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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):

$$\mu_A(x) = \begin{Bmatrix} \frac{x}{m-l} - \frac{l}{m-l}, & x\epsilon[l,m] \\ \frac{x}{m-u} - \frac{u}{m-u}, & x\epsilon[m,u] \\ 0, & otherwise \end{Bmatrix} \quad (1)$$

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. $M_{gi}^1, M_{gi}^2, \ldots, M_{gi}^3$ 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} $(j=1, 2,\ldots, m)$ 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):

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

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

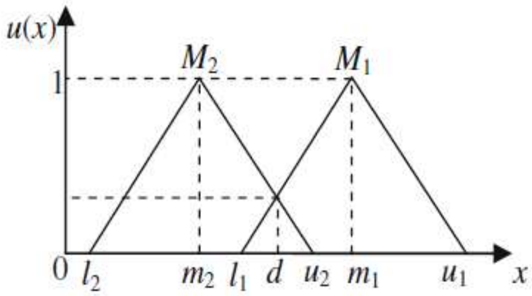

Fig 1. Membership functions of M_1 and M_2

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

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

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):

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

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

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)
Compatibi lity 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)).

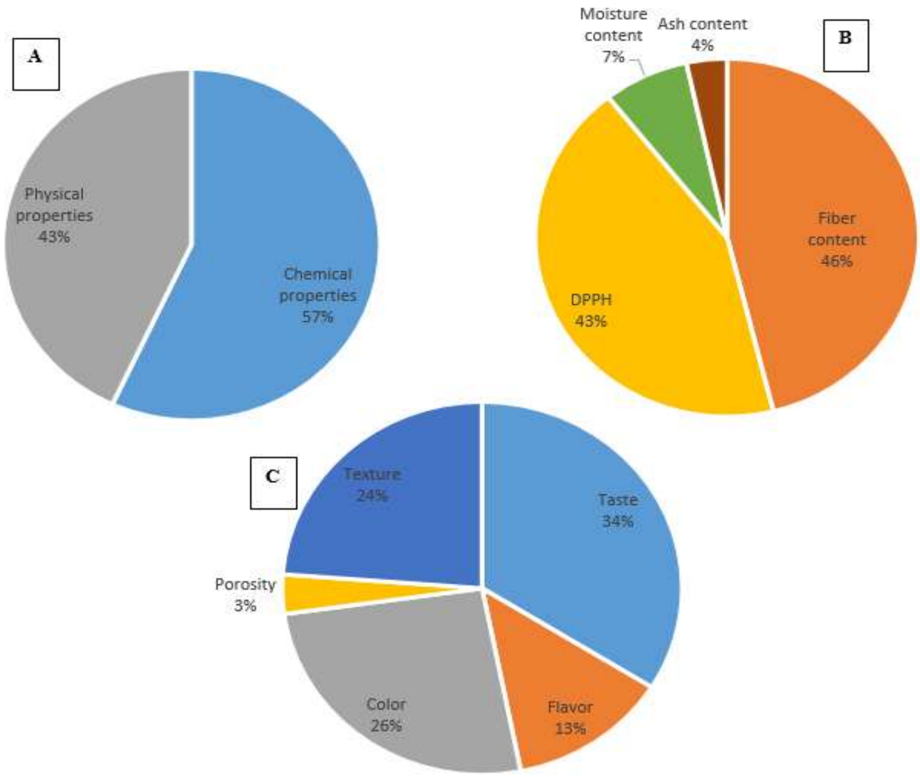

Fig. 2. Weight relative importance of criteria (A), sub-criteria of chemical properties (B), sub-criteria of physical properties (C)

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.

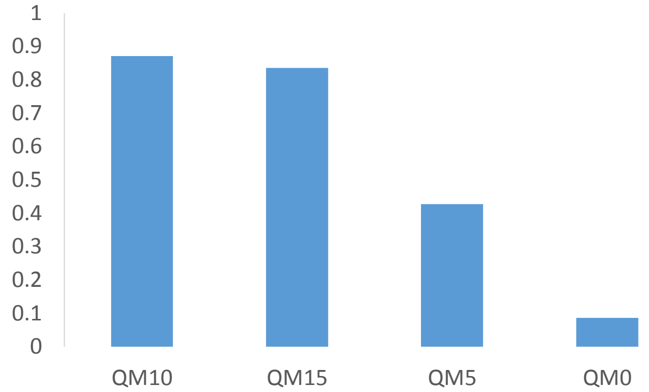

Fig. 3. Proximity index of products

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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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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