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Setting up of a sensory panel for the analysis of water (SUSPAW)

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ABSTRACT

Legislation on the quality of water intended for human consumption requires routine taste and odour controls. So far, no procedures or technical documents exist which can be used as a reference in the training of sensory assessors for tap water. This work presents the procedure for the development of a trained panel and it describes all the steps carried out: the recruitment, pre-selection, selection and training phase considering the different odours and flavours that tap water may contain. In order to analyse the performance of the assessors in the training phase, 6 parameters and 15 criteria are proposed. The assessors who fulfilled the criteria, will integrate a qualified panel to carry out tap water sensory controls. This process has shown to be suitable and strict enough to train assessors on tap water evaluation, and can therefore function as a reference for other laboratories on which to base their training and qualification of assessor panels on tap water quality control.

1. Introduction

By definition, water is a clear liquid, without colour, odour or taste. However, water dissolves substances that can give it odour, taste, flavour and/or colour. Odour and taste compounds in tap water may have several origins, such as natural sources (for example biological activities of algae and heterotrophic microorganisms), anthropogenic contamination, or the treatment or distribution of tap water (Cees et al., 1974; Lin et al., 2019). Consumers mainly judge the quality of water by its taste and odour. They expect it to "taste good" and often associate off-flavours with possible health risks, which often leads to a lack of trust in water supply companies (Suffet et al., 2004). The odours and flavours are produced by substances that can be in very low concentrations that, although perceptible by humans, cannot be measured by instrumental methods (Sancho et al., 1999; Widen et al., 2005; Burlingame et al., 2017). Therefore, in the case of the European Union, the quality of water for human consumption compels water supply companies to carry out routine sensory controls in order to ensure that waters' taste and odour are acceptable to consumer and without abnormal changes (European Commission, 2020). The World Health Organization (WHO) also emphasises the sensory control of organoleptic characteristics of drinking water (WHO, 2022). Thus, in the guidelines for the quality of tap water, it was reported that it must be free of odours and tastes that can be unpleasant for consumers (WHO, 2022). Routine controls with consumers are unfeasible; therefore, to comply with these guidelines and with the previously cited directive (European Commission, 2020), laboratories could apply standardized methods for the determination of waters' flavour and odour by dilution number tests (European Standard, 2006; ASTM, 2021; American Public Health Association, American Water Works Association and Water Environment Federation, 2017) as indicated in previous directives (European Commission, 1980). To comply with goal trained assessors are needed (European Standard, 2006; ASTM, 2021; American Public Health Association, American Water Works Association and Water Environment Federation, 2017).

To set up a trained panel, specific selection and training processes need to be developed. Although there are several general standards for guidance on how to develop assessor selection and training processes (ISO, 2006; ISO, 2011; ISO, 2012), and also specific procedures for some

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products (ISO, 2023; International Olive Council, 2020; Pérez-Elortondo et al., 2007; Etaio et al., 2010; Callejo et al., 2015; Gutiérrez and Barrera, 2015; González-Casado et al., 2019), there are not procedures for water. A standard guide exists entitled "Standard methods for the examination of water and wastewater", where compounds responsible for odour and taste are proposed for the training of tap water assessors (American Public Health Association, American Water Works Association and Water Environment Federation, 2017). There is also an article dedicated to the training and validation of a trained panel for mineral waters (Rey-Salgueiro et al., 2013) it does not detail any procedure (the training process, the description of the sessions or the tests, etc.). In addition, since its aim is the evaluation of bottled mineral waters and carbonated waters, it focuses on the characteristics of these products and the odour compounds used are not compounds previously detected in tap water.

This work aims to describe SUSPAW, a process to create a trained panel for the sensory evaluation of tap water, which includes describing the recruitment, selection, training, and final selection, and also the indicators and criteria that the assessors have to pass. SUSPAW constitutes a guide to design and carry out the creation of a sensory panel for water control that can be very useful for other laboratories working on this field.

2. Materials and methods

2.1. Facilities, apparatus, reference water and chemical compounds (CC)

2.1.1. Facilities

All tests were carried out in sensory evaluation booths designed according to ISO 8589 (ISO, 2007) in the sensory analysis laboratory at the University of the Basque Country (LASEHU), except for general training tests (first phase of the training) which were carried out in another room due to the COVID-19 pandemic (to ensure greater distances between assessors and also better air circulation).

2.1.2. Apparatus

Odour and flavour samples were presented as aqueous solutions. For odour evaluations, 50 mL of sample was served in covered transparent glasses (ISO, 1977). For flavour 40 mL of sample was served in 50 mL glasses to enable candidates to test samples several times before deciding on their answer and to taste the sample again once the exercise had been corrected. Samples were codified with 3-digit random numbers.

2.1.3. Reference water (RW)

RW is a water described as odourless and tasteless by the assessors' panel (European Standard, 2006). It was used to compare with the samples and determine if differences in odour/flavour intensity were detected; it was also used to prepare dilutions (the successive dilutions of drinking water samples and the dilutions of chemical references). The European Standard 1622 (European Standard, 2006) proposes different types of water that can be used for this purpose: tap water, bottled mineral water, or water prepared using activated carbon, but it does not indicate how to choose between these different options. Experience has shown us that not all waters are useful for these purposes: i) bottled mineral waters can provide different flavour depending on the mineral content; ii) tap water can have both odours and flavour and its organoleptic properties are not constant throughout the year; iii) water obtained by activated carbon requires a more laborious and expensive procedure.

After a preselection phase involving several waters (milliQ, distilled and tap water, and three bottled waters [Aquabona by Santolín spring, Fontecelta and Evian]) carried out by five members from the research team, it was determined that bottled mineral waters had lower levels of odours and flavour.

To select the RW among the mineral waters, the three mineral waters were compared using unforced triangular tests by 34 assessors (who had previously passed the preselection and selection phases). The test was carried out twice (n = 68). In each session, assessors monadically evaluated six sample triads for odour and six sample triads for flavour. If assessors detected differences in the odour/flavour intensity among the samples of the triad, they had to indicate which sample was different and why by choosing either: "smells/tastes more" or "smells/tastes less". The six possible sample presentation orders were presented the same number of times.

According to the results of the odour tests, there were no statistically significant differences between the three waters ($\alpha = 0.05$). For flavour, the differences were statistically significant between Evian and Fontecelta (Evian has a higher intensity of flavour) and between Aquabona and Fontecelta (it was not possible to know which water had a higher intensity of flavour). Therefore, Evian was excluded as a possible RW, and Aquabona (Santolín spring, by Coca-Cola) was selected for availability reasons. Aquabona has weak mineralization and low sodium content. Its chemical composition is the following, expressed as mg/L: dry residue (180 °C): 271; bicarbonates: 276; sulphates: 6.5; chlorides: 4.4; calcium: 92.2; magnesium: 2.8; sodium: 2.0.

2.1.4. Chemical compounds (CC)

For the specific training, odour and flavour compounds reported as present in water and recommended for the specific training of drinking water panels (American Public Health Association, American Water Works Association and Water Environment Federation, 2017) were used. Some of them are also included in general assessors' selection and training standards (ISO, 2006; ISO, 2011; ISO, 2012). The concentration of the references prepared with these CC was adjusted throughout the different phases of the study, according to the objective of each test.

Odour and flavour CC and concentrations used during all the process are shown in Tables 1 and 2.

2.2. Phases for sensory panel development

The process of panel development was carried out in the four different phases described below.

2.2.1. Recruitment

To recruit the candidates a message was distributed using different means: emails to consumers included in the laboratory's database, internal dissemination through the university, social media, etc. The interested candidates had to complete a questionnaire with their data (name and surname, place of residence, employment status, and smoking habits), and their availability during the week.

On the basis of an estimate of 40 samples to be evaluated per month in four sessions for the future routine quality control, the objective was to form a panel of 20 assessors.

According to ISO 8586 (ISO, 2012), at least two or three times the number of assessors needed should be recruited. Teillet reported recruiting 74 candidates to form a panel of 15 water assessors (Teillet, 2009). As a result, in the present study, 91 candidates were recruited (out of a total of 135 interested people) to begin the preselection phase (Table 3).

The criteria used to preselect candidates from those interested people included the following: under 60 years old, place of residence in Vitoria-Gasteiz, non-smokers, and non-students.

2.2.2. Preselection

The aim was to detect and exclude those candidates who were significantly unable to detect odours in water.

A triangle test (ISO, 2021) was used to accomplish the objective: 10 odour triads were presented, which consisted of two samples of an odorous CC diluted in water and one sample of milli Q water (odourless sample), or one sample of an odorous CC diluted in water and two samples of milli Q water. Each sample (S) was presented in the two types of triads (1RW – 2S: 1 RW samples and 2 CC dilution sample; 2RW – 1S: 2

Table 1
Tests, CC and concentrations used in the selection of sensory assessors.

Test	Objective	Sample presentation	CC and [C]
Triangle[a]	Determining the smell/flavour sensitivity	8 triads	1. Geosmin / 2-methylisoborneol mixture[b, c]: $5{\cdot}10^{-3}$ µg/L[c] 2. 4-clorophenol[b]: 4 µg/L[c] 3. Sodium hypochlorite[c]: 200 µg/L[c] 4. Cis-3-hexen-1-ol[a, b, d]: $5{\cdot}10^{3}$ µg/L[d] 5. 1-octen-3-ol[a, d]: 500 µg/L[d]
		9 triads	1. Citric acid[b, c]: 0.2 g/L[a] 2. Caffeine[a, b, d]: 0.2 g/L[a] 3. Sodium chloride[a, b, d]: 1.3 g/L[a] 4. Sucrose[a, b, d]: 6 g/L 5. Bicarbonate of soda[c]: 1.25 g/L[c]
Ranking[a]	Determining the ability to discriminate between different concentrations of the same stimulus	4 series of 3 samples	1. Geosmin / 2-methylisoborneol mixture[b, c]: $5-10-20\cdot10^{-3}$ µg/L[c] 2. 4-clorophenol[b]: 2 – 8 – 32 µg/L[c] 3. Sodium hypochlorite[c]: 100 – 200 – 400 µg/L[c] 4. Cis-3-hexen-1-ol[a, b, d]: $2.5-5-10\cdot10^{3}$ µg/L[d]
			1. Citric acid[b, c]: 0.25 – 0.5 – 1 g/L[a] 2. Caffeine[a, b, d]: 0.25 – 0.5 – 1 g/L[a] 3. Sodium chloride[a, b, d]: 2 – 3.5 – 5 g/L[a] 4. Sucrose[a, b, d]: 5 – 10 – 15 g/L[a]
Pairing test[a]	Determining the ability to detect and link the same stimulus	3 blocks of 6 samples	1. Geosmin / 2-methylisoborneol mixture[b, c]: $5{\cdot}10^{-3}$ µg/L[c] 2. 4-clorophenol[b]: 12 µg/L[c] 3. Vanillin[a, e]: $10{\cdot}10^{6}$ µg/L[c] 4. Sodium hypochlorite[b, c]: 180 µg/L[c] 5. Cis-3-hexen-1-ol[a, b, d]: $5{\cdot}10^{3}$ µg/L[f] 6. 1-octen-3-ol[a, d]: $0.5{\cdot}10^{3}$ µg/L[d]
			1. Citric acid: 0.3 g/L[a] 2. Caffeine: 0.3 g/L[a] 3. Sodium chloride: 2 g/L[a] 4. Sucrose: 10 g/L[a] 5. Tannic acid: 1 g/L[a] 6. Ferrous sulphate heptahydrate: 0.01 g/L[a]
Stimulus identification/ description[a]	To gain knowledge about the ability to detect and describe different stimuli.	8 samples	1. Hexanal[b]: 30 µg/L[c] 2. Dimethyl disulphide[b]: 30 µg/L[c] 3. 2-Isopropyl-3-methoxypyrazine[b]: 30 µg/L[c] 4. 2-methylisoborneol[b]: 0.1 µg/L[c] 5. Geosmin[b]: 0.3 µg/L[b] 6. 2,4-diclorophenol[b, c]: 16 µg/L[c] 7. Cis-3-hexen-1-ol[a, b, d]: 500 µg/L[b] 8. β-ionone: 500µg/L[d] 9. Citral: 1000µg/L[d] [g]
		9 samples	1. Citric acid: 0.28 g/L[e] 2. Caffeine: 0.195g/L[e] 3. Sodium chloride: 1.19g/L[e] 4. Sucrose: 5.76g/L[e] 5. Tannic acid: 1g/L[e] 6. Ferrous sulphate heptahydrate: $3.6{\cdot}10^{-3}$ g/L[e] 7. RW [h]

CC: chemical compounds; [C]: concentration; RW: reference water. In the "CC" and "[C]" columns: grey lines indicate odour and white lines flavour. [a]Tests/CC/[C] proposed by ISO 8586 [15]. CC/[C] proposed by: [b]APHA, AWWA and WEF [11]; [c]Internal criterion; [d]ISO 5496 [13]; [f]ISO 3972 [14]. [e]At the first time, CC nº 1, 2, 3 and 4 were presented and in the repetition of the test CC nº 1, 2, 3 and 5. [g]At the first time, all CC except nº 9 were presented and in the repetition all CC except nº8. [h]2 CC were presented twice: At the first time, CC nº 1 and 6 were presented twice and in the repetition CC nº 2 and 4.

CC: chemical compounds; [C]: concentration; RW: reference water. In the "CC" and "[C]" columns: grey lines indicate odour and white lines flavour. [a]Tests/CC/[C] proposed by ISO 8586 (ISO, 2012). CC/[C] proposed by: [b]APHA, AWWA and WEF (American Public Health Association, American Water Works Association and Water Environment Federation, 2017); [c]Internal criterion; [d]ISO 5496 (ISO, 2006); [f]ISO 3972 (ISO, 2011). [e]At the first time, CC nº 1, 2, 3 and 4 were presented and in the repetition of the test CC nº 1, 2, 3 and 5. [g]At the first time, all CC except nº 9 were presented and in the repetition all CC except nº8. [h]Two CC were presented twice: At the first time, CC nº 1 and 6 were presented twice and in the repetition CC nº 2 and 4.

RW sample and 1 CC dilution samples).

The odorous CC used were those that frequently appear in tap water (Lin et al., 2019; Zhang et al., 2022): a mixture of geosmin and 2-methylisoborneol (5 and 10 ng/L, respectively) (Piriou et al., 2009; Kakimoto et al., 2014; Zamyadi et al., 2015; Shawwa et al., 2022), 4-chlorophenol (4 µg/L) and 2,4-dichlorophenol (8 and 16 µg/L) (Zhang et al., 2022; Jiang et al., 2023; Bruchet et al., 2008). All concentrations were determined based on preliminary tests carried out by the research team. A commercial mixture of geosmine and 2-methylisoborneol (AccuStandard) was used because the two compounds belong to the same family of odours: earthy/musty/mouldy (American Public Health Association, American Water Works Association and Water Environment

Federation, 2017).

All candidates evaluated the triads in the same order. The samples were presented to the candidates in two groups of five triads. Between the groups, the candidates took a 5 min rest.

The preselection test was considered passed if the following criteria were fulfilled: at least one correct answer for each compound used in the test (as the main aim of the criteria was to make sure that the candidates perceived the CC as they appear commonly in tap water) and at least 60% of correct answers (to pre-select those candidates with the higher acuity, also taking into account that the used concentrations were a bit higher than the threshold).

2.2.2.1. Selection. Before initiating the selection phase, an e-mail was sent to each candidate with information about the basic guidelines for

Table 2
Training phase tests, chemical compound and concentrations.

Tests	Sample presentation	CC and [C]	S
		Familiarization with sensory analysis tests and CC	
Stimulus description[a]	19 samples	Methyl tert-butyl ether (MtBE)[b] 100 μg/L[c]; Phenol[b] 3mg/L[c]; Iodomethane[b] 500 mg/L[c]; *trans, trans*-2,4-Heptadienal[b] 2 mg/L[c]; Decanal[b] 2mg/L[c]; Hydrogen Sulphide[b] 2 mg/L[c]; Isopropyl mercaptan[b] 0.25 mg/L[c]; cis-3-Hexenyl acetate[b] 500 μg/L[b]; β-cyclocitral[b] 2 mg/L[c]; 2,3-Dichloroanisole[b] 2 mg/L[c]; 1-Dodecanol[b] 2 mg/L[c]; 2-methylisoborneol[b] 100ng/L[c]; 4-Chlorophenol[b] 20 μg/L[c]; 2,4-Dichlorophenol[b] 32 μg/L[c]; Geosmin[b] 300 ng/L[b]; Hexanal[b] 30μg/L[c]; Dimethyl Disulphide[b] 30 μg/L[c]; 2-Isopropyl-3-Methoxypyrazine[b] 30μg/L[c]; cis-3-Hexenol[a,b,d] 500 μg/L[b].	1
	15 samples	Decanal[b] 2mg/L[c]; Trimethyl Disulphide[b] 30 μg/L[c]; Iodomethane[b] 75 mg/L[c]; Hexanal[b] 100μg/L[c]; Phenol[b] 6 mg/L[c]; trans-2,cis-Nonadienal[b] 2mg/L[c]; Octanal[b] 2mg/L[c]; 3-Hexenylacetate[b] 500 μg/L[b]; Isopropyl mercaptan[b] 0.15mg/L[c]; 1-Dodecanol[b] 2mg/L[c]; 4-Chlorophenol[b, c] 40 μg/L[c]; Dimethyl Disulphide[b] 100μg/L[c]; β-cyclocitral[b] 2mg/L[c]; Cis-3-hexenol[a, b, d] 2mg/L[c]; 2,3-Dichloroanisole[b] 2mg/L[c].	2
		4-Chlorophenol[b] 60 μg/L[c]; Hexanal[b] 100μg/L[c]; 1-Dodecanol[b] 2 mg/L[c]; 2-Methylisoborneol[b] 0.1 μg/L[c]; Decanal[b] 3 mg/L[c]; *trans, trans*-2,4-Heptadienal[b] 2 mg/L[c]; Phenol[b] 6 mg/L[c]; Dimethyl Disulphide[b] 200 μg/L[c]; 2,4-Dichlorophenol[b] 32 μg/L[c]; trans-2,cis-Nonadienal[b] 2 mg/L[c] ; 3-Hexenylacetate[b] 500 μg/L[c]; Geosmin[b] 0.3 μg/L[b]; 2,3-Dichloroanisole[b] 2mg/L[c]; 2-Isopropyl-3-Methoxypyrazine[b] 30 μg/L[c]; β-cyclocitral[b] 2 mg/L[c]; MtBE[b] 400 μg/L[c].	3
	7 samples	4-Chlorophenol[b] 60 μg/L[c]; MtBE[b] 550 μg/L[c]; 1-Dodecanol[b] 2 mg/L[c]; 2,3-dichloroanisole[b] 2 mg/L[c]; *trans, trans*-2,4-Heptadienal[b] 2 mg/L[c]; 3-Hexenylacetate[b] 500 μg/L[b]; β-cyclocitral[b] 2 mg/L[c].	4
	1 samples	MtBE[b] 550 μg/L[c].	5
Familiarization[c]	4 samples	Caffeine 0.195 g/L[e]; Sodium chloride 1.19 g/L[e]; Ferrous sulphate heptahydrate 0.0036 g/L[e]; Tannic acid: 1 g/L[a,c].	1
Identification[a]	4 samples	Caffeine 0.195 g/L[e]; Sodium chloride 1.19 g/L[e]; Ferrous sulphate heptahydrate 0.0036 g/L[e]; Tannic acid 1 g/L[a,c].	1
	4 samples and 2 reps.	Caffeine 0.5 g/L[c]; Sodium chloride 1.5 g/L[c]; Ferrous sulphate heptahydrate 0.0036 g/L[e]; Tannic acid 0.8 g/L[c].	2
		Caffeine 0.35 g/L[c]; Sodium chloride 1.3 g/L[c]; Ferrous sulphate heptahydrate 0.0036 g/L[e]; Tannic acid 0.7 g/L[c].	3
		Caffeine 0.35 g/L[c]; Sodium chloride 1.3 g/L[c]; Ferrous sulphate heptahydrate 0.0036 g/L[e]; Tannic acid 0.6 g/L[c].	4
Ranking and identification[a,c]	3 series	2,4-Dichlorophenol[b] 2 – 8 – 16 μg/L[c]; Geosmin[b] 0.1 – 0.2 – 0.4 μg/L[c]; Sodium hypochlorite[b]: 100 – 200 – 400 μg/L[c] .	3
	4 series	Caffeine 1 – 0.5 – 0.25 g/L[c]; Tannic acid 1 – 0.4 – 0.16 g/L[c]; Ferrous sulphate heptahydrate 0.0108 – 0.0036 – 0.0012 g/L[c]; Sodium chloride 5 – 2 – 0.8 g/L[c].	1
		Caffeine 1 – 0.5 – 0.25 g/L[c]; Tannic acid 0.9 – 0.45 – 0.225 g/L[c]; Ferrous sulphate heptahydrate 0.0126 – 0.0036 – 0.00102 g/L[c]; Sodium chloride 3.2 – 1.6 – 0.8 g/L[c].	2
		Caffeine 0.9 – 0.45 – 0.225 g/L[c]; Tannic acid 0.8 – 0.4 – 0.2 g/L[c]; Ferrous sulphate heptahydrate 0.0126 – 0.0036 – 0.00102 g/L[c]; Sodium chloride 3 – 1.5 – 0.75 g/L[c].	3
		Caffeine 0.8 – 0.4 – 0.2 g/L[c]; Tannic acid 0.72 – 0.36 – 0.18 g/L[c]; Ferrous sulphate heptahydrate 0.0126 – 0.0036 – 0.00102 g/L[c]; Sodium chloride 2.8 – 1.4 – 0.7 g/L[c].	4
Ranking[a]	3 series	2,4-Dichlorophenol[b] 2 – 8 – 16 μg/L[c]; Geosmin[b] 0.08 – 0.2 – 0.5 μg/L[c]; Sodium hypochlorite[b]: 100 – 250 – 625 μg/L[c] .	4
Paired comparison and stimulus description[a,c]	19 pairs and 2 CP	Geosmin[b] 35 and 70ng/L[c]; 4-Chlorophenol[b] 8 and 20 μg/L[c]; 2-Methylisoborneol[b] 40 and 60ng/L[c]; 2,4-Dichlorophenol[b] 1.6 and 3.2 μg/L[c]; Sodium hypochlorite[c] 0.09 and 0.2mg/L[c]; Decanal[b] 0.04 mg/L[c]; Trimethyl Disulphide de[b] 6 μg/l[c]; Hexanal[b] 20 μg/L[c]; trans-2,cis-Nonadienal[b] 0.04 mg/L[c]; Octanal[b] 0.05 mg/L[c]; 3-Hexenilacetato[b] 80 μg/L[c]; Isopropyl mercaptan[b] 0.025 mg/L[c]; β-cyclocitral[b] 0.1 mg/L[c]; Iodomethane[b] 18 mg/L[c].	5
	11 pairs and 1 CP	Caffeine 0.1 and 0.2 g/L[c];Citric acid 1.3 and 1.7 g/L[c]; Ferrous sulphate heptahydrate 0.0005 y 0.001 g/L[c]; Tannic acid 0.09 and 0.18 g/L[c]; Sodium chloride 0.35 g/L[c].	
	24 pairs and 3 CP	4-Chlorophenol[b,c] 10 y 16 μg/L[c]; Geosmin[b] 20 y 30 ng/L[c]; Sodium hypochlorite[c] 0.4 mg/L[c]; 2-Methylisoborneol[b] 20 y 30 ng/L[c]; 2,4-Dichlorophenol 0.7 y 1 μg/L[c]; Dimethyl Disulphide[b] 30 μg/L[c]; 2,3-Dichloroanisole[b] 0.3 mg/L[b]; 1-Dodecanol[b] 0.8 mg/L[c]; 2-isopropyl-3-methoxipyrazine[b] 5μg/L[c]; Hydrogen Sulphide[b] 1 mg/L[c]; Cis-3-Hexenol[a,b,d] 200μg/l[c]; Phenol[b, c] 1.8 mg/L[c]; MtBE [b] 200μg/l[c]; *trans, trans*-2,4-Heptadienal[b] 0.5 mg/L[c].	6
	10 pairs	Ferrous sulphate heptahydrate 0.00035 y 0.0005 g/L[c]; Caffeine 0.12 y 0.18 g/L[c]; Citric acid 0.8 y 0.4 g/L[c]; Tannic acid 0.13 y 0.09 g/L[c]; Sucrose 5 g/L[c]; Sodium chloride 0.35 g/L[c].	
	18 pairs and 3 CP	Dimethyl Disulphide[b] 8 μg/L[c]; 2,3-Dicloroanisole[b] 30 μg/L[c]; 1-Dodecanol[b] 0.17 mg/L[c]; Hydrogen Sulphide[b] 0.1 mg/L[c]; Cis-3-Hexenol[a,b,d] 70 μg/L[c]; Phenol[b, c] 0.8 mg/L[c]; MtBE[b] 90 μg/L[c]; *trans, trans*-2,4-Heptadienal[b] 0.1 mg/L[c]; Trimethyl Disulphide[b] 1.8 μg/L[c]; Hexanal[b] 10.8 μg/L[c]; trans-2,cis-Nonadienal[b] 6 μg /L[c]; Decanal[b] 0.036 mg/L[c]; Octanal[b] 0.016 mg/L[c]; 3-Hexenylacetate[b] 20 μg/L[c]; Isopropyl mercaptan[b] 10 μg/L[c]; β-cyclocitral[b] 0.22 mg/L[c]; Iodomethane[b] 10 mg/L[c]; 2-isopropyl-3-methoxipyrazine[b] 0.3 μg/L[c].	7
	8 pairs and 3 CP	Caffeine 0.14 and 0.17 g/L[c]; Sodium chloride 0.41 g/L[c]; Ferrous sulphate heptahydrate 0.00033 and 0.00035 g/L[c]; Tannic acid 0.06 and 0.08 g/L[c]; Citric acid 0.36 g/L[c].	
Paired comparison[a]	3 pairs	Sodium Hipoclorite 0.1mg/L[c]; Geosmin[b] 80ng/L[c]; 2,4-Dichlorophenol[b] 2 μg/L[c].	4
	5 pairs	Ferrous sulphate heptahydrate 0.001 g/L[c]; Sodium chloride 0.7 g/L[c]; Caffeine 0.2 g/L[c]; Tannic acid 0.18 g/L[c].	
	9 pairs and 3 CP	Tap water and its dilutions (1/2 and 1/4)	8, 9 and 10
	6 pairs and 2 CP	Tap water and its dilutions (1/2 and 1/4)	
	7 pairs	4-Chlorophenol[b,c] 8μg/L[c]; 2,4-Dichlorophenol[b,c] 0.4 μg/L[c]; Geosmin[b] 4ng/L[c]; 2-Metilisoborneol[b] 4 ng/L[c]; Trimethyl Disulphide[b] 0.18 μg/L[c]; Dimethyl Disulphide[b] 1 μg/L[c]; *trans, trans*-2,4-Heptadienal [b] 10 g/L[c].	9

	15 pairs	Geosmin[b] 2.5ng/L[c]; MtBE[b] 6μg/L[c]; Iodomethane[b] 1μg/L[c]; Phenol[b,c] 1 μg/L[c]; Octanal[b] 25 μg/L[c]; Hexanal[b] 5 μg/L[c]; trans-2,cis-Nonadienal[b] 150 μg/L[c]; Cis-3-Hexenol[a, b, d] 17 μg/L[c]; 1-Dodecanol 4 μg/L[c]; β-cyclocitral[b] 0.018 μg/L[c]; 3-Hexenylacetate[b] 0.03 μg/L[c]; Dimethyl Disulphide[b] 3 μg/L[c]; 2-Isopropyl-3-Methoxypyrazine[b] 500 μg/L[c]; Trimethyl Disulphide[b] 1 mg/L[c]; 2,3-Dichloroanisole[b] 10 μg/L[c].	10
	23 pairs and 1 CP	2,4-Dichlorophenol[c] 0.55 μg/L[c]; Octanal[b] 11 μg/L[c]; Hexanal[b] 7 μg/L[c]; trans-2,cis-Nonadienal[b] 3.5 μg/L[c]; 3-Hexenylacetato[b] 10 μg/L[c]; β-cyclocitral[b] 120 μg/L[c]; Cis-3-Hexenol[a, b, d] 5 μg/l[c]; Dimethyl Disulphide de[b] 6 μg/l[c]; 2-Isopropyl-3-Methoxypyrazine[b] 0.25 and 1 ng/L[c]; 2,3-Dichloroanisole[b] 0.3 and 0.9 μg/L[c]; 1-Dodecanol[b] 0.1 and 1 μg/L[c]; 2-Methylisoborneol[b] 3 ng/l[c]; Trimethyl Disulphide[b] 0.035 and 0.07 μg/L[c]; Iodomethane[b] 4 mg/L[c]; MtBE[b] 40 μg/L[c]; *trans, trans*-2,4-Heptadienal[b] 25 μg/L[c]; Isopropyl mercaptan[b] 15 μg/L[c]; Phenol[b, c] 50 μg/L[c]; Hydrogen Sulphide[b] 500 μg/L[c].	11
	28 pairs and 1 CP	2,4-Dichlorophenol[b, c] 0.45 and 0.5 μg/L[c]; Geosmine[b] 2 ng/L[c]; 2-Methylisoborneol[b] 2 ng/L[c]; Cis-3-Hexenol[a, b, d] 1 and 3 μg/L[c]; Hexanal[b] 8 and 9 μg/L[c]; Octanal[b] 8 μg/l[c]; β-cyclocitral[b] 110 μg/L[c]; 1-Dodecanol[b] 0.5 μg/L[c]; trans-2,cis-Nonadienal[b] 1.5 μg/L[c]; Dimethyl Disulphide[b] 5 μg/L[c]; Trimethyl Disulphide[b] 0.02 μg/L[c]; Hydrogen Sulphide[b] 150 and 200 μg/L[c]; Phenol[b, c] 150 and 200 μg/ [c]; Iodomethane[b] 2 mg/L[c]; 4-Clorophenol[b, c] 10μg/L[c]; 3-Hexenylacetate[b] 6 μg/L[c]; MtBE[b] 50 and 60 μg/L[c]; *trans, trans*-2,4-Heptadienal[b] 15 μg/L[c]; Isopropyl mercaptan[b] 16 μg/L[c]; 2-Isopropyl-3-Methoxypyrazine[b] 0.05 ng/L; 2,3-Dichloroanisole[b] 1.5 μg/L[c].	12
	13 pairs and 1 CP	1-Dodecanol[b] 1.5 μg/L[c]; Trimethyl Disulphide[b] 0.02 μg/L[c]; trans-2,cis-Nonadienal[b] 2 and 2.5 μg/L[c]; Cis-3-Hexenol[a, b, d] 4 μg/L[c]; 2-Isopropyl-3-Methoxypyrazine[b] 0.1 ng/L[c]; 2,3-Dichloroanisole[c] 2.5 μg/L[c]; β-cyclocitral[b] 100 μg/L[c]; 3-Hexenylacetate[b] 6 μg/L[c]; Dimethyl Disulphide[b] 3 μg/L[c]; Iodomethane[b] 1.3 mg/L[c]; MtBE[b] 45 μg/L[c]; Hydrogen Sulphide[b] 120 μg /L[c].	13
	12 pairs	1-Dodecanol[b] 1.5 μg/L[c]; Decanal[b] 30 μg/L[c]; 3-Hexenylacetate[b] 5.5 μg/L[c]; β-cyclocitral[b] 80 μg/L[c]; Octanal[b] 7.5 μg/L[c]; 2-Isopropyl-3-Methoxypyrazine[b] 0.15 ng/L[c]; Dimethyl Disulphide[b] 4 μg/L[c]; MtBE[b] 40 μg/L[c]; Trimethyl Disulphide[b] 0.025 μg/L[c] ; Iodomethane[b] 1.6 mg/L[c] ; Isopropyl mercaptan[b] 16 μg/L[c]; Hydrogen Sulphide[b] 100 μg/L[c].	14
	19 pairs and 1 CP	Isopropyl mercaptan[b] 20 and 25 μg/L[c]; 2-Isopropyl-3-Methoxypyrazine[b] 0.25 and 0.5 ng/L[c]; Decanal[b] 20 and 25 μg/L[c]; trans-2,cis-Nonadienal[b] 2.25 μg/L[c]; 3-Hexenylacetate[b] 4 and 5 μg/L[c]; Trimethyl Disulphide[b] 0.025, 0.03 and 0.05 μg/L[c]; β-cyclocitral[b] 60 and 70 μg/L[c]; 1-Dodecanol[b] 2.5 and 4 μg/L[c]; Hydrogen Sulphide[b] 50, 70 and 85 μg/L[c].	15
Familiarization with the routine control method			
Paired comparison[a]	17 pairs and 2 CP	Tap water and its dilutions (1/2, 1/4) or only dilutions (1/2, 1/4, 1/8), depending on the odour/flavour of the original sample	16-20
		Tap water and its dilutions (1/2, 1/4) or only dilutions (1/2, 1/4, 1/8) depending on the odour/flavour of the original sample	
Determination of the individual odour threshold			
Paired comparison[a]	15 pairs	Geosmina[b] 1.25, 2.5, 5, 10 and 20 ng/L[c]; 2-metilisoborneol[b] 0.625, 1.25, 2.5, 5 and 10 ng/L[c]; 2,4-diclorofenol[b,c] 1, 2, 4, 8 and 16 μg/L[c].	21
		4-chlorophenol[b,c] 0.0078, 0.0156, 0.0313, 0.0625, 0.125, 1.25, 2.5, 5, 10 y 20 μg/L; Hypochlorite[c] 0.1, 0.2, 0.4, 0.8 y 1.6 mg/L[c].	22

CC: chemical compounds; [C]: concentration; RW: reference water; S: session; CP: Control pairs. The series were made up of three samples. In the "CC" and "[C]" columns: grey lines indicate odour and white lines flavour. [a]Test/CC/[C] proposed by ISO 8586 [15]; CC/[C] proposed by: [b]APHA, AWWA and WEF [18]; [c]Internal criterion; [d]ISO 5496 [13]; [e]ISO 3972 [14]. All flavour CC were proposed by ISO [14,15] and APHA, AWWA and WEF [11].

CC: chemical compounds; [C]: concentration; RW: reference water; S: session; CP: Control pairs. The series were made up of three samples. In the "CC" and "[C]" columns: grey lines indicate odour and white lines flavour. [a]Test/CC/[C] proposed by ISO 8586 (ISO, 2012); CC/[C] proposed by: [b]APHA, AWWA and WEF (Pérez-Elortondo et al., 2007); [c]Internal criterion; [d]ISO 5496 (ISO, 2006); [e]ISO 3972 (ISO, 2011). All flavour CC were proposed by ISO (ISO, 2011; ISO, 2012) and APHA, AWWA and WEF (American Public Health Association, American Water Works Association and Water Environment Federation, 2017).

Table 3
Number of candidates who started, completed and passed each phase.

Phase	Starting candidates	Candidates who passed the criteria (n and %)	
Recruitment	**135** (71/64)	**91** (50/41)	**67**
Preselection	**78** (45/33)	**61** (37/24)	**78**
Selection	**46**[a] (30/16)	**36** (26/10)	**78**
Training	**35**[b] (25/9)	**22** (17/5)	**61**

Numbers in brackets: women/men.
[a] 49 candidates started the selection phase, but 3 of them did not complete it.
[b] 36 candidates started the training phase but, one of them did not complete it.

carrying out the sensory analysis tests.

The aim of the selection tests were to detect smelling and tasting problems, to check the sensory acuity of the candidates and to evaluate their ability to describe and communicate sensory perceptions (ISO, 2012). In order to achieve this, the tests described in Table 1 were carried out twice through four sessions of 90 min each. All candidates conducted the same tests in the same order.

The criteria to overcome the selection phase was to respond correctly to no less than 60% of the trials in at least six of the eight tests.

2.2.3. Training

Training was carried out in three phases organised according to the objective to be achieved in each one (Fig. 1).

At the beginning of the training phase, high concentrations were used so that assessors could clearly identify and perceive the odour or flavour emitted by each CC and to learn to recognise and differentiate among them. As the sessions progressed, the concentrations were gradually decreased until they were perceived by three-quarters of the panel (Table 2).

A total of 22 training sessions of approximately 90 min were held over seven months. Assessors did not attend more than one session per week.

2.2.3.1. First phase: familiarization with sensory tests and CC. The aim of this first phase was to develop the ability to recognise, describe, and distinguish sensory stimuli that may appear in tap water, and to train assessors to detect very low concentrations.

In all sessions, after carrying out the tests individually, the answers were checked and assessors smelled or tasted the samples again, and discussed the difficulties. To avoid sensory fatigue, odour and flavour tests were alternated and, where it was not possible, breaks of 10 min were established between consecutive tests.

The paired comparison odour tests were based on those described in the ISO standard (ISO, 2005), but with the following variations: unforced selection, sample pairs where both were RW, pairs with the same concentration of the same compound, pairs with different concentrations of the same compound, and, in some cases, questions about intensity and descriptors. WR pairs or pairs with samples with the same concentration were used as controls to detect assessors who tended to answer even when there were no differences between samples.

Besides training in detecting odour compounds that may appear in tap water, assessors began to familiarise themselves with evaluating tap water samples. Therefore, in some sessions samples prepared with odour CC were used, while in other sessions samples prepared from tap water

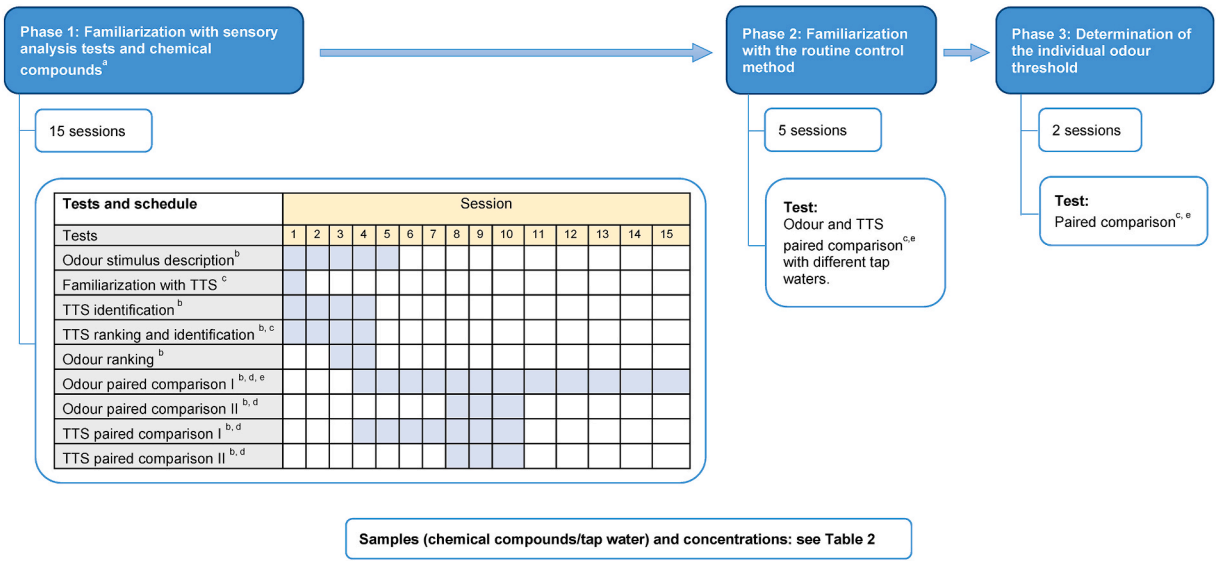

Fig. 1. Phases of the training. TTS: Taste and trigeminal sensations; Odour/TTS paired comparison I: samples prepared with chemical compounds; Odour/TTS paired comparison II: samples were tap water from different municipalities and its dilutions. [a]A Phase designed according to ISO standards (ISO, 2006; ISO, 2011; ISO, 2012) and the methodology that the panel would use in the future routine controls. [b]Test proposed by ISO 8586 (ISO, 2012); [c]Test proposed by internal criterion; [d]Test proposed by ISO 5495 (ISO, 2005). [e]Unforced-choice paired comparison tests.

and its dilutions were used.

Concentrations of the CC were adjusted according to the correct answer percentage of the previous session, and based on the results for each pair (S - RW), until about three-quarters of the panel perceived the odour.

In the sessions focused on evaluating tap water samples and its dilutions, tap water samples from several municipalities were used. The samples were presented as a series of three concentrations: the sample (FD1), half-diluted sample (FD2) and quarter-diluted sample (FD4). The series were always presented in order of increasing concentrations, starting with the most diluted (FD4). One of the series was presented twice to check the repeatability of the assessors.

2.2.3.2. Second phase: familiarization with the routine control method. The second phase aimed to train and familiarise the assessors with the method. These sessions reproduced what would later be performed in routine tap water control sessions, once the panel had been formed. The method was based on the determination of the TON and TFN (European Standard, 2006).

2.2.3.3. Third phase: determination of the individual odour threshold. The third phase aimed to determine the individual odour thresholds for the four compounds most frequently found in water (Lin et al., 2019) in order to calculate the panel thresholds (Piriou et al., 2009). Different concentrations of each compound were presented (Table 2) at increasing concentrations. A maximum of 15 pairs of samples were evaluated in each session. To avoid sensory fatigue, assessors had to rest for a minute between pairs of samples, and 5 min between the 5th and 6th and 10th and 11th pairs.

If there were any inconsistencies in the assessor's responses (they perceived a stimulus at lower concentrations and did not perceive it at higher concentrations), the evaluation of the sample in question was repeated. If in the second evaluation this incoherence in perception was repeated, the lowest concentration detected without any incoherence was recorded as the detection threshold.

From the individual thresholds determined in these tests, a panel threshold was calculated according to the method described by Lawless (2010). The panel threshold was the concentration in which 75% of the assessors perceived differences between the sample and the RW (International Olive Council, 2020).

2.2.4. Final selection

In order to evaluate the competence of the assessors in the training process, six parameters and 15 criteria were established (Table 3). Studied parameters were established based on the results of the three training phases: familiarization with sensory analysis tests and CC (7th to 15th sessions); familiarization with the method of these familiarity tests (16th to 20th sessions), and individual odour threshold determination tests (21st to 22nd sessions).

To pass the training phase and be incorporated into the panel, assessors had to overcome at least 10 of the 15 criteria (66%) (Table 3). When an assessor passed the final selection, her/his attitude during the training (sessions' attendance, responsibility …) was also taken into consideration.

3. Results and discussion

3.1. Assessor preselection, selection and panel training

Table 3 shows the number of assessors who started, finished and passed each training phase, and the final selection. From the 91 recruited candidates, 78 began the process. Not all candidates who passed the recruitment began the preselection, and the same happened in the selection, for various reasons: unavailability, lack of interest in evaluating always the same product, illness and change of residence. After the entire process, a panel of 22 assessors was formed. Table 3 also shows the ratio of women and men who started and finished each phases. Although recruited women/men ratio was 1.2, the women/men ratio for assessors making up the final panel was 3.4. These results may suggest that women have greater sensory acuity than men, a fact that has also been reported by other authors (Pepino and Mennella, 2007). Regarding the influence of age on sensory abilities, the literature reports that capacity decreases with age (Burlingame et al., 2017; Doty et al., 2001). Fot this reason, people over sixty years were excluded in the recruitment process. In this study, 20 candidates aged 18–35 started the pre-selection tests, 32 candidates aged 36–50 and 26 candidates aged 51–59 and became panel members 9 (45.0%), 10 (31.3%) and 3 (11.5%), respectively. Thus, the candidates with the highest pass rate were the youngest.

3.1.1. Preselection

Table 5 shows the concentrations detected by approximately 75% of participants.

There was little difference in the number of correct answers among the different compounds (between 67% and 78% correct answers). The triad with the greatest difficulty to obtain correct answers was that containing low concentration of 2,4-dichlorophenol.

3.1.2. Selection

The results of the selection tests are shown in Table 6. From the 49 candidates who started the selection phase, 46 completed the entire process. All tests were passed by at least 31 assessors (67.4%), except for the odour stimulus description test, which was only passed by 17 assessors (37.0%). That test proved to be the most difficult, since candidates, in addition to detecting and arranging different intensities, also had to assign descriptors. Another factor that could have influenced the results was that participants were not used to these kinds of odour compounds.

3.1.3. Training

In order to evaluate the results of the first phase, two parameters and three criteria were established (Table 4). 72.7% and 93.9% of the assessors fulfilled these criteria.

In the second phase, five parameter were established (Table 4). The results for the parameter "control pair" (CP) were better in the first phase than in the second, which may be because only tap water samples were evaluated in the 2nd phase, as it is easier to detect a sample without odour/flavour in pairs where one of them has a fairly clear odour/flavour than in pairs with tap water where the odour/flavour difference was very subtle. Hence, the importance of the training to reduce the

Table 4
Studied parameters and criteria established for the final selection of the assessors. This table also includes the number (and percentage) of candidates who passed each criterion.

Phase	Parameter	Parameter definition	Criteria	Assessors who passed the criteria (nº and %[a])
Phase 1: Familiarization with odour/flavour CC	CP	In CP both sample were RW or the same [C] of a CC. Assessors had to mark "NPD" option.	NPD ≥ 50%	31 (93.9%)
			NPD ≥ 50%	24 (72.7%)
	Agreement	Perceive the CC [C] that 75% of the candidates perceived in the final phase of the training.	≥ 70% of the CC	27 (%81.8)
Phase 2: Familiarization with the routine control method	Incoherences	Incoherence was when a difference was perceived between RW and CC at a lower [C] and not in a higher [C].	≤ 30%	25 (%75.8)
			≤ 30%	21 (63.6%)
	CP		NPD ≥ 50%	18 (54.5%)
			NPD ≥ 50%	20 (60.6%)
	Wrong answers	Incorrect answers included RW being marked as the sample with greater odour/flavour intensity.	≤ 30%	29 (87.9%)
			≤ 30%	27 (81.8%)
	Repeatability	Providing the same answer when the same sample was evaluated again during the same session	≥ 50%	14 (42.4%)
			≥ 50%	13 (39.4%)
	Agreement	Agreement means consensus in the panel answers for the same sample. To pass this parameter assessors had to perceive the stimulus in panel threshold [C]. For this parameter, the panel threshold was that [C] where 4 of 6 candidates perceived the stimulus.	≥ 50%	29 (87.9%)
			≥ 50%	15 (45.5%)
Phase 3: Determination of the individual odour threshold	Minimum perception	Perceived at least the greatest [C]	At least 60% of the CC	29 (87.9%)
	Agreement	Perceive the stimulus in panel threshold [C][b].	At least 60% of the CC	20 (60.6%)

CC: chemical compound; CP: control pairs; RW: reference water; [C]: concentration; NPD: I do not perceive any difference. In the "criteria" and "candidates who passed the criteria" columns: grey lines indicate odour and white lines flavour. [a]Percentages were calculated on the number of assessors who finished the training phase (34 assessors). [b]Panel threshold [C] was determined according to the method described by Lawless [36].

CC: chemical compound; CP: control pairs; RW: reference water; [C]: concentration; NPD: I do not perceive any difference. In the "criteria" and "candidates who passed the criteria" columns: grey lines indicate odour and white lines flavour.

predisposition of some assessors to mark one of the samples as the most intense in odour/flavour even when clear differences are not perceived, and also considering that method applies an unforced selection. Furthermore, in the second phase, the parameter which the lowest rate of assessors passed (42.4% in odour and 39.4% in flavour), was repeatability. This could have been caused by several factors, such as fatigue (since the three repeated pairs were presented at the beginning and at the end of the evaluation session) or the random response (marking a sample as more intense in odour/flavour without being sure of it), which provided different results between the two evaluations. Regarding the parameter "agreement" in odour tests, 87.9% of the assessors perceived odour at the panel threshold concentration. For flavour, the percentage of assessors perceiving them at panel threshold concentrations was reduced to 45.5%.

Finally, to evaluate the results of the third phase, two parameters related to the individual threshold were established (Table 4) with the aim to ensure a minimum threshold and to obtain a homogeneous threshold panel. The results for those two parameters were positive: 87.9% detects the greatest concentration of at least three of five CC and 60.6% detects the panel threshold concentration.

To overcome the training phase and become part of the panel, assessors had to overcome at least 10 of the 15 criteria included in Table 4. Twenty-three assessors achieved but one of them did not become part of the panel because she reported that she would not be available for several months, so the panel was made up of 22 assessors: 17 women (77,3%) and five men (22,7%) between 30 and 55 years old.

Although there were no references to guide the definition of passing criteria, all the criteria established (Table 4) were shown to be appropriate for the purposes they were designed for, so the recommendation is to maintain all of them. In fact, the parameters and criteria used have allowed to select the assessors and discard those assessors with the worst results, also allowing to select an appropriate number to constitute the panel. It might be interesting to detect those assessors who perceive some of the CC at lower concentrations (lower individual thresholds) than the majority of the assessors with the purpose of removing them from the final panel, in order to avoid non-concordance in results in the systematic evaluations of samples.

Table 7 shows the data obtained from the paired comparison tests carried out during the last sessions of the first phase of the training. This table displays the concentrations of odorous CC for which, at the end of the training, at least 75% of the assessors perceive differences between the sample and the RW. Dimethyl trisulphide was excluded due to the marked inconsistency in the responses.

Table 5
Preselection phase results: correct answers for each chemical compound, concentration and triad type used in the triangle test.

CC and [C]	Correct answers[a]		
	Triad type		Total
	1RW – 2S	2RW – 1S	
4-Chlorophenol (4 μg/L)	65 (83.3%)	50 (64.1%)	115 (73.1%)
2,4-Dichlorophenol (8 μg/L)	49 (62.8%)	56 (71.8%)	105 (67.2%)
2,4-Diclorophenol (16 μg/L)	57 (73.1%)	61 (78.2%)	118 (75.6%)
Geosmin/2-methylisoborneol (5 ng/L)	54 (69.2%)	57 (73.1%)	111 (71.1%)
Geosmin/2-methylisoborneol (10 ng/L)	57 (73.1%)	66 (84.6%)	123 (78.6%)
Total correct answers	282 (72.3%)	290 (74.4%)	572 (73.3%)

CC: chemical compound; [C]: concentration; RW: reference water; S: sample = chemical compound (CC) dilution. 1RW – 2S = 1 RW sample and 2 CC dilution sample; 2RW – 1S = 2 WR samples and 1 CC dilution sample.

[a] 156 triads were evaluated for each CC concentration, 78 triads for each triad type. Total presented triads = 780 (390 1RW-2S and 390 2RW-1S).

Table 6
Selection phase results: Average of the correct answers for each test and number and percentage of assessors passing each test.

Test	Average of correct answers (%)	Assessors passing the test (% in brackets)
Pairing test	82.4 84.5	41 (89.1) 42 (91.3)
Triangle	73.2 71.2	39 (84.8) 42 (91.3)
Ranking	67.3 94.6	33 (71.7) 46 (100)
Stimulus description/ identification	51.5 65.6	17 (37.0) 31 (67.4)

In the second and third columns: grey lines: odour; white lines: flavour.

Regarding the panel odour detection thresholds (calculated from the data of individual odour thresholds) for four of the most common compounds in tap water (geosmine, 2-methylisoborneol, 2,4-dichlorophenol and 4-chlorophenol), obtained threshold for geosmine (3.9 ng/L) and 2-methylisoborneol (6.4 ng/L) were similar to the concentration range found in the literature: 5–10 ng/L (Wang and Suffet, 2006; Mallevialle and Suffet, 1987; Suffet et al., 1995). In the case of 2,4-dichlorophenol, the threshold concentration (3.6 μg/L) was similar to the concentration specified in another study: 1.4 μg/L (Czerny et al., 2008). For 4-chlorophenol, the calculated threshold was 12.4 μg/L, similar to that obtained in another study: 20 μg/L (Young et al., 1996); although the temperature used was considerably higher (40 °C).

3.2. Validation of the procedure after training

Test were conducted after all training to evaluate the performance of the panel resulting from the selection and training procedure. For that, the five parameters evaluated during the training phase (Table 4) were monitored. The mean percentage of correct answers provided by this panel one year after starting the routine water controls (a total of 44 sessions; 6–8 sessions per assessor) for odour and flavour, respectively, were the following: CP = 69.0% and 70.0%; agreement = 83.2% and 83.7%; incoherences = 8.4% and 6.6%; wrong answers = 9.1% and 11.2% and panel repeatability = 72.2% and 81.9%. The authors consider these data to be satisfactory and they demonstrate the validity of SUSPAW.

3.3. Difficulties observed and recommendations

3.3.1. Overlapping of similar sensations

In the description of odour stimuli, difficulty in recognizing and distinguishing among CC that produce odours classified in the same family (family classification by American Public Health Association [APHA], American Water Works Association [AWWA] and Water Environment Federation [WEF] (American Public Health Association, American Water Works Association and Water Environment Federation, 2017)) was observed: 4-clorophenol and 2,4-diclorophenol for medicinal odour; geosmin and 2-methylisoborneol for earthy/musty/mouldy odour; dimethyl disulphide, dimethyl trisulphide, hydrogen sulphide and isopropyl mercaptan for marshy/swampy/septic/sulphurous odour; octanal, decanal and hexanal for vegetable/fruity/flowery odour, and cis-3-hexenyl acetate and cis-3-hexen-1-ol for grassy odour. There were also difficulties in recognizing and distinguishing between CC from different odour families, such as vegetable/fruity and grassy. Human variability in odour detection has been described by several authors (Dietrich et al., 2014; Dietrich and Burlingame, 2020; Phetxumphou et al., 2017; Yeshurun and Sobel, 2010). Such variability may be due to

Table 7
The odour/flavour produced by the CC used in the procedure according to the literature and the concentrations for which nearly 70% of the assessors perceived odour differences with respect to reference water in the last sessions of the first phase of training.

CC	Odour/flavour characteristics		[C]	% of assessors who perceived
	Family	Specific		
Geosmin*[a]	Earthy/Musty/Mouldy[a]	Earthy, red beets[a]	2,5 ng/L	76.7
2-Methylisoborneol*[a]		Musty, earthy, peat-like, Brazil nut, soil[a]	4 ng/L	77.4
2-Isopropyl-3-methoxypyrazine		Earthy, potato bin[a]	0,25 ng/L	93.9
Hexanal[a]	–	Lettuce heart, pumpkin, Green pistachio[a]	8 μg/L	78.8
Decanal[a]	Fragant/vegetable/fruity/flowery[a]	Fruity, orange like[a]	30 μg/L	77.4
trans-2,*cis*-6-Nonadienal*		Cucumber, green vegetation[a]	2 μg/L	71.9
cis-3-Hexen-1-ol*[a]	Grassy/hay/straw/woody[a]	Grassy (green, Sharp), green apple[a]	4 μg/L	75.0
cis-3-Hexenyl acetate*[a]		Grassy (fresh, sweet[a]	5 μg/L	70.0
β-cyclocitral*[a]		hay/woody[a]	60 μg/L	82.1
Dimethyl disulphide*[a]	Marshy/Swampy/Septic/sulphurous[a]	Decaying vegetation, septic[a]	4 μg/L	77.4
Hydrogen sulphide*[a]		Rotten eggs [a]	85 μg/L	82.1
Isopropyl mercaptan*[a]		Onion	15 μg/L	73.3
MtBE*[a]	Chemical/Hydrocarbon miscellaneous[a]	Sweet solven[a]	40 μg/L	74.2
trans, trans-2,4-Heptadienal*[a]	Fishy/rancid[a]	Rancid fish[a]	10 μg/L	75.0
Octanal[a]		–	8 μg/L	78.8
4-Chlorophenol*[a]	Medicinal/Phenolic [a]	Medicinal [a]	10 μg/L	90.9
2,4-Dichlorophenol*[a]		Medicinal [a]	0,55 μg/L	80.0
Iodomethane*[a]		–	2 mg/L	93.9
2,3-Dichloroanisole[b]	–	Leather, earthy[a]	3 μg/L	86.7
Phenol[a]	–	–	200 μg/L	78.8
1-Dodecanol[a]			0,1 μg/L	70.0
Flavour				
Caffeine[a,c]	Bitter[a]	Bitter[a,c]	0,14 g/L	77.4
Sodium chloride[a,c]	Salty[a]	Salty[a,c]	0,35 g/L	73.5
Ferrous sulphate heptahydrate[a,c]	Mouth/nose feel[a]	Metalic[a,c]	0,001 g/L	79.4
Tannic acid[c]	–	Astringent[c]	0,08 g/L	77.4

Confirmed in drinking water*. CC: chemical compound; [C]: concentration.
[a] APHA, AWWA and WEF (American Public Health Association, American Water Works Association and Water Environment Federation, 2017).
[b] Based on 2,3,6-Trichloroanisole proposed by APHA, AWWA and WEF (American Public Health Association, American Water Works Association and Water Environment Federation, 2017).
[c] ISO 8586 (ISO, 2012).

different factors like genetic (Doty et al., 2011), intricate biochemical reactions that can lead to differences in perceptions and descriptors (Dietrich and Burlingame, 2020) and also by the previous personal experience and memory (Köster et al., 2014).

As far as flavour compounds are concerned, the greatest difficulty was the identification of caffeine and ferrous sulphate heptahydrate, since the assessors did not know which sensation was perceived in each case. With caffeine, they doubted between bitter and metallic. With ferrous sulphate heptahydrate, although at higher concentrations metallic sensation was clearly perceived, at low concentrations it was confused with a sensation of bitterness. This observation has been reported by other authors who have reported ferrous iron as metallic, bitter and also astringent (Omur-Ozbek and Dietrich, 2011; Glindemann et al., 2006; Lim and Lawless, 2006; Yang and Lawless, 2005).

Therefore, it is important to begin the training with high concentrations of odourous and flavour CC in order to allow clear perception and identification of the sensation that each compound produces, and continue to reduce it gradually. It is also important to correct the tests and return the results to the assessors so they can evaluate the samples again once they know the result.

3.3.2. Concentrations to initiate training

For some odour CC, it is recommendable to begin training with higher concentrations, since the concentrations used in the first sessions of this training process did not permit a clear recognition of the associated odour. Thus, for phenol, hexanal and cis-3-hexen-1-ol, concentrations used in the second session are recommended; for the decanal, with the concentration used in the third session; and for MtBE and 4-chlorophenol, with the concentration used in the fourth session (Table 2).

As far as iodomethane goes, the use of very high concentrations is not recommended since its odour quality varies depending on the concentration: in water-related literature it is classified in the family of medicinal compounds (American Public Health Association, American Water Works Association and Water Environment Federation, 2017; Richardson, 2003), but, in this training, at high concentrations (500 mg/L) its odour was garlic-like. However, at lower concentrations (75 mg/L), it was described as medicine-like. Since it is highly unlikely to find these high concentrations in tap water, the concentration used in the second session would be suitable for initiating training (Table 2).

Regarding flavour compounds, the concentrations proposed for ferrous sulphate heptahydrate by the ISO standard (0.0036 g/L) (ISO, 2011) is too low for use in the first sessions, so slightly higher concentrations (approximately 0.01 g/L) are proposed for the initiation of training.

On the contrary, the concentration proposed by for tannic acid (1 g/L) was considered to be too high, so initiating training with lower concentrations (such as 0.7–0.8 g/L) is recommended. In addition, it was observed that tannic acid left a permanent residual sensation in the mouth, so, when the concentrations of tannic acid are high, it is proposed to evaluate these samples the last, so as not to affect the evaluation of the next samples.

3.3.3. Avoiding highly volatile CC for evaluating assessors' aptitudes

Dimethyl disulphide and trimethyl disulphide are highly volatile CC and they caused incoherent results (higher concentrations did not always elicit greater intensity of sensation). For dimethyl disulphide, the problem was solved by preparing the solution immediately prior to the evaluation and evaluating those samples first at the beginning of the session or after the rest. Nevertheless, for trimethyl disulphide the problem was not resolved. We therefore recommend using it in the training phase as it can be present in tap water, but not considering it in the final selection of assessors.

3.3.4. Feedback of test results to the assessors

Throughout the selection and training sessions, it is important to correct the results of each test just after doing them and give the assessors some minutes to smell/taste samples again, in order to improve their training.

4. Conclusions

The procedures described in this article have been demonstrated to be valid, complete, and rigorous enough for the preselection, selection, and training of assessors for tap water evaluation and also to recommend a series of parameters and criteria to be used in the process. SUSPAW is a useful tool for other laboratories in the process of forming tap water assessors' panels, as they could use the same procedure (phases, tests, CC and concentrations, and criteria for overcoming each phase) in order to design their own training process and optimise their time. In addition, the results of this present work facilitate the selection of concentrations for many compounds, which will help to reduce the number of sessions and previous tests necessary to design the process and/or the number of samples presented during training.

Since water is a product which requires high sensory acuity, the selection processes must be very rigorous. Therefore, in contrast to what was stipulated in the ISO 8586 (ISO, 2012) for this product, and based on the laboratory experience, the recruitment of at least four or five times the number of assessors required to form the final panel is recommended.

CRediT authorship contribution statement

Garazi de la Fuente Aldazabal: Conceptualization, Methodology, Data curation, Formal analysis, Writing – original draft. **Iñaki Etaio Alonso:** Conceptualization, Methodology, Writing – review & editing. **Maria del Pilar Fernández Gil:** Conceptualization, Methodology, Data curation. **Mónica Ojeda Atxiaga:** Conceptualization, Methodology, Data curation. **Wendy Alicia Rivera Ramos:** Conceptualization, Data curation. **Francisco José Pérez-Elortondo:** Conceptualization, Methodology, Supervision, Writing – review & editing, Resources, Project administration, Funding acquisition.

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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

No data was used for the research described in the article.

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