract special features of image using the data of each pixel of the digital image and provide it basis for decision-making. At first, the grains were separated from the main background by performing the preprocessing and image optimization. Then, the images were prepared for final processing and extraction of the desired quality indicators. With regard to the quality properties in this study, the important features which should be processed and measured in the captured images include the total number of grains in the image, the number of broken grains in the image, and degree of milling. After obtaining the total number of grains in the image, the morphological and dimensional characteristics of each identified grain (including main axis length, minor axis length and area) were measured using pixels data related to each grain (Courtois et al., 2010). Then, according to the provided standards (Iran National Standard No. 127) that announced the length of broken grain is less than three-quarters of the length of healthy grain and definition of this standard index to the desired image processing algorithm, the number of broken and intact grains in each image was calculated. The ratio of broken grains to the total grains (NPBK) was calculated using Equation (1) (Payman et al., 2014).

$$NPBK = \frac{N_{bk}}{N_t} \qquad (1)$$

In which N_{bk} is the number of broken grains and N_t is the number of total grains in the image.

The main steps of leading the app to classify rice have been provided as a template in the following (Figure 2).

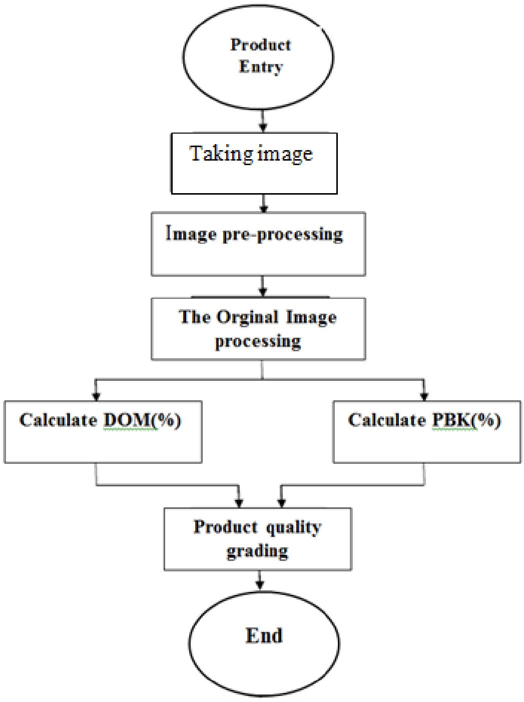


Figure 2 Major stages of program progress for the classification of rice using image processing

In order to evaluate the performance of algorithm in determining the number of broken grains (PBK), 100 grains of rice were placed manually in imaging chamber. The length of this grain was measured using a digital caliper and recorded before imaging. The experiment was replicated 10 times. After comparing the values obtained for PBK in manual measurement and image processing method, the precision of image processing algorithm to determine the PBK was determined via Equation (2).

$$A_{bk} = \left(1 - \left(\frac{|P_m - P_{ip}|}{P_m}\right)\right) \times 100 \qquad (2)$$

PBK values obtained by manual measurement and image processing algorithms respectively.

To measure the degree of milling (DOM) grains, intensity of white rice grains in each image recorded was measured by the camera. Precision of image processing algorithms to determine the DOM was calculated using Equation (3).

$$A_{dm} = \left(1 - \left(\frac{|D_{wm} - D_{ip}|}{D_{wm}}\right)\right) \times 100 \qquad (3)$$

Where A_{dm} is the precision of image processing algorithms to determine the DOM (%), D_{wm} and D_{ip} are the degree of milling obtained by manual measurement and image processing algorithm respectively.

2.3 Development a fuzzy model

Fuzzy inference system was implemented in the fuzzy toolbox of MATLAB software (MATLAB 2011). The input variables of the fuzzy system designed in this study were degree of milling (DOM) and percentage of broken grains (PBK) that were obtained from an image processing algorithm as a real numbers. The fuzzy system initially converted this definite numbers to the fuzzy values. Then, the (minimum) Mamdani fuzzy rules were imposed using the product inference engine and the necessary processing carried out on them. Finally, the result was defuzzified by the center of maximums (COM) defuzzification method and displayed as a real number which represents the price of the tested rice grains. The process of constructing a fuzzy expert system is shown in Figure 3.

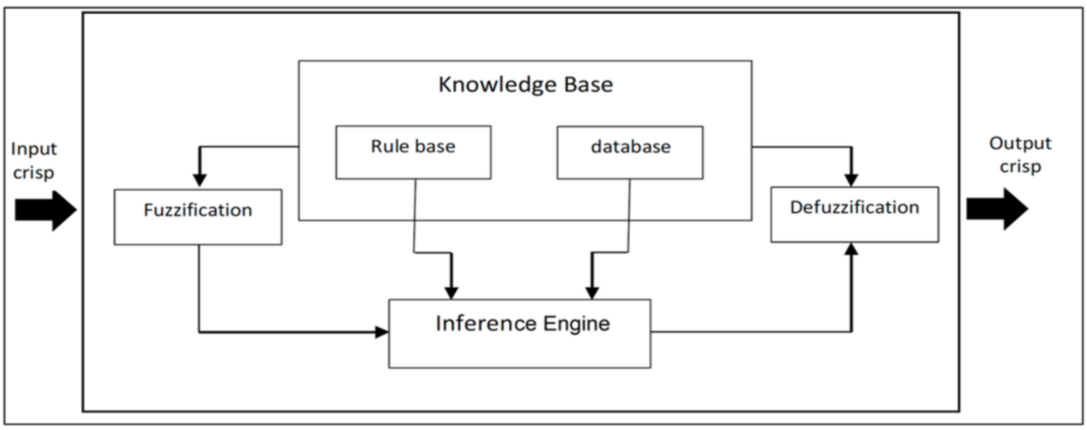


Figure 3 Steps of implementation of a fuzzy expert system

At first, five membership functions, namely very low, low, medium, high and very high were considered to write the fuzzy inputs for degree of milling and percent of broken grains in the ranges of 43.1%-47.4%, 45.8%-54.7%, 51.1%-61.8%, 58.3%-68.6% and 66.7%-74.6% for degree of milling, and 5.4%-13.2%, 10.3%-25.3%, 21.5%-30.6%, 27.4%-43.6% and 37.3%-54.6% for the percentage of broken grains. In general, given the number of input linguistic variables, 25 rules were obtained with the AND logical operator. As well as, five membership functions including very low, low, medium, high and very high were considered as Rials for output of the fuzzy system in the ranges of (55000-60000), (59000-64000), (63000-68000), (67000-72000) and (71000-75000). These ranges were selected based on assessments performed on production quality of rice in the rice mill factories in north of the country. In this research, two variables i.e. degree of milling the grains and percent of broken grains were used for pricing the product in the introduction of fuzzy rules. Because the two variables were used simultaneously in the decision-making fuzzy, the AND logical operator was used for the development of fuzzy rules. After determining the appropriate ranges for variables, membership functions were determined for the fuzzy inference systems. Accordingly, five membership functions (MFs) in fuzzy inference system were considered for the input and output variables. The membership function is a curve which defines the mapping the each point of input space to a membership value (degree of membership) between 0 and 1. The simplest membership function is composed of the straight lines. This is the triangular membership function which called "trimf". The trapezoidal membership function is called "trapmf" which is actually a triangle function cropped from above. These two membership functions benefit the advantage of simplicity. A defuzzifier converts the fuzzy results obtained from inference to definite outputs. There are many different methods of fuzzification such as the center of gravity (COG), mean of maximum (MOM), smallest of maximum (SOM), largest of maximum (LOM), center of maximum (COM) and center of area (COA) that the method of COA was chosen in this study as one of the most common methods of fuzzification to perform the process of fuzzification. In order to evaluate the developed model, the results obtained from image processing algorithms for 250 rice samples were given to fuzzy system designed in this study for pricing, and the results obtained from fuzzy logic were compared by an expert with the results of product pricing.

3 Results and discussion

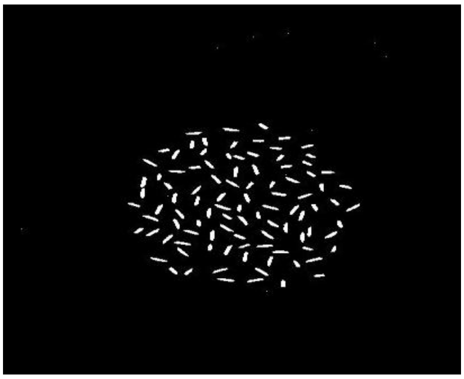
The results of the laboratory analysis to determine the level of DOM, PBK and product prices are presented in Table 1. These values were identified at different rice mill factories in Gilan province according to surveys obtained from five experienced experts. Changes of indexes DOM, PBK and product price were from very low to very much respectively, roughly in the ranges of 43%-75%, 5%-55% and 55000- 75000 Rials.

Table 1 Results of the laboratory analysis to determine the level of DOM, PBK and product prices

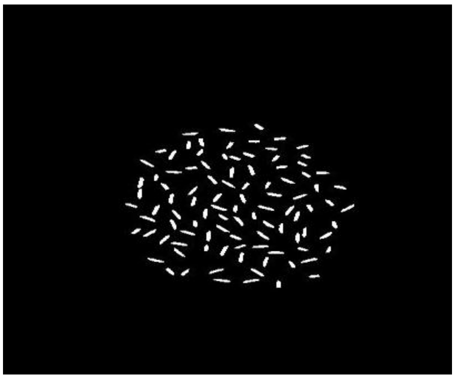
Measured range	Quality level	Quality index, %
43.1-47.4	(VL)	DOM (%)
45.8-54.7	(L)	
51.1-61.8	(M)	
58.3-68.6	(H)	
66.7-74.6	(VH)	
5.4-13.2	(VL)	PBK (%)
10.3-25.3	(L)	
21.5-30.6	(M)	
27.4-43.6	(H)	
37.3-54.6	(VH)	
55000-60000	(VL)	Price (Rials)
59000-64000	(L)	
63000-68000	(M)	
67000-72000	(H)	
71000-75000	(VH)	

3.1 Investigation of the image processing algorithm

The program related to image processing operations was initially designed in an *m-file* which includes the following. The desired image was recalled. After recalling, the image was converted to binary ones using *im2bw* function. Then, noises in the image were removed with the *bwareaopen* function, so that only the image of rice grains was remained. Figure 4 shows the sample of rice binary image, and the image after executing the *bwareaopen* function respectively by MATLAB software.



(a)



(b)

(a) Binary Image of rice grains (b) Image of rice grains after execution of bwareaopen function

Figure 4 Sample of rice grains image processing

Bwlabel function was used to count the rice grains, in which *n* was the number of rice grains in the image. The total number of rice grains was 100 in Figure (4-b).

To calculate the percentage of broken grains, the number of broken grains in the image was obtained and it was divided by the total grains in the image. In the sample image (Figure 4-b), the number of broken grains was 45 and the number of healthy grains was 55 and the percentage of broken rice grains in the above image was obtained 45%. To calculate the length of rice grains, the length of Hashemi cultivar of rice was initially measured in terms of millimeters with a digital caliper and then, the length of the same grains was measured in terms of pixels in MATLAB software environment. Then, values obtained were entered in the CurveExpert software and its corresponding equation was obtained. According to this equation, the length obtained in millimeters can be converted to its corresponding pixel. The average length of whole grain of Hashemi cultivar of rice was equal to 7.47 mm that $\frac{3}{4}$ of this value was 5.6 mm which is considered same as the length of broken grain.

The equation obtained to convert the length of rice in millimeters to pixels is y= 9/0467x + 18/588 with R^2=0.9216 and S=1.3912 where X is the length of rice in millimeters and Y is the length of rice in pixels (Figure 5).

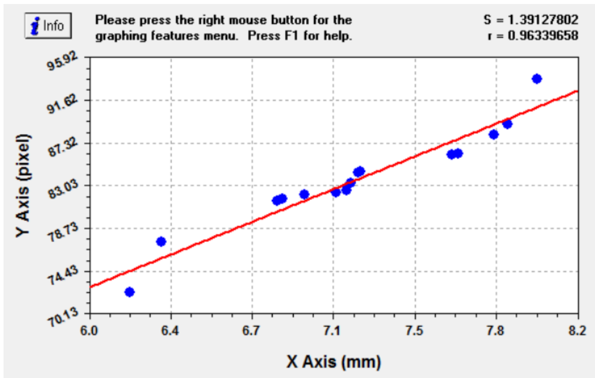


Figure 5 Conversion of grains length from millimeters to pixels.

In the next step, rice grains' degree of milling should be determined. To do this, the desired image should be converted to gray scale and then, the created matrix should be used equal to brightness level or intensity. A command was written in a for loop in MATLAB to obtain the amount of brightness in which each pixel apart from rice grains pixels in the image was equal to zero, otherwise it placed the same pixels in the matrix. Consequently, a matrix was obtained which included only the pixels related to rice grains and brightness level of rice was obtained by averaging these numbers. Finally, the program written was tested for 250 images of rice and result was obtained with precision of 92%. Then, the results of image processing algorithms in fuzzy inference system were as input variables of the system and the results of fuzzy inference systems were determined as the desired output variable which is the product price.

3.2 Formation of FIS

Fuzzy inference system had two inputs including the degree of milling and percentage of broken grains and one output (product price). The related ranges of each listed factors were prepared in questionnaire forms according to expert opinion and determined in Table 1. Then, the related rules were also defined according to certified experts which provided in Table 2. These rules were applied for communication between input and output variables. In this system, the Mamdani method and triangular MF (trimf) were used.

Table 2 Fuzzy rules used for creating a relationship between the input and output variables

1. If (Whiteness is Very Low) and (Breakage is Very Low) then (price is Low)
2. If (Whiteness is Very Low) and (Breakage is Low) then (price is Low)
3. If (Whiteness is Very Low) and (Breakage is Medium) then (price is Very Low)
4. If (Whiteness is Very Low) and (Breakage is High) then (price is Very Low)
5. If (Whiteness is Very Low) and (Breakage is Very High) then (price is Very Low)
6. If (Whiteness is Low) and (Breakage is very Low) then (price is High)
7. If (Whiteness is Low) and (Breakage is Low) then (price is Medium)
8. If (Whiteness is Low) and (Breakage is Medium) then (price is Low)
9. If (Whiteness is Low) and (Breakage is High) then (price is Very Low)
10. If (Whiteness is Low) and (Breakage is Very High) then (price is Very Low)
11. If (Whiteness is Medium) and (Breakage is Very Low) then (price is Very High)
12. If (Whiteness is Medium) and (Breakage is Low) then (price is High)
13. If (Whiteness is Medium) and (Breakage is Medium) then (price is Medium)
14. If (Whiteness is Medium) and (Breakage is High) then (price is Low)
15. If (Whiteness is Medium) and (Breakage is Very High) then (price is Low)
16. If (Whiteness is High) and (Breakage is Very Low) then (price is Medium)
17. If (Whiteness is High) and (Breakage is Low) then (price is Medium)
18. If (Whiteness is High) and (Breakage is Medium) then (price is Medium)
19. If (Whiteness is High) and (Breakage is High) then (price is Low)
20. If (Whiteness is High) and (Breakage is Very High)then (price is Very Low)
21. If (Whiteness is Very High) and (Breakage is Very Low) then (price is Medium)
22. If (Whiteness is Very High) and (Breakage is Low) then (price is Medium)
23. If (Whiteness is Very High) and (Breakage is Medium) then (price is Low)
24. If (Whiteness is Very High) and (Breakage is High) then (price is Very Low)
25. If (Whiteness is Very High) and (Breakage is Very High) then (price is Very Low)

The process of defining MFs for evaluated indices and determining the fuzzy rules for qualitative grading of rice grains in MATLAB software is shown in Figure 6.

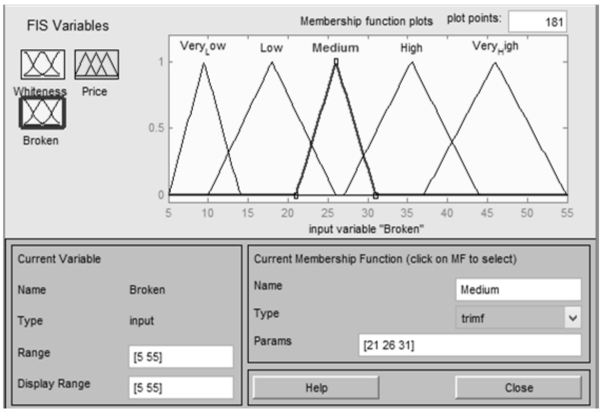


Figure 6 Overall form of the membership functions for PBK

According to the opinion of experts, the samples were classified to five classes (s1-s2-s3-s4-s5). Several images were prepared from each sample, and the degree of milling for each sample was obtained in image processing algorithms. Through averaging the results obtained of image processing algorithm for each sample, intervals were specified in terms of intensity index in image processing algorithm that the values for each samples s1-s2-s3-s4-s5 were (161-166) - (159-163) - (156-160) - (154-158) - (150-155), respectively.

Intervals obtained in the image processing algorithm were used in the fuzzy inference system which its results can be seen in Figure 7.

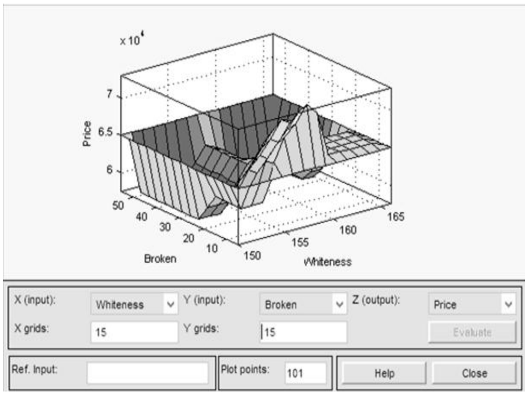


Figure 7 Surface viewer of the fuzzy rules in MATLAB software considering DOM and PBK as input variables

The graphic relationship of displaying the levels offers very useful information about issues with two inputs and one output. It can be seen in Figure 7 that how two input values (degree of milling the grains and percentage of crushed grains) affect one output value (product price); i.e. reaction can be seen in a single view. After creating the fuzzy sets and determining the fuzzy rules, pricing the rice grains that which had already been done by certified experts was compared with values that was prepared through using the model based on fuzzy logic. Figure 8 shows the evaluation of fuzzy rules in the fuzzy model provided in MATLAB software environment. This Figure shows the fuzzy model output with respect to degree of milling and percentage of broken grains in (Medium) and (Very-Low) ranges respectively. In such circumstances, the model output (product price) is located in (Very-High) range. This result is consistent with the basic definitions of fuzzy rules.

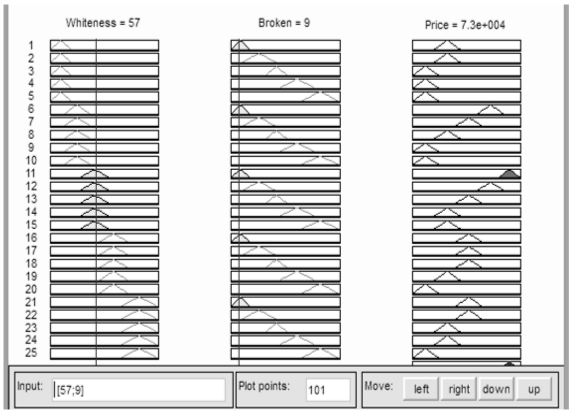


Figure 8 Evaluation of the developed fuzzy model in MATLAB software.

As seen in Figure 8, if the degree of milling of rice grains is medium (57) and the percentage of broken grains is very low (9), the product price will be very high (73000 rials). Through analyzing the model and expert opinion, it was found that the product value decreases by increasing the percentage of broken grains; but because there is a certain level of this index about the degree of milling grains in which the product quality is desirable in terms of producers, thus increasing the degree of milling increases the product price to a certain extent. In order to evaluate the fuzzy model, specifications related to the intensity and size characteristics of samples which their price were determined by certified experts according to two desired quality indices were calculated by using image processing algorithm and used as input in fuzzy model. The results of comparing these two methods and evaluating the precision of fuzzy grading model have been provided in Table 3.

Table 3 Results of evaluation of the fuzzy grading model

Percentage	Sample number	(VH)	(H)	(M)	(L)	(VL)	Fuzzy grading
90%	50	0	0	0	5	45	(VL)
92%	50	0	0	3	46	1	(L)
86%	50	0	4	43	3	0	(M)
92%	50	2	48	2	0	0	(H)
100%	50	50	0	0	0	0	(VH)

The results obtained showed that the fuzzy model used in the research had good predictability for determining the price of rice grains. The percentage of diagnosis thee correct model to estimate the price of rice grains in the ranges "very low", "low", "medium", "high" and "very high" was obtained 90%, 92%, 86%, 92%, and 100% respectively.

4 Conclusions

According to the developed algorithm, it became clear that the written image processing algorithm has high precision and accurate results were achieved from it in most images. Also, the quality of the studied rice can be realized by obtaining the percentage of breakage and brightness level of rice that this would be very effective in the classification and pricing the rice by using fuzzy inference system and an acceptable rate can be determined for it based on the rice quality. In this study, a model based on fuzzy logic was developed and used successfully as a decision support method for pricing the rice grains. The results of pricing through fuzzy logic indicated good overall matching with results obtained from product pricing by the expert (overall accuracy of 92%). It was also observed that the selection of two indices i.e. degree of milling grains and percentage of the broken grains was suitable for pricing the rice product.

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