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Quality and sensory profiling of gluten free bread as a function of quinoa, corn and xanthan content: Statistical analysis and modeling study

Simin Ghasemizadeh[1], Behzad Nasehi[2*], Mohammad Noshad[1]

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Abstract

In the study, the effect of compositional parameters (Xanthan, Corn flour and quinoa flour content) on sensory characteristics and image features of gluten free bread were evaluated. Results showed, addition of quinoa and corn flour significantly decreased L^* value and increased a^* value of crust and crumb of gluten free bread. Also, increased percentage of corn flour has led to decreased amount of FD_{L*} that indicates the area appears less nonhomogeneous on surface of gluten- free bread. The results also showed that using complete flour of quinoa causes softness in bread due to the presence of bran and networking, therefore, resulting in increased contrast, homogeneity and entropy, and decreased energy and correlation of produced breads. The results of sensory analysis showed that all samples containing quinoa flour have higher overall acceptance score than that of the control treatment. Correlation analysis showed a good linear relationship between image features and overall acceptance of gluten- free bread. Results showed that the optimized Adaptive Neuro-Fuzzy Inference System (ANFIS model) provide best accurate prediction method for overall acceptance of gluten-free bread (R^2= 0.994 and MSE= 0.0015) and it could be a useful tool in the food industry to design and develop novel products.

Key words: Image processing; Sensory analyzer; Gluten free bread; ANFIS model.

Introduction

Patients with coeliac disease should avoid regular consumption of grain-based products such as wheat, barley because they are intolerance to the gliadin fraction, so taking food products made with wheat flour for these patients is not recommended. As a result, gluten-free products were produced for these patients. Low quality, poor mouth feel and flavor are the most challenges in producing these products. This is due to removal of gluten from the flour. The important rheological characteristics of dough, such as elasticity, extensibility, resistance to stretch, mixing tolerance, and gas holding ability depend on the quality of gluten matrix (Lazaridou *et al.*, 2007; Stikic *et al.*, 2012; Yazar *et al.*, 2017).

Quinoa flour is one of the compounds used as a substitute for wheat flour in gluten free productions. Quinoa (*Chenopodium quinoa* Willd.), is distinguished as being a cereal with high-quality protein and absence of gluten and it has high levels of essential fatty acids, with good oxidative stability. Therefore, partially replaced wheat flour with quinoa in gluten- free products, increases its nutritional value in terms of dietary fibre, minerals, proteins of high biological value and healthy fats (Alvarez-Jubete *et al.*, 2009; Stikic *et al.*, 2012; Świeca *et al*., 2014).

Xanthan, guar gum, galactomannans, are the most common hydrocolloids which are being used in gluten-free formulations for a variety of purposes including texture improvement and water retention. In this study, the xanthan gum (XG) was selected because it forms a high-viscosity pseudo plastic semisolid. XG produces a viscose solution with shear thinning flow behavior when dissolved in cold water. The shear thinning property of XG is important during dough preparation, i.e. kneading and rolling(Matuda *et al*., 2008; Naji-Tabasi and

1. Department of Food Science & Technology, Faculty of Animal Science and Food Technology, Khuzestan Agricultural Sciences and Natural Resources University, Mollasani, Iran.
2. Department of Agricultural Engineering and Technology, Payame Noor University (PNU), Iran.
*-Corresponding author Email: Nasehi.b@pnum.ac.ir

Mohebbi, 2015).

A multiple regression analysis such as the response surface method has been applied for modeling and predicting the different procedures. An adaptive neuro-fuzzy inference system or adaptive network-based fuzzy inference system (ANFIS) is based on Takagi–Sugeno fuzzy inference system. The technique was developed in the early 1990s. Since it integrates both neural networks and fuzzy logic principles, it has potential to capture the benefits of both in a single framework. Once the ANFIS is trained using experimental data, it can be used in a predictive mode to calculate the dependent variable(s) for any values of input variables. ANFIS techniques appear to be very applicable tools to overcoming some of the difficulties in sensory evaluation(Al-Mahasneh *et al.*, 2016).

Overall acceptance of a new product considers as one of the important parameters is a food products' quality. This can be assessed by trained sensory panels or by consumer tests. But, organizing a sensory panel needstoo much time and is labour consuming. To solve this problem, computer vision as a novel technology used for extracting quantitative information of morphology, structure and microstructure from digital images in order to provide objective, rapid, non-contact, and non-destructive quality evaluation(Katina *et al.*, 2006; Soukoulis *et al.*, 2010).

The aim of this study was to develop new techniques for the investigation and modeling the effect of quinoa and XG on color and macrostructure (porosity, fractal dimension and crumb texture) and overal acceptance of gluten-free bread and for the first time, as well as the efficiency of ANFIS simulation for prediction of overall acceptance of this product.

Material and methods

Bread ingredient

Rice flour (powderineh North group, Iran), Corn flour (Tarkhineh group, Iran), Xanthan gum (Rhodia Food, France), fast active dry yeast (Razavi group, Iran), salt, sugar and sunflower oil (Oila group, Iran) were the materials used in the study. Also, quinoa flour mill grains variety of *Santamaria* were cultivated and obtained at Ramin university of Agriculture and Natural Resources field.

Preparation of breads

The materials used in formulation for gluten- free bread consist of rice flour, corn flour (0-30 % base on flour), quinoa flour (0-30 % base on flour), Xanthan gum (0-1.5 % base on flour), fast active dry yeast (2%), salt (2%), sugar (2%), sunflower oil (3%) and the amount of water used in all sample breads was kept the same (80%).

The method of Foste *et.al* (2014) was used to produce of gluten– free bread. All ingredients were mixed at 100 rpm for 2 min and kneaded at 200 rpm for 2 min (MHM-X3P, Mayson, Japan). After weighing 250 g into baking tins (resulting in 4 tins per recipe), samples were proofed at 30°C and 80% relative humidity for 30 min and baked at 220°C for 35 min with initial 0.5 L steam in a deck oven (Karl Walker, Germany) *(Föste et al.*, 2014).

2.3. Sensory evaluation

Gluten- free breads were evaluated for their organoleptic characteristics (color, flavor, taste, texture, and overall acceptability) by performing a five-point hedonic test using trained panelists. The panelists were asked to evaluate the samples and score them between 1 (most disliked) to 5 (most liked) (Stone, *et al.*, 2012).

2.4. Image processing

A computer vision system consisted four fluorescent lights (8W; 60 cm in length) with a color index close to 95% was employed. The illuminating lights were placed (45 cm above the sample and at the angle of 45° with sample) in a wooden box and the interior walls of the wooden box were painted black to give a uniform light intensity over the bread. A color digital camera (Canon PowerShot SX60 HS, Japan) with lens focal length of 35 mm for color analysis and 45 mm for investigation of pore properties was located vertically. The iris was operated in manual mode, with the lens aperture of 5.6, ISO 100 and shutter speed of 1/100 s to achieve high uniformity and repeatability.

The image analysis was carried out using MATLAB (version 2011 b). The features of crust and crumb color, porosity, fractal dimension of crust color and crumb texture were investigated(Mogol and Gökmen, 2014; Naji-Tabasi and Mohebbi, 2015).

Fractal texture Fourier image

A methodology similar to the one developed by Noshad *et al* (2015) was followed: first, color image was transformed form RGB space color to L*a* b* space color. Second, pixel coordinates (x,y) were plotted against their L* levels in the z-axis. Surface intensity obtained from L* channel, was called "SI_{L*}", corresponding to L* channel. Third, SIL* was quantified using the fractal theory. The Fourier fractal method was used to compute the fractal dimension of a 2-D image came from the L* channel. A fractal dimension (FDL*) was determined from the Fourier power spectrum of image data (Noshad *et al*., 2015).

Image texture analysis

The Grey-level co-occurrence matrix (GLCM) was used to obtain the statistical texture features. A GLCM is a matrix where the number of rows and columns is equal to the number of gray levels, G, in the image. The GLCM's are very sensitive to the size of the texture samples on which they are estimated. Thus, the number of gray levels is often reduced. The center of each slice was cropped in a square of 1400 * 1400 pixels and converted to grey-level image (8 bits). During our study, the features were investigated in four directions (0°, 90 °, 180° and 270°) and a distance of 1 pixel. The GLCM analysis was managed using MATLAB (version 2011 b). The average of five textural features: angular second moment, contrast, correlation, inverse difference moment and entropy were studied (Jackman and Sun, 2013; Naji-Tabasi and Mohebbi, 2015).

Adaptive Neuro-Fuzzy Inference System (ANFIS) Architecture

Hybrid neuro-fuzzy system (ANFIS) combines a Neural Networks (NN) and a fuzzy system together. ANFIS has been proved to have significant results in modeling nonlinear functions. In ANFIS, the membership functions (MF) are extracted from a data set that describes the system behavior. The ANFIS learns features in the data set and adjusts the system parameters according to given error criterion (Mohebbi, *et al.*, 2013). In a fused architecture, NN learning algorithms are used to determine the parameters of fuzzy inference system. Among many Fuzzy Inference System (FIS) models, the Sugeno fuzzy model is the most widely used for its high interpretability and computational efficiency, and built-in optimal and adaptive techniques (Al-Mahasneh, *et al.*, 2016;Mohebbi,*et al*., 2013).

For a first-order Sugeno fuzzy model, a common rule set with two fuzzy if-then rules can be expressed as:

Rule 1: If x is A_1 and y is B_1, then $Z_1 = p_1x+q_1y+r_1$

Rule 2: If x is A_2 and y is B_2, then $Z_2= p_2x + q_2y+r_2$

Where Ai, B_i(i=1,2) A_i and B_i are fuzzy sets in the antecedent, and p_i, q_i,r_i (i=1,2) are the design parameters that are determined during the training process.

As in Fig.1, the ANFIS consists of five layers:

Layer 1, every node i in this layer is an adaptive node with a node function:

$O_i^1 = \mu A_i (x)$, i=1,2

$O_i^1 = \mu B_i (y)$, i=3,4

Where x,y are the input of node i, and $\mu A_i(x)$ and $\mu B_i(y)$ can adopt any fuzzy membership function (MF). In this paper, generalized membership function was used.

Layer 2, every node in the second layer represents the ring strength of a rule by multiplying the incoming signals and forwarding the product as:

$O_i^2=w_i=\mu A_i(x)\mu B_i(y)$, i=1,2

Layer 3, the i^{th} node in this layer calculates the ratio of the i^{th} rule's ring strength to the sum of all rules' ring strenghs:

$O_i^3=\varpi_i=\frac{w_i}{w_1+w_2}$, i=1,2

Where ϖ_i is referred to as the normalized ring strengths.

Layer 4, the node function in this layer is represented by:

$O_i^4=\varpi_i z_i=\varpi_i(p_i x+q_i y+r_i)$, i=1,2

Where ϖ_i is the output of layer 3, and {p_i, q_i, r_i}7 are the parameter set. Parameters in this layer are referred to as the consequent parameters.

Layer 5, the single node in this layer computs the overall output at the summation of all incoming signals.

$O_1^5=\sum_{l-1}^{2}\varpi_i z_i=\frac{w_1z_1+w_2z_2}{w_1+w_2}$

It is seen from the ANFIS architecture that when the values of the premise parameters are fixed, the overall output can be expressed as a linear combination of the consequent parameters:

$Z=(\varpi_1 x)p_1+(\varpi_1 y)q_1+(\varpi_1)r_1+(\varpi_2 x)p_2+(\varpi_2 y)q$

The Matlab (2011 b) software was used to obtain the results, and to build a fuzzy model for overall acceptance of gluten- free bread.

Statistical analysis

Response surface methodology (Box-Behnken) was applied for the determination of the main effects of the investigated independent factors (quinoa flour, corn flour and xanthan gum) and their interactions on the image features and overall acceptance.

Also, ANFIS for modeling , the relationship between image features and overall acceptance using the correlation coefficient (r), which is a measure of the linear relationship between two variables, were first evaluated. All statistical treatments were carried out using Minitab 16 (statistical software, USA).

Results

Crust and crumb color

The results of variance analysis of the bread crust color were shown in table1. The results of variance analysis showed that second-level models fitted to responses of crust color were significant ($p<0.05$) (table 1). Also, the non-fitness indexes of significant models for responses of crust color were significant ($p<0.05$). Statistical analysis showed that Quinoa and corn flour had a considerable effect on the value of crust color. As shown in figure 2, adding Quinoa and corn flour significantly decreased L^* value ($p<0.05$). The increased L^* value (brightness) enhanced the non-enzyme browning of Millard reaction due to higher level of lysine amino acid in Quinoa flour(Alencar *et al*., 2015).

Table 1. ANOVA evaluation of linear, quadratic, and interaction terms for each response variable and coefficient of prediction models

source	Energy	Contrast	Entropy	Correlation	homogeneity	L*crust	a*	L* crumb	FD $_{L*}$	Porosity	Overall acceptance
Model	0.54	0.17	5.66	0.64	0.92	67.02	-6.16	65.9	0.64	0.096	**6.33**
$_1\beta$	0.01^{ns}	-0.05^{ns}	-0.48^{ns}	0.09^{ns}	0.05^{ns}	-0.09^{*}	-0.21*	-0.19*	0.6^{ns}	0.18*	**0.064^{ns}**
$_2\beta$	-0.17*	0.08^{ns}	0.075*	-0.013*	0.03^{*}	-0.25*	-0.03*	-0.5*	0.08*-	0.02^{ns}	**-1.94***
3β	-0.02^{ns}	0.011^{ns}	0.17*	-0.03*	-0.025^{ns}	-2.13*	0.71*	-8*	0.01^{ns}	3.8*	**0.74***
$_2\beta_1\beta$	0.07^{ns}	-0.012^{ns}	0.019^{ns}	0.04^{ns}	0.06^{ns}	0.01*	0.001*	-0.04^{ns}	-0.09^{ns}	0.01^{ns}	**0.36^{ns}**
$_3\beta_1\beta$	-0.08^{ns}	0.02^{ns}	0.036^{ns}	0.06^{ns}	-0.034^{ns}	0.09*	0.01*	0.01^{ns}	0.13^{ns}	0.06*	**$-.38^{ns}$**
$_3\beta_2\beta$	-0.03^{ns}	0.03^{ns}	0.014^{ns}	-0.07^{ns}	0.065^{ns}	2.85^{ns}	0.76^{ns}	5.44*	0.01^{ns}	0.04*	**0.49*-**
$_1{}^2\beta$	-0.01^{ns}	-0.04^{ns}	0.057^{ns}	-0.06^{ns}	0.01^{ns}	0.01*	0.01^{ns}	0.01^{ns}	-0.4^{ns}	0.03*	**0.16^{ns}**
$_2{}^2\beta$	0.04^{ns}	0.06^{ns}	-0.034^{ns}	-0.01^{ns}	-0.04^{ns}	0.2^{ns}	-0.01^{ns}	0.01^{ns}	-0.08^{ns}	1.74^{ns}	**-0.078^{ns}**
$_3{}^2\beta$	0.04^{ns}	-0.04_{ns}	-0.07^{ns}	-0.037^{ns}	-0.007^{ns}	0.06^{ns}	-0.06^{ns}	0.18*	0.28^{ns}	0.82*	**0.28^{ns}**
Model (p-value)	0.006	0.005	0.007	0.013	0.028	0.001	0.001	0.001	0.042	0.001	**0.002**
Lack of fit (p-value)	0.489	0.09	0.18	0.76	0.27	0.842	0.59	0.482	0.14	0.54	**0.406**
R^2	0.9	0.84	0.82	0.84	0.86	0.94	0.94	0.95	0.81	0.96	**0.925**
Adj-R^2	0.81	0.79	0.77	0.76	0.75	0.9	0.88	0.89	0.74	0.91	**0.857**

^{ns} is not significant at α=0.05; * is significant at α=0.05; lack of fit is not significant at p>0.05

Bran or crust of quinoa also causes darkness in bread crumb. Considering the fact that complete flour of quinoa is darker that wheat flour and the color of bread crumb depends on ingredients rather than browning reactions, adding quinoa flour into free-gluten bread formulation would decrease the brightness of bread crumb (L^* value). Moreover, the results showed that added xanthan hydrocolloid leads to increase lightness and yellowing index, and decrease redness (Naji-Tabasi and Mohebbi, 2015).

Fractal dimension

To represent how distributing spatial L* values on the area analyzed, FD_{L*} value can be used and it does not have physical significance here. Decreasing FD_{L*} value showing decreasing irregularity of SI_{L*} in other word distribution of L* values on the area appears less nonhomogeneous during the browning kinetics (Noshad et al., 2015). The results of variance analysis of the data from FD_{L*} showed that the only linear effect of corn flour was significant ($p<0.05$) (table 1). Figure 1 shows that increased percentage of corn flour has led to decreased amount of FD_{L*}. The decrease in the amount of FD_{L*} indicates the area appears less nonhomogeneous on surface of gluten- free bread.

Porosity of bread texture

The results from figure 2 show that Quinoa four is more effective in increasing the porosity of bread texture than xanthan gum thus the linear effect of Quinoa flour in porosity factorial was significant ($p<0.05$) and positive and linear effect of corn flour was significant ($p<0.05$) and negative and xanthan gum was not significant. Furthermore, the second-level effect of Quinoa was insignificant and the second-level effects of corn flour and xanthan gum were significant ($p<0.05$). The results showed that linear effect of Quinoa flour and xanthan gum on cells circularity was significant ($p<0.05$) and the second-level effects of Quinoa flour and xanthan were significant ($p<0.05$) and the second-level effect of corn flour was significant ($p<0.05$). The interaction of Quinoa and xanthan and also the interaction of corn and xanthan were significant ($p<0.05$) (table 1). Adding xanthan to bread causes reduction in cell area and increased number of pores compared to control. The parameter of pore number to cell area was considered as porosity. Therefore, adding xanthan increased the porosity while increased quinoa flour caused reduction in cell density and cell number. Additionally, increased xanthan gum and quinoa flour resulted in increasing the volume. The increased volume compared with control is due to the increased viscosity by quinoa flour, improved water gas distribution in the paste trapping more produced bubbles in bread resulting to increased porosity *(Elgeti et al.*, 2014).

Crumb texture: evaluation by gray level co-occurrence matrix (GLCM)

Resulted shows that adding Quinoa flour to free-gluten bread formulation leads to increased homogeneity in all treatments compared to control. Also, energy and correlation of all treatments showed reduction in comparison to control. The decreased amount of contrast indicates the softer texture of product while the increased amount of energy, correlation and homogeneity, results in increased softness of texture (Karimi *et al.*, 2012).

The results showed that increased percentage of Quinoa has led to decreased amount of energy and correlation while homogeneity and entropy were increased. The increase in the amount of contrast and homogeneity indicates the softer texture of product on one hand, and decreased energy and correlation, on the other hand, resulted in increased texture softness. It seems that using complete flour of Quinoa causes softness in bread due to the presence of bran and networking, therefore, resulting in increased contrast, homogeneity and entropy, and decreased energy and correlation of produced breads.

Overall acceptances

The results of variance analysis of the data from overall acceptances showed that the linear effect of corn flour and xanthan gum were significant ($p<0.05$). The second effect of xanthan gum was also positive and significant ($p<0.05$). Moreover, the interaction of them was not significant (Table 1). Figure 3 shows the response-surface chart of overall acceptance.

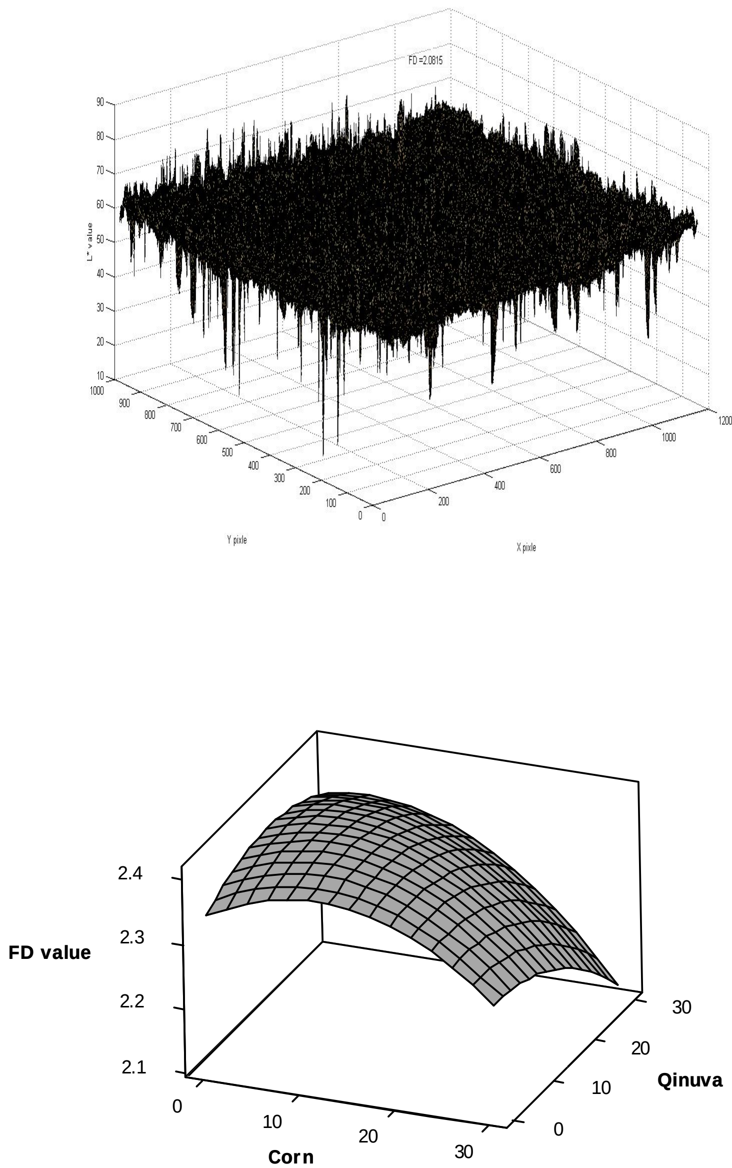

Fig. 1. Surface intensity and Response surface plots for FD $_{L*}$ value

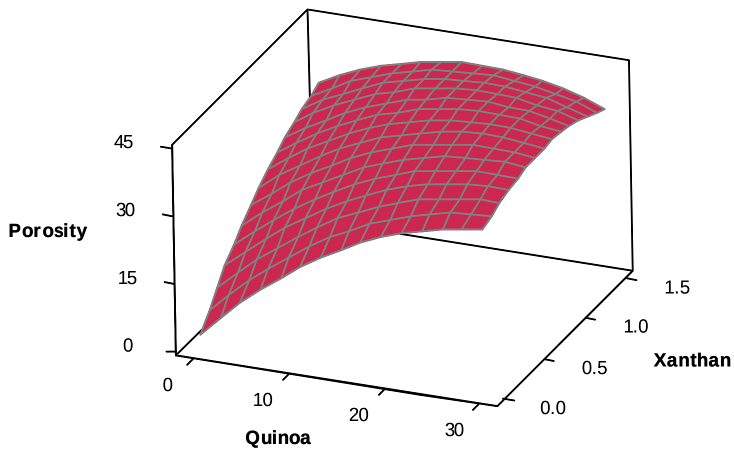

Fig. 2. Response surface (3D) plot for porosity

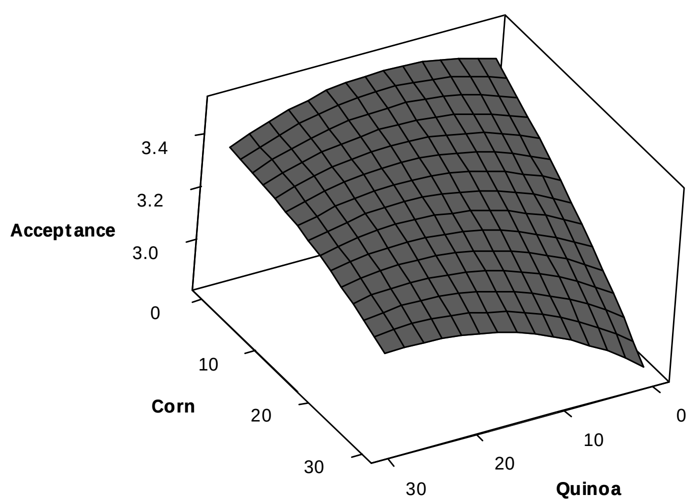

Fig. 3. Response surface (3D) for overall acceptance

The results of sensory analysis show that in most of the treatments, sense response received from panelists had increase in comparison to free-quinoa samples. Finally, the score of overall acceptances for all treatments containing Quinoa flour were higher than control treatment sample indicating higher acceptance of tested samples among consumers and panelists. Generally, the breads with formulations containing quinoa flour were different in terms of smell and taste. The bread crust color was yellow to bright red and texture contained small pores and bran particles of quinoa and in all breads containing quinoa flour, the sweet smell and taste were enjoyable to consumers. Furthermore, adding xanthan gum resulted in better texture and more sensory analysis for consumers(Naji-Tabasi and Mohebbi, 2015).

Correlation analysis

In evaluating the correlation analysis, negative coefficient indicates an inverse relationship, and a positive coefficient indicates a direct relationship between variables. Correlation analysis showed a good linear relationship between image features and overall acceptance of gluten- free bread. Thus, according to the results of correlation analysis (table2), machine vision and image processing techniques can be a useful tool in predicting and evaluating overall acceptance of gluten-free bread.

Table 2. Correlation coefficients between overall acceptance and image features

	FD L*	L* crumb	a*	L*crust	homogeneity	Correlation	Entropy	Contrast	Energy	porosity
Overall acceptance	-0.14*	0.79*	-0.56*	0.73*	0.69*	0.1*	0.12*	-0.68*	0.73*	0.71*

* is significant at α=0.05

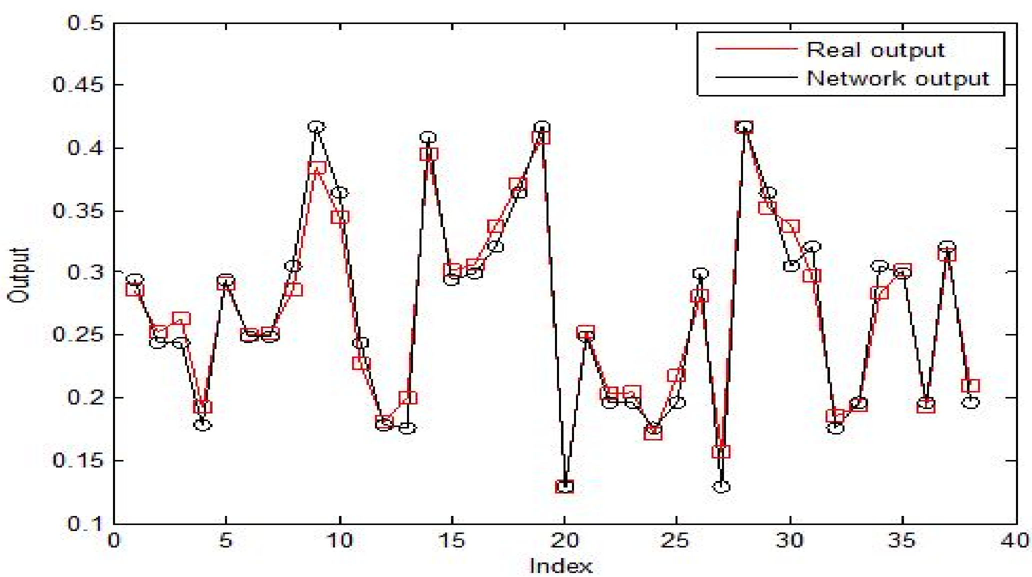

Fig. 4. The actual values of the overall acceptance versus predicted values by ANSIF (R^2=0.994)

ANFIS model

An experimental data was used for building a fuzzy model and training the system to predict the overall acceptance of gluten-free bread. A comparison between the actual and ANFIS predicted overall acceptance for testing data is shown in figure 4, which shows that the system is well-trained to model the actual chemical outputs. It must be mentioned randomizing the data set done before training the ANFIS prediction system and Gaussian curve built-in membership function (gaussmf) was chosen. The experimental values of overall acceptance versus ANFIS predictions for each test data sets were plotted for estimation the performance of developed ANFIS model. Resulted showed that the optimized ANFIS model provide best accurate prediction method for overall acceptance of gluten-free bread (R^2= 0.994 and MSE= 0.0015). Therefore, this method can be applied to model the operating conditions.

Conclusion

According to this study, adding quinoa flour decreased L^* value, amount of energy and correlation and increased a* value, homogeneity, entropy and the score of overall acceptances. Also, addition of corn flour significantly decreased L^* value and amount of FD_{L^*} but increased a* value. The increase in the amount of contrast and homogeneity indicates the softer texture of product on one hand, and decreased energy and correlation, on the other hand, resulted in increased texture softness. Correlation analysis showed a good linear relationship between image features and overall acceptance of gluten- free bread. Results showed that the optimized ANFIS model provide best accurate prediction method for overall acceptance of gluten-free bread (R^2= 0.994 and MSE= 0.0015). Therefore, this method can be applied to model the operating conditions.

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بررسی آماری و مدل‌سازی کیفیت و ویژگی‌های حسی نان بدون گلوتن به‌عنوان تابعی از مقادیر آرد کینوا، ذرت و گزانتان

سیمین قاسمی‌زاده[1]– بهزاد ناصحی[2*]– محمد نوشاد[1]

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چکیده

در این پژوهش اثر افزودن آرد کامل کینوا، ذرت و صمغ زانتان به فرمولاسیون نان بدون گلوتن بر ویژگی‌های حسی و کیفی مورد بررسی قرار گرفت. نتایج این پژوهش نشان داد که افزودن آرد کینوا و ذرت باعث افزایش معنی‌دار شاخص L* و کاهش شاخص a* پوسته و مغز نان شد. همچنین افزایش درصد آرد ذرت باعث کاهش شاخص FDL* در نمونه‌ها شد که این امر نشان‌دهنده کاهش ظاهر ناهمگن سطح نان است. یافته‌ها نشان داد با افزایش درصد کینوا، میزان انرژی و همبستگی کاهش یافته و همگنی و انتروپی و تباین افزایش می‌یابد. افزایش میزان تباین و همگنی نشان دهنده بافت نرم‌تر محصول بوده، از سوی دیگرکاهش انرژی، همبستگی نیز سبب افزایش نرمی در بافت می‌شود. به‌نظر می‌رسد استفاده از آرد کامل کینوا به دلیل وجود سبوس و ایجاد شبکه، سبب نرم‌تر شدن نان نسبت به نمونه شاهد و در نتیجه سبب افزایش تباین، همگنی و آنتروپی و کاهش انرژی و همبستگی نان‌های تولیدی گردید. نتایج داده‌های حسی نشان می‌دهد که امتیاز پذیرش کلی تمامی تیمارهای حاوی آرد کینوا نسبت به تیمار نمونه کنترل بیشتر بود که نشان‌دهنده بالا بودن مقبولیت نمونه‌های مورد آزمایش در بین مصرف‌کنندگان و ارزیاب‌ها بود. نتایج آنالیز همبستگی به‌خوبی نشان داد شاخص‌های بینایی، همبستگی بالایی ($p<0/05$) با ویژگی‌های حسی نان بدون گلوتن داشتند که بیان‌کننده توانایی تکنیک‌های پردازش تصویر در پیش بینی پذیرش مصرف کننده بود. مقادیر بالای ضریب همبستگی (0/994) و کم MSE (0/0015) گویای کارایی بالای سیستم استنتاج تطبیقی فازی- عصبی (ANFIS) در پیش‌بینی میزان پذیرش کلی نان‌های بدون گلوتن می باشد. که می‌تواند به‌عنوان یک ابزار دقیق برای طراحی و توسعه محصولات جدید در صنعت مواد غذایی استفاده شود.

واژه‌های کلیدی: پردازش تصویر، ارزیابی حسی، نان بدون گلوتن، سیستم استنتاج تطبیقی فازی- عصبی (ANFIS)

1- گروه علوم و مهندسی صنایع غذایی، دانشکده علوم دامی و صنایع غذایی، دانشگاه علوم کشاورزی و منابع طبیعی خوزستان.
2- دانشیار، گروه مهندسی و فناوری کشاورزی، دانشگاه پیام نور، ایران
(*- نویسنده مسئول: Email: mo. Nasehi.b@pnum.ac.ir)