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Applying fuzzy quality function deployment and fuzzy analytical hierarchy process approach in industrial bread production

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ABSTRACT

Quality of bread, as one of the most important foodstuff, can be improved by applying advanced instruments and technology, composite flour and different kinds of ingredients like emulsifiers and acidic food additives. Implementation of food safety measures and application of quality management systems will reduce microbial and chemical hazards. This study aimed to improve industrial bread production through different approaches regarding customers' and technical requirements. Fuzzy Quality Function Deployment (FQFD) as a quality management tool deals with improving quality factors, optimizing technological costs and increasing market size considering technical and customer requirements. Fuzzy Analytical Hierarchy Process (FAHP) results in cost decline, efficiency enhancement and effectiveness of economical index in the mentioned systems. Through FQFD and FAHP, requirements of developing industrial bread production such as responsible components of quality, hygiene and safety and also technical aspects were defined and prioritized. Prioritization of technical and customers' requirements can be used as the basis of developing a prototype and then operational implementation in industry to provide food security and safety as well as a source of customer's satisfaction and market development.

1. Introduction

Bread has been always considered as one of the most important foodstuff with steady and increasing consumption. One of technical efforts to improve bread production quality is to use composite flour of different crops with higher nutritional value to be replaced with wheat flour (1). To extend the shelf life of products in the bakery industry and also for improving dough machinability and automation, technological aids and additives such as enzymes and emulsifiers have been highly used (2). Different technological parameters and formulations using various raw materials and additives like hydrocolloids, emulsifiers or proteins, have been recently studied to improve both quality

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and nutritional value of produced bread (3). Microbial spoilage and also physical and chemical changes responsible for stalling process altogether have resulted in relatively short shelf life of fresh bakery products. In order to prevent these undesirable changes and therefore to extend bread shelf life, new technologies and approaches have been developed (4).

Increasing customer awareness of quality, rapid technology exchange and companies contest to gain a more portion in market by reducing the costs have all made drastic changes in trading environment. For enhancing competitiveness and performance, many companies have implemented different quality improvement initiatives. Producers have noticed that sustainable and profitable trend in progress results from customer relations and meeting their needs and expectations (5). Sustainable competitive advantages and enhanced business performance and improvements are because of quality initiatives have been a major subject of interest for business (6). Because of the importance of customers' ideas on quality standards of a product, knowing about their expectations is a preliminary step forward to develop quality products (7).

Pairwise comparisons were to be made of the elements of each hierarchy by means of a nominal scale. Since the evaluation criteria is subjective and qualitative in nature, for the experts and decision makers it is a complicated matter to express the preferences using exact numerical values and to provide exact pairwise comparison judgments (8,12). Some researchers introduced Fuzzy Analytical Hierarchy Process (FAHP) method which is originally based on the concept of fuzzy set theory (13,14). It can properly manage the inherent uncertainty and imprecision of the human decision making process. The fuzzy set theory resembles human reasoning by using of approximate information and uncertainty to generate decisions. It implements strata and grouping of data with boundaries that are not sharply defined (i.e., fuzzy), meanwhile it is easier to understand (9).

QFD (Quality Function Deployment) is a method for the following purposes such as developing the quality in order to increase the satisfaction of consumer, and translating the customer requirements into design targets and major quality assurance points to be used throughout the production stage (15). According to Yang et al (16), this procedure consists of three steps:

- Assigning linguistic terms
- Translating the linguistic terms into triangular fuzzy numbers
- Computing an average triangular fuzzy number from the triangular fuzzy numbers.

This study aimed to improve the industrial bread production by implementing FQFD and FAHP approach while identifying the customers' needs and technical requirements.

2. Materials and Methods

In order to solve multiple criteria decision problems, AHP was used according to Saaty to divide a complicated system into a hierarchical system of elements (11). Pairwise comparisons were made of the elements of each hierarchy by means of a nominal scale. Strata and grouping of data was implemented with boundaries, since it was not sharply defined.

QFD was applied in order to translate the customer requirements into design targets and major quality assurance points to be used throughout the production. Since customer opinions are inherently imprecise, the fuzzy set theory was integrated into House of Quality (HOQ) to capture the degree of importance of each customer requirements to the residential unit. The computational procedure for fuzzy numbers in the QFD system was adapted from Yang et al (16) and as mentioned before it involved assigning linguistic terms, translating the linguistic terms into triangular fuzzy numbers and then computing an average triangular fuzzy number from the triangular fuzzy numbers.

According to descriptive information about the importance of customer requirements, we applied computational method of Yang et al. in 2003 (16) for using fuzzy numbers to determine the numeral rate which is offered to customer requirements. In triangular fuzzy calculation technique, for descriptive

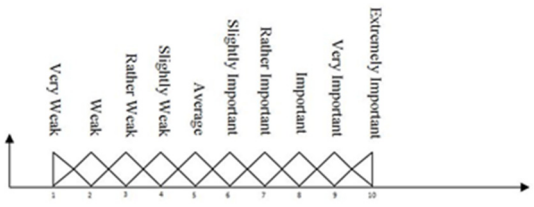

Figure1. The fuzzy linguistic importance

Table1. List of Customer Requirements

Category	CRs	Priority weight	Code
Rheological properties	Bread texture	0.014	D_1
	chewingability	0.028	D_2
Organoleptic properties	Bread taste	0.142	D_3
	Bread aroma	0.047	D_4
Safety & hygiene factors	HACCP	0.041	D_5
	ISO 22000	0.29	D_6
Shelf life	None spoilage	0.084	D_7
	Bread waste	0.042	D_8
Final price		0.033	D_9
Nutrients	carbohydrates	0.047	D_{10}
	gluten	0.061	D_{11}
	minerals	0.017	D_{12}
	Ferrous	0.058	D_{13}
	vitamins	0.019	D_{14}
	proteins	0.035	D_{15}
packaging	Impervious to gas and moisture	0.019	D_{16}
	Appearance of packages	0.003	D_{17}
	Weight & number of each loaf	0.004	D_{18}
labeling	Nutritional facts	0.000	D_{19}
	Production & expiration date	0.002	D_{20}
	Health permit	0.002	D_{21}
	Storage condition	0.001	D_{22}
	Intended group of consumers	0.000	D_{23}
Shape of bread		0.012	D_{24}

information in a specific domain, the peak of the so called domain is considered as the triangular fuzzy number (9) equivalent for the related descriptive information in Figure 1 (17). The obtained scores from questionnaires (including 10 cross-type options), were weighted using FAHP and entered into Software Expert Choice v. 11.

3. Results

3.1. FAHP-FQFD approach

Based on studies reporting experiences of experts in the field of renewable energy and bread industry, we gathered a list of customer requirements (CRs) in Table 1. The output data for giving weight to the criteria using FAHP is summarized in Table 1.

Then the Technical Requirements (TRs) were gathered by receiving questionnaire from experts in the area of industrial bread, as shown in Table 2.

Table 2. List of Technical Requirements

Category	TRs	Code
Bread technology	Continuous	TR_1
	Discontinuous	TR_2
Production method	Industrial	TR_3
	Semi industrial	TR_4
	Traditional	TR_5
standards	HACCP	TR_6
	ISO 9001	TR_7
	ISO 22000	TR_8
	National standard	TR_9
Bread operation	Flour preparation	TR_{10}
	Mixing and preparation of dough	TR_{11}
	fermentation	TR_{12}
	Dividing	TR_{13}
	Cooking	TR_{14}
	Cooling	TR_{15}
	Packaging	TR_{16}
Instrument durability	PM & calibration	TR_{17}
	Capability to use different mold	TR_{18}
Time & temperature control		TR_{19}
Types of oven	Tunnel ovens	TR_{20}
	Class oven	TR_{21}
	Rotating ovens	TR_{22}
Raw materials	Valid suppliers	TR_{23}
	Fresh raw materials	TR_{24}
	Using permitted materials	TR_{25}

TRs and CRs were entered into House of Quality (HOQ) as shown in Figure 3 in order to consider relationships and correlations. Triangle Fuzzy Numbers (TFN) which are denoted as a triplet (a, b, c) and non-fuzzy number by convention in Figure 2 (18,19) were considered to ease of calculation.

$$\mu_N(x): \begin{cases} (x-a)/(b-a), & x \in [a,b] \\ (c-x)/(c-b), & x \in [b,c] \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

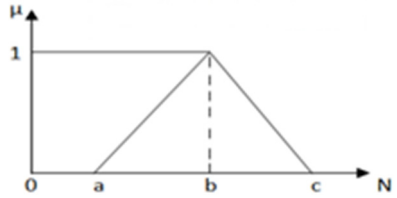

Figure 2. Triangular fuzzy number (TFN)

Furthermore, the degree of correlation between TRs was then expressed by TFNs in the fuzzy HOQ. Both of these correspondences are shown in Tables 3 and 4 (20).

If M= (a_1, b_1, c_1) and N= (a_2, b_2, c_2) represent two TFNs, then the required fuzzy calculations (21):

Fuzzy addition:

$$M \oplus N = (a_1 + a_2, b_1 + b_2, c_1 + c_2) \quad (2)$$

Fuzzy multiplication:

$$M \otimes N = (a_1 \times a_2, b_1 \times b_2, c_1 \times c_2) \quad (3)$$

$$M \otimes 1/N = (a_1/c_2, b_1/b_2, c_1/a_2) \quad (4)$$

Fuzzy and natural number multiplication:

$$r \otimes M = (r.a, r.b, r.c) \quad (5)$$

The scope of calculating these two parameters was to determine which TR has the most effect on the developing solar drying system. RI_j was computed by fuzzy multiplication of W_i to R_{ij}

$$RI_j = \sum_{i=1}^{n} W_i \otimes R_{ij} \qquad j = 1, \ldots, m \quad (6)$$

$$RI_j^* = RI_j \oplus \sum_{k=j} T_{kj} \otimes RI_K \quad j = 1, \ldots, m \quad (7)$$

Normalization was performed by dividing each RI^*_j by the highest one according to the fuzzy set algebra (19). Then, in order to rank the TRs, the normalized scores of RI^*_j were defuzzified. Suppose M (a, b, c) is a TFN; then, the crisp values are calculated as follows.

$$(a + 4b + c)/6 \quad (8)$$

Priority of TRs has been illustrated in Table 5.

Table 3. Degree of relationships, and corresponding fuzzy numbers

Degree of relationship	Fuzzy numbers
Strong (S)	(0.7, 1, 1)
Medium (M)	(0.3,0.5 ,0.7)
Weak (W)	(0,0,0.3)

Table 4. Degree of correlations, and corresponding fuzzy numbers

Degree of Correlation	Fuzzy numbers
Strong Positive★	(0.7,1,1)
Positive▲	(0.5,0.7,1)
Negative◆	(0,0.3,0.5)
Strong negative●	(0,0,0.3)

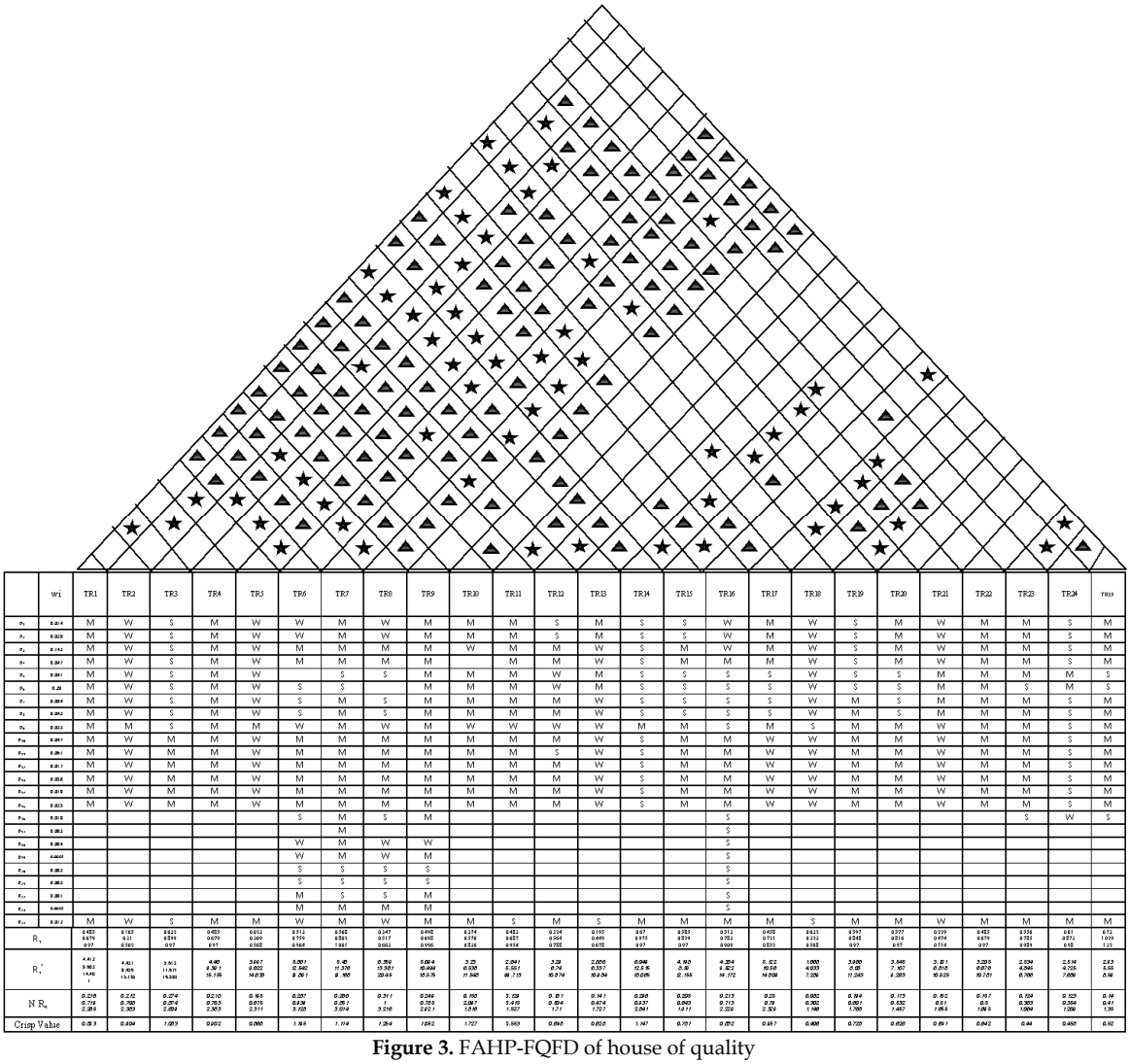

Figure 3. FAHP-FQFD of house of quality

Table 5. Prioritization of TRs

Row	Prioritization of TRs	Crisp Value	Row	Prioritization of TRs	Crisp Value
1	TR_{10}	1.727	14	TR_{15}	0.781
2	TR_{8}	1.254	15	TR_{19}	0.728
3	TR_{6}	1.195	16	TR_{12}	0.648
4	TR_{14}	1.147	17	TR_{22}	0.624
5	TR_{7}	1.114	18	TR_{21}	0.641
6	TR_{3}	1.063	19	TR_{13}	0.628
7	TR_{9}	1.052	20	TR_{20}	0.626
8	TR_{17}	0.957	21	TR_{11}	0.553
9	TR_{2}	0.904	22	TR_{25}	0.526
10	TR_{4}	0.902	23	TR_{24}	0.458
11	TR_{1}	0.893	24	TR_{23}	0.44
12	TR_{16}	0.882	25	TR_{18}	0.406
13	TR_{5}	0.868			

4. Discussion

According to prioritization of factors discussed throughout this study, importance of each technical requirements is indicated which plays a key role in development and improvement in industrial bread production. Additionally in this research, by considering customer requirements, it has been tried to use both Fuzzy Quality Function Deployment and Fuzzy Analytical Hierarchy Process method to choose ideal way for the stakeholders to enhance quality level of this system and generate more economical and competitive system in the future. Finally these efforts could lead into achieving and implementing a sustainable manufacturing in industrial bread. Production process affects the content of compounds responsible for color, taste and aroma of bread and also its quality and physical and rheological characteristics. Hence, having a more comprehensive knowledge from customer's requirements such as hygienic characteristics and organoleptic properties and also technical requirements like as controlling flour preparation, implementing ISO 22000 and HACCP for food safety aspects, ISO 9001 for quality management and cooking process improvements could be mentioned as key factors in declining the defects of production processes. Stalling process which is raised from microbial and physico-chemical spoilage will be responsible in reducing the shelf life of fresh bakery products.

Technological aids as well as using some ingredients such as additives, enzymes, emulsifier and hydrocolloids can help in extension of shelf life. Formulation of rice flour with hydroxyl propyl methyl cellulose (HPMC) as alternative baking ingredient accompanied with several levels of acidic food additives (like acetic acid, lactic acid, citric acid and monosodium phosphate) and also different fractions of rice bran containing different amount of protein, fat, dietary fibers were shown to improve the quality of gluten-free bread (2,3). Applying advanced instruments and technology such as development in packaging and new approaches which could meet the requirements of customers can be used to postpone the undesired changes and eventually extend the shelf life (4).

Prioritization of technical requirements resulted from this study can be the base of developing a prototype and then operational implementation in industrial scale. FAHP and FQFD which are two crucial techniques for improving competitive market in food industry need to understand customer needs and requirements and then attempting to provide them. This integrated approach may satisfy and meet the requirements of price, quality, time of delivery, after sales service or a combination of the above services. On the other hand, efficiency, productivity and competitive advantages are essential factors in production area which need to be considered (8). It is clear that priority of TRs which is illustrated in Table 5 must be considered for providing industrial bread. Through FQFD and FAHP in defining the requirements of customers as well as technological area (8, 9) for developing an industrial and sustainable bread production, we could provide an inexpensive and effective product for different groups of people in order to receive nutritious factors such as vitamins, minerals, and proteins and to have a balanced diet. In this regards, some technical efforts such as using composite flour of different crops with high nutritional value to replace with a portion of wheat have been investigated and performed. Soybeans and plantain were used with wheat to produce combined flour (1).

Industrial bread production must be considered as a sustainable industry which has the following definition according to sustainable development UN; development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts; the concept of 'needs', in particular, the essential needs of the world's poor, to which overriding priority should be given; and the idea of limitations imposed by

the state of technology and social organization on the environment's ability to meet present and future needs (10).

5. Conclusion

In this paper using FQFD and FAHP for defining different aspects of both customer and technical requirements made new methodological approach such as following:

- Economical method of production
- Development of safety and quality of industrial bread
- Intensify level of consumer's satisfaction for bread in market
- Sustainable development and manufacturing in bread industry

Conflict of interests

The authors have no conflict of interests.

References

1. Olaoye OA, Onilude AA., Idowu OA. Quality characteristics of bread produced from composite flours of wheat, plantain and soybeans. African J Biotech 2006; 5: 1102-6.
2. Sciarini LS, Ribotta PD, Leon AE, et al. Incorporation of several additives into gluten free breads: effect on dough properties and bread quality. J Food Eng 2012; 111: 590–7.
3. Phimolsiripol Y, Mukprasirt A, Schoenlechner R. Quality improvement of rice-based gluten-free bread using different dietary fiber fractions of rice bran. J Cereal Sci 2012; 56: 389-95.
4. Minervini F, Pinto D, Cagno RD, et al. Scouting the application of sourdough to frozen dough bread technology. J Cereal Sci 2011; 54:296-304.
5. Andronikidis A, Georgiou AC, Gotzamani K, et al. The application of quality function deployment in service quality management. The TQM J 2009; 21: 319-33.
6. Arumugam V, Chang HW, Keng-Boon O, et al. Self-assessment of TQM practices: a case analysis. The TQM J 2009; 21: 46-58.
7. Parasuraman A. Customer service in business-to-business market: an agenda for research. J Bus Ind Market 1998; 13: 309-21.
8. Feili HR, Molaee Aghaee E, Bairampour M, et al. Development of solar drying systems in saffron industry using FAHP & FQFD. 3rd international conference on nuclear & renewable energy resources. Istanbul, Turkey. 2012.
9. Feili HR, Bairampour M, Akar N, et al. Development of integrated wind and solar systems using FAHP and FQFD. 3rd international conference on nuclear & renewable energy resources. Istanbul, Turkey. 2012.
10. Brundtland Commission. 1987. Report of the world commission on environment and development. Brundtland Commission, United Nations. 1987.
11. Saaty TL. The analytic hierarchy process: planning, priority setting, resources allocation. London, McGraw-Hill. 1980.
12. Felixchan TS, Niraj K. Global supplier development considering risk factors using fuzzy extended AHP-based approach. J Omega 2007; 35: 417–31.
13. Zaddeh LA. Fuzzy sets. Inform Control 1965; 8: 338-53.
14. Ju Y, Wang A, Liu X. Evaluating emergency response capacity by fuzzy AHP and 2-tuple fuzzy linguistic approach. J Exp Sys Appl 2012; 39:6972–81.
15. Bottani E, Rizzi A. Strategic management of logistics service: A fuzzy QFD approach. Int J Prod Econ 2006; 103: 585–99.
16. Yang YQ, Wang SQ, Dulaimi M, et al. A fuzzy quality function deployment system for buildable design decision-makings. J Autom Const 2003; 12: 381–93.
17. Luu VT, Kim SY, Truong TQ, et al. Quality improvement of apartment projects using Fuzzy-QFD approach: a case study in Vietnam. KSCE J Civil Eng 2009; 13: 305-15.
18. Chamodrakas I, Alexopoulou N, Martakos D. Customer evaluation for order acceptance using a novel class of fuzzy methods based on TOPSIS. J Exp Sys Appl 2009; 36: 7409–15.
19. Zimmermann HJ. Fuzzy set theory and its applications. 2nd edition. Boston, Kluwer Academic Publishers. 1991.
20. Zarei M, Fakhrzad M.B, Paghaleh MJ. Food supply chain leanness using a developed QFD model. J Food Eng 2011; 102:25–33.
21. Chien CJ, Tsai HH. Using fuzzy numbers to evaluate perceived service and quality. J Fuzzy Sets Sys 2000; 116: 289–300.