Fuzzy Linguistic Olive Oil Sensory Evaluation Model based on Unbalanced Linguistic Scales

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Fuzzy Linguistic Sensory Evaluation Model for Olive Oil with Unbalanced Linguistic Scale

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Sensory evaluation is a process that involves knowledge acquired via human senses. Generally, sensory evaluation processes are defined in unbalanced contexts because these are focused on one side of the scale used to collect sensory information. The olive oil sensory evaluation is defined in this kind of context to establish the quality of the olive oil, being the quality a key factor in its marketing. The international olive council established three quality categories and a quantitative method based on statistical analysis to classify a sample of olive oil. The perceptions in sensory evaluation processes involves imprecision and uncertainty that has a non-probabilistic nature. Therefore for modeling and management, the use of the fuzzy linguistic approach has provided successful results. This paper provides the results obtained in the validation of a fuzzy linguistic sensory evaluation model that uses an unbalanced linguistic scale in order to classify olive oil, such a validation process has involved taster panels to validate the scale to measure the intensity of the sensory features and the classify olive oil, using an unbalanced linguistic scale. Finally, a software prototype that is developed to carry out the classification of olive oil samples with the fuzzy linguistic sensory evaluation model is also presented.

Key words: Sensory Evaluation, Fuzzy Linguistic Approach, Unbalanced Linguistic Scale, Olive Oil

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1 INTRODUCTION

The sensory evaluation is an evaluation discipline that is carried out to evoke, measure, analyze, and interpret reactions of the sensory features of products [8]. This evaluation discipline has an important impact on many industrial areas such as comestibles, cosmetic and textile by its broad use for determining the quality of end products, solving conflicts between customers and producers, developing new products, and exploiting new markets adapted to the consumer's preference [14, 23, 26].

The sensory information is perceived by the human senses of *sight, smell, taste, touch and hearing* and always implies uncertainty and imprecision. In whatever process of sensory evaluation is necessary to establish a panel with a number of trained or untrained individuals which provides the sensory information of products in a scale [13].

In sensory evaluation is very common to find process whose sensory features need to be assessed with greater distinction on one side of the scale than on the other side [17]. For example, when a company carries out a consumer test to study the satisfaction of its product, the company is focused on obtaining the degree of satisfaction consumer: *completely satisfied*, *very satisfied*, *slightly satisfied*. However, if customers are dissatisfied, generally, the company is not interested in knowing at what level. This kind of sensory evaluation process is defined in an unbalanced context [9][18].

In this paper, we are focused on the sensory evaluation process of olive oil defined in an unbalanced context. The quality of a sample of olive oil is established by its sensory profile in which each sensory attribute (positive or negative) is measured by a trained tasters panel. So, a olive oil sample is classified into one of three quality categories defined:

- *Extra virgin* is the category with the highest quality, olive oils under this label are free of defects and fruity flavor (positive attribute) is perceived in these.

- *Virgin* is the category in which olive oils have slightly negative sensory features or have not fruity flavor. These olive oils are suitable for consumption.

- *Lampant*, olive oils under this label present significant sensory negative features, being unpalatable.

The sensory evaluation process of olive oil is a key factor in its marketing because *an excellent quality implies a higher price in the market* [1, 7]. The

International Olive Council (IOC)* fixes the official procedure to assess the sensory features of olive oil and the methodology for its classification. To do so, sensory information is collected accurately by a taster panel and treated statistically [5].

During many years, the statistical procedure was used to model and manage sensory evaluation processes [20]. However, the sensory information implies uncertainty and imprecision that has a non-probabilistic nature [16]. Researches have shown that the fuzzy linguistic approach [30] and the fuzzy sets theory [29] are useful tools to model and manage consistently the uncertainty and vagueness presented in sensory evaluation processes of many products [2, 16, 21] like mango drink [12], tea [25], coffee [24] sausages [15] or Indian yogurt [22].

Therefore, the procedure fixed by the IOC to assess the sensory evaluation features and obtain the classification of olive oil is becoming to be a hot topic of discussion and debate because manages inconsistently the uncertainty and vagueness presented in the sensory evaluation process of olive oil. This fact involves some issues as a high level of training of tasters to provide accurate sensory information that implies a long-term training and, sometimes, frustrated tasters or wrong classifications.

In our previous research, we have proposed a fuzzy linguistic sensory evaluation model [17] to establish the quality category of a sample of olive oil through the definition of an unbalanced linguistic scale [9][18]. So, the proposed fuzzy linguistic sensory evaluation model [17] for olive oil uses the fuzzy linguistic approach [30] to model and manage consistently such an uncertainty and can provide a solution to the mentioned issues.

The aim of this paper is to validate with two taster panels the fuzzy linguistic sensory evaluation model applied to olive oil to assess sensory features and obtain the quality category. To do so, first it was validated an adequate unbalanced linguistic scale to assess the intensity with which tasters perceive sensory features (negatives and positives). It was then validated the classification obtained by the fuzzy linguistic sensory evaluation model with the unbalanced linguistic scale, carrying out a sensory evaluation case study for a set of samples of olive oil, belonging to different categories.

Furthermore, due to the fact that the fuzzy linguistic sensory evaluation model uses the computational model for unbalanced linguistic terms set in order to classify the olive oil, in this paper is presented a software prototype to carry out sensory evaluation processes of olive oil with the fuzzy linguistic

* http://www.internationaloliveoil.org/

sensory evaluation model, using an unbalanced linguistic scale [17] in an automatic way.

The paper is organized as follows. Section 2 reviews the methodology for the sensory evaluation of olive oil established by International Olive Council. Section 3 introduces in short the fuzzy linguistic sensory evaluation model that will be used in the following sections. Section 4 presents the validation process of the fuzzy linguistic sensory evaluation model applied to olive oil. Section 5 presents the software prototype that is developed to support the fuzzy linguistic sensory evaluation model. Finally, in Section 6, conclusions are drawn.

2 ASSESS SENSORY FEATURES AND CLASSIFY OLIVE OIL. METHODOLOGY IOC

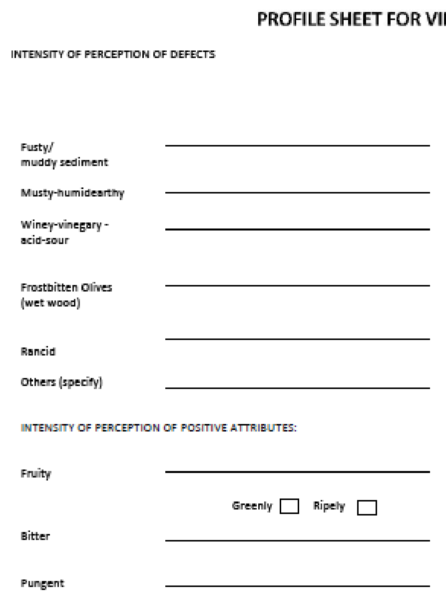
The sensory evaluation methodology of olive oil is regulated by the International Olive Council (IOC) with several guidelines and instructions concerning the tasting of olive oil [5]. In order to understand our proposal, here it is reviewed some concepts about this methodology.

Three different quality levels are distinguished for the olive oil from a sensory point of view: *virgin extra*, *virgin* and *lampant*. The methodology establishes the category of a sample of olive oil, according to the intensity of its defects perceived (negative features) and its fruitiness (positive feature) by an official tasting panel, i.e., a group of tasters selected, trained and monitored by a leader.

Each taster on the panel smell and then taste the olive oil under consideration. Following, they provide the intensity which they perceive each feature (negatives and positives) on a 10-cm scale shown in the profile sheet provided (see Figure 1).

The panel leader collects the profile sheets completed by each taster and reviews the intensities assigned to the different sensory attributes. The olive oil is categorized, taking into account the median for the fruity attribute and the median of the defects, being this the median of the defect perceived with the greatest intensity. It is noteworthy that the median of the defects and the median of the fruity attribute are expressed by a real number and the value of the robust coefficient of variation must not be greater than 20%.

The category of olive oil is established, comparing the median value of the defects and the median for the fruity attribute with the reference ranges. The range references are shown in Figure 1.


PROFILE SHEET FOR VIRGIN OLIVE OIL

INTENSITY OF PERCEPTION OF DEFECTS

Fusty/
muddy sediment

Musty-humidearthy

Winey-vinegary -
acid-sour

Frostbitten Olives
(wet wood)

Rancid

Others (specify)

INTENSITY OF PERCEPTION OF POSITIVE ATTRIBUTES:

Fruity

Greenly ☐ Ripely ☐

Bitter

Pungent

	Median Defects (Med-n)	Median Fruity (Med-f)
Extra Virgin	Med-n=0	Med-f> 0
Virgin	Med-n=0	Med-f=0
Virgin	0<Med-n≤3.5	
Lampant	3.5<Med-n	

FIGURE 1
IOC profile sheet and reference ranges

A detailed description about the procedure, the number of tasters as well as the basic vocabulary, test glasses and test booth can be found in [3, 4, 6].

3 LINGUISTIC BACKGROUND

Due to the use of linguistic information and processes of computing with words [19] in the fuzzy linguistic sensory evaluation model for olive oil that will be review in the following section, here we introduce some basic concepts used in this model.

Fuzzy Linguistic Approach

As it was pointed out, sensory information implies uncertainty, vagueness and imprecision and the use of the Fuzzy Linguistic Approach [30] has provided successful results modelling this type of information. The fuzzy linguistic approach represents such a information as linguistic values by means of linguistic variables and the semantics of the terms are given by fuzzy numbers defined in the [0,1] interval, which are usually described by membership functions. [30].

2-tuple Linguistic Representation Model
The use of linguistic information implies to operate with such a type of information, i.e., processes of Computing with Words (CW). In [10] was presented a linguistic representation model based on linguistic 2-tuples that carries out processes of CW in a precise way when the linguistic term sets are symmetrical and uniformly distributed. This representation model was extended in [9] in order to accomplish such processes, dealing with unbalanced linguistic scales similar to the used in our proposal.

The linguistic 2-tuple representation model is based on the concept of *symbolic translation* [10] and represents the linguistic information through a 2-tuple (s, α), where $s \in S = \{s_0, \ldots, s_g\}$ is a linguistic term and α is a numerical value representation of the symbolic translation [10]. Thereby, being $\beta \in [0, g]$ the value generated by a symbolic aggregation operation, we can assign a 2-tuple (s, α) that expresses the equivalent information of that given by β.

Definition 1 [10]. Let $S = \{s_0, \ldots, s_g\}$ be a set of linguistic terms. The *2-tuple set associated with* S is defined as $\langle S \rangle = S \times [-0.5, 0.5)$. We define the function $\Delta_S : [0, g] \longrightarrow \langle S \rangle$ given by,

$$\Delta_S(\beta) = (s_i, \alpha), \;\text{ with } \begin{cases} i = \text{ round } (\beta), \\ \alpha = \beta - i, \end{cases} \tag{1}$$

where *round* assigns to β the integer number $i \in \{0, 1, \ldots, g\}$ closest to β.

We note that Δ_S is bijective [10] and $\Delta_S^{-1} : \langle S \rangle \longrightarrow [0, g]$ is defined by $\Delta_S^{-1}(s_i, \alpha) = i + \alpha$. In this way, the 2-tuples of $\langle S \rangle$ will be identified with the numerical values in the interval $[0, g]$.
Remark 1: From definition 1, it is obvious that the conversion of a linguistic term into a linguistic 2-tuple consist of adding a value 0 as symbolic translation: $s_i \in \langle S \rangle \Longrightarrow (s_i, 0)$.

The linguistic 2-tuple representation model has a linguistic computing model associated that accomplishes CW processes in a precise way. Different aggregation operators have been proposed for linguistic 2-tuple [10][27],[28]. In our proposal, we will use the median aggregation operator for linguistic 2-tuple since the IOC computes collective sensory intensities based on the calculation of their medians [17].

Definition 2 [17]. Let $((s_1, \alpha), \ldots, (s_n, \alpha)) \in \langle S \rangle^n$ be a vector of linguistic 2-tuples. The *2-tuple Median operator* is the function $Med : \langle S \rangle^n \longrightarrow \langle S \rangle$ defined by:

if n is odd $\quad Med\big((s_1,\alpha),...,(s_n,\alpha)\big) = (s_i,\alpha)$
if n is even $\quad Med\big((s_1,\alpha),...,(s_n,\alpha)\big) = \Delta_S(\frac{\Delta_S^{-1}(s_i,\alpha)+\Delta_S^{-1}(s_{i+1},\alpha)}{2}$
where (s_i,α) is the $round(\frac{n+1}{2})$-th largest element of $\langle S\rangle^n$.

Hierarchical Linguistic

In this contribution, the hierarchical linguistic structure is used to manage unbalanced linguistic scale.

A *linguistic hierarchy* [11] is a set of levels, where each level is a linguistic term set with different granularity from the remaining of levels of the hierarchy. Each level belonging to a linguistic hierarchy is denoted as $\mathbf{l}(\mathbf{t},\mathbf{n}(\mathbf{t}))$, being it t, indicates the level of the hierarchy and *n(t)* the granularity of the linguistic term set of the level *t*. The levels belonging to a linguistic hierarchy are ordered according to their granularity, i.e., for any two consecutive levels t and $t+1$, $n(t+1) > n(t)$. This provides a linguistic refinement of the previous level.

From the above concepts, a linguistic hierarchy is defined LH, as the union of all levels t: $LH = \bigcup_t l(t,n(t))$. Given a LH, $S^{n(t)}$ denotes the linguistic term set of LH corresponding to the level t of LH with a granularity of uncertainty of $n(t)$: $S^{n(t)} = \{s_0^{n(t)},...,s_{n(t)-1}^{n(t)}\}$

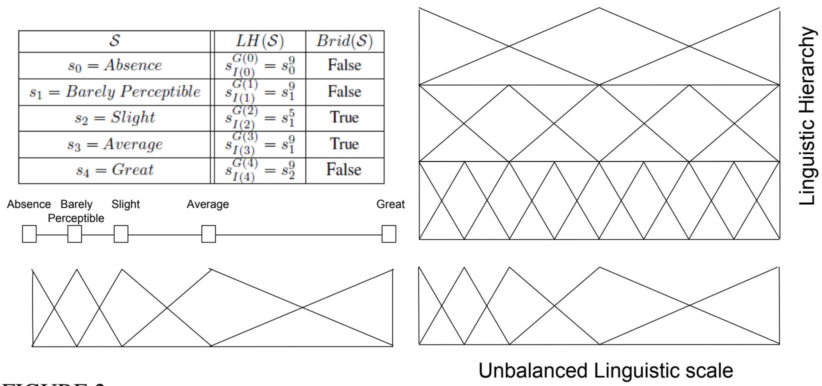
In [11] was defined a transformation function between labels from different levels to carry out processes of CW in multi-granular linguistic information contexts without loss of information, it has been defined as $TF_{t'}^t$: $l(t,n(t)) \longrightarrow l(t',n(t'))$:

Unbalanced Linguistic Information

In [9] was developed a methodology to obtain a semantic representation algorithm for unbalanced linguistic term sets. This methodology acts in two different aims.

First, it defines an algorithm to build the semantics for an unbalanced linguistic term sets using Linguistic Hierarchies, a further and detailed description can be found in [9]. The algorithm returns a *Hierarchical semantic representation,* $LH(S)$ for an unbalanced linguistic term set $\mathcal{S} = \{s_i,\ i=0,...,g\}$ and obtains its representation in the Linguistic Hierarchy, LH.

The semantic obtained $LH(\mathcal{S}) = \{\int_{\mathcal{I}(\rangle)}^{\mathcal{G}(\rangle)},\ \rangle = \prime,...,\}\}$, it is such that $\forall s_i \in \mathcal{S}\ \exists l(t,n(t)) \in LH$ that contains a label $s_k^{n(t)} \in S^{n(t)}$, in such a way that $I(i) = k$ and $G(i) = n(t)$, being I and G functions that assign to each label $s_i \in \mathcal{S}$ the index of the label that represents it in the linguistic hierarchy and the granularity of label set of linguistic hierarchy in which it is represented, respectively.



$\mathcal{S}$	$LH(\mathcal{S})$	$Brid(\mathcal{S})$
$s_0 = Absence$	$s_{I(0)}^{G(0)} = s_0^9$	False
$s_1 = Barely\ Perceptible$	$s_{I(1)}^{G(1)} = s_1^9$	False
$s_2 = Slight$	$s_{I(2)}^{G(2)} = s_1^5$	True
$s_3 = Average$	$s_{I(3)}^{G(3)} = s_1^9$	True
$s_4 = Great$	$s_{I(4)}^{G(4)} = s_2^9$	False

FIGURE 2
Unbalanced linguistic scale

Second, the methodology defines a computational model for unbalanced linguistic term sets based on the 2-tuple computational model. To accomplish the processes of CW without loss of information dealing with LH and linguistic 2-tuples. The algorithm proposed in [9] builds a structure as the table illustrated in Figure 2 with information that supports the computations with unbalanced labels. This table reports which label of the LH represents a label $s_i \in S$ and additionally uses a boolean function noted as $Brid$ to indicate when a label is represented by means of two different labels in the LH.

To accomplish the CW processes were introduced two unbalanced linguistic transformation functions that converts an unbalanced linguistic term $s_i \in \mathcal{S}$ into a linguistic term in the LH $s_k^{n(t)} \in LH = \bigcup_t l(t, n(t))$ and vice versa such a way the 2-tuple computational model can be used.

1. $\mathfrak{LH}$: It is a transformation function that associates with each unbalanced linguistic 2-tuple (s_i, α), $s_i \in S$, its respective linguistic 2-tuple in LH $(s_k^{n(t)}, \alpha)$, $s_k^{n(t)} \in LH$, it is defined as $\mathfrak{LH} : (S \times [0.5, -0.5)) \to (LH \times [0.5, -0.5))$, such that, $\forall (s_i, \alpha_i) \in (S \times [0.5, -0.5)) \implies \mathfrak{LH}(s_i, \alpha_i) = (s_{I(i)}^{G(i)}, \alpha_i)$.

2. $\mathfrak{LH}^{-1}$: Transformation function that associates with each linguistic 2-tuple expressed in LH its respective unbalanced linguistic 2-tuple in S, it is defined as $\mathfrak{LH}^{-1} : (LH \times [0.5, -0.5)) \to (S \times [0.5, -0.5))$, being t a level of LH, then it was defined by cases see [9].

4 FUZZY LINGUISTIC SENSORY EVALUATION MODEL

The aim of this paper is to validate the fuzzy linguistic sensory evaluation model based on fuzzy linguistic approach with an adequate unbalanced linguistic scale [17] to carry out the classification of olive oil, taking into account the nature of the uncertainty in sensory evaluation processes. In this section, we point out general features of this model and describe its phases.

The fuzzy linguistic sensory evaluation model manages the uncertainty involve in the tasters' perceptions, using the fuzzy linguistic approach. It is noteworthy that the linguistic aggregation operator to compute the collective intensity for each sensory attribute as well as the reference ranges of intensities to classify the samples of olive oil are equivalent to the quantitative methodology proposed by IOC.

The fuzzy linguistic sensory evaluation model with an unbalanced linguistic terms set consists of the following phases [17] that are illustrated in the Figure 3:

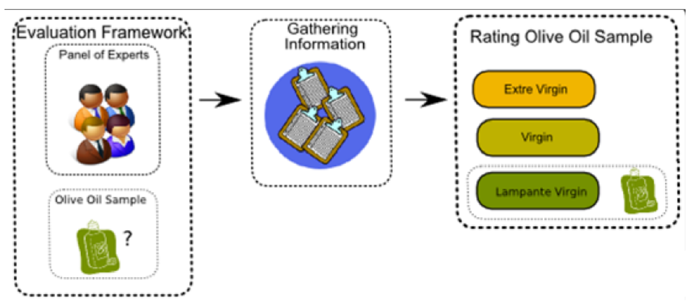


FIGURE 3
Fuzzy Linguistic Sensory Evaluation Model

The linguistic sensory evaluation model with an unbalanced linguistic terms set consists of the following phases that are illustrated in the Figure 3 [17]:

1. *Evaluation Framework*: It defines the structure of the sensory evaluation process: the set of tasters, the set of samples of olive oil that will be evaluated and, finally, the unbalanced linguistic scale in which tasters' perceptions will be expressed.

   In order to define this scale, it is necessary to set its number of terms, its syntaxis and its distribution. The semantic of each term is calculated with the algorithm proposed in [9] to build the semantics for an unbalanced linguistic terms set, using a Linguistic Hierarchy (LH) [11] and the linguistic 2-tuples representation model [10] (a detailed description about the algorithm can be found in [9]). So, the algorithm provides a *Hierarchical semantic representation,* $LH(S)$ for an unbalanced linguistic terms set $\mathcal{S} = \{s_i,\ i = 0, ..., g\}$ and obtains its representation in a LH. Finally, in the evaluation framework, it is necessary to transform the reference ranges to classify the sample of olive oil into linguistic 2-tuples in the unbalanced linguistic scale.

2. *Gathering Sensory Information*: Once the framework has been defined to evaluate the set of samples of olive oil, the sensory information must be provided by the taster panel. In a profile sheet with the unbalanced linguistic scale fixed in the evaluation framework, each taster provides the intensity perceived about each sensory characteristic.

3. *Rating Samples*: This phase computes a collective intensity for each sensory attribute in order to classify each sample of olive oil, according to the perceived intensities. Therefore, it is necessary to accomplish CW processes for unbalanced linguistic terms set presented in [9],[18]. To do so, first, it is computed a collective value for each sensory feature, using the *2-tuple Median operator* (see Definition 2). Second, each sample of olive oil is classified among one of three quality categories established: *virgin extra*, *virgin* and *lampant*, taking into account the reference ranges [17] as well as the collective intensity of the fruity attribute and the collective intensity of the defect perceived with the greatest intensity (negative attributes).

5 PROCESS OF VALIDATION

Here, it is presented the validation of the fuzzy linguistic sensory evaluation model based on fuzzy linguistic approach with an adequate unbalanced linguistic scale to carry out the classification of olive oil.

The validation process is conducted in two phases. The aim of the first phase is to analyze and validate a suitable unbalanced linguistic scale that will be used by tasters to assess the sensory features of olive oil. The objective of the second phase is to validate the classification obtained with the fuzzy linguistic sensory evaluation model, carrying out a sensory evaluation case study.

In the validation process are involved two accredited taster panels. The first panel was accredited in 2008 and the second panel in 2010. So, in this process are implied two panel leaders and 18 tasters (7 women and 11 men between 22 and 65 years old) that was selected, trained and monitored by the panel leader in accordance with their skills in distinguishing among similar samples.

The following sections show in detail each phase of the validation process.

5.1 Validation of the Unbalanced Linguistic Scale

The aim of this phase is to obtain a suitable unbalanced linguistic scale to measure tasters' perceptions, using linguistic terms.

The scale initially proposed to use in the fuzzy linguistic evaluation sensory by taster panels was illustrated in Figure 2. During several meetings, taster panels was analyzing it and proposed a better alternative. They agreed that 7 is an adequate number of labels to measure tasters' perceptions in order to classify doubtful samples between two categories. Another important point was the distribution of the scale. Clearly, the left side of the scale marks the difference between an olive oil classified as *virgin extra*, *virgin* and *lampant* because this side measures the absence of a sensory attribute as well as significant and soft intensities. The another side, right side, measures strong intensities. Therefore, it is necessary a higher distinction on the left side of the scale than on the right side. So, the taster panels agreed the following distribution of the scale: a central linguistic term, four terms on the left side and two terms on the right side. The syntaxis provided by taster panel for the scale was the following: $\mathcal{S} = \{$*Absence, Almost Negligible, Very Soft, Soft, Average, Large and Extreme*$\}$.

Once tasters have validated the unbalanced linguistic scale, it is necessary to compute the semantic of each linguistic term. Therefore, it was used the algorithm to build the semantics for an unbalanced linguistic terms set, using a Linguistic Hierarchy (LH) [9]. The *Hierarchical semantic representation,* $LH(S)$ for the unbalanced linguistic terms set $\mathcal{S}$ is illustrated in the figure 7.

5.2 Validation of the Classification provided by the Fuzzy Linguistic Sensory Model

Here, the aim is to validate the classification provided by the fuzzy linguistic sensory evaluation model to samples of olive oil, using the unbalanced linguistic scale validated previously.

Therefore, a sensory evaluation case study for a set of samples of olive oil, belonging to different categories was carried out. Here, it is necessary to define a set of sensory profiles, select a set of samples, according to defined sensory profiles and verify the classification obtained for the samples,

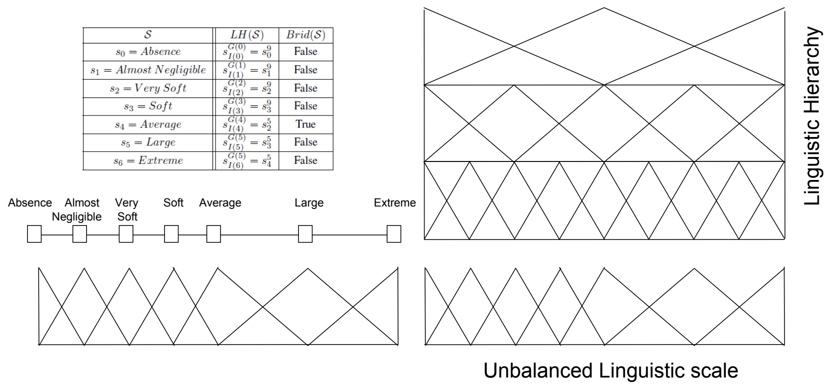


FIGURE 4
Hierarchical semantic representation of the Unbalanced Linguistic Scale

using the IOC methodology. Finally, olive oil samples are classified by the fuzzy linguistic sensory evaluation model in order to compare classifications obtained. Figure 5 illustrates the validation process scheme and the following sections show the performance of these phases in our sensory evaluation case study.

Definition, selection and classification of olive oil samples

In order to show the validity of the fuzzy linguistic sensory evaluation model, it is necessary to start from a set of olive oil samples which have previously been classified. In this section is presented the definition, selection and classification carried out in our sensory evaluation case study.

The definition of the set of samples of olive oil was established with different sensory profiles that includes samples clearly classified as one category and samples doubtful between two categories. So, seven sensory profiles are defined and three olive oil samples are searched for each sensory profile.

The set of 21 samples of olive oil according to the set of defined sensory profiles were searched and were selected during the 2012 olive campaign in the province of Jaén (Spain) by two panel leaders. Figure 5 shows the sensory profiles defined in this sensory evaluation case study.

It is noteworthy that a key factor is to verify the correct selection of samples by panel leaders, according to the defined sensory profiles. Hence, each sample is classified using the IOC methodology by two accredited taster panels in order to detect misclassifications and to avoid its negative impact in the validation process of the fuzzy linguistic sensory evaluation model with the

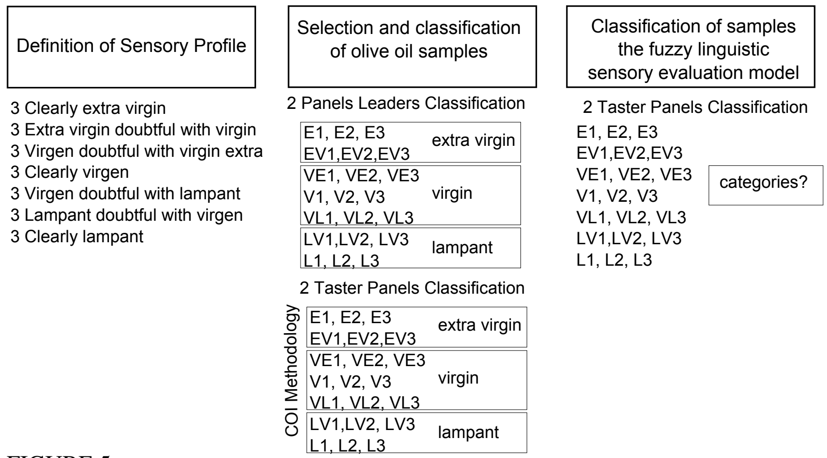


FIGURE 5
Scheme of the validation process of Sensory Evaluation Model

unbalanced linguistic scale.

During five sessions, two taster panels evaluated the set of the 21 samples of olive oil. For the set of samples, the classification obtained by the IOC methodology, reviewed in the section 2, and the classification provided by two panel leaders was the same. Therefore, the selected set of olive oil samples was correctly classified.

Classification of samples by the fuzzy linguistic sensory evaluation model

Once we obtained a reference classification of each olive oil sample of the set, taking into account taster panels and panel leaders, the fuzzy linguistic sensory evaluation model was used to obtain the classification of the set of olive oil samples under study.

The set of olive oil sample was classified with the fuzzy linguistic sensory evaluation model reviewed in the section 4, using the unbalanced linguistic scale validated in the first step of the validation process, presented in section 5.1.

First of all, the profile sheet to collect the sensory information by taster panels was defined, using the suitable unbalanced linguistic scale. Furthermore, it was necessary to transform the reference ranges proposed by IOC methodology into linguistic 2-tuple on the unbalanced linguistic scale to classify samples of olive oil. The profile sheet and reference ranges based on the unbalanced linguistic scale are shown in Figure 6.

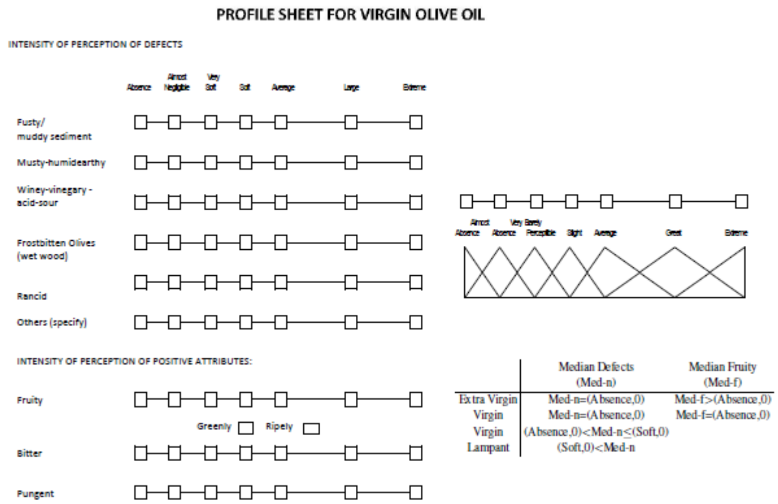


FIGURE 6
Proposed profile sheet and reference ranges

During one month, two taster panels were trained in the fuzzy linguistic sensory evaluation model, using the validated unbalanced linguistic scale. Once the panel was trained, the sensory evaluation case study took place during seven weeks and was carried out following the test conditions and standards fixed by the methodology proposed by IOC [3, 4, 6], the set of 21 olive oil samples were classified conducting the fuzzy linguistic sensory evaluation model, using the unbalanced linguistic scale.

In order to clarify the classification provided by the fuzzy linguistic sensory evaluation model, using the unbalanced linguistic scale, an example of classification of the olive oil sample "*VE1*" is shown.

A panel with eight tasters measured the intensity with which they perceive negative and positive features of the olive oil sample "*VE1*". These intensities, sensory information, were provided by filling the profile sheet (see Figure 6). Table 1 shows the sensory information provided by the taster panel. Following, it is computed the collective intensity for each sensory attribute.

Here, it is illustrated the obtained collective intensity for the *Fusty* attribute. First, the sensory information provided by the tasters is transformed into linguistic 2-tuples, using the *Remark 1*. Then, these linguistic 2-tuples are transformed into the corresponding level of the LH by means of $\mathfrak{LH}$.

TABLE 1
Sensory information about the sample of olive oil: "*VE1*"

Taster	Fusty	Musty	Winey	Frostbitten	Rancid	Others	Fruity	Bitter	Pungent
A	Absen.	Absen.	Absen.	Absen.	Absen.	Absen.	Alm. Neg.	Alm. Neg.	Alm. Neg.
B	Absen.	Absen.	Absen.	Absen.	Absen.	Absen.	V. Soft	Soft	Average
C	Absen.	Absen.	Absen.	Absen.	Absen.	Absen.	V. Soft	Alm. Neg.	Alm. Neg.
D	Absen.	Absen.	Absen.	Absen.	Absen.	Absen.	Soft	Soft	V. Soft
E	Alm. Neg.	Absen.	Absen.	Absen.	Absen.	Absen.	Soft	V. Soft	V. Soft
F	Alm. Neg.	Absen.	Absen.	Absen.	Absen.	Absen.	V. Soft	Soft	V. Soft
G	Alm. Neg..	Absen.	Absen.	Absen.	Absen.	Absen.	V. Soft	V. Soft	Soft
H	V. Soft	Absen.	Absen.	Absen.	Absen.	Absen.	V. Soft	Alm. Neg.	Alm. Neg.
Median	(Alm. Neg.,0)	(Absen.,0)	(Absen.,0)	(Absen.,0)	(Absen.,0)	(Absen.,0)	(V. Soft,0)	(V. Soft,0)	(V. Soft,0)

$$\mathfrak{LH}(Absence) = \mathfrak{LH}(s_0, 0) = (s_0^{n(3)}, 0) = (s_0^9, 0)$$
$$\mathfrak{LH}(Almost\ Negligible) = \mathfrak{LH}(s_1, 0) = (s_1^{n(3)}, 0) = (s_1^9, 0)$$
$$\mathfrak{LH}(VerySoft) = \mathfrak{LH}(s_2, 0) = (s_2^{n(3)}, 0) = (s_2^9, 0)$$

When these linguistic 2-tuples belong to different levels of the LH will be necessary to conduct these 2-tuples into an unique level of the LH by means of $TF_t^{t'}$. In our example, it is not necessary because linguistic 2-tuples belong to level $(3, 9)$ of the LH.

Second, the collective intensity for the *Fusty* attribute is computed, using the *2-tuple Median operator* (see Definition 2). Then, this collective value is conducted to the unbalanced linguistic scale by means of $\mathfrak{LH}^{-1}$.

$$Med\big((s_0^9, 0), (s_0^9, 0), (s_0^9, 0), (s_0^9, 0), (s_1^9, 0), (s_1^9, 0), (s_1^9, 0), (s_2^9, 0)\big) =$$
$$= \Delta_S\big(\tfrac{\Delta_S^{-1}(s_0^9,0)+\Delta_S^{-1}(s_1^9,0)}{2}\big) = \Delta_S(\tfrac{0+1}{2}) = \Delta_S(0.5) = (s_1^9, -0.5)$$

$$\mathfrak{LH}^{-1}(s_1^9, -0.5) = (s_1, -0.5) = (Almost\ Negligible, -0.5)$$

Finally, the olive oil sample "*VE1*" is classified as ***virgin***, taking into account the reference ranges shown in Figure 6 as well as the median for the fruity attribute, *(Very Soft,0)*, and the median of the defect perceived with the greatest intensity which corresponds to *Fusty* sensory feature, *(Almost Negligible,-0.5)*.

For each olive oil sample of the set, the category provided by the fuzzy linguistic sensory evaluation model, using the validated unbalanced linguistic scale, matched with the category computed by IOC methodology and the expert opinion provided by two panel leaders. Therefore, in view of the results, we can conclude that the use of the fuzzy linguistic sensory evaluation model is a valid model as the IOC methodology to classify olive oil

5.3 Analysis and Discussion

In this section, we analyze the results of the conducted sensory evaluation case study in order to validate the fuzzy linguistic sensory evaluation model with the unbalanced linguistic scale.

The proposed unbalanced linguistic scale models and manages consistently the uncertainty and vagueness presented in sensory evaluation process. Furthermore, the fuzzy linguistic sensory evaluation model offers more flexibility to express perceptions since it does not require a high level of precision, providing the same classification that the IOC methodology and the expert opinion of two panel leaders. This fact implies two consequences.

- The first consequence is that a more flexibility (lower level of accuracy) is not opposed with an misclassification of olive oil samples.
- The second consequence is that the unbalanced linguistic scale is appropriate to discriminate between categories, providing more flexibility.

Therefore, the fuzzy linguistic sensory evaluation model implies a midterm training of the taster panel.

Finally, it is noteworthy that linguistic results of the sensory evaluation process of olive oil, i.e., median for the fruity attribute and the median of the defect perceived with the greatest intensity, are easily interpretable and understandable by consumers. Therefore, in order to clarify to consumers what kind of olive oil they are buying, it might be advisable to include close to the category of the olive oil, its linguistic results.

6 SOFTWARE PROTOTYPE

To accomplish the validation process, we have used a software prototype to carry out the sensory evaluation case study, using the fuzzy linguistic sensory evaluation model with an unbalanced linguistic scale.

The functionality of the software prototype is based on the phases of the fuzzy linguistic sensory evaluation model, reviewed in the section 3. The phases of the fuzzy linguistic sensory evaluation model are carried out by an user with *panel leader* role. The functionality of the software prototype is presented bellow, evaluating the sample of the olive oil: "*EV1*".

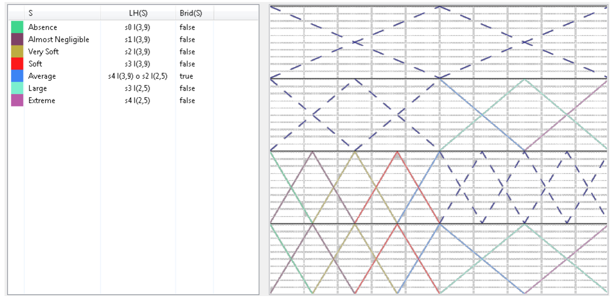


FIGURE 7
Hierarchical semantic representation of the Unbalanced Linguistic Scale

6.1 Evaluation Framework

In this phase, firstly, the unbalanced linguistic scale utilized to assess the intensity of sensory attributes is defined by introducing the number of the linguistic terms, 7, their distribution and their syntaxis. The software prototype executes the algorithm to build the semantic for an unbalanced linguistic terms set, using a LH. In the Figure 7 is illustrated the unbalanced linguistic scale in the LH.

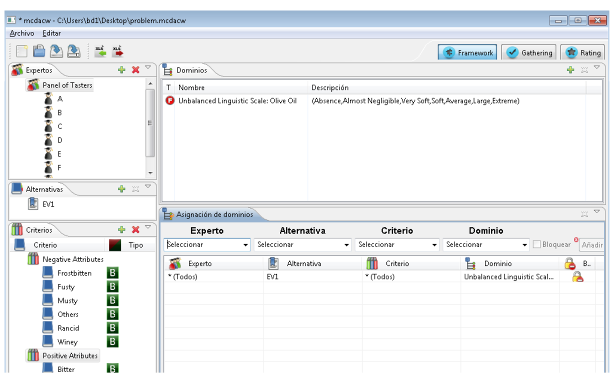


FIGURE 8
Evaluation framework

The elements involved in the sensory evaluation case study are included in the software prototype, i.e, the panel of eight tasters, positives and negatives attributes, and the sample of olive oil. Finally, the unbalanced linguistic scale is assigned as expression domain for the taster panel. The definition of the evaluation framework in the software prototype is shown in the Figure 8.

6.2 Gathering Sensory Information

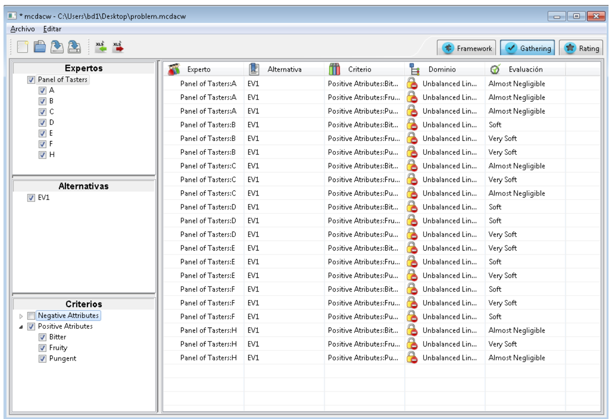


FIGURE 9
Gathering Information

In this phase, the sensory information about sensory attributes expressed in the unbalanced linguistic scale is included in the software prototype. Figure 9 shows the sensory information provided by the panel for the olive oil sample "*EV1*".

6.3 Rating Sample

The classification of the olive oil sample is carried out according to the median of the negative attributes perceived with the greatest intensity and the median of the fruity attribute. The software prototype accomplishes directly processes of CW without loss of information, dealing with the LH [11],[18] and linguistic 2-tuples [10]. The software prototype computes the median for the negative attribute and median for the fruity attribute. These results are shown in Figure 10.

The main advantage of this software prototype is the automation of complex processes as: building of the semantic for an unbalanced linguistic terms set using a LH and processes of computing with words.

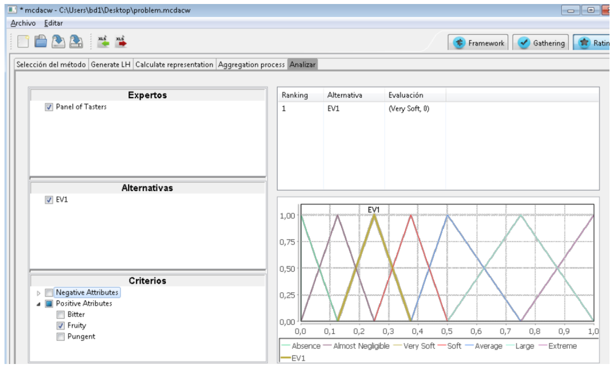


FIGURE 10
Rating Sample

7 CONCLUSIONS

Sensory evaluation process imply uncertainty and vagueness and, generally, are defined in unbalanced contexts. In our previous research, we proposed a fuzzy linguistic sensory evaluation model [17] based on the fuzzy linguistic approach in order to provide a suitable model to deal with such uncertainty in unbalanced sensory evaluation process. In this paper, we have focused on the sensory evaluation process of olive oil, which lies in unbalanced context, in order to obtain the quality category, using the fuzzy linguistic sensory evaluation model. In this paper, we have validated with a group of tasters an adequate unbalanced linguistic scale to assess sensory features of the olive oil as well as the classification obtained with the fuzzy linguistic sensory evaluation model, carried out a sensory evaluation case study. In this paper, we have demonstrated that the fuzzy linguistic sensory evaluation model applied to olive oil provides more flexibility to express the perceptions, offering the same classification that the official method, using the validated unbalanced linguistic scale. Finally, we have presented the software prototype that we have developed to conduct the sensory evaluation case study, following the fuzzy linguistic sensory evaluation model. This software prototype offers an useful tool to carry out such process in a an automatic, easy and fast way.

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