Journal of Food Engineering 357 (2023) 111625

Contents lists available at ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

Healthy bread quality index based on food label information

Hakan Şimşek *, Şevval Sarı

Department of Industrial Engineering, Antalya Bilim University, Antalya, Türkiye

ARTICLE INFO

Keywords:
Healthy bread
Nutrient content
Additives
Fuzzy inference system (FIS)

ABSTRACT

The label on the package shows important information such as the origin, type, price, and nutritional and energy value of the product during the purchase of the product. A decision support system is aimed at obtaining health index corresponding to energy and nutritional values with different inputs by using fuzzy logic on bread, one of the most consumed food products, in order to increase the awareness of consumers about using label information and to make a healthy and accurate evaluation among product types. The proposed model consists of two subs and one main Mamdani type fuzzy inference systems. The main fuzzy inference system has six inputs consisting of nutrient content, total fat, sugar, salt, additives, and energy. Sub-fuzzy inference systems, on the other hand, produce outputs for total fat and nutrient content inputs, where the inputs for total fat are fat and saturated fat; the inputs for nutritional content are fiber, protein, and carbohydrates. The healthy bread quality index is determined by processing the data related to these inputs on the label into the system. Label data of 54 breads packed in 18 different types sold in supermarket chains is used. Finally, the graphical user interface and sensitivity analysis of the methodology are presented.

1. Introduction

Knowing how healthy and high quality the food products sold in market chains are is one of the most important issues in our daily lives. Label information is very important in consuming healthy, reliable, conscious, and appropriate food products, in facilitating the behavior of consumers at the purchasing stage and in making the right choices. Reading the label information is developed to protect consumers from false information and is also the first step of healthy nutrition. Various research, review and meta-analysis studies related to the concepts, such as social, economic, commercial, food health and safety, etc. about label information show that food label information is a very important public health tool that primarily communicates about the product, aimed at providing consumers with information that can influence their purchasing decisions (Hutt and Gonzalez, 2014; Peterman and Žontar, 2014; Temple and Fraser, 2014; Roche, 2016; Sax and Doran, 2016; Shangguan et al., 2019; Anastasiou et al., 2019; Díaz et al., 2020; Peonides et al., 2022). For instance, a quantitative analysis was presented to investigate the impact of the nutrition logo on the development of healthier products by food manufacturers (Vyth et al., 2010). The habits of Turkish consumers to use food and nutrition labels and the restrictions on the use of this information were examined and it was recommended to develop new strategies to encourage consumers to use food and nutrition labels effectively (Besler et al., 2012). A qualitative study aimed to assess consumers' views on current Brazilian food label uses and their reactions to the introduction of a pre-package warning label (Sato et al., 2019). A survey study was conducted to examine the impacts of incoherencies in food labeling with health claims, such as single or multiple benefits listed on food packaging (Tanemura and Hamadate, 2022). More research on the subject can be found in the literature (Stran and Knol, 2013; Huang and Lu, 2016; Talati et al., 2017; McCrickerd et al., 2019; Truong et al., 2021; Jaoudé et al., 2022).

The Nutri-Score, known as the 5-Color Nutrition label and introduced by the French public health agency in 2017, is the most widely used front-of-pack nutrition label determinant in the European Union in order to help consumers make healthier choices (Peonides et al., 2022). It has five nutritional quality color categories from dark green to dark orange, determined through a validated algorithm developed in 2005 by a research team at the University of Oxford (Julia and Hercberg, 2017; Egnell et al., 2018; Andreeva et al., 2021). It is observed that the use of the Nutri score on food labels has a positive effect on customers' preferences for distinguishing and determining the nutritional quality and the healthiness of products (Dréano-Trécant et al., 2020; De Temmerman et al., 2020; Andreeva et al., 2021). Studies on effects of Nutri-Score continue extensively with many different studies, such as the effects of a combined Nutri-Score and Eco-Score on food purchase intentions, the

* Corresponding author.
E-mail addresses: hakan.simsek@antalya.edu.tr (H. Şimşek), sevval.sari@std.antalya.edu.tr (Ş. Sarı).

https://doi.org/10.1016/j.jfoodeng.2023.111625
Received 23 February 2023; Received in revised form 25 April 2023; Accepted 13 June 2023
Available online 26 June 2023
0260-8774/

effect of Nutri-Score on adolescents' perceptions of food choice, the influence of the Nutri-Score on foods labelled with a nutrition claim of sugar and so on (De Bauw et al., 2021; Ducrot et al., 2022; Jürkenbeck et al., 2022). In this research, it is aimed to present a study that will provide an alternative contribution to the literature in this field, eliminate the deficiencies and support the development of Nutri-Score, and have a positive effect on the selection of the right and healthy food.

Information obtained by looking at food labels, such as fewer calories, more fiber, less salt, fewer additives etc. can be consumer demands for a healthier diet. For example, the effect of different nutritional information on preferences, such as *low salt* bread or *high fiber* bread was examined (Gebski et al., 2019). Sandvik et al. (2018) aimed to investigate consumers' health-related quality characteristics of bread according to age, gender and education level using terms such as *whole grain, fiber rich, less sugar, rye*. There are similar studies in the literature (Lambert et al., 2009; Antúnez et al., 2013; Murniece and Straumite, 2014; Angelino et al., 2020; Sajdakowska et al., 2020; Vargas and Simsek, 2021). Although vague words such as low, medium, less, high, rich are used in research to evaluate food labels of breads based on consumer's responses, the use of fuzzy logic, which is an artificial intelligence method, could not be clearly found in the articles in this sense. The main purpose of fuzzy set theory is to deal with uncertain phenomena mathematically and to create control and decision-making processes with models close to human thought by using meaningful information. Vivek et al. (2019) presented a review article, which investigates general sensory evaluation methods based on fuzzy approach unlike traditional or qualitative techniques, and their advantages and limitations for food products. Generally, the review paper refers to the use of fuzzy scales corresponding to sensory scores of food samples or quality attributes, which is comprehensive methodology for the sensory evaluation of the food product. From all the above discussion and studies in the literature, we can draw the following conclusions:

- It has not been found that a food product is evaluated on the label information (energy value, nutritional elements, and additives) using fuzzy logic.
- Since expressions such as "less" salt, "less" additives are very suitable in terms of fuzzy logic, it is seen that the method to be used is suitable for the desired purpose.
- It has been observed that there is no practical specific evaluation of bread, which is one of the most basic food products, in terms of health based on label information.
- Thanks to the digital and/or phone application of the proposed model, it is considered that it will contribute to the easy entry of all necessary label information into the system and the comparison and evaluation of the product.
- The fact that the system can be easily updated and used for other important food products also strengthens its importance and widespread impact.

Evaluation of basic food products such as bread in practical ways may contribute to the increase of the consumer's understanding of nutritional value and quality, to reduce product waste and to raise consumer appreciation. Thus, the aim of the research is to increase the awareness of consumers about using the labels on the food, and accordingly, to develop an inference system that reflects the human judgment that determines the health index for bread and helps them to choose the healthy and suitable product among the product types. The proposed method and data-based results are presented in section 2. In addition, the graphical user interface and sensitivity analysis of the proposed system are discussed. Finally, section 3 is devoted to the discussion and conclusion part. In the appendix, basic information about fuzzy approach, and the data used are added.

2. Proposed system

Conscious consumers could make their choices by examining the food labels and comparing them with the food labels on other bread types when deciding on the type and brand of bread they intend to consume. For this reason, Label information is conveniently gathered under a single output to provide a general inference about the health quality of bread, one of the basic food products. A set of FISs is developed to examine and compare bread types in different market chains, turn them into numerical data, guide consumers better and help them make quick decisions. This system quantitatively explains the quality of ready-made bread varieties and their importance for human health using qualitative fuzzy logic tools. The proposed system includes two sub-fuzzy inference systems and the main FIS (see Fig. 1). The first subsystem makes inferences about the Nutrient Content (NC) of the bread, the determinants of which are fiber, protein, and carbohydrates. The second system provides an inference about the Total Fat (TF) contained in the bread and the inputs of this system are fat and saturated fat. Finally, Healthy Bread Quality Index (HBQI) is computed through the main FIS whose input variables are NC, TF, Sugar, Salt, Additives and Energy. Some parameters were evaluated in subsystems in order to capture the appropriate number of parameters in the main FIS. Fiber, protein, and carbohydrate were considered in the NC subsystem as they are more related to each other than other parameters in terms of nutritional values, while fat and saturated fat naturally formed the TF subsystem. All parameters in this model were obtained by examining the food labels of 54 breads packed in 18 different types sold in supermarket chains. For instance, the information desired to be used for the proposed system is shown in a table in Turkish on the label of the product in Fig. 2.

The Nutri-Score uses a letter scale from "A" to "E" that corresponds to five colors from dark green to dark orange. There are two categories where points are attributed for the computation of the Nutri-Score. The first one scores between 0 and 40 by considering energy, sugar, saturated fat and salt values, while the other scores 0–15 using fiber, protein and fruit and vegetable values. By taking the difference between these two categories, a scale from −15 to +40 emerges and the 5-color Nutri-Score is determined according to this scale (Julia and Hercberg, 2017; Egnell et al., 2020). While scoring the nutritional and energy values, a score between 0 and 10 is generally defined for each and this definition is determined by considering whether the values are large or small on a certain scale. However, one of the major criticisms in this calculation is the lack of information on additives; in fact, the Nutri-Score sometimes categorizes more processed food more favorably than less processed food (Andreeva et al., 2021). Moreover, it may be necessary to determine a specific measurement system and criteria for food product groups such as milk and dairy products, meat, and meat products. On the other hand, the fuzzy approach including linguistic variables and human thought instead of this biggerness-smallness relationship may lead to the opinion that more sensitive and better results can be obtained.

2.1. *The first FIS: nutrient content*

In this FIS, we aim to obtain a numerical value for the NC quality of a bread, which is a dimension in evaluating the health quality of bread. There are three factors affecting the NC in the FIS, which are fiber, protein, and carbohydrates. Table 1 given below shows the linguistic labels and fuzzy counterparts of the input factors and the output of the system. Triangular (trimf), Z-shaped (Zmf) and S-shaped (Smf) fuzzy numbers are used for the inputs and outputs of the system. Ranges are determined according to the label information of 54 breads packaged in 18 different varieties. There are 27 fuzzy IF-THEN rules in total for the first FIS, some of which are given in Table 3. High fiber, high protein and low carbohydrate breads were evaluated as healthy and quality breads in terms of the NC while forming the fuzzy linguistic rules. In order to define these rules in a certain order and in an optimal way, a scoring system is arranged for the linguistic labels of the factors, and the

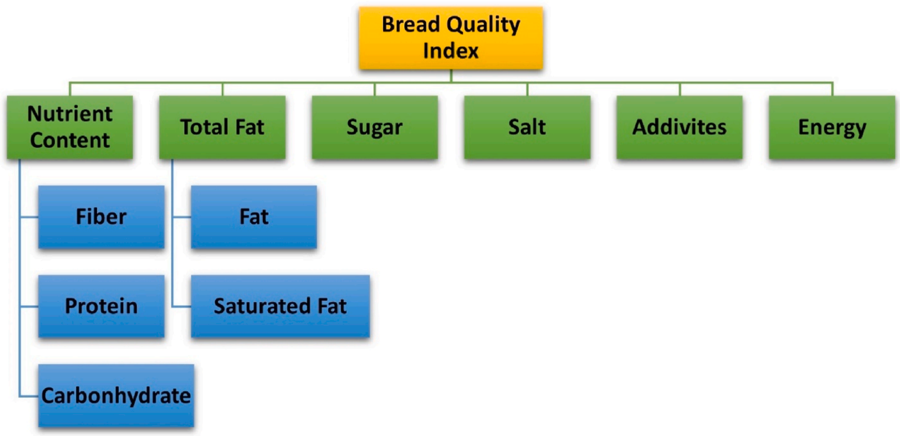


Fig. 1. Parameter diagram of the proposed system.

Fig. 2. Label information of a packaged bread.

Table 1
Fuzzy classification of input and output variables for NC.

Linguistic Variables	Fuzzy Membership Function				
Input 1-Fiber	Low	Medium	High		
Range [0 12]	Zmf [0 6]	Trimf [2 6 10]	Smf [6 12]		
Input 2-Protein	**Low**	**Medium**	**High**		
Range [3 15]	Zmf [3 9]	Trimf [5 9 13]	Smf [9 15]		
Input 3-Chydrate	**Low**	**Medium**	**High**		
Range [25 65]	Zmf [25 45]	Trimf [30 45 60]	Smf [45 65]		
Output- NC	**Low**	**Little Low**	**Medium**	**High**	**Very High**
Range [0100]	Zmf [0 30]	Trimf [10 30 50]	Trimf [30 50 70]	Trimf [50 70 90]	Smf [70 100]

linguistic label of the NC is determined by using this scoring system, which is given in Table 2. For instance, the corresponding score for the fuzzy IF-THEN rule below is

2 (Fiber) + 3 (Protein) + 3 (Chydrate) = 8 (NC); and thus, the linguistic label of the nutrient content is *Very High* according to Table 3.

IF Fiber is *Medium* AND Protein is *High* AND Chydrate is *Low* **THEN** NC is *Very High.*

The Center of gravity defuzzification method is applied to get the exact value of the output. The rules and parameters were decided according to the food labels on the bread packages. Fig. 3A and B show the effect of the nutritional values on quality assessment in 3D form as a rule surface performed in MATLAB. The results obtained in this FIS will later be used in the Main FIS containing six inputs.

2.2. The second FIS: total fat

In this FIS, we aim to obtain a numerical output for the TF in bread types. Two parameters, fat and saturated fat, are used in the second FIS. Table 4 explains the linguistic labels and corresponding fuzzy numbers of the input factors and the output of the system. Nine rules are established for the second FIS given in Table 5. The Centroid defuzzification method is chosen, similarly. What you need to watch out for are especially saturated fat and *trans*-fat, as these are linked to obesity and heart-related diseases, negatively affecting human health. Excessive saturated fat intake increases the risk of cardiovascular diseases, obesity, and cancer. For this reason, one package of the product should contain appropriate levels of low saturated fat. Fig. 4 illustrates the impact of the factors on total fat in 3D form as a rule surface performed in MATLAB. The results obtained in this FIS will be used in the Main FIS containing six inputs.

2.3. The final FIS: healthy bread quality index (HBQI)

Now, we can consider the final system for measuring the HBQI. Parameters running the main FIS are NC, TF, Sugar, Salt, Additives and Energy. Table 6 explains the linguistic labels of input-output and the

Table 2
Scoring the linguistic variables for the rule base.

	Fiber	Protein	Chydrate	Nutr. Cont.
Low	1	1	3	3
Medium	2	2	2	5,6
High	3	3	1	7
Little Low	–	–	–	4
Very High	–	–	–	8,9

Table 3
A few rules for the first FIS.

Inputs			Output
Fiber	Protein	Chydrate	Nutr. Con.
Low	Low	Low	Medium
Low	Low	Medium	Little
Low	Low	High	Low
Medium	High	Low	Very High
High	High	Medium	Very High
High	High	High	High

corresponding membership functions. A graphical representation of the output of the main system, which classifies the HBQI, is given in Fig. 5. NC and TF values are obtained from the first and second sub-FISs. Sugar, Salt, and Energy are determined by using the Energy and Nutrient Elements table of the food label. The number of additives is calculated by looking at the contents of the label. Ranges are determined according to the label information of 54 breads packaged in 18 different varieties. Similarly, Triangular, Z-shaped, and S-shaped fuzzy numbers are used for the linguistic variables of the related factors of system. A total of 639 IF-THEN rules are constructed, some of which are seen in Table 8. Breads with high NC, high energy, low TF, low sugar, low salt, and low additives were evaluated as healthy and quality breads in terms of the HBQI while forming the fuzzy linguistic rules. The proposed fuzzy rules are formed via the scoring system given in Table 7, like the first FIS, and are scoped to almost all possible cases. Centroid method is chosen as the defuzzification method. 3D image of the rule surface performed in MATLAB is given in Fig. 6 for Energy and NC parameters. As a result, when FIS containing 6 inputs is used, customers may have a supportive knowledge about the quality of bread varieties, and they may be able to turn to the healthy bread type.

2.4. Application of the methodology

One of the most important issues that a conscious consumer should pay attention to when buying a food product is to understand in a practical way whether it is suitable for healthy and dietary consumption through the label information. In this research, 54 breads packed in 18 different types sold in supermarket chains were examined. In addition to the normal bread in the market, the bread types commonly found in market chains; Whole Wheat, Grain, Rye, Toast, Sour Dough, Sandwich, Hamburger, Lavash, Village Bread, Bran, Yufka, Bazlama, Isparta, Regional, Yellow Wheat, Black Sea, Honey Oat and Pan bread can be

Table 4
Fuzzy classification of input and output variables for TF.

Linguistic Variables	Fuzzy Membership Function		
Input 1-Fat	Low	Medium	High
Range [0 10]	Zmf [0 5]	Triangular [2.5 5 7.5]	Smf [5 10]
Input 2-Total Fat	**Low**	**Medium**	**High**
Range [0 4]	Zmf [0 2]	Triangular [1 2 3]	Smf [2 4]
Output- Total Fat	**Low**	Medium	High
Range [0100]	Zmf [0 30]	Triangular [20 50 80]	Smf [70 100]

Table 5
IF-THEN rules for the second FIS.

Inputs		Output
Fat	Sat. Fat	Total Fat
Low	Low	Low
Low	Medium	Low
Low	High	Medium
Medium	Low	Low
Medium	Medium	Medium
Medium	High	High
High	Low	Medium
High	Medium	High
High	High	High

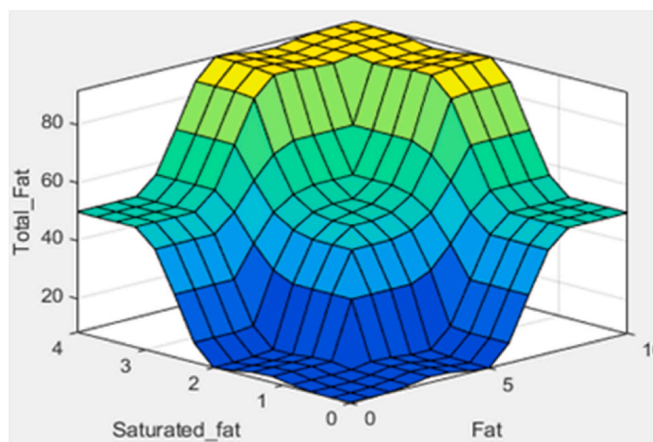


Fig. 4. Surface view of the rule base for the second FIS.

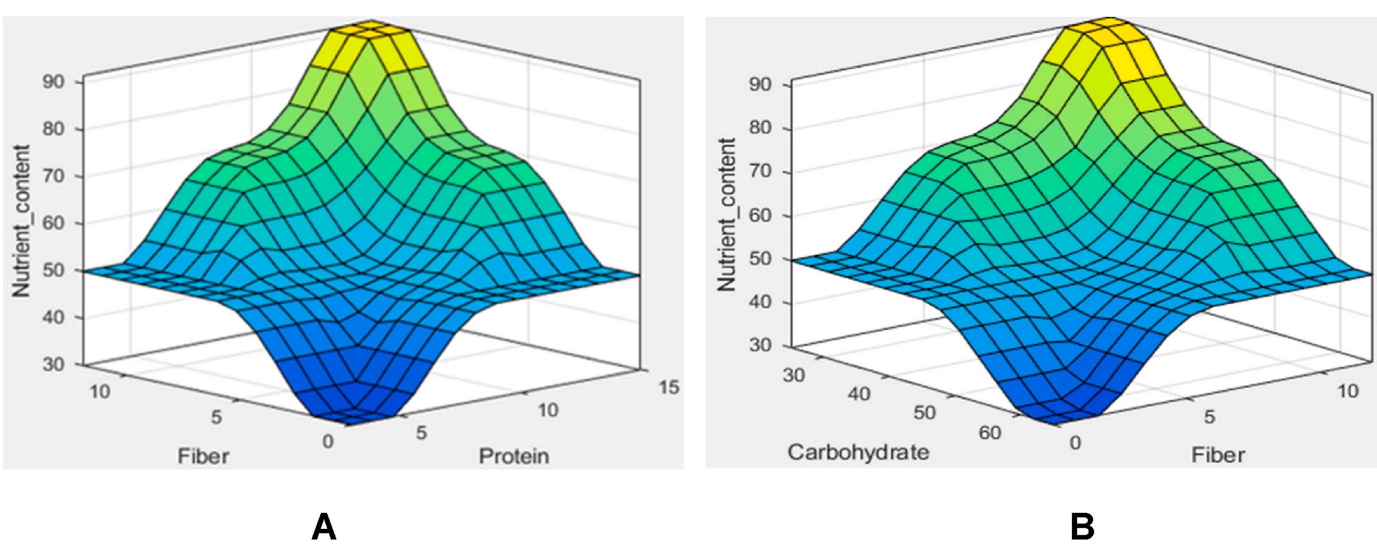


Fig. 3. Surface views of the rule base for the first FIS.

Table 6
Fuzzy classification of Input and Output Variables for the main FIS.

Linguistic Variables	Fuzzy Membership Function				
Input 1-Nut. Con.	Low	Medium	High		
Range [0100]	Zmf [0 50]	Triangular [25 50 75]	Smf [50 100]		
Input 2-Total Fat	**Low**	**Medium**	**High**		
Range [0100]	Zmf [0 50]	Triangular [25 50 75]	Smf [50 100]		
Input 3- Sugar	**Low**	**Medium**	**High**		
Range [0 6]	Zmf [0 3]	Triangular [1.5 3 4.5]	Smf [3 6]		
Input 4- Salt	**Low**	**Medium**	**High**		
Range [0 2]	Zmf [0 1]	Triangular [0.5 1 1.5]	Smf [1 2]		
Input 5- Additives	**Low**	**Medium**	**High**		
Range [0 12]	Zmf [0 6]	Triangular [3 6 9]	Smf [6 12]		
Input 6- Energy	**Low**	**Medium**	**High**		
Range [150 350]	Zmf [150 250]	Triangular [200 250 300]	Smf [250 350]		
Output: HBQI	**Very Low**	**Low**	**Medium**	**High**	**Very High**
Range [0 100]	Zmf [0 20]	Triangular [5 27.5 50]	Smf [40 50 60]	Smf [50 72.5 95]	Smf [80 100]

counted. These breads vary according to the type and number of additives they contain, as well as the amount of carbohydrates, protein, fat, fiber, sugar, and salt. The system results calculated according to the label information given in APPENDIX A of these breads sold in supermarket chains are given in Table 9. In this table, the results were calculated separately according to the brand-market type and bread types. 10 different brands are named A, B, C, D, E, F, G, H, I, J and 5 different markets are named X, Y, Z, T, W. For example, it determines that the A1-X&Y&Z type of whole wheat bread is sold in X, Y and Z markets and corresponds to the 1st variety of the A brand. A2-X type, which is another type of whole wheat bread, indicates that it is sold as the 2nd type of the same brand and in the X market. Similarly, others can be classified in this perspective. When the results obtained from the proposed system are examined, it can be concluded that some brands of whole wheat bread and Isparta bread, which is only available in a market and sold by only one brand, are good, sufficient in terms of health, and at a level that meets the requirements; on the other hand, almost every brand of lavash bread and hamburger bread are not good for health-diet; in other words, it can be concluded that those who do not want to gain weight, those who are on a diet, and those who want to eat healthy should prefer less. C1-T whole wheat bread has the highest HBQI value, while D-X hamburger buns have the lowest. Except for the A1-Y brand, all brand varieties of Lavash bread have HBQI values close to

Table 7
Scoring the linguistic labels for the main FIS.

	Nut. Con.	T. Fat	Sugar	Salt	Add.	Energy	HBQI
Low	1	3	3	3	3	1	9, 10
Medium	2	2	2	2	2	2	11,12,13
High	3	1	1	1	1	3	14,15,16
Little Low	–	–	–	–	–	–	6,7,8
Very High	–	–	–	–	–	–	17,18

Table 8
A few rules for the main FIS.

Inputs						Output
Nut. Content	T. Fat	Sugar	Salt	Additives	Energy	HQI
Low	Low	Low	Low	Low	Low	High
Low	Low	Medium	Low	Medium	Low	Medium
Low	High	High	High	High	Low	Very Low
Low	Low	High	High	Medium	Low	Low
High	Low	Low	Low	Medium	High	Very High

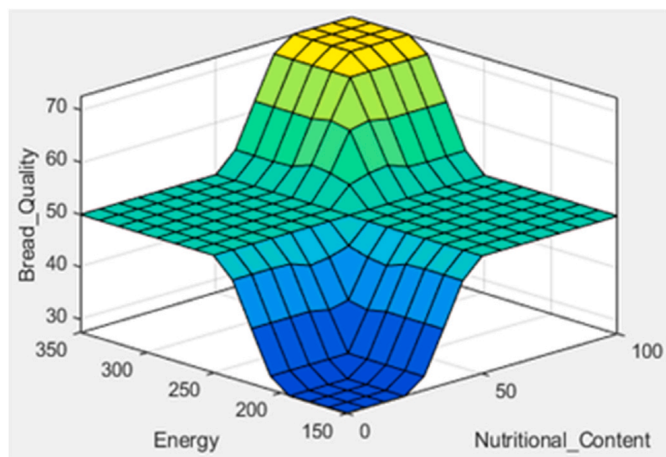


Fig. 6. Surface view of the rule base of the main FIS for energy and nutrient content.

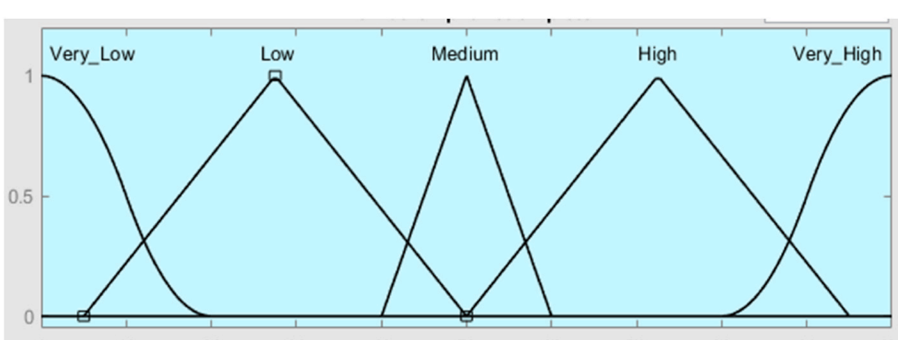


Fig. 5. Graph of output membership functions of the main FIS.

Table 9
System results for bread types sold in shopping market chains.

Bread Types	Brand Market	First FIS	Second FIS	Main FIS (HBQI)
Multigrain	A-X&Y	66,9	9,37	**59,1**
	B–W	75,4	64,4	**55,3**
Whole Wheat	A1-X&Y&Z	66,3	10,1	**52,9**
	A2-X	65,4	8,47	**74,8**
	D-X	66,9	10,1	**64,5**
	B–W	68,4	9,37	**57,9**
	C1-T	90,9	29,4	**78,7**
	C2-T	65,4	8,47	**74,8**
	C3-T	56,8	8,62	**62,1**
	A3-T	65,4	8,47	**74,8**
Rye	A1-X&Y	59,4	8,9	**59,3**
	A2-X&Y&T	53,5	8,53	**64,9**
	B–W	54,2	9,44	**68,1**
	C-T	61,4	10,6	**73,9**
	A3-Z	47,5	9,06	**71,8**
Toast	A-X&Y&Z&T	34,4	11	**69,2**
	D-X	70,7	9,89	**49,5**
	B–W	50	35,8	**52,1**
	C1-T	34,4	9,37	**69,2**
	C2-T	53,4	8,83	**50**
Sourdough	A-X&Y	56,5	8,98	**70,9**
Sandwich	A1-Y	32	10,1	**66**
	A2-X&T	49	10,1	**73,2**
	A3-X	69,3	27,43	**71,3**
	B1–W	51,2	48,1	**31,7**
	B2–W	49,1	8,83	**65,2**
Hamburger Bun	E-Y	32	10,1	**66**
	F–Y	45,7	66,5	**47,7**
	A1-X&Z	38,2	9,48	**65**
	A2-C	61,1	50,1	**50**
	D-X	53,8	46,6	**28,1**
	B–W	38,2	9,48	**70,6**
	C-T	32	10,1	**67,3**
Lavash	G-Y	67,7	89,3	**36**
	A1-Y	48,8	90,7	**49,8**
	A2-X&Z	50	90,3	**28,9**
	H–Y	44,5	90	**34,8**
	I–W	44	34,4	**32,9**
	C-T	35,8	48,9	**32,7**
Village	A1-Y	56,5	9,16	**63,3**
	A2-Z	51,2	8,71	**58,8**
	B–W	58,4	8,71	**56,3**
Wholemeal	B–W	58,4	9,26	**56,3**
	A1-T	50,6	8,9	**67,9**
	C-T	50,1	9,68	**72,5**
	A2-C	50,1	9,68	**72,5**
Yufka	B–W	44,8	45	**53,4**
Flatbread	J-W	49,1	8,73	**71,8**
Isparta	C-T	45,8	9,64	**74,1**
Local	C-T	48,6	11,2	**72,6**
Yellow wheat	C-T	52,3	9,61	**72,8**
Black sea	C-T	46,4	11,1	**72,8**
Honey oat	A-Y	51,8	9,26	**50**
Pan Bread	A-X&Z&T	56,8	8,83	**71,5**

D-X, which are actually values that pose a threat to our health. Care should be taken while consuming, excessive consumption should not be preferred. Moreover, for rye bread, C-T and A3-Z breads are better than others and show that these breads are more preferable. Toast bread, on the other hand, is generally in the middle of the range discussed, while Pan bread is a type that can be easily preferred by consumers. Besides, one of the results that draw our attention here is that black sea bread and yellow wheat bread have the same HBQI values, which are not a health hazard. Sourdough bread is also a type that can be preferred by conscious consumers who take care of their health. While the B1–W brand for sandwich bread seems insufficient in the perspective of the recommended system, the A2-X&T and A3-X brands offer us the HBQI values that can be preferred in terms of health. Similarly, it is concluded that C-T and A2-C brands of wholemeal bread are more prominent and preferable in terms of HBQI value compared to other wholemeal bread brands.

From all the discussions and results above, we can deduce that the proposed system is workable, and practical in packaged brand and bread comparisons can have a significant and positive impact on customers' preferences, and can be easily updated, taking into account many parameters. When looking at the food label information of packaged breads, one has a good sugar level for health, another has a normal salt level, another has a high nutritional value of fiber, protein and carbohydrates, and another bread has better fat values than others. It can be said that this system, which can consider all these situations at once, may have an important auxiliary role in decision making.

In this study, a graphical user interface (GUI) shown in Fig. 7 is developed by using the MATLAB App Designer to get HBQI results more practically and automatically, as well. The functionalities of each component of the proposed approach can be arranged in the MATLAB App Designer. With the help of the MATLAB Standalone application, the exe file can be installed, and the application can be run. By entering the information on the label during the purchase of the bread, results can practically be obtained with the help of this digital application. Considering the proposed system as a decision support system and examining the HBQI results, the customer or the decision maker can generate the health inference about the related bread types and brands in less than a minute through this interface without the need for professional knowledge about the system. For example, in Fig. 8, parameter values of the label information for the A-X&Y multigrain bread and the fuzzy system results can be seen. As soon as the user enters the bread label information in the *input parameters* part, calculations are made automatically, and the results are seen on the right side of the HBQI interface.

2.5. Sensitivity analysis

In this section, the sensitivity analysis was developed to characterize the relative impact of each input variable on HBQI value in the proposed fuzzy model. Some studies on this issue were examined in the literature (Antonini, 1996; Javadian et al., 2018; Vilela et al., 2020). The rate of change of each input parameter at appropriate equal intervals was evaluated separately from the perspective of sensitivity analysis, keeping the other input variables constant.

For each parameter in the main FIS, the membership functions corresponding to its linguistic variables are shifted to the left and right by 10%, leaving the other parameters the same. For instance, when the NC parameter is shifted to the left by 10% as given in Table 10, the new values for HQBI are as in Fig. 9a. In other words, when we bring the limit values of linguistic variables closer to zero, higher HBQI values are obtained inasmuch as the *High* NC linguistic variable corresponds to a wider range than normal, which shows the accuracy and validity of the proposed model. Similarly, when the additive parameter is shifted to the right by 10% as given in Table 10, the new values for HQBI are as in Fig. 9e. In other words, when we bring the limit values of linguistic variables closer to maximum value, higher HBQI values are obtained inasmuch as the *Low* linguistic variable of the parameter corresponds to a wider range than normal. Thus, the methodology is valid and correct. Other parameters can be interpreted similarly as given in Fig. 9 and Table 11. As a result, it can be said that each input parameter affects the output parameter as expected in general.

Within the scope of the analysis of HBQI values, narrowing or stretching the membership functions of the linguistic variables can also be similarly investigated. When the approaches mentioned in this section are applied to subsystems, it can be seen that similar results can be obtained for these subsystems, as well.

3. Discussion and conclusion

In this article, a fuzzy approach is proposed in order to measure the healthy bread quality index (HBQI) of packaged breads purchased from market chains in a practical and fast way by using label information

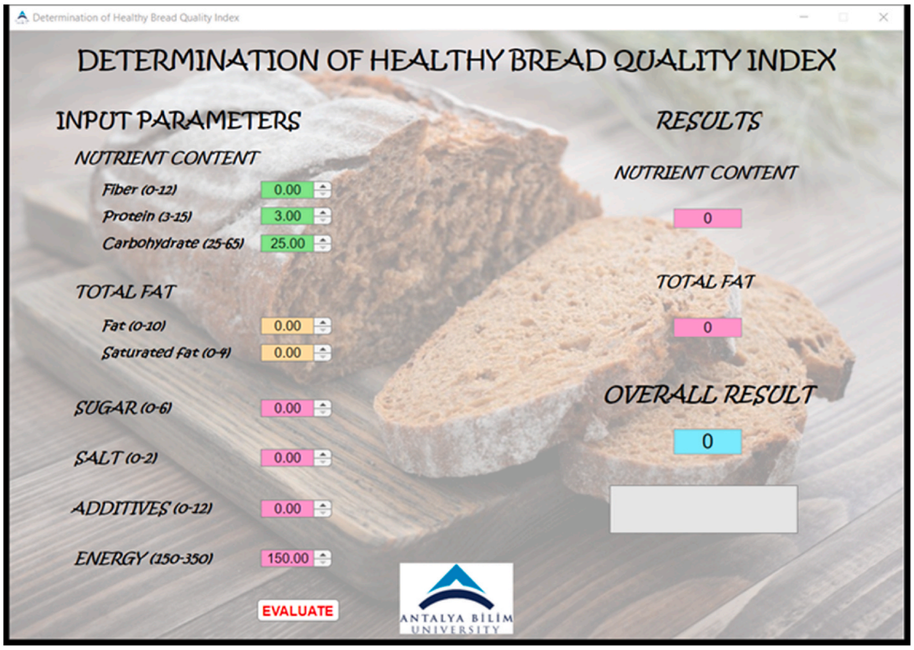


Fig. 7. Graphical user interface of the proposed system.

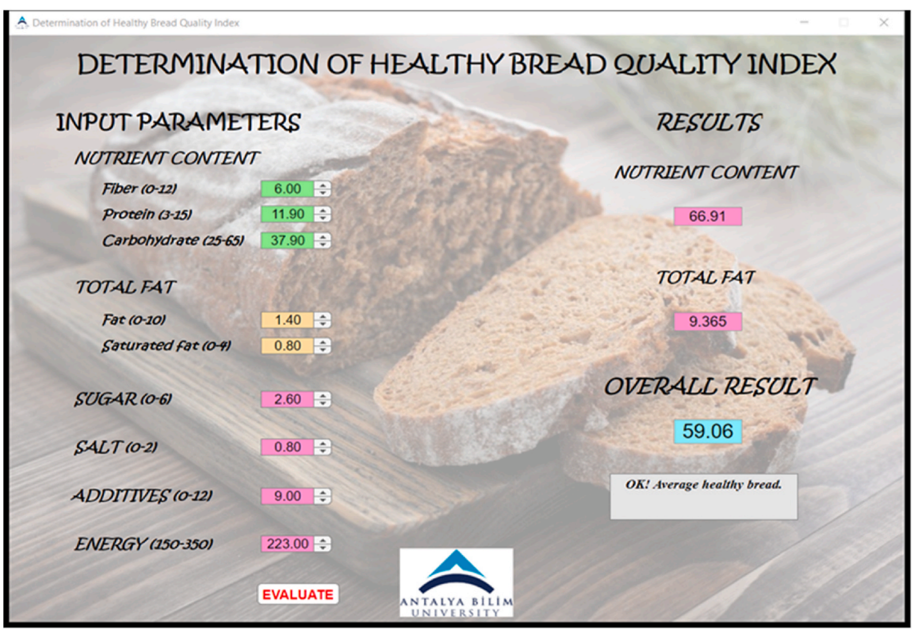


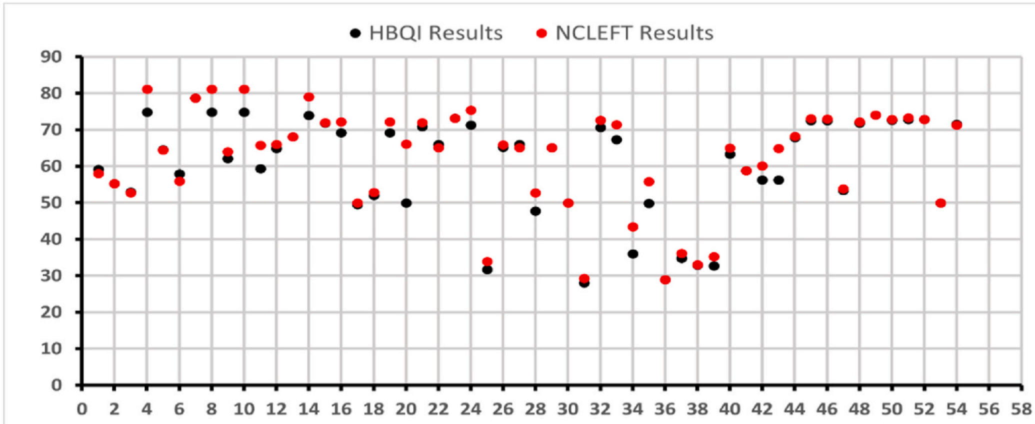
Fig. 8. An HBQI value obtained with a graphical user interface.

Table 10
Linguistic variables shifted 10% to the left for NC and shifted 10% to the right for Additives.

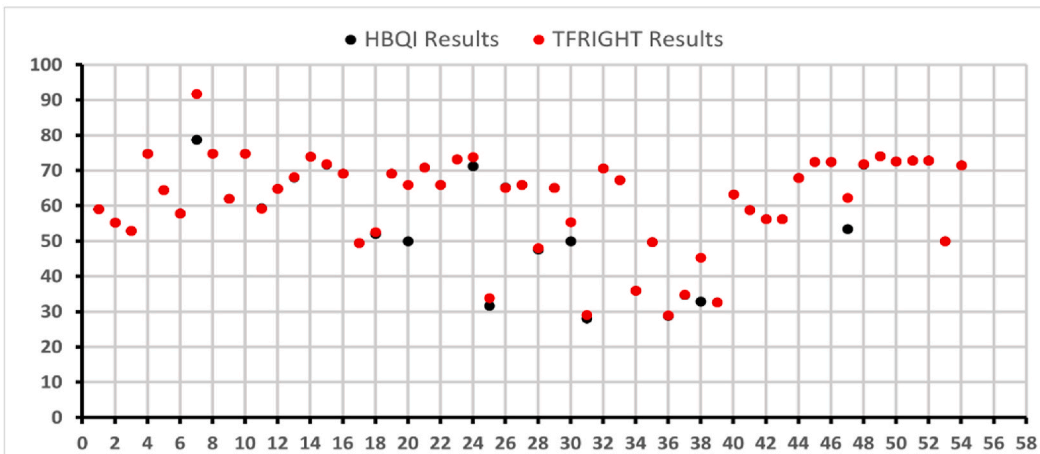
Input 1-Nut. Con.	Low	Medium	High
Range [0100]	Zmf [0 40]	Triangular [15 40 65]	Smf [40 100]
Input 5- Additives	**Low**	**Medium**	**High**
Range [0 12]	Zmf [0 7.2]	Triangular [4.2 7.2 10.2]	Smf [7.2 12]

containing nutritional and energy content. The system includes two sub and one main FISs: NC, TF and HBQI. The HBQI value is determined by the main FIS including six parameters, which are NC, TF, sugar, salt, additives, and energy contents. In the creation of the system, the label data of 54 breads packed in 18 different types sold in supermarket chains is used. In addition, a graphical user interface is developed so that customers and decision makers can use this system efficiently and practically in daily life in order to contribute to finding the most suitable bread type in terms of health or diet. Lastly, the sensitivity analysis of the model is studied.

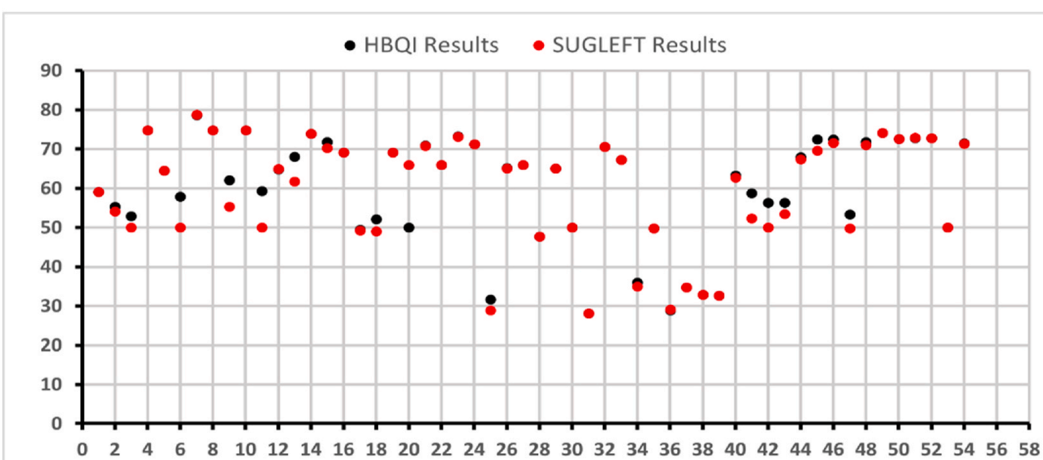
The system introduces an artificial intelligence methodology that can consider all the parameters in the additives, energy, salt, sugar, and nutritional contents of the product label together; hence, the resulting



9a



9b



9c

Fig. 9. 9a, 9b, 9c, 9d, 9e, and 9f. Variation in HBQI value while shifting the membership functions.

numerical data can be used to make various inferences about bread types. The results can also be useful for a consumer's self-determination to help him/her make a decision on the choice of the most suitable product for themselves by examining different products in market chains and the nutritional labels of these products.

Competent health experts in the field or experts on bread food can contribute to updating the system according to various geographical regions, disease groups, age groups etc., similar situations and developments, and making it more perfect by examining IF-THEN rules, membership functions, and taking into account the specific values of the regions of the countries, and thus, users can use this system by means of label information with the digital application on their mobile phones while buying packaged bread in daily shopping. In other words, the proposed methodology can be updated and improved easily, and optimizes the food label information related to nutrient and energy content in terms of a healthier diet. In addition, the methodology of the current study can be practically applied to other packaged staple foods such as *meat and meat products*, *milk, and dairy products*, which seems to increase

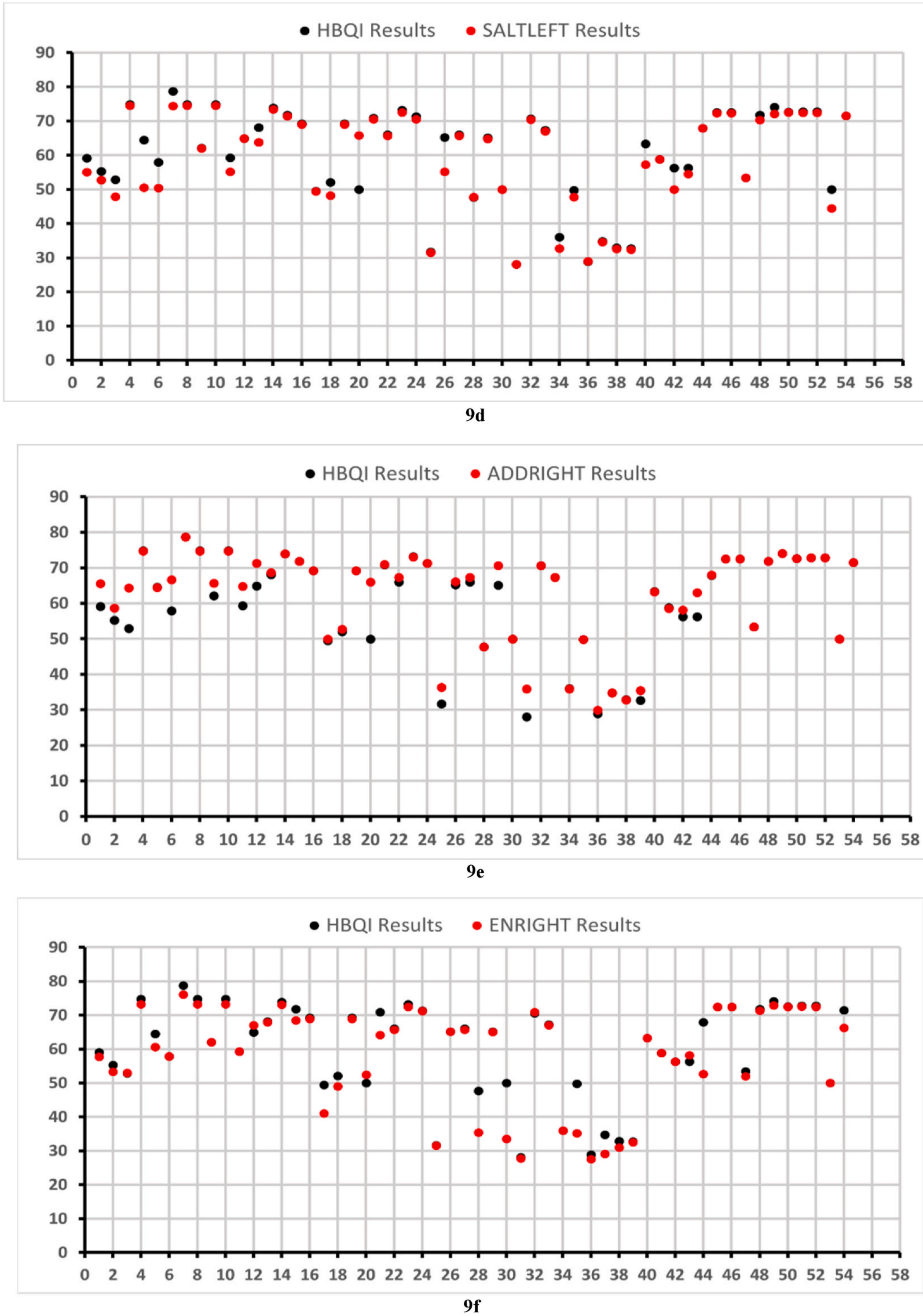


Fig. 9. (*continued*).

the widespread impact of the study.

Temple and Fraser (2014) in their review study found that most consumers in North America have difficulty understanding the information provided by food labels; also, they stated that food labels should also provide information on key nutrients (such as total fat, sugar and sodium or salt) and their energy value; therefore, they recommend the use of colors and words denoting levels such as "high", "medium" and "low". Especially, they say that more research is needed on food label designs to encourage consumers to choose healthier foods. Hence, the current study contributes to the literature for understanding the information provided by food labels in an easier and more practical way and to make a healthy choice. In addition, the techniques or considerations recommended by the authors square with our study. Moreover, it is understood from the systematic review study by Anastasiou et al. (2019) that there is not enough research on the relationship between the use of food labels and dietary intake, and professionals should continue to promote education programs and policies on how to interpret and use food labels, which appears that our current research can make a

Table 11
Modifications of main model parameters.

Inputs	Input Change	HBQI Change
Nutrient Content	Shift left (%10)	Increase
	Shift right (%10)	Decrease
Total Fat	Shift left (%10)	Decrease
	Shift right (%10)	Increase
Sugar	Shift left (%10)	Decrease
	Shift right (%10)	Increase
Salt	Shift left (%10)	Decrease
	Shift right (%10)	Increase
Additives	Shift left (%10)	Decrease
	Shift right (%10)	Increase
Energy	Shift left (%10)	Increase
	Shift right (%10)	Decrease

remarkable contribution in this perspective. Similarly, the meta-analysis study of Shangguan et al. (2019) states that more research is needed and that food labels have effects on consumers' dietary intake and health outcomes.

It can be thought that the current fuzzy approach can be more exhaustive and better than Nutri-Score, which includes the biggerness-smallness relationship, because it can be said that the calculation method and 5-color application of Nutri-Score essentially reflect the nature of the proposed methodology.

Ethics approval

Ethical approval or formal consent is not required for this manuscript.

Funding

There is no involvement of the funding source(s).

Credit authors statement

Hakan Şimşek: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Writing-original draft, Writing-review & editing, Visualization. Şevval Sarı: Data curation, Investigation, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data is given in the Appendix.

Acknowledgements

We would like to thank Ömer Faruk Öncel for his support in the development of the GUI. This work was supported by 2209-A TUBITAK (The Scientific and Technological Research Council of Türkiye) Program.

APPENDIX A. Food Label Information of 54 different packaged breads sold in supermarket chains

Food label information of 54 different packed breads

Bread Types	Brand Market	FIS Parameter Values								
		First FIS			Second FIS		3.	4.	5.	6.
		Fi (g)	Pro (g)	Ch (g)	Fat (g)	Sat. Fat (g)	Sugar (g)	Salt (g)	En (kcal)	Add (n)
Multigrain	A-X&Y	6	11,9	37,9	1,4	0,8	2,6	0,8	223	9
	B–W	7,17	12,3	33,2	7,15	1,62	1,87	0,87	261	10
Whole Wheat	A1-X&Y&Z	6,6	12,2	40,2	2,2	1,5	3,9	0,9	243	9
	A2-X	7,9	11,8	39,2	0,3	0,1	0,6	0,9	223	3
	D-X	10,4	10,6	48,9	2,2	1	7,9	1,4	254	4
	B–W	5,9	11	39,9	2	0,63	2,5	1	234	9
	C1-T	7,23	10,8	43,6	3,11	1,1	2,5	0,62	245	0
	C2-T	7,9	11,8	39,2	0,3	0,1	0,6	0,9	223	2
	C3-T	5,4	11,2	51,2	0,7	0,4	4,3	0	253	5
	A3-T	7,9	11,8	39,2	0,3	0,1	0,6	0,9	223	2
Rye	A1-X&Y	6,5	11,4	42,8	1	0,6	4,1	0,7	234	9
	A2-X&Y&T	4,4	10,4	43,6	0,7	0,3	2,4	0,9	231	4
	B–W	5,6	10,2	41	2,07	0,65	1,79	1	235	8
	C-T	8,6	10,01	44,4	2,79	0,45	2,3	0,65	254	0
	A3-Z	5	7,4	47,3	1,7	0,5	3,3	0,9	234	2
Toast	A-X&Y&Z&T	2,3	6,8	54,5	2	1,3	2,9	0,9	263	2
	D-X	10,3	8,8	41,7	2,4	0,8	3,6	1,5	246	4
	B–W	3,1	9,5	46,6	3,2	1,2	2,8	0,9	259	9
	C1-T	2	6,8	54,5	2	0,4	2,9	0,9	263	2
	C2-T	5,9	9,4	40,3	1,4	0,4	3,2	0,9	212	2
Sourdough	A-X&Y	5,9	10,4	39,6	1,6	0,3	2,2	1,1	226	2
Sandwich	A1-Y	2,3	7,1	57,2	2,5	1,9	3	0,9	274	4
	A2-X&T	3,8	9,4	47,6	3,8	1	0,9	0,8	269	3
	A3-X	4,9	13	40,9	3,4	1,1	2,6	0,8	256	3
	B1–W	3,86	9,9	46,6	4,13	1,82	4,21	0,89	271	9
	B2–W	3,41	8,93	46,9	1,4	0,48	2,83	0,66	243	5
Hamburger Bun	E-Y	2,3	7,1	57,2	2,5	1,9	3	0,9	274	4
	F–Y	4,86	7,76	50,03	7,22	1,62	4,4	1,94	305,8	3
	A1-X&Z	2,1	9,7	55,6	2,1	1,9	2,9	0,9	281	4
	A2-C	8,7	9,2	51,5	4,8	2,1	5,7	1,5	303	5
	D-X	4,28	10,5	44,5	3,97	1,55	5,02	0,91	264	9
	B–W	2,1	9,7	55,6	2,1	1,9	2,9	0,9	281	3

(*continued on next page*)

(*continued*)

Bread Types	Brand Market	FIS Parameter Values								
		First FIS			Second FIS		3.	4.	5.	6.
	C-T	2,3	7,1	57,2	2,5	1,9	3	0,9	274	3
Lavash	G-Y	10,4	7,7	42,5	6,6	3,3	2,9	1,3	283	7
	A1-Y	4,6	9	47,7	8,1	3,4	2,5	0,9	308	8
	A2-X&Z	6,2	7,6	45,4	7,7	3,7	3,2	1,9	272	5
	H–Y	3,4	7,6	47,7	6,2	3,2	2,6	0,9	289	11
	I–W	4,11	8,54	58,4	2,99	1,61	4,55	1,07	286	10
	C-T	2,66	7,51	55,2	4,3	2,08	4,51	1,29	290	8
Village	A1-Y	5,1	11	43,7	1,8	0,3	2,4	0,7	245	6
	A2-Z	6,5	9,7	49,2	1,2	0,4	2,3	0,9	198	3
	B–W	6,4	11,3	44,5	1,2	0,29	3,9	0,8	247	9
Wholemeal	B–W	7,1	10,5	38,5	1,9	0,49	2,1	0,9	227	9
	A1-T	6,5	6	44,5	1,5	0,4	3,5	0,9	216	2
	C-T	5,7	9,4	47,5	1,9	0,9	1,4	0,9	223	3
	A2-C	5,7	9,4	47,5	1,9	0,9	1,4	0,9	235	2
Yufka	B–W	3,47	10,1	52	3,67	1,67	2,8	1,57	288	1
Flatbread	J-W	2,54	8,28	44,6	1,24	0,42	1,05	1,15	228	1
Isparta	C-T	4,32	9,41	55,9	4,01	0,18	0,2	0,86	296	0
Local	C-T	4,3	9,38	48,13	3,2	0,46	0,27	0,86	259	0
Yellow wheat	C-T	4,8	10,71	52,62	2,2	0,31	1,28	0,86	273	0
Black sea	C-T	4,32	9,41	50,13	3,1	0,27	0,27	0,85	267	0
Honey oat	A-Y	4,5	10	45,4	1,9	0,5	5	1	248	9
Pan Bread	A-X&Z&T	5,6	10,7	40,6	1,4	0,3	2,5	0,9	229	2

APPENDIX B. Basic Theoretical Knowledge of Fuzzy Logic

Fuzzy Logic is a field of science that includes artificial intelligence approaches like human reasoning to handle diverse types of ambiguity. Fuzzy Inference Systems (FIS) provide an output by operating the values of the vague inputs of a problem that can be associated with linguistic parameters. FIS is a combination of a **fuzzification interface** that transforms the crisp inputs into fuzzy values with linguistic parameters; **a rule base** including fuzzy IF-THEN rules; a database describing the membership functions of the linguistic parameters used in the IF-THEN rules; **a decision-making** unit accomplishing the consequence operations on the IF-THEN rules; and eventually, a **defuzzification interface** that converts the fuzzy values of the consequence into a crisp output (Fig. B.1). Further information on this topic can be found in many studies of literature (Zadeh, 1965; Mamdani and Assilian, 1975; Zimmermann, 1996; Ross, 2010).

A **fuzzy set** $\widetilde{A}$ in a universe of discourse X is defined by a membership function,

$$\mu_{\widetilde{A}} : X \rightarrow [0, 1]$$

such that it associates a real number, which gives a membership degree of each element x in the range $[0, 1]$. **Fuzzy numbers** are fuzzy sets providing the following conditions:

- Convex fuzzy set (if $\mu_{\widetilde{A}}(\lambda x_1 + (1-\lambda)x_2) \geq min\{\mu_{\widetilde{A}}(x_1), \mu_{\widetilde{A}}(x_2)\}$ for all $\lambda \in (0, 1]$ and $x_1, x_2 \in X$, then $\widetilde{A}$ is a convex fuzzy set.),
- Normalized fuzzy set (if $Core(\widetilde{A}) = \{x \in X : \mu_{\widetilde{A}}(x) = 1\} \neq \emptyset$, then $\widetilde{A}$ is normalized.),
- Its membership function is piecewise continuous,
- It is defined in the real number.

There are different classes of fuzzy numbers such as Triangular, Trapezoidal, Gaussian, S-shaped, G-bell, Z-shaped, Sigmoidal fuzzy numbers, which appear in real-world problems. Fuzzy numbers are used to fuzzify input and output linguistic variables or parameters in an inference system.

A fuzzy **rule base** consists of a set of fuzzy IF-THEN rules, which are the main theme of the FIS. All other components such as membership functions are used to implement these rules in a reasonable, realistic, and efficient manner. A fuzzy IF-THEN rule generally assumes the form,

$$R : If\ x_1\ is\ \widetilde{A}_1\ AND\ (OR)\ x_2\ is\ \widetilde{A}_2, THEN\ \mathbf{y}\ is\ B,$$

where, $\widetilde{A}_1$, $\widetilde{A}_2$ and B are linguistic variables of the FIS defined by fuzzy numbers on input and output universes, respectively. Logical operators AND, OR are known as the fuzzy intersection or conjunction (AND), and fuzzy union or disjunction (OR), respectively and defined as follows:

$$\widetilde{A}_1 \text{ AND } \widetilde{A}_2 : min\left\{\mu_{\widetilde{A}_1}, \mu_{\widetilde{A}_2}\right\},$$

$$\widetilde{A}_1 \text{ OR } \widetilde{A}_2 \quad : max\left\{\mu_{\widetilde{A}_1}, \mu_{\widetilde{A}_2}\right\}.$$

After determining the rule base, we apply the process by which the fuzzy sets that represent the outputs of each rule are combined into a **single fuzzy number** (set), which is known as **aggregation** of rules. Aggregation could be done by different operators, such as Max, Sum or Probor. The Max operator is generally preferred when compensation between input variables is desirable. The Max operator is given by:

$$\mu_{output} = max\{\mu_{rule^1}, \mu_{rule^2}, \mu_{rule^3}, \ldots, \mu_{rule^r}\}.$$

The last step is the **defuzzification interface** such that output fuzzy set obtained after the aggregation step is changed to a crisp number.

Defuzzification techniques used in FIS are generally Center of area or centroid (CoA), Bisector of area, Small of maxima (SoM), Mean of maxima (MoM), and Largest of maxima (LoM). **Centroid defuzzification** (Fig. B.2) gives a defuzzified crisp value x^* corresponding a vertical line that divides the region under the curve into two sub-regions of equal mass.

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

$$\mathbf{Zmf}(x; a, b) = \begin{cases} 1 & , x \le a \\ 1 - 2\left(\frac{x-a}{b-a}\right)^2, & a \le x \le \frac{a+b}{2} \\ 2\left(\frac{x-b}{b-a}\right)^2 & , \frac{a+b}{2} \le x \le b \\ 0 & , b \le x \end{cases}$$

$$\mathbf{Smf}(x; a, b) = \begin{cases} 0, x \le a \\ 2\left(\frac{x-a}{b-a}\right)^2, a \le x \le \frac{a+b}{2} \\ 1 - 2\left(\frac{x-b}{b-a}\right)^2, \frac{a+b}{2} \le x \le b \\ 1, b \le x \end{cases}$$

All these mathematical operations explained above can be done using the MATLAB Fuzzy Logic Designer. In this paper, a set of FISs is used for the quality index. We apply the **max-min inference** method for composition and minimum operator for implication. Triangular (**trimf**), Z-shaped (**Zmf**) and S-shaped (**Smf**) fuzzy numbers defined above are used for the inputs and outputs of proposed systems. The aggregation is determined as the Max operator.

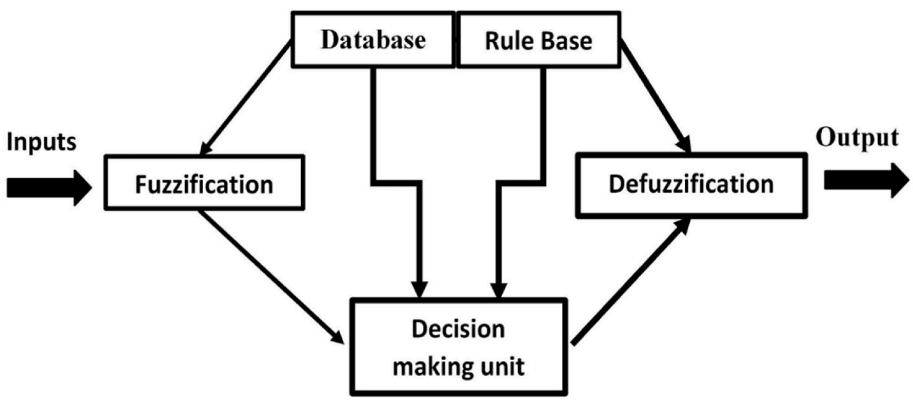


Fig. B.1. Fuzzy inference system.

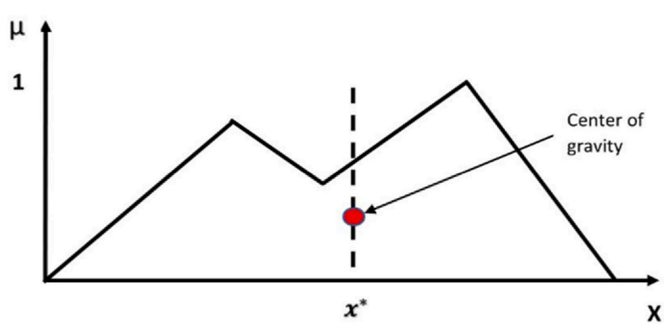


Fig. B.2. Centroid defuzzification.

References

Anastasiou, K., Miller, M., Dickinson, K., 2019. The relationship between food label use and dietary intake in adults: a systematic review. Appetite. https://doi.org/10.1016/j.appet.2019.03.025.

Andreeva, V.A., Egnell, M., Touvier, M., Galan, P., Julia, C., Hercberg, S., 2021. International evidence for the effectiveness of the front-of-package nutrition label called Nutri-Score. Cent. Eur. J. Publ. Health 29 (1), 76–79. https://doi.org/10.21101/cejph.a6239.

Angelino, D., Rosi, A., Ruggiero, E., Nucci, D., Paolella, G., et al., 2020. Analysis of food labels to evaluate the nutritional quality of bread products and substitutes sold in

Italy: results from the food labelling of Italian products (FLIP) Study. Foods 9 (12), 1905. https://doi.org/10.3390/foods9121905.
Antonini, C., 1996. Sensitivity analysis of a fuzzy expert system. IFAC Proc. Vol. 29 (3) https://doi.org/10.1016/S1474-6670(17)44710-0.
Antúnez, L., Vidal, L., Sapolinski, A., Giménez, A., Maiche, A., Ares, G., 2013. How do design features influence consumer attention when looking for nutritional information on food labels? Results from an eye-tracking study on pan bread labels. Int. J. Food Sci. Nutr. 64 (5), 515–527. https://doi.org/10.3109/09637486.2012.759187.
Besler, H.T., Buyuktuncer, Z., Uyar, M.F., 2012. Consumer understanding and use of food and nutrition labeling in Turkey. J. Nutr. Educ. Behav. 44 (6), 584–591. https://doi.org/10.1016/j.jneb.2012.01.005.
De Bauw, M., Matthys, C., Poppe, V., Franssens, S., Vranken, L., 2021. A combined Nutri-Score and "Eco-Score" approach for more nutritious and more environmentally friendly food choices? Evidence from a consumer experiment in Belgium. Food Qual. Prefer. 93, 104276 https://doi.org/10.1016/j.foodqual, 2021.10427.
De Temmerman, J., Heeremans, E., Slabbinck, H., Vermeir, I., 2020. The impact of the Nutri-Score nutrition label on perceived healthiness and purchase intentions. Appetite 157, 104995. https://doi.org/10.1016/j.appet.2020.104995.
Díaz, D.L., Fernández-Ruiz, V., Cámara, M., 2020. An international regulatory review of food health-related claims in functional food products labeling. J. Funct.Foods 68, 103896. https://doi.org/10.1016/j.jff.2020.103896.
Dréano-Trécant, L., Egnell, M., Hercberg, S., Galan, P., Soudon, J., Fialon, M., Touvier, M., Kesse-Guyot, E., Julia, C., 2020. Performance of the Front-of-Pack nutrition label Nutri-Score to discriminate the nutritional quality of foods products: a comparative study across 8 European countries. Nutrients 12 (5), 1303. https://doi.org/10.3390/nu12051303.
Ducrot, P., Julia, C., Serry, A.J., 2022. Nutri-Score: awareness, perception and self-reported impact on food choices among French adolescents. Nutrients 14 (15), 3119. https://doi.org/10.3390/nu14153119.
Egnell, M., Ducrot, P., Touvier, M., Allès, B., Hercberg, S., Kesse-Guyot, E., Julia, C., 2018. Objective understanding of Nutri-Score Front-Of-Package nutrition label according to individual characteristics of subjects: comparisons with other format labels. PLoS One 13 (8), e0202095. https://doi.org/10.1371/journal.pone.0202095.
Egnell, M., Talati, Z., Galan, P., Andreeva, V.A., Vandevijvere, S., et al., 2020. Objective understanding of the Nutri-score front-of-pack label by European consumers and its effect on food choices: an online experimental study. Int. J. Behav. Nutr. Phys. Activ. 17 (1) https://doi.org/10.1186/s12966-020-01053-z.
Gębski, J., Jezewska-Zychowicz, M., Szlachciuk, J., Kosicka-Gębska, M., 2019. Impact of nutritional claims on consumer preferences for bread with varied fiber and salt content. Food Qual. Prefer. 76, 91–99. https://doi.org/10.1016/j.foodqual.2019.03.01.
Huang, L., Lu, J., 2016. The Impact of package color and the nutrition content labels on the perception of food healthiness and purchase intention. J. Food Prod. Market. 22 (2), 191–218. https://doi.org/10.1080/10454446.2014.1000434.
Hutt, C.A., Gonzalez, M., 2014. Food labeling. Encyclopedia of Agriculture and Food Systems 167–185. https://doi.org/10.1016/B978-0-444-52512-3.00061-9.
Jaoudé, L.A., Denis, I., Teyssier, S., Beugnot, N., Davidenko, O., Darcel, N., 2022. Nutritional labeling modifies meal composition strategies in a computer-based food selection task. Food Qual. Prefer. 100, 104618 https://doi.org/10.1016/j.foodqual.2022.104618.
Javadian, H., Asadollahpour, S., Ruiz, M., Sastre, A.M., Ghasemi, M., Hosseini, S. M. Asl, Masomi, M., 2018. Using fuzzy inference system to predict Pb (II) removal from aqueous solutions by magnetic Fe_3O_4/H_2SO_4-activated Myrtus Communis leaves carbon nanocomposite. J. Taiwan Inst. Chem. Eng. 91, 186–199. https://doi.org/10.1016/j.jtice.2018.06.021.
Julia, C., Hercberg, S., 2017. Development of a new front-of-pack nutrition label in France: the five-colour Nutri-Score. Public Health Panorama 3 (4), 712–725.
Jürkenbeck, K., Mehlhose, C., Zühlsdorf, A., 2022. The influence of the Nutri-Score on the perceived healthiness of foods labelled with a nutrition claim of sugar. PLoS One 17 (8), e0272220. https://doi.org/10.1371/journal.pone.0272220.
Lambert, J.L., Le-Bail, A., Zuniga, R., Van-Haesendonck, I., Vnzeveren, E., et al., 2009. The Attitudes of european consumers toward innovation in bread; interest of the consumers toward selected quality attributes. J. Sensory Stud. 24 (2), 204–219. https://doi.org/10.1111/j.1745-459x.2008.00203.x.
Mamdani, E.H., Assilian, S., 1975. An Experiment in linguistic synthesis with a fuzzy logic controller. Int. J. Man Mach. Stud. 7, 1–13. https://doi.org/10.1016/S0020-7373(75)80.
McCrickerd, K., Tang, C.S.N., Forde, C.G., 2019. The independent and combined impact of front-of-pack labelling and sensory quality on calorie estimations and portion selection of commercial food products. Food Qual. Prefer. 79, 103766 https://doi.org/10.1016/j.foodqual.2019.103766.
Murniece, I., Straumite, E., 2014. The information presented on labels for bread produced in Latvia. Food Chem. 162, 117–121. https://doi.org/10.1016/j.foodchem.2014.04.048.
Peonides, M., Knoll, V., Gerstner, N., Heiss, R., Frischhut, M., 2022. Food labeling in the European Union: a review of existing approaches. Int. J. Health Govern. 27 (4), 460–468. https://doi.org/10.1108/IJHG-07-2022-0072, 4.
Peterman, M., Žontar, T.P., 2014. Chapter 39: consumer information and labeling. Food Safety Management 1005–1016. https://doi.org/10.1016/B978-0-12-381504-0.00039-1.
Roche, K.A., 2016. Food labeling: applications. Encyclopedia of Food and Health 49–55. https://doi.org/10.1016/B978-0-12-384947-2.00785-6.
Ross, T.J., 2010. Fuzzy Logic with Engineering Applications, third ed. John Wiley & Sons, Ltd., ISBN 978-0-470-74376-8
Sajdakowska, M., Gębski, J., Jeżewska-Zychowicz, M., Królak, M., 2020. Consumer choices in the bread market: the importance of fiber in consumer decisions. Nutrients 13 (1), 132. https://doi.org/10.3390/nu13010132.
Sandvik, P., Nydahl, M., Kihlberg, I., Marklinder, I., 2018. Consumers' health-related perceptions of bread – Implications for labeling and health communication. Appetite 121, 285–293. https://doi.org/10.1016/j.appet.2017.11.092.
Sato, P.M., Mais, L.A., Khandpur, N., Ulian, M.D., Martins, B.A.P., et al., 2019. Consumers' opinions on warning labels on food packages: a qualitative study in Brazil. PLoS One 14 (6), e0218813. https://doi.org/10.1371/journal.pone.0218813.
Sax, J.K., Doran, N., 2016. Food labeling and consumer associations with health, safety, and environment. J. Law Med. Ethics 44 (4), 630–638. https://doi.org/10.1177/1073110516684805.
Shangguan, S., Afshin, A., Shulkin, M., Ma, W., Marsden, D., et al., 2019. A Meta-Analysis of food labeling effects on consumer diet behaviors and industry practices. Am. J. Prev. Med. https://doi.org/10.1016/j.amepre.2018.09.024.
Stran, K.A., Knol, L.L., 2013. Determinants of food label use differ by sex. J. Acad. Nutr. Diet. 113 (5), 673–679. https://doi.org/10.1016/j.jand.2012.12.014.
Talati, Z., Norman, R., Pettigrew, S., Bruce, N., Kelly, B., et al., 2017. The impact of interpretive and reductive front-of-pack labels on food choice and willingness to pay. Int. J. Behav. Nutr. Phys. Activ. 14, 171. https://doi.org/10.1186/s12966-017-0628-2.
Tanemura, N., Hamadate, N., 2022. Association between consumers' food selection and differences in food labeling regarding efficacy health information: food selection based on differences in labeling. Food Control 131, 108413. https://doi.org/10.1016/j.foodcont.2021.10841.
Temple, N.J., Fraser, J., 2014. Food labels: a critical assessment. Nutrition 30, 257–260. https://doi.org/10.1016/j.nut.2013.06.012.
Truong, V.A., Conroy, D.M., Lang, B., 2021. The trust paradox in food labelling: an exploration of consumers' perceptions of certified vegetables. Food Qual. Prefer. 93, 104280 https://doi.org/10.1016/j.foodqual.2021.10428.
Vargas, M.C.A., Simsek, S., 2021. Clean label in bread. Foods 10, 2054. https://doi.org/10.3390/foods10092054.
Vilela, M., Oluyemi, G.F., Petrovski, A., 2020. Sensitivity analysis applied to fuzzy inference on the value of information in the oil and gas industry. Int. J. Appl. Decis. Sci. 13 (3) https://doi.org/10.1504/IJADS.2020.108484.
Vivek, K., Subbarao, K.V., Routray, W., Kamini, N.R., Dash, K.K., 2019. Application of fuzzy logic in sensory evaluation of food products: a comprehensive study. Food Bioprocess Technol. 13 (1), 1–29. https://doi.org/10.1007/s11947-019-02337-4.
Vyth, E.L., Steenhuis, I.H., Roodenburg, A.J., Brug, J., Seidell, J.C., 2010. Front-of-pack nutrition label stimulates healthier product development: a quantitative analysis. Int. J. Behav. Nutr. Phys. Activ. 7 (1), 65. https://doi.org/10.1186/1479-5868-7-65.
Zadeh, L.A., 1965. Fuzzy sets. Inf. Control 8, 338–353.
Zimmermann, H.J., 1996. Fuzzy Set Theory and its Applications, third ed. Kluwer Academic Publishers, Boston/Dordreht/London.