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Development and test of a new fuzzy-QFD approach for characterizing customers rating of extra virgin olive oil

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ABSTRACT

This paper presents the development of an innovative fuzzy-QFD based methodology for characterizing customer rating of food products. The method has been tested on different samples of extra virgin olive oil to verify its suitability.

The results demonstrated the effectiveness of such multi-criterion technique not only for the design and development of new products that meet customers' requirements, but also for testing the quality of existing ones.

The main innovation of the method, consists in the application of the fuzzy logic to address the issue, common in many decisional techniques, of dealing with data deriving from subjective verbally expressed evaluations that cannot be treated with mathematical models.

The objective of this work was to test the combined assessment technique based on quality function deployment and fuzzy logic method for determining which characteristics of extra virgin olive oil influence most of the acceptance of the consumers toward the product. The relationship between consumer expectations, defined by a market survey, and main attributes of the examined products were assessed by means of the House of Quality (HOQ). The results obtained allowed to classify the quality of different brands of olive oil with respect to customer preferences.

1. Introduction

This research work deals with the application of a fuzzy-QFD based method for assessing the characteristics that determine the quality and acceptability of EVOOs from a potential consumer and link these expectations and needs to measurable and modifiable parameters.

Nowadays the quality of olive oil reflects nutritional, sensory and commercial aspects and is regulated by European legislation (EC), the International Olive Council (IOC) and also the Codex Alimentarius. According to Inarejos-García, Santacatterina, Salvador, Fregapane, and Gómez-Alonso (2010), the fine flavor (aroma and taste) and color of virgin olive oil distinguish it from other edible vegetable oils, giving it a superior quality that is traditionally appreciated by the consumers in the mediterranean countries and now all over the world. In fact, the definition of quality is the combination of characteristics of a product that significantly determines its acceptance by consumers. This leads to the demand for innovative products that can meet the customers' expectations and consequently of tools that help in reaching and maintaining the highest level of food quality.

Olive oil is present in the market with a broad variety of trade names, each one represents a product with different characteristics. The main features are related to the chemical composition and to the organoleptic notes that depend on the specific cultivar and on the characteristics acquired after the processing. These determine an oil's difference from another but the knowledge and the way in which the oil can influence the final quality is not well known even from the specialists of the sector.

Different methods and techniques, such as sensorial analysis (Guerrero, Romero, & Tous, 2001) have been applied to understand and anticipate customer needs and preferences in the olive oil field; a consumer study to evaluate preferences and attitudes regarding extra virgin olive oil (EVOO) in the US emergent market was performed; generic descriptive analysis was used on 22 samples of EVOO in order to identify the diverse liking for this consumer population (Delgado & Guinard, 2010).

Starting from those considerations, this study was conducted to demonstrate for the first time (since does not exist any application of fuzzy-QFD for olive oil in literature), the feasibility of this combined technique.

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The following paragraphs address the following topics: in Section 2 the relevant literature in the field has been presented; in Section 3 the material and methods used to perform the research have been discussed (QFD, fuzzy logic concepts and fuzzy-QFD have been explained); Section 4 is devoted to the presentation of the results with the description of all the steps performed to develop the HOQ such as the definition of customers' requests (WHATs) and their weight by the survey, the evaluation of the HOWs, the assessment of the relationship scores "hows–whats" and calculation of the hows weights and finally the evaluation of Fuzzy Suitability Index (FSI) for different type of EVOOs and their relative classification. In the last paragraph some conclusions have been presented.

2. Relevant literature

QFD is a widely used quality tool developed to satisfy customer's need in products' design and development and there are many papers describing the application of the technique in different fields except that of the food sector for which there are few works available in literature. Most of the relevant information is confidential and unavailable for the general public (Costa, Dekker, & Jongen, 2010); nevertheless a detailed literature review on the topic of the application of QFD in the food industry with a thorough description of the methodologies involved in the practice of QFD within food companies, exemplified with the help of a case study on ketchup quality improvement, was presented. Benefits, drawbacks and challenges of QFD's application in food research and development were also addressed. One of the first applications of QFD in the food field explains the modality of translating consumer needs for good sensory quality of food into sensory attributes measurable using HOQ by conventional sensory descriptive analysis. The method was based on the assumption that consumers' and panelists' perceptions were non-identical, statistically significant relationships Bech, Hansen, and Wienberg (1997), used ANOVA (analysis of variance) and experimental design as intermediate methods. The importance of considering the relationships between sensory attributes, technical attributes, and consumer requirements when using the HOQ methodology to develop new or improve existing products has been demonstrated during market-based studies to improve the quality of frozen peas (Bech, Juhl, Hansen, Martens, & Andersen, 2000) and chocolate coverture (Viaene & Jenuszewska, 1999). A similar approach was adopted for a Danish butter cookie company (Holmen & Kristensen, 1996). QFD method was used to define the importance of various sensory characteristics for the design of a new functional snack food; the analysis showed that flavor was the major determinant of snack success in the market place (Wangcharoen, Ngarmsaka, & Wilkinson, 2005).

Other applications of QFD in the food sector, can be found in the development of gold kiwifruit leather product (Vatthanakul, Jangchuda, Jangchuda, Therdthaia, & Wilkinson, 2010); in chocolate industry where the product specifications were established through physic-chemical and instrumental methods and analyzing the mutual relations between technical and sensory measurements and integrating the results in the House of Quality (Viaene & Jenuszewska, 1999).

It has been acknowledged that the use of QFD would enlarge the chance of success, produce higher quality products and decrease the cost and the development time. However, a careful evaluation of the available literature dealing with the use of QFD for food product development revealed that the number of examples of QFD used on the actual development or improvement of food products is limited and this is due to the fact that the application of QFD in the food industry is more complicated than what current literature suggests (Benner, Linnemanna, Jongena, & Folstara, 2003).

3. Materials and methods

3.1. Quality function deployment

QFD belongs to the sphere of quality management methods, offering a linear and structured guideline for converting the customer's needs into specifications for, and characteristics of new products and services. Quality function deployment (QFD) can be defined as a key tool for the application of concurrent engineering and implementing total quality management (TQM). QFD emphasizes the multifunctional teams required for integrating all corporate functions to be responsive to the customers' requirements so that product planning, product design, process planning, and production planning provide a coherent response to customers' needs. In other words, QFD can be seen as a set of planning tools, which help in introducing new or improved products faster to market by focusing on customer satisfaction (Guinta & Praizler, 1993).

The main aim of this study was to test a method which is able to assess the key characteristics of olive oil that are determinant factors for the customers and influence the acceptance of the product.

The HOQ can be considered as the hub of the whole QFD method: it provides the specifications for product characteristics in terms of their relative importance and of target values that have to be reached in production, enabling to proceed from the customers' requirements to the design specifications (Schmidt, 1997; Fariborz & Rafael, 2002).

HOQ represents a powerful tool for the product development, nevertheless when applied to food products, its general structure has to be adapted. In this paper, it has been used as a modified HOQ developed with the aim of creating a better integration between sensorial analysis and market analysis for food products (Bech et al., 1997); the relationships between sensorial attributes, technical attributes and customer requirements are deeply detailed as showed in Fig. 1.

In the present study the HOQ was used to link the customer requests (WHATs) to the sensorial and technical features of the EVOO (HOWs).

The modified HOQ reflects in a better way for the development specifications of a food product (namely of the sensorial properties of the food). The QFD approach is based on the hypothesis that if

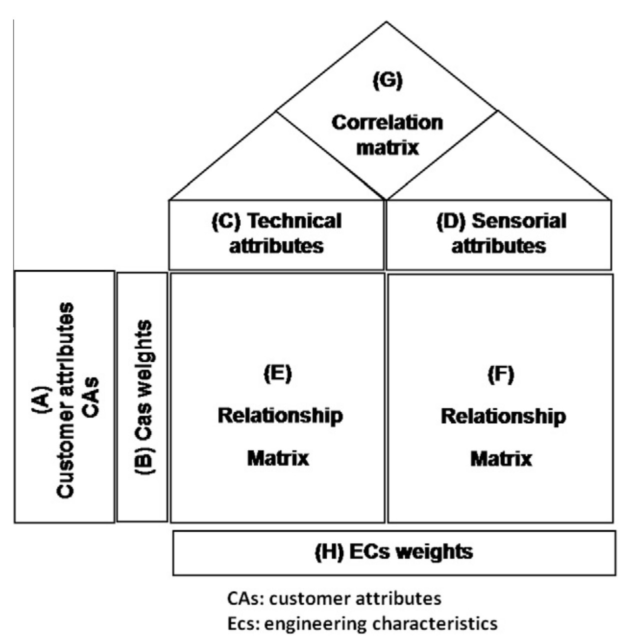

Fig. 1. Modified HOQ for food application.

the relationship between the sensorial and technical features is known and they can be correlated to the customer voice, it will be possible to reach a high percentage of success in the development of the product.

The steps followed to build the HOQ are described herein after:

1. WHATs identification: the benefits desired from the EVOO in the customer's own words are customer needs and are usually called customer attributes (CA) or "WHATs", area (A) in Fig. 1.
2. Market survey to determine the relative importance of each WHAT (customer attributes). The priorities are usually indicated in the area designated as (B) in Fig. 1.
3. Determination of HOWs. Identification of the main sensorial features and of the technical analysis that characterize the extra virgin olive oil quality. In the modified HOQ the HOWs have been divided into sensorial and technical attributes and positioned on the areas marked as (C) and (D) on the matrix diagram, Fig. 1.
4. Preparation of the relationship matrix (E) and (F). Determination of which WHATs impact which HOWs and to what degree.
5. Elaboration of the correlation matrix. The physical relationships among the technical requirements are specified on an array known as "the roof matrix" and identified as (G) in Fig. 1.
6. Assessment of the HOWs weights. The weights of the HOWs, identified as area (H), are placed at the base of the quality matrix. These weights are one of the main outputs of the HOQ, and are determined by:

$$\mathrm{Weight(HOW)}_i = \mathrm{V(HOW)}_{i1} \times \mathrm{imp(WHAT_1)} + \ldots + \mathrm{V(HOW)}_{in} \times \mathrm{imp(WHAT}_n)$$

where $\mathrm{V(HOW)}_{in}$ is the correlation value of HOW_i with WHAT_n, and imp (WHAT_n) represents the importance or priority of WHAT_n.

The entire procedure has been carried on using fuzzy numbers.

3.2. Fuzzy logic

In dealing with a decision process, the decision-maker is often faced with doubts, problems, and uncertainties. To cope with and "handle" such uncertainties and inaccuracies, he generally relies on tools provided by probability theory, accepting the principle that an inaccuracy, whatever its nature, is governed by random law. In a real decision-making process, however, it is necessary to deal with different types of uncertainty and inaccuracy, which have to be treated with the aid of a specific tool.

Probability theory is suitable for representing the stochastic nature of decisional analysis, but is unable to measure the inaccuracies or uncertainty that stem from human behavior, which is neither stochastic nor random. The fundamental role of the decision-maker or other parties involved in the decisional process poses a number of problems that cannot be handled appropriately by probability theory. Referring specifically to a multi-criterion analysis, this means that the values of a certain alternative concerning a given attribute often cannot be precisely defined, the decision-maker is unable (or unwilling) to express his preferences precisely, the evaluations or opinions are expressed in linguistic terms, and so on. To deal with this type of uncertainty the use of fuzzy logic represents an effective approach (Zadeh, 1965). The logical tools that people can rely on are generally considered the outcome of a bivalent logic (yes/no, true/false), but the problems posed by real-life situations and human thought processes and approaches to problem-solving are by no means bivalent. Just as conventional, bivalent logic is based on classic sets, fuzzy logic is based on fuzzy sets (Tong & Bonissone, 1980). A fuzzy set is a set of objects in which there is no clear-cut or predefined boundary between the objects that are or are not members of the set. The key concept behind this definition is that of "membership": each element in a set is associated with a value indicating to what degree the element is a member of the set. This value comes within the range [0, 1], where 0 and 1, respectively, indicate the minimum and maximum degrees of membership, while all the intermediate values indicate degrees of "partial" membership.

There are various types of fuzzy numbers, each of which may be more suitable than the others for analyzing a given ambiguous structure; the present analysis uses triangular fuzzy numbers. These numbers are represented by the terms of the type $A = (xL, x^*, xR)$, where xL and xR are, respectively, the lower and upper limits of the fuzzy number considered, while x^* is the element that denotes the closest fit. Triangular fuzzy numbers are often used to quantify linguistic data. The use of triangular fitness functions is fairly common in the literature because this kind of numbers are among the few fuzzy one forms that are easy to manage from the computational point of view (Karsak, 2004; Chan & Wu, 2005).

For instance, let U = {VL, L, M, H, VH} be a linguistic set used to express opinions on a group of attributes (VL = very low , L = low, M = medium, H = high, and VH = very high). The linguistic variables of U can be quantified using triangular fuzzy numbers as follows (Fig. 2): VL $\rightarrow (0,1,2)$; L $\rightarrow (2,3,4)$; M $\rightarrow (4,5,6)$; H $\rightarrow (6,7,8)$; VH $\rightarrow (8,9,10)$.

The linguistic variable M for example means that the decision-maker's assessment contains elements of grades $xL = 4$ up to a grade $xR = 6$, with a maximum degree of membership in $x^* = 5$.

3.3. Fuzzy-QFD

In traditional QFD, most of the input variables are assumed to be precise and are treated as numerical data. However, QFD as a concept and mechanism for translating the voice of the customer into product attributes through various stages of product planning, engineering, processing, and production are required linguistic data to be inherently vague and ambiguity (Kahraman, Ertay, & Buyukozkan, 2006). Linguistic data can be treated to approximate exactness with the help of fuzzy set theory. When implementing QFD using linguistic data, some factors may affect the final results such a ranking of technical characteristics. The factors include the type of fuzzy numbers, defuzzification strategies, and the degree of fuzziness of fuzzy numbers. Besides, capturing the elasticity of imprecise requirements is an important issue. Customers' prefer-

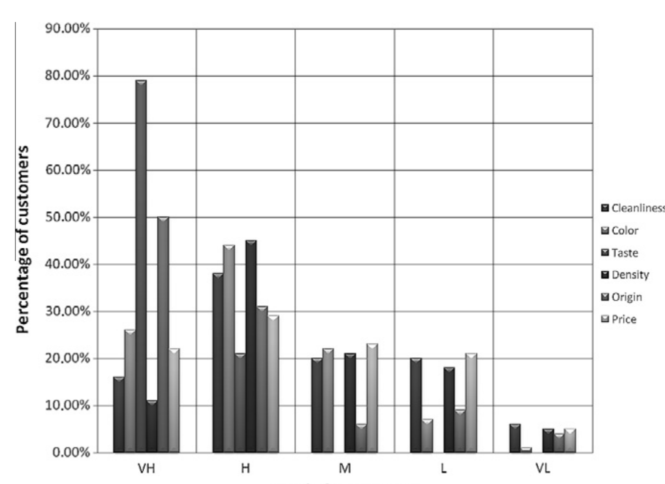

Fig. 2. Evaluation of importance of the defined WHATs.

ences are often fuzzy and imprecise. In addition, relationships between customer needs and product technical requirements are identified qualitatively. This qualitative identification requires to be translated into numerical scales.

Research on fuzzy-QFD has received a certain amount of attention (Temponi, Yen, & Tiao, 1999; Harding, Popplewell, Fung, & Omar, 2001), and made substantial progress: an approach centered on the application of possibility theory and fuzzy arithmetic to address the ambiguity in QFD operations (Khoo & Ho, 1996) and a hybrid system to incorporate the principles of QFD, analytical hierarchy progress (AHP), and fuzzy set theory to determine the design targets (Fung, Tang, Tu, & Wang, 2002), have been developed. Moreover a fuzzy outranking approach to prioritize HOWs (Wang, 1999), and a fuzzy procedure to examine the sensitivity of the ranking of HOWs to the defuzzification strategy and degree of fuzziness of fuzzy numbers (Shen, Tan, & Xie, 2001) were demonstrated. A fuzzy-QFD methodology was proposed also for suppliers selection (Bevilacqua, Ciarapica, & Giacchetta, 2006); the conceptual and procedural approaches of the HOQ remain, though the roles have been inverted: in traditional QFD applications, the company has to identify its customers' expectations and their relative importance (external variables) in order to identify which design characteristics (internal variables) should be allocated for the most resources; when the HOQ is used in supplier selection, on the other hand, the company starts with the features that the outsourced product/service must have in order to meet certain requirements that the company has established – and consequently knows very well (so the customer's expectations become internal variables, since the company itself is the customer) – and then tries to identify which of the suppliers' attributes (external variables) have the greatest impact on the achievement of its established objectives.

In this paper, a similar approach is used for the sensorial characterization of the olive oil.

4. Results

In this study the EVOOs characteristics taken into account for building the HOQ have been defined considering the existent literature and involving three groups of experts (olive oil producers, researchers and marketing experts, and non professional tasters), each one composed by five panelists led by a panel leader drawn from the "consortium for the valorization of the extra virgin olive oil of Marche Region". The three panel leaders, were in charge of the panelists training, preparing the test sections and collecting and analyzing the evaluations provided by the panelists.

4.1. Identification of the customer requests (WHATs)

The main and critical step of QFD method is the identification of the customer expectations that, in this case, are represented by the qualitative attributes that influence the purchase of the EVOO. There are many characteristics considered relevant by the consumer but to make effective the analysis it is necessary to limit the number of attributes to test in a bid to identify the most relevant ones. Over the past 20 years, there have been numerous attempts to define a methodology for the evaluation of olive oil in terms of its sensory qualities, consumer preferences, and chemical composition (Delgado & Guinard, 2010), with most of the work being conducted on volatile compounds and their possible relationship to extra virgin olive oil flavor (Aparicio & Morales, 1998; Caporale, Policastro, Carlucci, & Monteleone, 2006). Researchers have explored consumer response to olive oil as a way of measuring quality in terms of customer satisfaction (Krystallis & Ness, 2005); have compared responses of distributors and olive oil consumers, and found that perceived quality defined in terms of sensory properties such as taste, aroma, color, appearance, texture, is important to both segments (Sandalidou & Baourakis, 2002; Matsatsinis, Grigoroudis, & Samaras, 2007). A quality index based on chemical parameters that are related to EVOO's microbiological/chemical safety, nutritional and technological aspects has been developed but without considering the sensory characteristics in the model (Finotti, Bersani, & Bersani, 2007). More recently, the effect of region of origin on EVOO's perceived quality, measuring the perceived quality in terms of the price that a consumer is willing to pay has been studied (Dekhili & d'Hauteville, 2009). Despite all these endeavors, no method has yet provided a comprehensive way of examining the diverse liking for the quality of extra virgin olive oil.

In this phase the three panels agree to consider the following WHATs as the most important for the proposed analysis: smell, taste, cleanliness, color, density, origin and provenience, and price.

4.2. Definition of the WHATs weights: consumer test

The second step in the application of QFD consisted in defining the relative importance of the seven attributes for the final consumer. For performing this task a questionnaire was elaborated and submitted to a sample of 100 consumers. The interviews were conducted in different days of the week, and in different time slots, outside three important stores selling different brands of high quality olive oil. The questionnaire was administered in a random way to people exiting from the store with at least a product. Eighty percent of the interviewed were females between 45 and 60 (40%); 49% were married or in a common low regime, with children, 31% were married or in a common low regime, with no children, 7% were single people with children, and 3% were single people with no children. Education level was distributed across four main categories as follows: advanced degree (32%), bachelor's degree (34%), high school diploma (27%), and other (7%). Income levels were divided in five categories: lower than 15.000 euros/year (0%), 15.000–28.000 euros/year (29%), 28.000–55.000 (37%), 55.000–75.000 (8%), and higher than 75.000 (0%).

Consumers were requested to evaluate the seven characteristics defined as WHATs giving a scale of importance for each one. The linguistic variables used were: very important, important, medium, slightly important, and not important. Five levels of importance have been used: very high (VH), high (H), medium (M), low (L), and very low (VL). The result of the survey is presented in the graph of Fig. 2.

The linguistic variables have been translated into triangular fuzzy numbers though the definition of a suitable membership function as in the following expressions:

VH $(0.7,1,1)$; H $(0.5,0.7,1)$, M $(0.2,0.5,0.8)$; L $(0,0.3,0.5)$; VL $(0,0,0.3)$.

The weights of the WATHs assigned by the consumers have been aggregated as described in the equation below:

$$\text{Weights}_{\text{WHAT}} = \{w_i,\ \text{with } i = 1,\ldots,k\} \quad w_i = \frac{1}{n} \otimes (w_{i1} \oplus w_{i2} \oplus \ldots \oplus w_{in})$$

k = number of WHATs considered, n = number of consumers interviewed. It has been decided to exclude from the analysis the characteristics that do not have any impact on the technical and sensorial features of the oil: the origin and the price; moreover the two characteristics related to the aspect, cleanliness and color, have been grouped in a single category; in this case $k = 4$ and $n = 100$.

The weights obtained from the aggregation are showed in Table 1.

Table 1
What's weight.

WHATs	Weights$_{what}$		
	$w_{i\alpha}$	$w_{i\beta}$	$w_{i\gamma}$
Taste	0.658	0.937	1
Smell	0.468	0.721	0.903
Appearance	0.3905	0.595	0.8585
Density	0.346	0.584	0.833

4.3. Experts evaluation of HOWs

The HOQ model proposed by Bech et al. (2000), outlined the importance, for a food product, of evaluating both technical and sensorial characteristics, e.g., the HOWs. In the first phase of the research work the three panel leaders with the respective experts groups, have been involved in the evaluation of the main parameters that characterize the EVOO quality. They established 10 relevant organoleptic features and five technical aspects related to chemical analysis. For the evaluation have been selected the ones that are closer to consumer requests as detailed in the following list.

1. Technical features
1.1. Acidity: due to chemical reactions of hydrolysis that cause the detachment of fat acids tied to the glycerol; its quantification is a fundamental parameter to evaluate the oil quality.
1.2. Color intensity and shade to determine if the oil tends to the yellow or green tone.
1.3. Viscosity: determination of the viscosity coefficient of the fluid; it is strictly correlated to the fluidity and consistency of the oil.
1.4. Total polyphenols: chemical components that determine the oil taste and color and prevent the oil from going rancid.
1.5. Volatile substances: constituent that characterizes the aromatic component of food and can be used for the qualitative evaluation of virgin olive oils.
2. Sensorial features
2.1 Fruitiness intensity: olfactory sensation typical of oils obtained from olives in full maturity. It is a fundamental and positive attribute of olive oil, that identifies the smell of ripen olives when pressed. It is a feature that only olive oils, obtained from fruits by mechanical process, posses; differently from other greases that undergo chemical refining processes.
2.2 Herbaceous intensity: olfactory sensation characteristic of a young and fresh oil; it is a smell that reminds of cut grass and is considered as a valuable feature.
2.3 Bitterness: taste characteristic of oil obtained from green olives. It indicates the presence of phenolic substances that are responsible for some of the health properties of EVOO, such as antioxidant capacities able to capture and neutralize free radicals. It is pleasant only until a certain intensity and indicates the capacity of preservation of the product and its healthy features.
2.4 Pungency: typical stinging sensation in the throat which can force a cough. Also this is an index of the capacity of preservation and healthy features.
2.5 Sweetness: this characteristic appears with time when phenols decay: it is intended as the absence of bitterness and pungency and not as honeyed or sugary and it is typical of mild oils.
2.6 Intensity of yellow: visual characteristic that defines the oil color.
2.7 Intensity of green: visual characteristic that defines the oil color.
2.8 Consistency and fluidity: cinestetic characteristic of the oil rheological state able to stimulate the mechanical receptors of the oral cavity during taste.
2.9 Cleanliness: visual characteristic due to the presence of particles in suspension.

4.4. Assessment of the relationship scores "hows–whats" and calculation of the hows weights

The panelists, lead by the three panel leaders, have been requested to express a judgment using a 0–5 numerical scale, relatively to the impact of each "hows" on each "whats"; then the results were translated into linguistic variables and averaged. Table 2 shows the summary of the experts' opinion for the three different panels. As an example on how to read the data, for the panel 1 the technical characteristic "acidity" (How) as a high correlation with "taste" (What), for the panel 2 a medium correlation and for the panel 3 a very high one.

Fig. 3 shows the correlation and relationship matrix corresponding to the (G), (E), and (F) areas of the HOQ (Fig. 1), that represents the relation existing between the sensorial and technical features.

In order to quantify linguistic variables, triangular fuzzy numbers have been used and the results obtained from each panel leader have been aggregated by the following equation:

$$\text{Rating} = \{r_{ij},\ \text{with } i = 1,\ldots,k\ e\ j = 1,\ldots,m\}$$
$$r_{ij} = \frac{1}{n} \otimes (r_{ij1} \oplus r_{ij2} \oplus \cdots \oplus r_{ijn})$$

with $k = 4$ = number of whats, $m = 15$ = number of hows and $n = 3$ = number of panels.

Rating is the scores matrix between "how"–"what", in which the elements r_{ij}, that are triangular fuzzy numbers defined by the tern $r_{ij} = (r_{ij\alpha}, r_{ij\beta}, r_{ij\gamma})$, represent the aggregated score between the i-th "what" and the j-th "how".

From this point it is possible to complete the HOQ proceeding with the calculation of the important weights for the hows as defined in the following equation:

$$\text{Weights}_{\text{HOWs}} = \{W_j,\ \text{with } j = 1,\ldots,m\} \quad W_j = \frac{1}{k} \otimes [(r_{j1} \otimes w_1) \oplus \ldots \oplus (r_{jk} \otimes w_k)]$$

W_j are triangular fuzzy numbers defined by the tern $W_j = (W_{j\alpha}, W_{j\beta}, W_{j\gamma})$ and represent the importance weight for each attribute.In Tables 3 are showed the data integrated in the HOQ corresponding to the areas (B) and (H) of Fig. 1.

The last step in the application of the method proposed is the evaluation and classification of the values obtained. There are several studies related to the fuzzy numbers ranking (Yager & Filev, 1999; Liou & Wang, 1992; Buckley, 1985; Chan, Kao, Ng, & Wu, 1999; Chan & Wu, 2005) and does not exist a single method univocally accepted. In this work it has been followed the approach of choosing the convex combination between pessimistic and optimistic methods that were applied to a triangular fuzzy number $FN = (FN_\alpha, FN_\beta, FN_\gamma)$ (Facchinetti, Ghiselli, Muzioli, & Ricci, 1998). This produces a score identified by the value:

$$\frac{FN_\alpha + 2 \cdot FN_\beta + FN_\gamma}{4}$$

The final scores and the consequent ranking are presented in Table 4.

Table 2
Relationship score between hows and whats defined by the three panels.

WHATs	Technical characteristics					Sensorial characteristics									
	Acidity	Color intensity	Viscosity	Volatile substances	Total polyphenols	Fruitiness intensity	Herbaceous intensity	Bitterness	Pungency	Sweetness	Yellow color	Green color	Consistency and fluidity	Cleanliness	Equilibrium taste–smell
HOWs panel 1															
Taste	H	M	L	H	VH	L	M	VH	VH	H	L	L	VL	VL	VH
Smell	H	L	VL	VH	L	VH	VH	VL	M	L	VL	L	VL	VL	VH
Appearance	L	VH	L	L	L	M	M	VL	L	VL	VH	VH	L	VH	VL
Density	VL	VL	VH	VL	VL	VL	VL	VL	VL	VL	VL	VL	VH	L	VL
HOWs panel 2															
Taste	M	L	L	M	VH	H	VH	VH	VH	H	L	M	VL	L	H
Smell	M	L	VL	VH	L	VH	VH	L	H	VL	VL	L	VL	L	H
Appearance	VL	VH	L	L	VL	L	L	VL	VL	VL	VH	VH	L	VH	VL
Density	VL	VL	VH	VL	VL	VL	VL	VL	VL	VL	VL	VL	VH	L	VL
HOWs panel 3															
Taste	VH	H	L	L	VH	H	H	VH	VH	VH	L	L	VL	VL	VH
Smell	H	L	L	VH	L	VH	VH	L	H	L	L	L	VL	VL	VH
Appearance	VL	VH	L	L	VL	VL	L	L	L	VL	VH	VH	M	VH	VL
Density	VL	VL	VH	VL	VL	VL	VL	VL	VL	VL	VL	VL	VH	L	VL

4.5. Evaluation of Fuzzy Suitability Index (FSI) for different type of EVOOs

The oils chosen for testing the method are the following:

- The "Correggiolo" from Emilia Romagna Region (Rimini province) of the Monte Colombo cultivar (Alt.1).
- The "Moraiolo" from Umbria Region (Colli Martani area) (Alt.2).
- The " San Felice" from Umbria Region (Alt.3).
- The Sicilian PDO (Protected Designation of Origin) from the Valleys of the Trapani area (Alt.4).
- The Sicilian PDO from from Mazara Valley (Alt.5).
- The oil produced from the olives of the hard kind in the Ascoli Piceno area of Marche Region (Alt.6).
- The oil produced from the olives of the soft kind in the Ascoli Piceno area of Marche Region (Alt.7).

4.6. Testing method

The sensory analysis of the oils was conducted by nine tasters (three panelist for each group) selected and trained by the respective panel leaders. Tests were carried out in the laboratories of the Università Politecnica delle Marche.

The tasters were presented the alternatives in a blind test, with the same sequence for all of them; the laboratory was at room temperature, the oils EVOOs samples were served at 28 °C in glasses for oil testing as defined by COI/T.20/Doc. No. 5. The evaluation was carried out in two sections of four and three samples each. The tasters were requested to express their judgments, for the nine selected sensorial attributes, on a 0–100 quality scale. The values (from the nine panelists) obtained for each characteristic were averaged and translated into linguistic variables as summarized in Table 5.

As previously, the linguistic variables have been quantified with triangular fuzzy numbers and have been identified as a new matrix called:

$$\text{Oil Rating} = \{OR_{ij},\ \text{per}\ i = 1,\ldots,p,\ j = 1,\ldots,m\},$$

where m = number of attributes (HOWs), p = number of examined oils.

The elements of the Oil Rating matrix are triangular fuzzy numbers defined by the terns that represent the aggregate evaluations OR_{ij} of the i-th oil for the j-th attribute with $OR_{ij} = (OR_{ij\alpha}, OR_{ij\beta}, OR_{ij\gamma})$. The last step of the procedure consists in the calculation of the FSI for the different types of oil analyzed and expresses the degree of compliance to the fixed specifications. The FSI has been calculated with the following equation:

$$\text{FSI} = \{\text{FSI}_i,\ \text{with}\ i = 1,\ldots,p\},$$

$$\text{FSI}_i = \frac{1}{m} \otimes [(OR_{i1} \otimes W_1) \oplus \ldots \oplus (OR_{im} \otimes W_m)]$$

The FSI vector contains the FSI_i index of each type of oil defined as $\text{FSI}_i = (\text{FSI}_{i\alpha}, \text{FSI}_{i\beta}, \text{FSI}_{i\gamma})$; the components of the tern are obtained from the following equation:

$$\text{FSI}_{i\alpha} = \frac{1}{m}\sum_{j=1}^{m} OR_{ij\alpha} \cdot W_{j\alpha}; \quad \text{FSI}_{i\beta} = \frac{1}{m}\sum_{j=1}^{m} OR_{ij\beta} \cdot W_{j\beta};$$

$$\text{FSI}_{i\gamma} = \frac{1}{m}\sum_{j=1}^{m} OR_{ij\gamma} \cdot W_{j\gamma}$$

In the case study examined the FSI_i index are presented in Table 6.

The FSI_i index obtained is used to identify the best alternative and makes a classification of the oil analyzed with respect to the parameter that represents the customer requests. In this work

Table 3
Hows and whats weight related to sensorial and technical characteristics.

HOWs																	
What weight			Acidity			Color intensity			Viscosity			Volatile substances			Polyphenols		
α	β	χ	α	β	χ	α	β	χ	α	β	χ	α	β	χ	α	β	χ
Technical analysis																	
−66	−93	1	−46	−73	−93	−23	−5	−76	0	−3	−5	−23	−5	−76	−7	1	1
−46	−72	−91	−4	−63	−93	0	−3	−5	0	−1	−36	−7	1	1	0	−3	−5
−39	−59	−95	0	0	−3	−7	1	1	0	−3	−5	0	−3	−5	0	−1	−36
−34	−58	−83	0	0	−3	0	0	−3	−7	1	1	0	0	−3	0	0	−3
			W1			W2			W3			W4			W5		
HOWs weight			α	β	χ	α	β	χ	α	β	χ	α	β	χ	α	β	χ
			−12	−28	−57	−11	−32	−57	−06	−28	−52	−12	−34	−58	−12	−30	−50

What weight			Fruitiness intensity			Herbaceous intensity			Bitterness			Pungency			Sweetness			Yellow color			Green color			Fluidity			Cleanliness			Equilibrium taste–smell		
α	β	χ	α	β	χ	α	β	χ	α	β	χ	α	β	χ	α	β	χ	α	β	χ	α	β	χ	α	β	χ	α	β	χ	α	β	χ
Sensorial analysis																																
−66	−93	1	−33	−56	−83	−46	−73	−93	−7	1	1	−7	1	1	−56	−8	1	0	−3	−5	−06	−36	−6	0	0	−3	0	−1	−36	−63	−9	1
−46	−72	−91	−7	1	1	−7	1	1	0	−2	−43	−4	−63	−93	0	−2	−43	0	−1	−36	0	−3	−5	0	0	−3	0	−1	−36	−63	−9	1
−39	−59	−95	−06	−26	−53	−06	−36	−36	0	−1	−36	0	−2	−43	0	0	−3	−7	1	1	−7	1	1	−36	−36	−6	−7	1	1	0	0	−3
−34	−58	−83	0	0	−3	0	0	0	0	0	−3	0	0	−3	0	0	−3	0	0	−3	0	0	−3	1	1	1	0	−3	−5	0	0	−3
			W6			W7			W8			W9			W10			W11			W12			W13			W14			W15		
HOWs weight			α	β	χ	α	β	χ	α	β	χ	α	β	χ	α	β	χ	α	β	χ	α	β	χ	α	β	χ	α	β	χ	α	β	χ
			−14	−35	−62	−16	−4	66	−11	−28	−49	−16	−37	−63	−09	−22	−48	−07	−23	−5	−08	−28	−56	−06	−2	−49	−07	−23	−51	−18	−37	−61

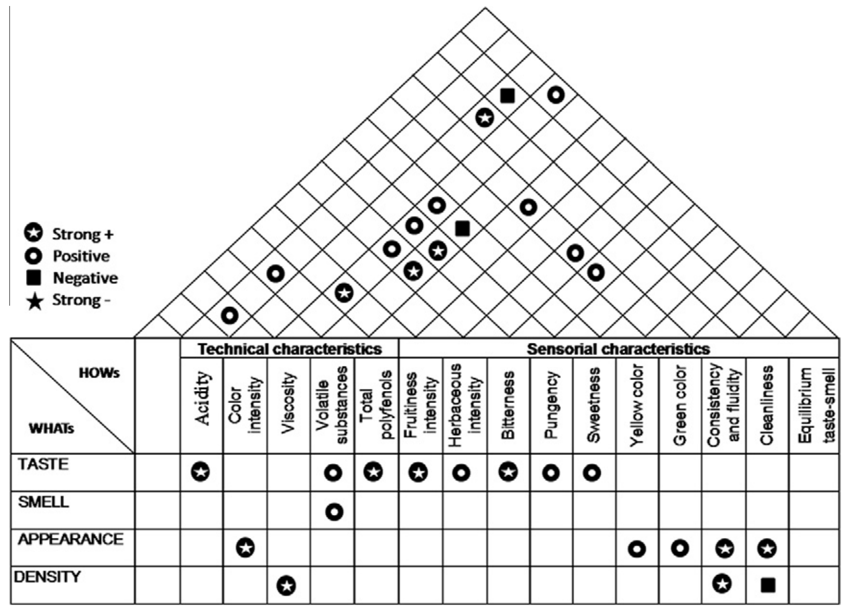

Fig. 3. Relationship and correlation matrix.

Table 4
Hows classification related to the technical and sensorial characteristics.

	HOWs	Scores	Ranking
Technical characteristics	Wl	0.3125	W4
	W2	0.3080	W1
	W3	0.2810	W2
	W4	0.3442	W5
	W5	0.3037	W3
Sensorial characteristics	W6	0.364	W7
	W7	0.4077	W9
	W8	0.2922	W15
	W9	0.3815	W6
	W10	0.253	W12
	W11	0.259	W8
	W12	0.3022	W14
	W13	0.2377	W11
	W14	0.26075	W10
	W15	0.3815	W13

the classification has been made by using the Facchinetti et al. (1998) formula that produces a score identified by the value:

$$\frac{FN_{\alpha} + 2 \cdot FN_{\beta} + FN_{\gamma}}{4}$$

The final scores and the consequent classification are presented in Table 7.

5. Discussion

The results presented in the previous section demonstrated the feasibility of the method; however, underlined also the necessity of a broader analysis to include, in a more standardized way, the sensorial evaluation of the EVOOs.

In the first phase of the work it was established that the weight of each defined attribute; than the method was applied on a selection of seven typologies of oil from different Italian regions with different organoleptic characteristics. The results of both phases were combined in order to obtain a final ranking that expresses to which extent the different types of oils are able to satisfy the specified prerogatives demonstrating, for the first time, an innovative method for analyzing the consumers perceptions; the results obtained showed indeed the feasibility of the fuzzy logic combined with a quality assessment technique for obtaining a valid indication of how some selected features can influence the acceptance of customers toward a certain product. The main innovation of the method consists in its multidisciplinary approach that relies in the competences of experts in different fields that have worked together for developing a feasible, reliable and repeatable assessment technique.

Quality and fuzzy logic experts have been responsible for the development and implementation of the fuzzy-QFD analysis; researchers and marketing experts, together with consumers, have been involved in the definition of the customers need (WHATs) and their relative importance (customers attributes); professional tasters lead the panels for evaluating the main technical and sensorial features that characterize the EVOO quality (HOWs). Olive oil producers provided the samples and helped in the execution of the tests. The results obtained were processed and analyzed by a team composed of one representative for each category.

It was demonstrated the possibility to use mathematical tools, such as fuzzy logic, for evaluating food products but it was also underlined the necessity of involving different competencies in order to transform an experimental research into a reliable and easy to use tool. A future task for standardizing the method will be the production of a series of guidelines with the contribution of all the professionals involved in the study.

6. Conclusions

The main aim of this study was not to provide a classification of the analyzed oils but to propose and test an innovative evaluation model based on a combination of fuzzy logic and quality function deployment technique capable of identifying the specific organoleptic characteristics that influence the acceptance or the refusal of the final customers. This combined technique has been widely used in many fields but never for the quality assessment of olive oil.

There are many brands of EVOO in the market each one with specific features that depend either on the cultivar or the working process used to obtain the oil and that determines the difference of an oil from another. The method was tested on 7 different brands of quality EVOO, on different cultivars and allowed a classification

Table 5
Averaged sensorial characteristics of the EVOOs alternative.

	Fruitiness intensity	Herbaceous intensity	Bitterness	Pungency	Sweetness	Yellow color	Green color	Fluidity	Equilibrium
Alt.1	VH	M	M	H	M	L	H	M	M
Alt.2	H	M	M	M	VL	VL	VH	VH	H
Alt.3	L	M	M	M	H	VH	VL	M	M
Alt.4	VH	M	M	M	VL	M	H	M	L
Alt.5	H	VL	L	L	H	H	M	L	M
Alt.6	L	VH	L	L	H	M	H	H	M
Alt.7	L	M	L	L	H	M	H	VH	M

Table 6
FSI index for the different alternative.

	FSI		
	α	β	γ
Alt.l	0.0376	0.179	0.472
Alt.2	0.0383	0.167	0.445
Alt.3	0.0254	0.1448	0.418
Alt.4	0.0278	0.155	0.427
Alt.5	0.0222	0.127	0.393
Alt.6	0.031	0.166	0.445
Alt.7	0.02345	0.1500	0.424

Table 7
Classification of the different oil alternatives.

Alternative	Score	Ranking
Alt.1	0.2169	Alt.1
Alt.2	0.2043	Alt.2
Alt.3	0.1832	Alt.6
Alt.4	0.1912	Alt.4
Alt.5	0.1673	Alt.7
Alt.6	0.202	Alt.3
Alt.7	0.1868	Alt.5

based on the product features that have the main impact on the consumer satisfaction.

It has been demonstrated that the proposed technique can be used not only for the development of new products but also for testing the quality of existing ones, and it is important to outline that in the few applications of the QFD in the food sector, only integer linear programming techniques have been used; since they are based on mathematical data, there are significant limitations in representing the qualitative factors that are used to assess preferences in the food field. In this work , for the first time, the combined application of the fuzzy logic with QFD approach in the food sector has been proposed. A Fuzzy Suitability Index has been calculated for each type of analyzed oil and the Facchinetti formula has been used to compare and classify them. The focus of this first step of the research was to demonstrate the suitability of the evaluation procedure for the food sector in general and for the EVOO in particular. In order to standardize the method, more tests on a wider variety of samples will be carried out, it will be also necessary to deal with the selection of the EVOOs (type and number of samples for each oil).

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