Sensory functionality of extra-virgin olive oil in vegetable foods assessed by Temporal Dominance of Sensations and Descriptive Analysis

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Current methods used to classify extra-virgin olive oils into sensory quality categories involve evaluation of oils on their own and thus do not take into account the actual conditions that consumers often experience them, that is, mixed with other foods. Descriptive Analysis (DA) and Temporal Dominance of Sensations (TDS) methods were used to assess the impact of two Italian extra-virgin olive oils with different sensory properties (oil A from Tuscany and oil B from Garda lake region) on the perceived sensory profiles of pureed beans and tomatoes. Both descriptive data and TDS curves showed that the addition of olive oils strongly influenced the sensory properties of tomato and bean samples by modifying the intensity and the dominance rate of their characteristic attributes (suppression of sowness and watery character of tomato and suppression of metallic flavour and creaminess in bean samples) and/or by contributing new sensations, peculiar for each oil (bitterness and grassy flavour for oil A and unripe fruit flavour for oil B). Modifications of the sensory properties of tomatoes induced by oils also affected consumers’ hedonic responses in terms of liking and perceived freshness. Furthermore, no relationships have been found between liking and freshness ratings for oil and those reported for the combination of oil with tomato or bean purees.

1. Introduction

The perceived sensory profile of a food depends on complex interactions between several different factors. Omitting those related to extrinsic food properties, such as expectation, context and individual physiological variation of perceptual abilities, and only considering the intrinsic factors related to its chemical composition, the network of interactions taking place in the context of food perception still remains extremely complex (Delwiche, 2003). When a single sensory modality, such as taste, is considered, at least three levels of interaction can be defined for a multiple stimuli mixture (Keast & Breslin, 2002). There are chemical interactions, leading to structural, compositional or physical modifications of molecules; oral physiological interactions, related to the potential for one compound to interfere with taste receptor cells or taste transduction mechanisms associated with another compound and there are cognitive interactions, related to the central processing of signals induced by different sapid compounds. Also, how these various interactions affect the perceived intensity of tastes does not follow a general rule. In fact, enhancement, suppression and asymmetrical intensity shifts can take place as a function of sapid compound concentrations and of their taste quality. Different sensory modalities can interact with each other thus resulting in synesthetic experiences, whereby the stimulation of one sensory modality gives rise to a perceptual experience in another sensory modality (Robertson & Sagiv, 2005). In the context of food perception, flavour represents one of the most well known examples of multisensory integration (Awray & Spence, 2008). The ability of odours to modify tastes depends on the sensory quality of the stimuli and on their relevant concentration/intensity. Mixing congruous odour and taste stimuli can induce enhancement while mixing incongruous stimuli can result in suppression of taste intensity (Caporale, Policastro, & Monteleone, 2004; Pfeiffer, Hort, Hollowood, & Taylor, 2006; Stevenson, Prescott, & Boakes, 1999). The modification of taste quality by odour seems to be a consequence of learning from previous instances of co-exposure such as might naturally occur during eating (Prescott, Johnstone, & Francis, 2004). Moreover, the intensity of flavour perception can be driven by the concentration/intensity of only one of the flavour components (Davidson, Linforth, Hollowood, & Taylor, 1999). As well as taste and smell, stimulation of the trigeminal and somatosensory systems by chemical irritation, temperature, texture and consistency of foods are able to influence the overall perception of flavour. For example, a decrease in both taste and flavour intensity ratings has been found when solution viscosity is increased.
without significant modification of the odorous volatile concentration released in the nose (Cook, Hollowood, Linforth, & Taylor, 2003; Hollowood, Linforth, & Taylor, 2000). Based on the multisensory interactions underlying flavour perception it has recently been proposed that the term flavour should be used to describe the combinations of smell, taste, touch and trigeminal system that influence human perception when tasting food (Awwari & Spence, 2008).

Finally, the adoption of either analytical (emphasizing the distinctiveness of the different sensory active compounds of a mix) or synthetic (encouraging the blurring of the perceptual boundaries between different sensory modality) experimental strategies has a significant effect on the extent of sensory interactions that are observed (Clark & Lawless, 1994; Prescott et al., 2004).

Another important aspect to consider is the dynamic nature of perception defined as a temporal series of events (Piggott, 2001). A two-step model has been proposed for flavour release and perception (Dijkstra & Piggott, 2001). The first step considers physical, chemical and physiological events taking place in the mouth during eating, including changes in food texture and temperature, the kinetics of stimulus diffusion towards receptors and of chemical reactions within food components and between sensory active molecules and receptor systems. The second step involves physiological and psychological processes including adaptation, sensitization, cognition and qual-quantitative judgment. The perception of sensory properties changes during consumption of a food product according to the sequence of events that develop from the first bite to swallowing.

From an applicative perspective of food production and development, the dynamic and multisensory aspects of food perception have important consequences for a better understanding of the processes used by consumers to assess acceptability and sensory properties of food products (Blake, 2004).

An awareness of the complexity of perception is crucial for the sensory characterization of food ingredients. Assessing the sensory functionality, defined as the ability to impact on the sensory profile and on the acceptability of the food matrix with which it is combined, should be an appropriate approach for evaluating the sensory performance of an ingredient.

In this study, extra-virgin olive oil was used as an added ingredient to certain foods. Olive oil represents a staple food in many countries of the Mediterranean area (Spain, Italy, Greece) and its market is rapidly growing in other Western countries. It is considered the most representative food in the traditional Mediterranean diet where it provides 85% of the fat content (Perez-Jmenez, Ruano, Perez-Martinez, Lopez-Segura, & Perez-Miranda, 2007). The popular acceptance of a Mediterranean diet has been related to its high fat content. The increased palatability of fat containing foods depends on the triacylglycerol fraction and its capacity to modify texture and carry many taste and aroma compounds (Mates, 2009). Furthermore, extra-virgin olive oil contains a variety of microcomponents that contribute odour, colour, taste and tactile sensations to food. The sensory profile of extra-virgin olive oil varies widely, depending on oil microcomponent composition which in turn is influenced by cultivars, pedoclimatic conditions, agricultural practices, olive ripening stage and extraction techniques (Servili et al., 2004). Olive oil is an extremely versatile ingredient with a wide range of uses (dressing for cold and hot dishes, recipe ingredient, cooking oil for roasting and frying). Flavour, taste and culinary use represent factors motivating olive oil purchase and consumption for both experienced and emergent market consumers (Caporale, Policastro, Carlucci, & Monteoleone, 2006; Delgado & Guinard, 2011; Krystalis & Ness, 2003). Despite numerous attempts (Caporale et al., 2006; Dekhil & d’Hautevue, 2009; Matsatsinis, Grigoroudis, & Samaras, 2007; Sandalidou & Baourakis, 2002; Stefani, Romano, Cavicchi, 2006) no method has yet provided a comprehensive model for evaluating the drivers of consumer’s liking of extra-virgin olive oil in relation to their perceived qualities.

Current methods used to classify extra-virgin olive oils into sensory quality categories involve evaluations of oils on their own and thus do not take into account the actual conditions that consumers often experience when consuming olive oil (i.e., mixed with other food). Categories based on the intensity of flavours in compliance with national regulations (Reg. CE N. 2568/1991, Reg. CE N. 796/2002) or defined by experts in award events, often do not relate to consumer hedonic responses. The relatively low expertise of consumers from emergent markets may account for this (Delgado & Guinard, 2011; Recchia, Monteoleone, & Tuorila, 2012). However, sensory expectations of extra-virgin olive oil’s contribution to the sensory profile of the food matrix to which it is added should also be taken into account. Information about conditions of use that allow an oil to express its best sensory potential would greatly help in optimizing both production and market positioning strategies for this ingredient.

An effective extra-virgin olive oil valorisation strategy based on culinary use should consider the expected effect of this ingredient on the whole sensory profile of a dish or in a recipe. The definition of olive oil styles based on the combined levels of bitterness and pungency and “harmonic” food pairing (intensely bitter and pungent oils suited for strong flavoured foods and those low in bitterness and pungency suited for delicately flavoured foods) have been suggested (Cerretani, Biasini, Bonoli-Carbognin, & Bendini, 2007). However, the wide spectrum of extra-virgin olive oil sensory profiles makes it possible to envisage the use of a classification that has several different aims, for example, adding complexity to a dish, enhancing/suppressing its flavour/taste and modifying its texture (Monteleone & Dinnella, 2011). The systematic collection of information relevant to the effects of adding oils with different sensory profiles to various food categories needs sensory methodologies capable of taking into account the complex network of phenomena underlying food perception. The multidimensionality of the perceptual space over time is well represented by the TDS method (Pineau et al., 2009). The product perception pattern is represented by curves reporting the frequency with which sensations reported in a list of several attributes, are considered as dominant by a trained panel during food consumption. This descriptive method allows the investigation of qualitative changes perceived during eating and explicitly considers sensory interactions taking place during food consumption (Labbe, Schlich, Pineau, Gilbert, & Martin, 2009; Lenfant, Loret, Pineau, Hartmann, & Martin, 2009; Meillon, Viala, Urbano, Guillot, & Schlich, 2010; Saint-Eve et al., 2011).

Descriptive Analysis (DA) and Temporal Dominance of Sensations (TDS) methods were used in the present work to assess the impact of two Italian extra-virgin olive oils with different sensory properties on the perceived profile of pureed beans and tomatoes. The relationships between these two data sets were analysed. The role of intensity and dominance rate of sensations in determining the consumer hedonic responses was also investigated.

2. Materials and methods

2.1. Samples

Two Italian extra-virgin olive oils produced in different regions were used. The first one (oil A) was from Tuscany (cultivar Frantoio 50%, Leccino 30%, Moraiole 20%) and the second one (oil B) from the area of Garda lake-Veneto (cultivar Grignano 100%).

Canned whole tomatoes (San Marzano) and canned whole beans (cannellini) were purchased at a local retailer. Immediately prior to the evaluation sessions, both canned products were homogenised in a mixer/blender until a puree was obtained.
All products were evaluated alone (without oil) and in combination with oil, by adding 3 g of oil to 30 g of tomato or bean puree i.e. 10% oil in the mixtures. Immediately prior to sample serving, combinations were mixed using a tea-spoon for around 15 s, until the oil was homogeneously dispersed as small drops in the puree. In total eight samples were considered: oil A, oil B, tomato, tomato with oil A, tomato with oil B, bean, bean with oil A and bean with oil B.

2.2. Trained panel

Thirteen subjects, seven males and six females, aged from 21 to 33 years were recruited from the students and staff of the University of Florence. The subjects had no history of disorders in oral perception. They were paid for their participation in the study. All subjects were very familiar with extra-virgin olive oil. Written informed consent was obtained from each subject after the description of the experiment.

The subjects developed a vocabulary describing differences between samples according to the Generic Descriptive Analysis method (Lawless & Heymann, 1998). Panellists participated in three training sessions of about 60 min each. A main list of attributes was developed (Table 1) which described the mouthfeel, taste and flavour of oils, tomato and bean samples, evaluated both with and without the two oils. In order to train the panellists to evaluate the descriptors, some standards were prepared as reported in Table 1. All standards were prepared to induce a moderate intensity, corresponding to the central point of the nine point scale. A nine point category scale labelled at the extremes with “extremely weak” and “extremely strong” was used for evaluation.

2.3. Temporal Dominance of Sensations

The most relevant attributes for describing the temporal evolution of sensations induced by each product were selected from the main lists by panellists. Three different lists consisting of five or nine attributes were used for TDS evaluation of oils or tomato and bean samples, respectively (Table 1).

The panel participated to five sessions. Two sessions were performed for training subjects with the use of the computer system for TDS data acquisition. Three evaluation sessions were performed, each sample was replicated four times. In the first session two sample sets were evaluated in duplicate: one consisting of the two oil samples and the other one of the three tomato samples (tomato without oil, tomato with oil A, tomato with oil B). Two sample sets were evaluated in duplicate in the second session: one consisting of the oil samples and the other one of bean samples (bean without oil, bean with oil A, bean with oil B). In the third session a set consisting of tomato samples and one consisting of bean samples were evaluated in duplicate. In each session the presentation order of sets was counterbalanced so that half subjects evaluated set 1 as first and set 2 as second whereas the other half did the opposite.

Oils (3 g) were presented in a test tube identified by a three digit code, subjects were instructed to pour the whole test tube content in a spoon for evaluation. Tomato and bean samples were presented in plastic cups identified by a three digit code. Subjects were instructed to thoroughly mix each sample immediately before taking a spoon for the evaluation. After 8 s, subjects were advised to swallow the sample. The total evaluation time was 90 s. The order of the subset presentation was randomized across subjects within and between subsets. The order of attributes was randomized between subjects and was always the same for a given panellist. After each sample, subjects rinsed their mouths with distilled water for 30 s, had some plain crackers for 30 s and finally rinsed their mouths with water for a further 30 s. Subjects took a 10 min break between subset evaluations. All evaluations were performed in individual booths under red lights.

Data were recorded using the FIZZ Software Version 2.40G (Biosystemes, Couteron, France) and automatically plotted as TDS curves (Dominance Rate – DR vs evaluation time).

### Table 1

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Definition</th>
<th>Standard</th>
<th>Products</th>
<th>Combinations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Oils</td>
<td>Pureed tomatoes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pureed beans</td>
<td>Pureed beans</td>
</tr>
<tr>
<td>Flavour</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bean</td>
<td>Odour of canned white beans</td>
<td></td>
<td>DA/TDS</td>
<td>–</td>
</tr>
<tr>
<td>Bitterness</td>
<td>Bitter taste</td>
<td>Quinine dichloride (0.025 g/l)</td>
<td>DA/TDS</td>
<td>–</td>
</tr>
<tr>
<td>Grassy</td>
<td>Odour of freshly mown grass</td>
<td>Cit-3-hexenol in seed oil (140 μl/l)</td>
<td>DA/TDS</td>
<td>TDS</td>
</tr>
<tr>
<td>Green olive</td>
<td>Odour of fresh green olive pulp</td>
<td>Fresh green olive pulp crushed in seed oil (1 g/ml)</td>
<td>DA/TDS</td>
<td>–</td>
</tr>
<tr>
<td>Metallic</td>
<td>Metallic taste typical of canned food</td>
<td>FeSO₄ (1.5 g/l)</td>
<td>–</td>
<td>DA/TDS</td>
</tr>
<tr>
<td>Peppery</td>
<td>Leaving a burning sensation in the oral cavity and on the tongue</td>
<td>Citric acid (0.25 g/l)</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Pungency</td>
<td>Leaving a burning sensation in the back of the throat</td>
<td>Sucrose (5.0 g/l)</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Sourness</td>
<td>Sour taste</td>
<td>–</td>
<td>DA/TDS</td>
<td>–</td>
</tr>
<tr>
<td>Sweetness</td>
<td>Sweet taste</td>
<td>–</td>
<td>DA/TDS</td>
<td>–</td>
</tr>
<tr>
<td>Tomato</td>
<td>Odour canned tomatoes</td>
<td>–</td>
<td>DA/TDS</td>
<td>–</td>
</tr>
<tr>
<td>Unripe fruit</td>
<td>Odour of unripe, “green” fruit</td>
<td>–</td>
<td>DA/TDS</td>
<td>–</td>
</tr>
<tr>
<td>Mouth feel</td>
<td>Creamy</td>
<td>–</td>
<td>DA/TDS</td>
<td>–</td>
</tr>
<tr>
<td>Watery</td>
<td>Thin, weak texture, opposite of viscous</td>
<td>–</td>
<td>DA/TDS</td>
<td>–</td>
</tr>
</tbody>
</table>

2.4. Descriptive analysis

A trained panel participated in three evaluation sessions. Each sample was replicated three times. In each session the following five sets were evaluated: set 1 – oil samples, set 2 – tomato with oil A and B; set 3 – bean with oil A and B; set 4 – tomato without oil; set 5 – bean without oil. Set and sample presentations were randomized across subjects. Evaluations were performed in the same conditions previously described. The order of attribute evaluation was balanced to minimize a possible “proximity” effect. Subjects had a five minute break between set evaluations.
The perceived intensity of each sensation was rated on a nine point category scale labelled at the extremes with “extremely weak” and “extremely strong”.

2.5. Consumer test

2.5.1. Subjects

Sixty-four subjects (24 males and 40 females, aged from 23 to 60) recruited in the Florence area took part in this experiment. All subjects were familiar with extra-virgin olive oils including PDO (Protected Denomination of Origin) products. They were also regular consumers of extra-virgin olive oil, with a self reported frequency of consumption greater than once a day.

2.5.2. Evaluations

Samples were presented monadically. The order of the sample presentation was randomized across subjects. Subjects were asked to hold the sample in their mouth for 8 s, swallow it and rate the overall liking and freshness. Liking was rated on a 9-point hedonic scale (Peryam and Pilgrim, 1957). This fully anchored 9-point category scale ranges from 1 (“dislike extremely”) to 9 (“like extremely”). A 9-point category scale ranging from 1 (“not at all”) to 9 (“extremely”) was used for freshness ratings. After each sample, subjects rinsed their mouths with distilled water for 30 s, had some plain crackers for 30 s and finally rinsed their mouths with water for a further 30 s. Evaluations were performed in the same conditions previously described in individual booths under white lights.

2.6. Data analysis

2.6.1. TDS data

Panel performance was assessed on the frequency values with which each attribute was selected as dominant by each subject, computed from raw software coding (1 selected; 0 not selected) (Pineau, Neville, & Lepage, 2011); for this purpose, the first 30 s of evaluation were considered. The obtained frequency values were computed from raw software coding (1 selected; 0 not selected). ANOVA mixed models (assessors as random effect) were independently submitted to a three-way ANOVA mixed model (assessors, sample and replicates as random effect) to reproduce their own results amongst replicates.

2.6.2. Descriptive data

A three-way ANOVA model (assessors, sample and replicates as fixed factors), with Fisher LSD post hoc test considered significant for \( p \leq 0.05 \), was used to validate descriptive data.

2.6.3. Consumer data

A two-way mixed ANOVA model with subjects taken as a random effect was used to evaluate the effect of the combination with olive oil on the sensory profile of tomato and bean samples. Liking and freshness ratings expressed for oil A and B, tomato + oil A and tomato + oil B, bean + oil A and bean + oil B were compared by paired t-tests. A two-way ANOVA model was used to estimate the effect of the combination with olive oil on liking and freshness ratings expressed for tomato and bean samples.

3. Results

3.1. Temporal Dominance of Sensations

Visual inspection of TDS curves showed that, for all products, several sensations were perceived as dominant during the first 30 s of evaluation, whereas after that only one clearly dominated each perceived profile. The maximum value of Dominance Rate (\( DR_{\text{max}} \)) of sensations perceived over the significance level are reported: pungency for oils, \( DR_{\text{max}} \geq 62 \); tomato flavour, \( DR_{\text{max}} \geq 58 \) for tomato samples; bean flavour \( DR_{\text{max}} \geq 55 \) for bean samples.

The Tuker-1 test performed on these frequency values, computed only for tomato and bean samples, showed that their correlation loadings are strongly related on the first consensus dimension for eight out of nine of the considered attributes, thus indicating the panel calibration. A pMSE plot of frequency values showed that, with the exception of one subject who was taken out from further data analysis on oil samples, assessors were able to discriminate between products using most of the attributes and to reproduce their own results amongst replicates.

The frequency with which attributes were selected as dominant during the first 30 s of evaluation of oil, tomato and bean samples were independently submitted to a three-way ANOVA mixed model (Table 2). No significant effect of replicates was found.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Three-way-ANOVA mixed model: sample effect (F values) and mean frequency values with which attributes were selected as dominant during the first 30 evaluation sec of dynamic profile.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bitterness</td>
<td>Pungency</td>
</tr>
<tr>
<td>Oil A</td>
<td>0.29(^{b})</td>
</tr>
<tr>
<td>Oil B</td>
<td>0.18(^{b})</td>
</tr>
<tr>
<td>( F_{1.31} )</td>
<td>4.92</td>
</tr>
<tr>
<td>Tomato</td>
<td></td>
</tr>
<tr>
<td>w/o Oil</td>
<td>0.01(^{b})</td>
</tr>
<tr>
<td>+ oil A</td>
<td>0.19(^{a})</td>
</tr>
<tr>
<td>+ oil B</td>
<td>0.13(^{a})</td>
</tr>
<tr>
<td>( F_{2.72} )</td>
<td>6.03</td>
</tr>
<tr>
<td>Bean</td>
<td></td>
</tr>
<tr>
<td>w/o Oil</td>
<td>0.00(^{b})</td>
</tr>
<tr>
<td>+ oil A</td>
<td>0.11(^{a})</td>
</tr>
<tr>
<td>+ oil B</td>
<td>0.05(^{a})</td>
</tr>
<tr>
<td>( F_{2.72} )</td>
<td>6.52</td>
</tr>
</tbody>
</table>

Values followed by different letters are significantly different (\( p \leq 0.05 \)).
Bitterness and grassy flavour frequency values were significantly higher in oil A than in oil B, while unripe fruit was selected as a dominant flavour more frequently in oil B than in oil A.

The combination of tomatoes with either oil caused a significant increase in the frequency with which bitter taste and grassy flavour were selected as dominant sensations, while inducing a decrease in watery frequency values. Furthermore, in tomato samples, oil A induced a significant increase in pungency frequency values and oil B a significant increase in unripe fruit flavour.

The combination of beans with either oil induced a significant decrease in frequency values for creamy, metallic and bean flavour. Moreover, frequency values in bean puree + oil A induced a significant increase in bitterness, pungency and grassy flavour and with oil B an increase in unripe fruit flavour.

The panel’s performance was considered reliable in view of the general results from the frequency value analysis.

Examples of dynamic sensory profiles, represented by TDS curves, are shown in Figs. 1–3. Based on the binomial distribution, the critical values of DR for a significance level of 95% resulted in 17% when thirteen subjects performed the evaluation using nine attributes, such as in the case of tomato and bean samples; and 29% when twelve subjects and five attributes were considered, such as in the case of oil samples.

Different dominant sensations characterize the initial part of oil TDS curves. Bitter taste and grassy flavour were perceived as dominant in oil A while unripe fruit flavour was the dominant sensation when oil B was evaluated. Also the grassy flavour DR reached significance during the first part of oil B evaluation. Pungency became the only dominant sensation for both oil samples from swallowing until the end of evaluation. The astringency DR value reached significance in the last part of oil A evaluation.

Sour taste, watery character and tomato flavour were the dominant sensations during the first part of the evaluation of tomato without oil. Tomato flavour remained the only dominant sensation after swallowing and lasted until the evaluation ended. The reduction in the sour taste DRmax value, the suppression of watery character dominance and the onset of bitter taste dominance were the main effects of combining tomato with oil A. Similar effects were induced by adding oil B to tomato. Moreover oil B contributes a typical unripe fruit flavour amongst the sensations dominating the first part of tomato/oil B evaluation.

The dominant sensations characterizing the initial part of the bean without oil curves were creamy texture and metallic flavour. Bean flavoured was perceived as dominant during the whole evaluation time. Combining bean with either oil A or oil B induced a decrease in the creamy DRmax value, suppression of the metallic flavour dominance and a delay in the onset of the bean flavour dominance. Also, bitter taste and grassy flavour were perceived as dominant sensations at the beginning of the bean + oil A evaluation, while unripe fruit flavour was one of sensations dominating the beginning of the bean + oil B evaluation.

3.2. Sensory profile of oil samples

A Fixed ANOVA model on the intensity data from oils A and B indicated a significant sample effect on the following attributes: pungency ($F_{1;77} = 4.33; p = 0.04$), bitterness ($F_{1;77} = 4.30; p = 0.04$), bitter taste ($F_{1;77} = 7.01; p = 0.01$), artichoke ($F_{1;77} = 4.40; p = 0.05$), grassy ($F_{1;77} = 5.48; p = 0.03$) and unripe fruit ($F_{1;77} = 7.35; p = 0.01$) (Table 3). No significant effects of replicates or assessor × product interactions were found. LDS post hoc test showed that mean intensity values of attributes were greater in oil A than in oil B except for unripe fruit flavour which was more intense in oil B than in oil A. Sensations perceived at a level greater than “moderate” (mean intensity rating > 5) were pungency, bitter taste, artichoke and grassy flavours in oil A and pungency and artichoke flavour in oil B.

3.3. Effect of olive oils on the sensory profiles of pureed tomato samples

Results from a Fixed ANOVA model on the intensity data of the sensory attributes of tomato with olive oil (Table 3) showed that the perceived intensities of pungency ($F_{1;24} = 4.99; p = 0.03$) and bitterness ($F_{1;24} = 29.30; p < 0.001$) were greater in tomato + oil A than in tomato + oil B samples and that unripe fruit flavour was greater in tomato + oil B than in tomato + oil A samples ($F_{1;24} = 3.95; p = 0.05$). No significant effects of replicates or assessor × product interactions were found Table 4.

The perceived intensities of attributes describing the sensory profile of all tomato samples were independently submitted to a mixed ANOVA model in order to estimate the sample effect (three levels: tomato without oil, tomato + oil A, tomato + oil B) (Table 3). A significant effect of sample on intensity of tomato flavour ($F_{2;116} = 2.52; p = 0.10$), watery ($F_{2;116} = 7.64; p = 0.003$) and sweet taste ($F_{2;116} = 3.71; p = 0.04$) was found. The combination with olive oil did not significantly affect the perceived intensity of sour taste. An LSD post hoc test showed that the watery character and sweet taste were perceived as less intense in tomato samples combined with either oil A or oil B, with respect to tomato without oil. The combination of tomato with oil A also induced a significant decrease in tomato flavour intensity.

3.4. Effect of olive oils on the sensory profile of bean samples

Results from a Fixed ANOVA model on the intensity data of sensory attributes of bean samples with olive oil (Table 3) showed that bitter taste ($F_{1;24} = 14.35; p < 0.001$), pungency ($F_{1;24} = 10.70; p = 0.001$) and sweet taste ($F_{1;24} = 5.60; p = 0.03$) were greater in bean + oil B than in bean + oil A samples. An LSD post hoc test showed that bitter taste was perceived as more intense in bean samples combined with oil B, while pungency and sweet taste were perceived as less intense in bean samples combined with oil A.
Fig. 2. TDS curves of tomato samples. $p_0$ represents the chance level, $ps$ represents the significance level (95%).

Fig. 3. TDS curves of bean samples. $p_0$ represents the chance level, $ps$ represents the significance level (95%).
0.003), artichoke (F_{1:247} = 11.34; p = 0.003) and grassy (F_{1:24} = 26.13; p = 0.0001) flavours were perceived as more intense in beans combined with oil B than in beans combined with oil A (F_{1:24} = 27.85; p = 0.001). No significant effects of replicates or assessor × product interactions were found.

The perceived intensities of attributes describing the sensory profile of all bean samples were independently submitted to a mixed ANOVA model in order to estimate the sample effects (three levels: bean without oil, bean + oil A, bean + oil B) (Table 3). Significant effects of sample on intensity of bean (F_{2:116} = 4.26; p = 0.03) and metallic (F_{2:116} = 12.12; p < 0.001) flavour and on sweet taste (F_{2:116} = 5.03; p = 0.01) were found. The combination with olive oil did not significantly affect perceived intensity of the creamy attribute. A LSD post hoc test showed that bean and metallic flavours and sweet taste were perceived as less intense in bean samples combined with either oil A or oil B, compared to beans without oil.

### 3.5. Effect of olive oils on liking and freshness ratings of pureed tomato and bean samples

Consumers’ liking and freshness ratings for oil alone A and B were compared (Fig. 4). A paired t-test indicated that oil A is more liked (t_{63,1,99} = 3.53; p < 0.001) and perceived as fresher (t_{63,1,90} = 3.90; p < 0.001) than oil B.

A two-way ANOVA model was used to estimate the sample effect (three levels: without oil, +oil A, +oil B) on liking and freshness ratings of tomato and bean samples (Fig. 5). A significant effect was found for tomato liking (F_{2:126} = 6.45; p = 0.002). An LSD post hoc test indicated a significant increase in liking for tomato combined with either oil A or oil B compared to tomato without oil. The ANOVA indicated that tomato combined with oil B was perceived as fresher than both tomato without oil and tomato + oil A (F_{2:126} = 5.17; p = 0.007). No significant sample effects were found for the bean samples.

The effect of liking and freshness expressed for oils alone, on liking and freshness expressed for tomato combinations, was further investigated. The arithmetic difference between liking for oil A and for oil B was computed for each subject, two groups of subjects were selected, one consisting of subjects preferring oil A (cluster {\text{Alik}}: liking oil A – liking oil B ≥ 1; n = 36) and the other consisting of subjects preferring oil B (cluster {\text{Blrik}}: liking oil A – liking oil B ≤ –1; n = 19). Similarly, two clusters of consumers were selected on the basis of their freshness ratings. One cluster considered oil A fresher than oil B (cluster {\text{Afrs}}: freshness oil A – freshness oil B ≥ 1; n = 42) and the other cluster considered oil B fresher than oil A (cluster {\text{Bfrs}}: freshness oil A – freshness oil B ≤ –1; n = 14).

The B clusters were not submitted to further analysis given the small number of subjects.

Liking and freshness ratings expressed by the A clusters for tomato + oil samples were independently compared by paired t-test. No significant difference was found between liking expressed for tomato + oil A and tomato + oil B samples, whereas freshness ratings of tomato + oil B were significantly greater than those expressed for tomato + oil A (t_{43,1,92} = –2.61; p = 0.013). The results indicate that consumers’ liking and freshness ratings for oils do not influence their liking for and perceived freshness of tomato in combination with olive oil.

### 4. Discussion

#### 4.1. Descriptive Analysis vs TDS curves

Available tools, such as TDS difference curves, are not always suitable for panel validation in dynamic sensory profile evaluations. Computing the frequency values proved to be a useful approach for assessing panel calibration and assessor performance especially when several sensations are perceived as dominant during the same time interval (Pineau et al., 2011). In this study, the results from data analysis of frequency values computed on the first 30 s of evaluation, showed significant differences amongst the selection of dominant attributes in the oil, tomato and bean samples.

Previous studies have demonstrated a good agreement between DA data and TDS curves in model food products (Labbe et al., 2009; Saint-Eve et al., 2011) and this was confirmed in olive oil samples where attributes with mean intensity ratings greater than 5, moderate, (pungency, bitter taste and grassy flavour) were also the dominant sensations in the oils. The only exception was unripe fruit flavour, which was the most dominant flavour in oil B; in fact the mean intensity rating of this attribute in oil B was less than 5 (4.13 ± 0.41) and was not significantly different from those expressed for grassy flavour (4.73 ± 0.40) and bitter taste (4.27 ± 0.37). Unripe fruit is an uncommon flavour of Tuscan extra-virgin olive oils (Laboratorio Chimico Mecceologico Camera di Commercio di Firenze, 2011) consequently, it may have caught more of the subjects’ attention than the very well known grassy and bitter notes. Moreover, TDS curves clearly showed the different dynamics of the perception of stimuli, with taste and flavour perceived as dominant when the sample is in the mouth and the irritant sensations dominating after swallowing (Sinesio, Moneta, & Esti, 2005).

The consistent relationship between TDS curves and DA data was confirmed in this study for tomato and bean samples, where most of the sensations dominating the dynamic sample profile were also the attributes rated with an intensity ≥ 5. However, the watery attribute and the metallic taste in tomato and bean samples, respectively, do not show such a relationship. The watery attribute did not reach a significant DR value in tomato samples combined with either oil even though it was perceived at a strong-moderate intensity (6.22 ± 0.23 in tomato + oil A; 6.49 ± 0.23 in tomato + oil B) whereas the metallic flavour was one of the perceived sensations dominating the bean without oil sample, despite being rated lower than moderate intensity (3.94 ± 0.36) and less intense than sweet taste (4.92 ± 0.28). Some specific flavours and tastes contributed by olive oils to the descriptive profile of tomato and bean combinations with oil were perceived as dominant sensations despite their weak–weak/ moderate perceived intensity: this was also the case with bitter taste (tomato + oil A: 3.40 ± 0.38; bean + oil A: 2.9 ± 0.32), grassy (tomato + oil A: 3.64 ± 0.35; bean + oil A: 4.10 ± 0.4) and unripe fruit (tomato + oil B: 4.35 ± 0.3; bean + oil B: 4.30 ± 0.36) flavours.
These comparison between DA data and TDS curves suggest that unexpected (unripe fruit flavour in oil B and its combinations, grassy flavour and bitter taste in tomato and bean samples combined with oil A) and less familiar (metallic flavour vs sweet taste in bean) sensations tend to catch the subjects' attention even when perceived at low intensity levels and they consequently become sensations dominating the perceived dynamic profile of the foods. The different dynamics of sensations induced by complex stimuli can account for differences between information from static and dynamic profiling (Labbe et al., 2009). The presence of olive oil induced an increase in the number and the type of sensations perceived while the sample is still in mouth (bitter taste, grassy and unripe flavours). The spreading of subjects' attention amongst a large number of transient sensations in the early evaluation stage, and the consequent decrease in DR values of the relevant attributes, may account for the suppression of the watery and metallic sensations in bean + oil and tomato + oil samples, respectively. The perceived profiles after swallowing were less complex and the subjects perhaps focussed their attention on a small number of long lasting sensations, such as tomato and bean flavours, and the dominance of these flavours was only slightly affected by the significant reductions in their intensities induced by the presence of oil. The use of the TDS method for the sensory characterization of oil, tomato and bean samples provides information which complements those from DA studies. DR values clearly indicate that the importance of a sensation during food consumption is not necessarily the same as that indicated by intensity ratings from static sensory profiles. Unripe fruit flavour perceived in oil B is a good example of this since, despite its low intensity ratings, it was
perceived as a sensation that clearly dominated the perception of oil B and marked its presence when combined with food.

4.2. Contribution of olive oils’ sensory properties to the perceived profiles of combinations

Both descriptive data and TDS curves showed that the addition of olive oils strongly influenced the sensory properties of tomato and bean purees either by modifying the intensity and the dominance rate of their characteristic attributes, or by contributing new sensations, peculiar for each oil. The main effects of oils, irrespective of their sensory profiles, were the lowering of the intensity, and the suppression as a dominant sensation, of the watery attribute in tomato + oil mixtures, and the metallic flavour in bean + oil combination. These modifications in the profiles of mixtures were not related to specific sensory properties of oils, and therefore may be attributable to a general consequence of adding a lipid phase to the aqueous vegetable matrix. Mixing lipid and aqueous phases has previously been shown to modify physical characteristics of food products, leading to changes in their texture and can influence the rate and the extent of stimuli transport towards specific receptors thus influencing the perception of the relevant sensations (Mattes, 2007; Miettinen, Hyvonen, & Tourila, 2003).

As expected, taste, flavours, irritant and tactile sensations perceived in each olive oil were also perceived in tomato + oil and bean + oil samples but at low intensity levels (from very weak to weak/moderate). The 10-fold dilution factor of oils in the food matrices may account for this. As expected, the decrease in the intensity of attributes in combinations was not proportional to their perceived intensity in oils alone. This may be due to different psychophysical curves relating the concentration of a stimulus to the intensity of the relevant sensation. Diffusion limits hindering the stimuli–receptor interactions, as well as chemical–physical interactions between sensory active molecules in olive oils and food matrix compounds, can also be envisaged (Pripp, Busch, & Wreeker, 2003). Furthermore, the change of lipid level can alter the portioning of aroma compounds between aqueous and non-aqueous phases, thus modifying the aroma profile in the headspace of a mixture compared to that of the same food without oil. Moreover, perceptual interactions between different sensory modalities should also be taken into account to explain the effect of olive oils on the perceived profile of combinations. The significant differences between attribute intensities rated in combinations correspond to the significant intensity differences perceived in olive oils. In fact, bitterness and pungency intensities are higher in tomato + oil A than in tomato + oil B and grassy and artichoke flavours and peppery sensations were significantly more intense in bean + oil A than in bean + oil B. In the same way unripe fruit flavour was always more intense in food matrices combined with oil B than in those combined with oil A. All these properties contributed by olive oils to tomato and bean samples play an important sensory role since they represent sensations dominating the dynamic evaluation of the relevant samples.

The data clearly indicate that the perceived intensity of a sensation in olive oil evaluated alone does not necessarily relate to that perceived in a combination with a food, thus highlighting the importance of chemical–sensory interactions in the perception of complex stimuli.

This is the case with grassy flavour, which was perceived at moderate-strong intensity in oil A alone, but dominated the dynamic profile only in combination with bean, and of unripe fruit flavour, rated weak-moderate in oil B alone, but perceived as a dominant sensation in combination with both tomato and bean purees. Moreover sensations considered critical for olive oil acceptability, such as pungency, can be completely suppressed when oil is combined with a given food.

4.3. Effect of olive oil on liking and perceived freshness of pureed tomatoes and beans

The sensory profile of oil A is typical of Tuscan extra-virgin olive oils. In fact, green notes of grassy and artichoke flavours, pungency and bitterness represent the main sensory properties of extra-virgin olive oils produced in this region (Laboratorio Chimico Meccologico Camera di Commercio di Firenze, 2011). The consumers participating in the study were probably more familiar with Tuscan extra-virgin olive oils than with products from other Italian regions and this might account for the higher liking ratings expressed for oil A with respect to oil B. High intensities of flavours, tastes and irritant sensations characterize recently produced extra-virgin olive oils (Esti, Contini, Moneta, & Sinesio, 2009). The strong intensity of grassy and artichoke flavours, bitter taste and pungency perceived in oil A and the moderate-weak intensity of the same sensations rated in oil B should be taken into account when assessing the perceived differences in freshness between these oils.

Several factors relating to the general effects of adding oil rather than specific modifications of the sensory profile could account for the increased liking of tomato + oil samples compared to that of tomato without oil. In fact, no significant differences in liking were found when comparing tomato + oil A with tomato + oil B, despite the significant differences in flavours and taste. Modifications of the sensory properties of tomato combinations induced by both oils, that is the reduction in both the watery attribute and the sour taste, as well as the well known positive effect of fat addition on food palatability, might account for the increased liking of these samples. Dressing tomato products with extra virgin olive oil is extremely common in Italian culinary tradition and the familiarity of subjects with this combination should also be considered. Consumers clustered on the base of their preference for oils, expressed liking ratings not significantly different for tomato + oil A and tomato + oil B, thus confirming the secondary role of the sensory properties specifically contributed by each oil. Tomato + oil B was considered as the freshest sample by all consumers and also by the subject subgroup that considered oil A to be fresher than oil B. The unripe fruit flavour, together with the other sensory properties specifically contributed by oil B to the tomato profile, could possibly account for the increased perceived freshness in tomato + oil B compared with tomato + oil A and tomato without oil.

The oil-induced modifications of the sensory profiles of pureed beans did not affect either liking or freshness ratings in the conditions adopted in this study. Beans are a well liked product, even when evaluated alone (6.2 ± 0.23), hence the lack of a positive effect of oil on the liking for combinations of beans and oil. Moreover, freshness may not have been considered an appropriate descriptor of pureed beans, hence the lack of a significant difference between the ratings of bean puree alone and with oils.

The positive effect of extra-virgin olive oils on palatability and the acceptance of several foods is generally accepted, however, the consumer data indicated that this effect strongly depends on the food with which oil is combined and cannot be related to the individual preference expressed for an oil. In fact, oils induced an increasing of mean liking scores in combination with tomato but not with bean. Furthermore, the liking ratings of tomato + oil A were not significantly different from those for tomato + oil B despite the greater preference expressed by consumers for oil A.

5. Conclusions

The TDS method has been shown to be a useful complementary tool to DA for describing the sensory properties of food products. The complex interactions occurring between food components represent one of the most important drivers of the perceived
sensory profiles and can be more clearly described by TDS than by DA. Moreover, studying the temporal evolution of sensations and their dominance seems to be more appropriate than the descriptive profile intensity data for interpreting consumer responses. In fact, sensations perceived at less than moderate intensity can instead dominate the dynamic profile thus likely playing a key role in freshness perception in tomato with oil.

Thus, TDS appears a suitable method to study the sensory functionality of ingredients in terms of their capacity to modify the sensory properties and acceptability of food pairings.

Both the panel and consumer data highlight the risk of using sensory data from extra-virgin olive oil evaluated alone to build up quality categories based on flavour, taste and mouth-feel sensation intensities. Key sensations marking the sensory identity of a given oil may not be experienced in conditions of normal use and weak relationships have been found between oils and oil/food pairing for both sensory properties and hedonic consumer responses.

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