

## The role of polyphenols sensorial attributes in olive oil preferences: Do consumers like the healthy bitterness?

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### ABSTRACT

Phenolic compounds are partly responsible for the healthy properties of extra virgin olive oil (EVOO), which is a central component of the healthy Mediterranean diet. The hypothesis presented in this study is that olive oils with different phenolic contents have different levels of acceptance by participants and are influenced by cultural traits and intrinsic sensorial attributes. A selection of three regional olive oils was characterized by their total phenolic composition, and evaluated by consumer participants on global acceptance and acceptance of their intrinsic sensorial attributes. The high-polyphenol EVOO had the lowest global acceptance by participants, and this low rating seemed to be more pronounced in women. While acceptance of high-polyphenol EVOO was more correlated with pleasantness to fruity, the favorite olive oil – with moderate amount of phenols - reveals a strong correlation between global acceptance and liking of the sweetness.

These findings suggest that when confronted with choosing olive oil based solely on sensorial attributes high-polyphenol olive oils may be at disadvantage. Future studies should explore how to increase valorization of these olive oils by consumers, and how to optimize marketing by producers and dietitians to achieve a common goal of promoting the consumption of high quality and healthier olive oils.

### 1. Introduction

Extra virgin olive oil (EVOO) is a central component of one of the healthiest dietary patterns described – the Mediterranean Diet. Due to the increased popularity of Mediterranean diet and the benefits of this “liquid gold”, production and consumption of olive oil has been growing, expanding even outside of the Mediterranean area (Clodoveo et al., 2014).

In contrast to other oils, olive oil does not need to be refined to be consumed. Therefore virgin and extra virgin olive oils can be found, obtained mechanically purely by cold pressing of the fruit of the olive tree (*Olea europaea L.*). This way of production allows olive oil to retain healthy bioactive compounds like polyphenols (Rébufa et al., 2021). The total phenolic content of olive oil can vary from 40 to 1000 mg/kg depending on many factors, including the cultivar, the ripeness of olives and extraction methods (Servili, 2014). Concentration of these bitter compounds decreases during “black maturation” of the fruit due to

increased activity of hydrolytic enzymes. Olive oils made with green olives are therefore expected to have higher amount of phenolic compounds (Vitaglione et al., 2015). The European Food Safety Authority has recognized the scientific evidence of the benefits of olive oil polyphenols to protect blood lipids from oxidative stress, in particular, olive oils with a minimum of 5 mg of hydroxytyrosol and its derivatives (e.g. oleuropein complex and tyrosol) per 20 g of olive oil (Panel on Dietetic Products, Nutrition & Allergies (NDA) E, 2011).

From a nutritional point of view the consumption of high-polyphenol olive oils it is advantageous (George et al., 2019). However, polyphenols- in particular secoiridoids- contribute to enhanced sensorial characteristics as pungency and bitterness of olive oils (Tripoli et al., 2005, Gutiérrez-Rosales et al., 2003).

Organoleptic (sensory) characterization is part of the olive oil quality assessment performed by trained experts, following EU regulation which assesses fruitiness and the absence of organoleptic defects. Extra virgin olive oil is the category with the highest quality with no organoleptic

*Abbreviations:* EVOO, Extra Virgin Olive Oil; HP-EVOO, High Polyphenols -Extra Virgin Olive Oil; MP-EVOO, Moderate Polyphenols -Extra Virgin Olive Oil; VOO, Virgin Olive Oil; BMI, Body Mass Index.

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defects, exhibits fruitiness, and with acidity not exceeding 0.8%. Virgin olive oils may have some sensory defects at low level and its acidity should not exceed 2% (European Commission, 1991). Sensory attributes have been pointed as one of the main determinants in food preferences in general, and in olive oil in particular (Del Giudice et al., 2015, Cavallo et al., 2019). In recent years, olive oil producers have been devoted to produce olive oils with enhanced sensory characteristics. This enhancement of sensory characteristics is a result of practices, both at agriculture and manufacture site, that result in an enhancement of their quality, preserving high levels of phenolic compounds (Rébua et al., 2021, Pérez et al., 2021).

Despite these efforts from the production side, many factors affect the individual preferences or perception of taste by consumers. For instance, chefs and consumers have different ratings about attributes of olive oil with bitterness being less appreciated by consumers than by experts (Pagliuca & Scarpato, 2014). Personal traits, age, sex, genetic variations on taste receptors have all been shown to affect taste. Liking of pungency, for example, has been associated to lower perceived intensity of burning and manifest differently in men and women (Duffy & Bartoshuk, 2000, Spinelli et al., 2018). Cultural aspects have also been shown to influence olive oil preferences, that can reflect differences between consumers from different countries but also cultural differences within the same country (Peršurić, 2020).

Olive oil production is part of the cultural heritage of some regions of Portugal (Rodrigues et al., 2019) and Trás-os-Montes is one of the main production region. In this area a traditional way of production is still maintained, resulting in olive oils with a high richness in polyphenols, however consumers preferences based on sensory analysis was never tested in this region before.

A better understanding of how distinct consumers evaluate different olive oils according to intrinsic product attributes and how this evaluation affects the global acceptance, is of utmost importance for producers dedicated to increasing the quality of their olive oils, as well as for dietitians and nutrition professionals willing to nudge clients into the healthier possible choices. The hypothesis present in this work is that olive oils with different phenols contents have different levels of acceptance by participants and that this acceptance is influenced by cultural traits and correlated with intrinsic sensory attributes.

## 2. Methodology

### 2.1. Participants recruitment and data collection

Participants were recruited by professors among the Institute Polytechnic of Bragança academic community as an untrained panel. We opted for the academic community to include participants from other regions and countries. The purpose of this project was explained to each volunteer participant prior to obtaining informed consent. To maximize data protection, and respecting the General Data Protection Regulation, all the information was collected anonymously. On the day of data collection, a unique code number was assigned to each participant and the information was anonymously collected and analyzed. Data was collected between June and July 2021 and all the experiments were performed respecting safety measures for preventing COVID-19 transmission and dissemination. This study was performed in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans and had ethical approval by the Ethic Commission of Institute Polytechnic of Bragança (n°51/2021).

### 2.2. Olive oil selection and phenols determination

Three olive oils from traditional production of Trás-os-Montes region (from a local producer) were selected to be tested: a) an extra-virgin olive oil, obtained from green olives and expected to be very high in polyphenols “HP-EVOO”; b) an extra-virgin olive oil made from mature

olives and also rich in polyphenols “MP-EVOO”; and c) a virgin olive oil “VOO” with moderate amount of polyphenols. These three olive oils were previously analyzed by trained panelists according to EU Commission Regulation (European Commission, 1991) and no organoleptic defects were detected for a) and b) and a wet wood defect was detected for olive oil c).

Phenolic compounds were extracted by micro methanol-water extraction according to Pizarro et al. (2013). Each extraction was performed in triplicate. To determine the total Polyphenol content, a solution was prepared with 1500 mm<sup>3</sup> of water, 100 mm<sup>3</sup> of phenolic extract and 100 mm<sup>3</sup> of reagent Folin-Ciocalteu, vortexed for 3 s and allowed to react for 3 min. Subsequently, 300 mm<sup>3</sup> of 20% sodium carbonate (w / v) was added, vortexed for 3 s and allowed to react for 60 min in the dark and at room temperature (20–22°C). This procedure was carried out in triplicate, in the extracts obtained in the MeOH-H<sub>2</sub>O 80% extraction. All were evaluated by VIS spectroscopy, on a UV-VIS/UV-1280 Shimadzu spectrophotometer and detected at 765 nm (Attard, 2013). The results were expressed in gallic acid equivalent (mg EAG kg<sup>-1</sup>).

### 2.3. Sociodemographic characterization of the participants

With the aim of studying the association of sociodemographic characterization with olive oil preferences and acceptance, information from 81 participants, about age, sex, nationality, education, household income, professional status, household composition, marital status, and area of residence was collected by questionnaire as previously used in national surveys (Lopes C et al., 2016). Body mass index (BMI), kg/m<sup>2</sup>, was classified accordingly to WHO (World Health Organization, 2021). Additional questions of olive oil consumption and purchasing were included. Data was collected immediately before the sensory analyses of the olive oils.

### 2.4. Sensory analysis and willingness to buy

A sensory analysis was performed to compare acceptance and preferences between the tested olive oils. Olive oils were coded using a three-digit random number, computer-generated, and presented in blinded conditions, at room temperature, to each participant. Participants were asked to not eat or smoke for 2 h before the sensory analysis. Evaluation of attributes turbidity, color, aroma, sweet, fruity, bitter and pungent of olive oils from different categories were performed for each attribute using an Unstructured Linear Hedonic Scale of 10 cm, as represented in Fig. 1, to give participants more discriminatory freedom (Pimentel et al., 2015). Each border of the scale represents the minimum and maximum pleasantness possible for that specific attribute. Global acceptance, i.e, overall appreciation, of each olive oil was measured using the same scale. Crackers were offered before and between tastings, the olive oil amount in each glass was approximately 40 mL, enough to allow for repetitions in case of hesitation by participants, and served at room temperature (around 25°C). After the sensory analysis of each olive oil, participants were asked about their willingness to buy the tested olive oil.

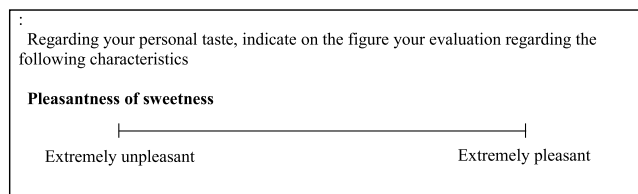


Fig. 1. Representation of the linear non-structured hedonic scale (100mm) used on sensorial analysis.

## 2.5. Data analysis

Descriptive analyses were made with IBM SPSS® - Statistics for Windows (version 25; IBM Corporation, Armonk, NY, USA). Baseline characteristics are presented as mean  $\pm$  standard deviation (SD), median and interquartile range (IQR) for numerical variables and frequency (n; %) for categorical variables. Statistical analysis of global acceptance by total and subgroups of population was performed using one-way anova followed by LSD pos-hoc for total of participants and kruskal-wallis for subgroup. Correlation analysis was employed using the Spearman test with Matlab software and spider web plots were obtained with the same software. This software was run on a computer with an intel core processor I5-5200 2.20GHz CPU with 8GB of RAM. The software version used was R2019a (9.0.0.341360). A correlation matrix was calculated to visualize the strength of the relationships between the attributes and global appreciation, where values that represent the Spearman ( $\rho$ ) correlation coefficient are presented. Values marked in red indicate pairs that have a statistically significant correlation ( $p$ -value $<0.05$ ). Of which there may be very strong correlations ( $\rho \geq 0.90$ ), strong correlations ( $0.7 \leq \rho < 0.9$ ), moderate ( $0.50 \leq \rho < 0.7$ ), weak ( $0.30 \leq \rho < 0.5$ ) to biologically negligible (not relatable) ( $0 < \rho < 0.3$ ). A negative  $\rho$  value represents an inverse correlation.

## 3. Results

### 3.1. Polyphenol content of olive oils

To confirm its content, each olive oil was analyzed to determine the total of phenolic compounds, expressed as equivalents of gallic acid. As shown in Table 1 the HP-EVOO had the highest content, with 692 mg of phenolic compounds per kg of olive oil, followed by the MP-EVOO with 321 mg. The lowest phenolic content was shown in the VOO with 265 mg of gallic acid equivalents per kg of olive oil. These three olive oils were used for the following sensory analysis.

### 3.2. Sociodemographic characterization of the participants

The questionnaire applied was composed of two parts:1) one of them referring to the identification of personal characteristics, as well as users' purchasing habits;2) the second part consisted of a tasting of various types of oil in order to identify taste patterns.

The application of this questionnaire had 81 responses in the first part and about 66 in the olive oil tasting. As it was a questionnaire with non-mandatory answers, there were some missing values, resulting from blank or null answers. From the answers obtained, a characterization of the sample was carried out, where the most important parameters for the study are identified.

Table 2 refers to the personal characterization of the respondents who were recruited from the academic community. As can be seen, the group has a relatively young median age of just 23 years old with an IQR of 4 years. The most representative sex is male with approximately 54.3% of responses. The average BMI of respondents is 23.7 kg/m<sup>2</sup>, with a standard deviation of 3.6 kg/m<sup>2</sup> and the majority of participants (51.9%) were classified as having normal weight (BMI between 18,5–25

**Table 1**  
Total phenolic compounds (mg gallic acid/ kg olive oil).

	P
HP-EVOO	692.0 $\pm$ 11.2
MP-EVOO	321.0 $\pm$ 10.7
VOO	265.5 $\pm$ 11.0

HP-EVOO- High-polyphenol extra virgin olive oil;  
MP-EVOO- Moderate-polyphenol extra virgin olive oil;  
VOO- Virgin olive oil

**Table 2**

Sociodemographic profile of respondents and olive oil consumption and purchasing habits.

Demographic data	
Age Mean $\pm$ SD	24.3 $\pm$ 4.7
Age Median (IQR)	23.0 (4.0)
BMI Mean $\pm$ SD	23.7 $\pm$ 3.6
BMI Median (IQR)	23.2 (4.5)
BMI categories N (%)	
<18.5 kg.m <sup>2</sup>	2 (2,5%)
18.5 $\leq$ $\leq$ 25 kg.m <sup>2</sup>	42 (51.9%)
>25 kg.m <sup>2</sup>	18 (22.2%)
NR	19 (23.4%)
Sex N (%)	
Male	44 (54.3%)
Female	36 (44.4%)
Nationality N (%)	
Portuguese	42 (51.9%)
Other	39 (48.1%)
City of living N (%)	
Bragança	51 (63%)
Other	30 (37%)
Scholarity N (%)	
High School	35 (43.2%)
Post- high school	10 (12.3%)
Higher education	16 (19.8%)
Postgraduate higher education	19 (23.5%)
Olive oil consumers N (%)	80 (98,7%)
Buys olive oil at supermarket	54 (67,5%)
Buys olive oil from producer	12 (15,0%)
Bought olive oil last year	65 (81,3%)
Production by household	11 (13,8%)

BMI-Body Mass Index; IQR-Interquartile Range; NR-Non-Respondent; N=81; SD: Standard Deviation

kg/m<sup>2</sup>).

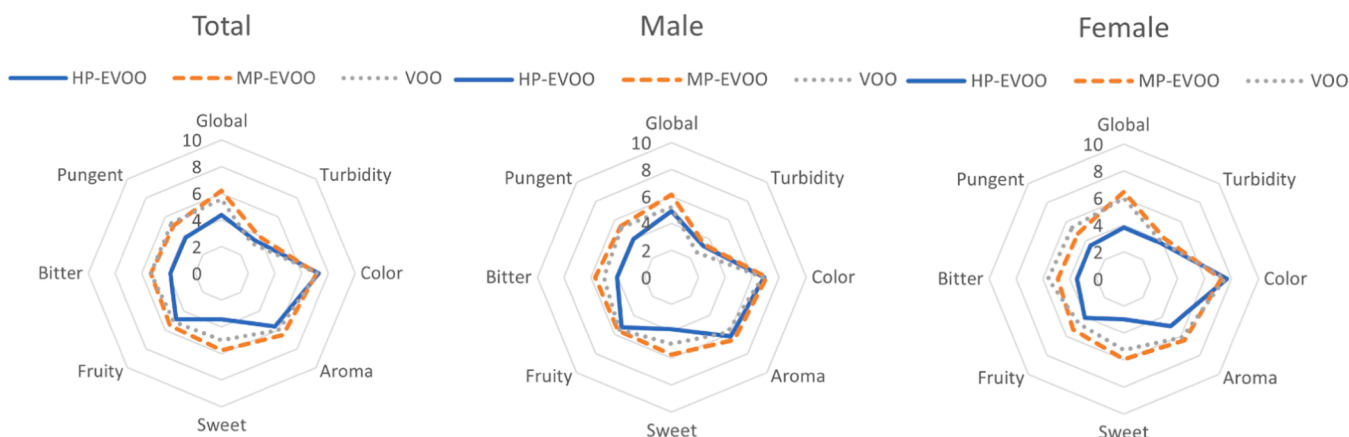
Analyzing in more detail the geographic distribution of the responses, it is possible to state that there was a large percentage of responses from other nationalities (48.1%), however, the most common nationality of responses is still Portuguese with about 42 responses (51.9%), in relation to the municipalities of residence, the municipality of Bragança was the most representative with 51 responses, 30 refer to respondents of another municipality. In terms of education, respondents had high levels of education, with 45 of the responses obtained (55.6%) having higher education than high-school.

Excepting one, all participants were identified as usual olive oil consumers (n=80) and most consumers buy their olive oil at the supermarket (67.5%). Within consumers, 65 people had already bought olive oil this year (Table 2). A group of 12 consumers (15%) buys olive oil directly from the producer/farmer. In third place were respondents who produce their own olive oil, or was produced by someone in their household, corresponding to about 13.8% of all consumer responses.

### 3.3. Pleasantness of olive oil characteristics and its correlation with global assessment

Results from hedonic evaluation of different olive oils and their sensorial attributes are represented in Fig. 2 for total participants, and separated by sex. It is possible to visualize the mean ratings attributed by participants and to observe that some attributes from HP-EVOO, as pungent and bitter, were particularly less appreciated by participants. The data resulting from this approach was analyzed by olive oil type using Spearman correlations. The correlation matrix analysis allowed the identification of the characteristics with the greatest influence on the global assessment of each oil.

In this way, the correlations for each of the sample types were determined. Results are shown in Fig. 3. Observing the global appreciation of HP-EVOO, it is noticeable that the characteristic that most correlated with it was the pleasantness of the fruity, with moderate correlation followed by the pleasantness of the sweet, pungent, bitter



**Fig. 2.** Spider web plot of pleasantness analysis of seven attributes (color, turbidity, aroma, sweet, fruity, bitter, pungent) and global appreciation for each oil. HP-EVOO - High-polyphenol extra virgin olive oil; MP-EVOO - Moderate-polyphenol extra virgin olive oil; Virgin olive oil (VOO) (n=81).

and aroma. Color and turbidity demonstrated, in this case, to have little influence on the global assessment of HP-EVOO.

From results referring to correlation analyses of the MP-EVOO it is possible to notice some differences from the first sample, it is noticeable that in this case the color of the sample also has some influence on its appreciation. Emphasizing that in this specific case the characteristic that most correlated with the global appreciation was the pleasantness of the sweetness. Once again, the turbidity of the sample does not have a great influence on the global appreciation. In the virgin olive oil – VOO – analysis it is possible to see that in this case, the characteristic that most correlates with global appreciation is the pleasantness to bitter.

### 3.4. Influence on sex, nationality on global acceptance of different olive oils

Acceptance of the HP-EVOO was lower than for other olive oils. As gender has been implicated in food taste and food preferences, we compared acceptance scores between men and women (Spinelli et al., 2018, Michon et al., 2009). As we can see in Table 3, there was a tendency for women to give lower scores to this olive oil ( $p=0.06$ ). Considering the representativeness of the international community within our sample, we also compared the global acceptance to the different olive oils by Portuguese and participants from other nationalities. Nationalities expressed here as other were mainly from Brazil and Cape Verde (12 and 23 respectively) and 4 from Guinea. The results showed that participants exhibited lower acceptance of the HP-EVOO while the MP-EVOO gather higher scores. Despite potential cultural differences, no significant difference were observed between Portuguese and International participants' evaluations.

## 4. Discussion

This study aimed to evaluate the acceptance of three different regional olive oils by the academic community. As olive oils have been previously categorized by a trained panel, here general consumers untrained in olive oil sensory analysis were deliberately selected. Two main goals were defined in this study, first to compare global acceptance of different olive oils - with different phenolic content- and identify which olive oil attributes were more related to it. Second, to compare the acceptance of different olive oils by sex and nationality. Our results showed that MP-EVOO, with moderate amount of phenols was the most appreciated. By contrast, the HP-EVOO was the least appreciated showing lower acceptance than VOO, a virgin olive oil, which has inherent lower market quality.

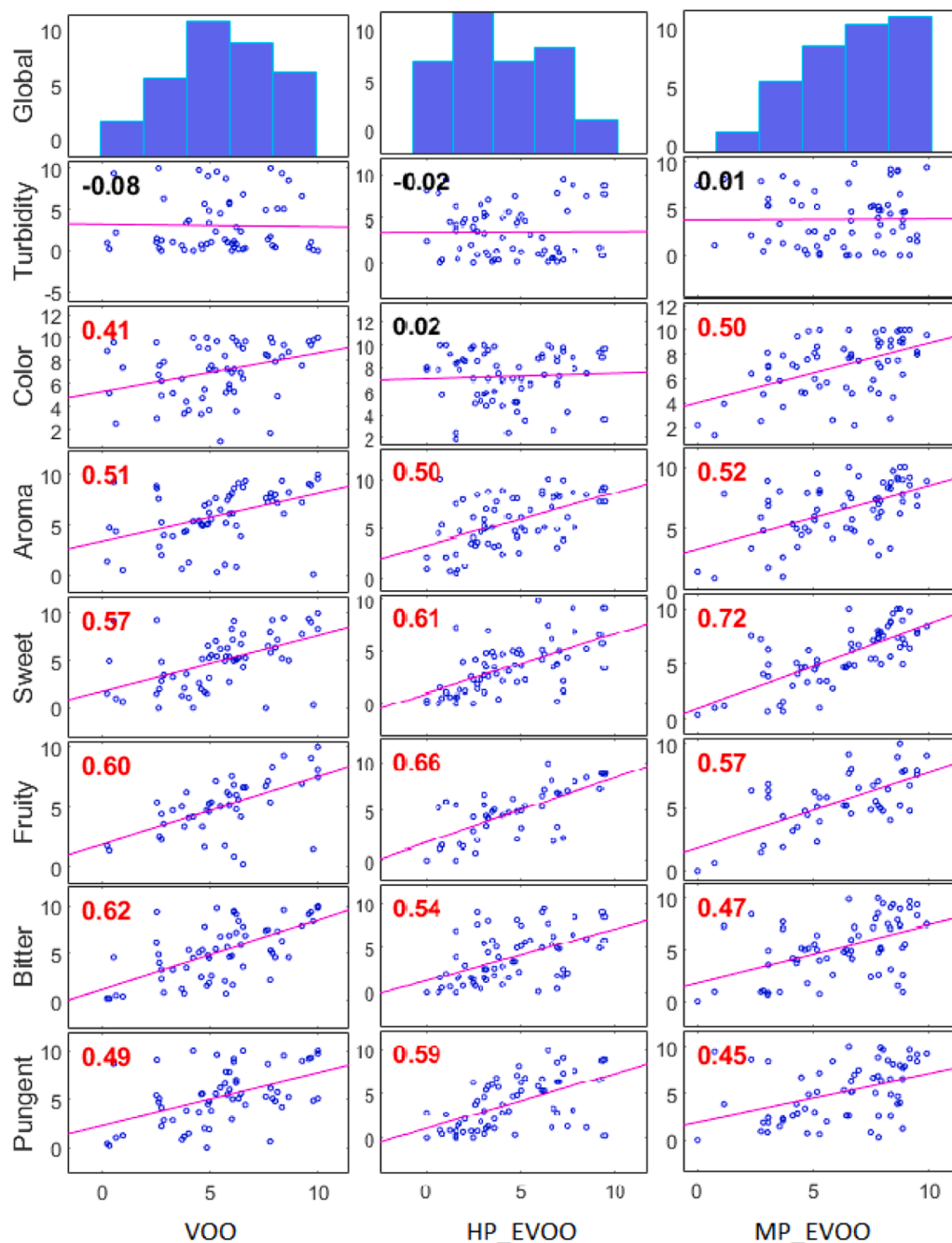
Polyphenols in olive oils are responsible for their bitterness, which may divide consumers, neglecting the fact that this bitterness is also

responsible for the healthier effects attributed to extra virgin olive oils and also in part to the benefits of the Mediterranean Diet. Previous studies have shown that consumers tend to prefer olive oils with neutral taste (Del Giudice et al., 2015). As shown by Caracciolo and colleagues in a field experiment (Caracciolo et al., 2020), consumers have a negative willingness to pay for bitterness in olive oils. This study and other acceptance studies have tested consumers in Italy and other Mediterranean countries. However, to our knowledge, it is the first time that this type of studies have been conducted with Portuguese olive oils and using participants both from the national and international community. Contrary to our expectations based on the global genetic diversity of bitter taste receptors, nationality did not influence olive oil sensory analysis. The findings of this study identify that women tend to score global acceptance HP-EVOO lower than men. Men have generally higher preferences for pungency and bitterness in food (Spence, 2019). By contrast women in general report higher perceived bitterness, as marked by sensitivity to taste 6-n-propylthiouracil (PROP), one marker of genetic variation in taste (Duffy & Bartoshuk, 2000). The lower values attributed to global acceptance to HP-EVOO may in part be explained by higher sensitivity to pungency and bitterness attributed to phenols.

This study allowed the identification of each type of olive oil which were the olive oils attributes more correlated with global sensorial acceptance of olive oil. The traditional characteristics of the olive cultivars and increased knowledge about production techniques have resulted in the production of olive oils with enhanced sensory characteristics (pungent, fruity, bitter) (Rodrigues et al., 2020), positive attributes defined by IOC to assess quality of extra-virgin olive oil (International Olive Council, 2017). However, as seen in the results from these participants, consumers do not always prefer these characteristics, confirming the discrepancy that has been emerging in literature between experts and consumers (Rébufa et al., 2021, Pagliuca & Scarpato, 2014). In this study, acceptance of HP-EVOO was more correlated with pleasantness to fruity, while the favorite olive oil – MP-EVOO reveals a strong correlation between global acceptance and likability of the sweet.

A lack of a low polyphenol olive oil, which is mainly due to the high quality of regional olive oils may be considered one of the limitations of this study, and future studies could consider broader composition analysis. Nevertheless, differences between the polyphenol content of tested olive oils are substantial and allowed some observations from this study. It should also be noted that in this study pleasantness of olive oil attributes were measured instead of the attribute itself. For example, an olive oil could be perceived as very sweet and consumers did not like it that way. So, it was tested how the pleasantness of the attribute was related to the global appreciation of the olive oil. These results can help producers to understand some of local consumers' taste preferences. The development of flavored olive oils, masking some of the attributes for

## Correlation matrix of attributes and global appreciation of olive oil



**Fig. 3.** Correlation between olive oil attributes and global acceptance of virgin olive oil (VOO), moderate-polyphenol extra virgin olive oil (MP-EVOO) and high-polyphenol extra virgin olive oil (HP-EVOO). Correlations were tested using Spearman test and presented in the left corner of the spot graphic. Significant correlations ( $p < 0.05$ ) are presented in red. The histograms of each variable appearing along the diagonal, show the range of values for the variable, revealing the underlying shape of distribution.

example, is already a solution with impact in some markets (Issaoui et al., 2016). Other strategies can be recommended to decrease bitterness and pungency attributed to phenols as adding small amounts of proteins to pungent and bitter oils (Gachons et al., 2021).

One of the strengths of this study is the ability to measure the acceptance of a food product without other triggers like brand, origin or price, which could affect the perception of the product, including its taste. While this is a strength of this study it also raises the question of how participants would rate the olive oils if they were aware of their polyphenolic content and their health potential. As also proposed by

Roselli et al. (2027) it is important to educate consumers around the benefits of phenolic compounds and understand how this awareness would influence food preferences and consumers' behaviour.

## 5. Conclusion

In conclusion, this is the first time that Trás-os-Montes olive oils are scientifically evaluated by non-trained consumer participants. These findings are important to understand that when confronted with choosing olive oil based solely on sensorial attributes high-polyphenol

**Table 3**  
Global acceptance of each olive oil by subgroups of the population.

	HP-EVOO	MP-EVOO	VOO
Global (i)	4.58 ± 2.5 <sup>a)</sup>	6.26 ± 2.5 <sup>b)</sup>	5.73 ± 2.5 <sup>b)</sup>
Sex			
Female	3.90 ± 2.2	6.46 ± 2.1	6.06 ± 2.4
Male	5.28 ± 2.7	6.22 ± 2.7	5.54 ± 2.7
p-value (ii)	0.063	0.925	0.510
Nationality			
Portuguese	4.58 ± 2.4	6.29 ± 2.5	5.66 ± 2.6
Other	4.60 ± 2.8	6.22 ± 2.6	5.83 ± 2.5
p-value (iii)	0.927	0.983	0.983

Results are expressed as mean ± SD

HP-EVOO- High-polyphenol extra virgin olive oil; MP-EVOO- Moderate-polyphenol extra virgin olive oil; VOO- Virgin olive oil

i) Upperletters represent differences between groups (when  $p < 0.05$ ) One-way Anova followed by LSD pos-hoc test.

ii) Kruskal-Wallis test statistical differences of acceptance of each oil by sex

iii) Kruskal-Wallis test statistical differences of acceptance of each oil by nationality

olive oils may be at a disadvantage. Since low acceptance of HP-EVOO seemed to be more pronounced in women, masking some of the identified less pleasant attributes may have different impact in men and women, and segmentation of the marketing strategies, or of future studies may be a reasonable approach. This knowledge also sets a framework for future studies targeting other determinants of food preferences in order to increase preference for high polyphenol olive oils. Considering that high polyphenol extra virgin olive oils have a higher potential for health benefits, it is of utmost importance to further explore how to increase valorization of these olive oils by consumers, and how to optimize marketing by producers and dietitians to achieve a common goal of promoting the consumption of high quality and healthier olive oils.

## Ethical Statement

This study was performed in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans and had ethical approval by the Ethic Commission of Institute Polytechnic of Bragança (n°51/2021)

## CRediT authorship contribution statement

**Manuela Meireles:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **João Mendes:** Writing – original draft, Software, Formal analysis, Data curation. **Ana I. Pereira:** Software, Funding acquisition, Conceptualization. **José Alberto Pereira:** Resources, Funding acquisition, Conceptualization. **Nuno Rodrigues:** Writing – review & editing, Resources, Methodology, Investigation, Conceptualization. **Juliana Almeida-de-Souza:** Writing – review & editing, Methodology, Formal analysis, Conceptualization. **Vera Ferro-Lebres:** Writing – review & editing, Resources, Methodology, Conceptualization.

## Declaration of competing interest

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

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## Data availability

Data will be made available on request.

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