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Flavour assessment of blends between desalinated and conventionally treated sources

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ABSTRACT

The drinking water supply in the Barcelona region has recently experienced a radical change because three new facilities with membrane technology have come into service (i.e. reverse osmosis and electrodialysis reversal in the Llobregat river and a sea water reverse osmosis desalination plant. The aim of the study was to predict the reaction of consumers to changes when blends between desalinated and conventionally treated sources were supplied. Seven blended samples of membrane and conventionally treated waters and three unblended water samples were assessed using ranking, scoring and triangle tests. Trained and untrained panels were used for taste assessment. The number of available tasters for each session was 13–14 trained tasters and between 22 and 32 volunteers. Therefore, the total number of tasters ranged between 36 and 46. Ranking and scoring results from both panels were similar (i.e. no significant difference in an independent *t*-Test), even though the trained panel displayed a better sensitivity in the triangle test. Water preference scores ranged from 3.6 to 6.5. Multiple comparison procedures (i.e. Fischer's Least Significant Difference Test) on global normalised liking results allowed us to define a grouping structure for water samples that were significantly different from the others. It was determined that membranes would contribute positively to consumer perception. For the relationship between the salinity represented by the total dissolved solids (TDS) and water preference, the overall trend indicated that water with lower salinity was preferred. These results confirm that the assessment of water is primarily driven by TDS even though other factors (i.e. pH, mineral composition) can play a significant role in the liking of water, which is consistent with previously published reports.

Keywords: Blends; Desalination; Drinking water; Flavour; Organoleptic; Taste

1. Introduction

Years ago, membrane technologies represented spectacular progress in the availability of drinking water in arid and semi-arid regions of the world. In recent years, due to the improvement in the energy efficiency of these facilities, this is possible at a reasonable and competitive cost compared to other options [1–3]. Extensive information is currently available concerning the performance of the different technologies

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and types of membranes. Therefore, it is possible to establish quality specifications for the permeates in advance. However, much less is known regarding the organoleptic characteristics of the water produced.

Several studies indicate that the taste of water fundamentally depends on its mineral composition, total dissolved solids (TDS) and the concentration of both cations and anions [4–7]. Chemicals added during the treatment and evolution of water in the distribution system influence the taste [8]. In addition, water may contain numerous minor compounds including organic and inorganic compounds from a natural or anthropogenic origin, which can endow the water with characteristic odours, flavours or sensations that are typically undesirable.

Some membrane techniques can greatly reduce the mineral content of water and alter the salt content. Therefore, the product requires remineralisation to mitigate the aggressiveness of the product, which typically involves the addition of calcium salts and sometimes carbon dioxide. In addition, this remineralisation process provides two advantages. First, the remineralisation contributes to improving the flavour of water. Second, the remineralised water is healthier for the human body because research suggests that alkaline-earth salts protect against heart and vascular diseases [9].

Several studies have reported the benefits of trained and untrained panels for the evaluation of different types of water, potabilisation treatments and alternative blending of resources [10–13].

This study reports the results of various sensory analyses of water flavour to predict the reaction of consumers to changes in water distributed in the metropolitan area of Barcelona when blends between desalinated and conventionally treated sources are supplied.

1.1. Membranes in the water supply of the Barcelona metropolitan district

The supply of drinking water to the city of Barcelona and its service area has traditionally been obtained from three primary sources, which used conventional treatment methods. In the north, the Ter water treatment plant (WTP) treats water from the Ter River, which is conveyed to the city by an approximately 40 km long underground pipe. In the south, the Abrera and Sant Joan Despí (SJD) WTPs, which treat water from the Llobregat River, treat only surface water and water from variable sources including wells, respectively. Aigües Ter-Llobregat is the company that operates the Abrera and Ter WTPs and supplies wholesale water. Aigües de Barcelona manages the SJD WTP and is responsible for the distribution network.

The water quality is considerably different in the two rivers. The Ter River passes through a less developed area and the catchment occurs after a system of three reservoirs (Sau-Susqueda-El Pasteral) that stabilises the quality of the raw water. The quality of the Llobregat River is worse due to the presence of sodium and potassium chloride mines in the upper part of the basin, which progressively salinates the river, and the basin passing through areas with a greater urban and industrial presence.

Recently, the Barcelona supply has experienced a radical change. First, the El Prat sea water reverse osmosis (SWRO) desalination plant, which has a capacity of 60 hm^3/year, has started operating to mitigate the drinking water shortage suffered by Catalonia in recent years. Second, the two Llobregat facilities (Abrera and SJD WTPs) have incorporated membrane technologies to treat part of the flow with the aim of improving its physicochemical qualities and water flavour. Finally, the interconnection between the Llobregat and Ter river networks permits better management of the resources.

The initial treatment (4 m^3/s maximum) at the Abrera WTP consisted of permanganate preoxidation, clarification, dioxychlorination, sand filtration, granular-activated carbon (GAC) filtration and post-chlorination stages. The biggest worldwide electrodialysis reversal (EDR) plant (nominal capacity: 2.3 m^3/s) has started operating at this facility [14]. This EDR plant is fed with GAC filtered water from the conventional treatment process. The water produced is remineralised prior to being blended with water from the conventional process.

For the SJD WTP (5 m^3/s), the initial treatment involved preoxidation (chlorine or chlorine dioxide), clarification, sand filtration, ozonation, GAC filtration and post-chlorination. A reverse osmosis (RO) treatment is now available with a capacity to treat 50% of the flow and this process is fed with sand-filtered water. Prior to entering the RO membranes, the water undergoes an ultrafiltration pre-treatment, and then, the water is remineralised prior to being blended with water from the conventional treatment process.

The only resource that has not faced any variation is the water from the Ter WTP (8 m^3/s), where treatment involves preoxidation (chlorine or chlorine dioxide), clarification, GAC filtration and post-chlorination steps.

2. Methods

2.1. Water samples

Five different water sources were considered in this study as follows: Abrera WTP (conventional treatment), Abrera EDR (pilot plant), El Prat SWRO (pilot plant), Ter WTP and Llobregat (SJD) WTP (only conventional treatment line). The physicochemical characteristics of these water samples (mean values) are shown in Table 1. Sodium, potassium, calcium, magnesium and silica levels were analysed by inductively coupled plasma optical emission spectrometry (ICP-OES) (Perkin–Elmer Optima 4300 DV). The bicarbonate content and pH were determined potentiometrically with a robotic titrosampler (Metröhm modules 855 and 856). Chloride and sulphate concentrations were analysed by ionic chromatography (Dionex ICS-2000). TDS (dry residue at 180˚C) levels were measured by gravimetry. The total organic carbon (TOC) was determined by a catalytic combustion analyser (Shimadzu VCPH). The water from the RO pilot plant at SJD WTP was not included because the installation was not in operation during the present study and the system has been previously studied [13].

All of the possible binary blends of the five water samples were studied, except for the three traditional blends without membrane treatment (Abrera Conv-Llobregat Conv, Abrera Conv-Ter and Lobregat Conv-Ter), whose behaviour was already well known [15]. The most likely ratio of the two water sources was chosen for each blend in accordance with the operating forecasts of the regional supply system. The seven studied blends are shown in Table 2.

Table 2
Composition of the considered blends

Blend	Composition	TDS (mg/L)
0	50% EDR + 50% Abrera-Conv.	522
1	75% Abrera-Conv + 25% SWRO	884
2	75% EDR + 25% SWRO	352
3	50% EDR + 50% Ter	305
4	75% EDR + 25% Llob-Conv.	445
5	75% SWRO + 25% Ter	257
6	75% SWRO + 25% Llob-Conv.	524

2.2. Conditioning of the samples

The EDR and SWRO water samples, which were obtained from pilot plants, were remineralised in the laboratory. For this purpose, these samples were agitated in the presence of an excess of calcite (1 g/L) and carbon dioxide was bubbled through the sample until a calcium concentration of approximately 30 mg/L was achieved. The excess calcite was precipitated and the supernatant was recovered for sensory analysis.

The waters from the Ter, Abrera and SJD WTPs were obtained prior to the final disinfection step and chlorinated in the laboratory with a sodium hypochlorite solution with 0.5 mg/L of free chlorine. Prior to tasting, the free chlorine levels in each of the blends were readjusted to 0.5 mg/L to prevent the different chlorination levels from biasing the perception of the samples. The free chlorine was analysed by a conventional DPD colorimetric method [16].

2.3. Panels and tasting sessions

Both a trained and untrained panel were used. The former was the Aigües de Barcelona panel, which was composed of university students (15 tasters, 4 males and 11 females, aged 20–23 years), that functioned in accordance with the requirements of the flavour profile analysis described in the standard method 2,170 [16]. The second panel was composed of volunteer company employees (38 volunteers, 15 males and 23 females, aged 23–62 years, median age was 37 and mean age was 39), without any training in the field of

Table 1
Quality parameters for the five water sources included in the study

	Units	Abrera-Conv.	EDR	Llob-Conv	Ter	SWRO
TDS	mg/L	1,077	383	1,163	302	243
Ca^{2+}	mg/L	103.3	29.1	176.6	52.0	32.2
Mg^{2+}	mg/L	34.4	4.2	64.4	9.5	0.3
Na^{+}	mg/L	203.6	79.8	257.1	22.9	36.0
K^{+}	mg/L	48.4	10.9	39.7	4.1	1.4
SiO_2	mg/L	1.3	0.5	4.1	2.2	<0.2
Cl^{-}	mg/L	371.2	87.4	429.0	36.6	52.8
SO_4^{2-}	mg/L	142.6	26.8	277.4	51.7	<10
HCO_3^{-}	mg/L	170.0	113.0	350.0	115.5	77.0
pH	units	7.8	7.9	7.5	7.7	7.9
TOC	mg/L	1.6	1.3	2.6	2.0	0.25

sensory analysis of foods. The number of available tasters for each session was 13–14 trained tasters and between 22 and 32 volunteers. Therefore, the total number of men and women tasters for each specific blend ranged between 36 and 46 who were between 20 and 62 years old.

The tasting occurred in a room specifically devoted to this purpose that was comfortable and free from odours. The flavour was tested using glasses with water maintained at 25°C. The samples were coded and did not provide the panellists with any information that could impact their perceptions. The order of presentation of the samples in each set was randomised for each participant. The codes consisted of two random digit numbers. The subjects sipped and swished the waters in their mouths. They were allowed to swallow or spit out the samples after the tasting. Tasting a blank sample consisting of mineral water defined previously as "neutral" by the trained panel (calcium bicarbonate water, TDS = 262 mg/L) was required at the beginning of the session and voluntarily between samples. A rest period was allowed between series of samples to avoid any risk of fatigue.

2.4. Sensory techniques

Both panels simultaneously participated in two types of experiments including ranking and scoring tests, which were used as effective techniques, and a triangle difference test, which was used as a discriminative tool [17].

2.4.1. Ranking test

In this test, n different samples are provided for the tasters to order in accordance with a certain characteristic (i.e. in this case, their overall assessment of the flavour). The sample perceived as the best receives n points and $n-1$ for the following until the last one, which is given one point.

2.4.2. Scoring test

The tasters are asked to give a score using a scale from 0 (extremely bad) to 10 (excellent). One set of samples was presented to each panellist from both panels per session for the ranking and scoring tests.

2.4.3. Triangle test

This test consists of presenting three samples where two are identical and one is different. The tasters are asked to identify the odd sample. The comparison of the number of correct responses with a critical number allows us to determine if the difference between the samples can be considered statistically significant using a specific confidence level (in our case, $\alpha = 0.05$ was used). The option of "difference plus preference" was also used in this study. The panellists were allowed to voluntarily indicate their preference for one of the samples. In other words, the tasters were allowed to report if the water sample that was perceived as different was better or worse than the other two, which were the same.

Tasters from both panels performed two triangle tests per session. The number of the two different samples used by the test was balanced for each subject.

2.5. Statistical analysis

Analysis of variance (ANOVA) has been applied to the scoring results. When the F-statistic exceeded a critical value ($\alpha = 0.05$) with the corresponding degrees of freedom, the null hypothesis assumption of equivalent average liking among water samples was rejected. To determine which of the means were significantly different, a multiple comparison procedure (Fischer's Least Significant Difference, $LSD_{scoring}$) was performed.

The scores of each blend, which were obtained in different tasting sessions, were normalised against the Ter water:

$$\text{Blend Sc}_{\text{norm}} = \text{Blend Sc} \times \text{Ter Sc}/6.48$$

where Blend Sc_{norm}: Normalised blend score, Blend Sc: Blend score, Ter Sc: Ter score for each specific blend session, and 6.48: overall mean value for Ter score (all the tasting sessions).

3. Results and discussion

3.1. Affective evaluation

The different blends were tasted separately in different specific sessions. A series of three samples (i.e. a blend and two reference samples) was always presented for tasting within one session. The reference samples were the typical waters of the metropolitan network (i.e. Ter and Llobregat) where the Llobregat samples were obtained from a conventional process without membrane-treated water (Llob-Conv). Fig. 1 show the results obtained for both panels in the ranking and scoring tests.

The results of trained and untrained panellists are in agreement. In some blends, nearly the same results are obtained (0, 1, 2, 3, 5 in ranking; and 2, 3, 4 in scoring), and in the rest of the blends, the differences are very small. The equivalence between the means for all of the pairs of results from the two panels has been demonstrated by the two sample (or independent) *t*-Test ($\alpha = 0.05$). This coincidence is important because it allows all of the results of both panels to be processed together ("mixed panel") resulting in greater statistical significance.

In most cases, the blends are placed between the Llob-Conv water and the Ter water even though a non-equidistant position was obtained (i.e. they are closer to Ter than to Llobregat). Therefore, the blends are clearly better than the Llob-Conv water and just slightly below (or even on the same level in some sessions in particular) the Ter water. Blend 1, which contains 75% Llobregat water, does not follow this behaviour and is not closer to the Llob-Conv water but is better than the Llobregat.

After this preliminary assessment of the results, an ANOVA and a Fischer multiple comparison test were applied. The scoring results required standardisation because they were obtained from different tasting sessions. It was observed that there was an important range in the variation in the scores of the blends, but there was also a relevant dispersion in the results of the reference water samples (Table 3 and Fig. 2). This variability, which is typical for this type of experiment, is due to the sum of two effects. First, the intrinsic uncertainty of the sensory measurements (i.e. flavour score), which is much higher than usual in chemical analyses. Second, the actual variability in the quality of the reference waters. It should be noted that the experiments with the different blends were performed in different sessions with waters from the distribution network obtained on different days.

Table 3
Scores for the blends reported as mean values and standard deviation

Blend	Score	Standard deviation
0	5.7	1.3
1	3.9	1.5
2	6.2	1.6
3	6.2	1.5
4	6.5	1.3
5	6.1	1.1
6	4.8	1.2
Ter	6.5	1.3–1.8
Llob-Conv	3.6	1.2–1.8

The variability of the scores for the Ter samples is lower than that for the Llob-Conv samples, which is in agreement with the more constant water quality over time (lower fluctuation) of the former in relation

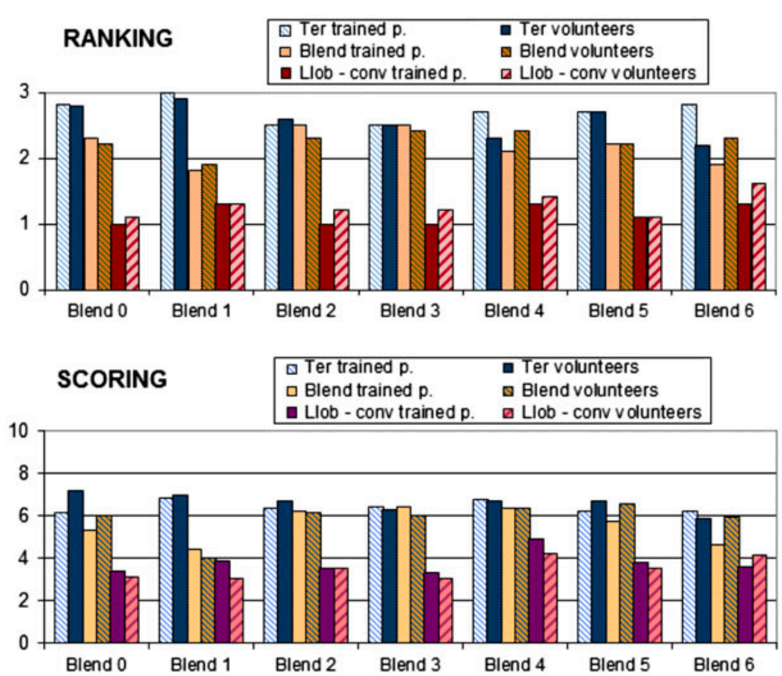

Fig. 1. Ranking and scoring results for the different blends and reference water samples by the two panels. The order of the bars for each blend from left to right corresponds to the legend from top to bottom.

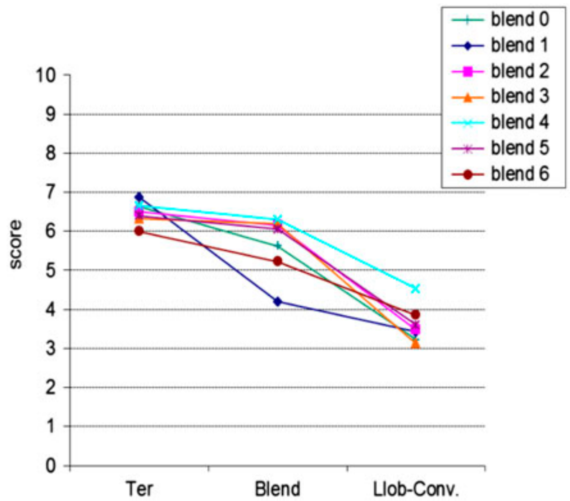

Fig. 2. Scores for reference water samples and blends (non-normalised).

to the latter. Therefore, the results were normalised against the Ter water.

The ANOVA analysis of the normalised results indicated that there were significant differences between water samples, and therefore, the LSD method was applied. The results are provided in Table 4. At the top of Table 4, no significant difference in the four blends compared to Ter water was observed. In addition, the Llob-Conv water and Blend 1, which contained 75% Llobregat water, were significantly different from the other samples.

3.2. Capacity of discrimination

The results separately obtained from volunteers and trained tasters indicated a significant difference between blends and the reference (Llobregat-Conv) for all of the blends (blends 0–6). Therefore, when the

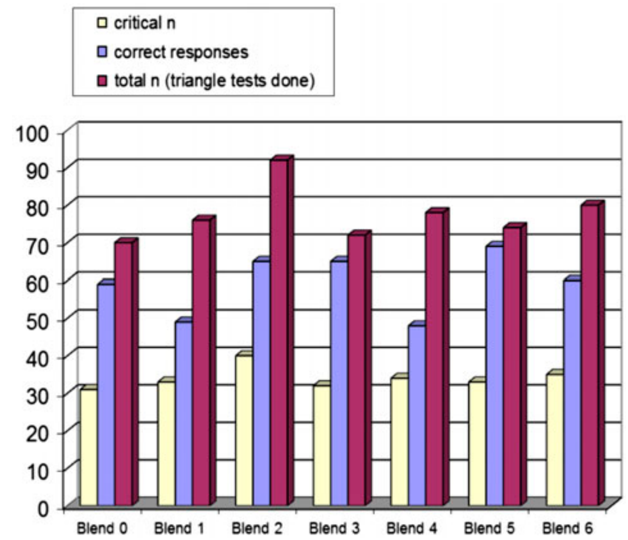

Fig. 3. Results of the triangular tests performed with the blends and Llob-conventional treatment water (reference).

results of both panels were aggregated, the difference was also significant (Fig. 3).

The dominant preference was for the blend because on a majority of occasions (85%) the blend was indicated to be better than the Llob-conv water, which was the reference.

3.2.1. Sensitivity of the panels

The triangle test is very useful because in addition to its intrinsic purpose of providing information about how different two samples are, it also allows for the assessment of the goodness of fit of the answers given by the panellists and the sensitivity of the panel. Fig. 4 shows a global comparison of the behaviour of both the trained and volunteer panels. The percentage of individuals that correctly chose the different sample

Table 4
Mean scores and LSD grouping for blends and reference samples (grey background)

				Sample	TDS (mg/L)	Score
a				Ter	302	6.5
a	b			Blend 4	445	6.3
a	b			Blend 2	352	6.2
a	b			Blend 3	305	6.2
a	b			Blend 5	257	6.1
	b	c		Blend 0	522	5.6
		c		Blend 6	524	5.2
			d	Blend 1	884	4.2
			d	Llob-Conventional	1163	3.6

Note: The water samples with the same letter are not significantly different.

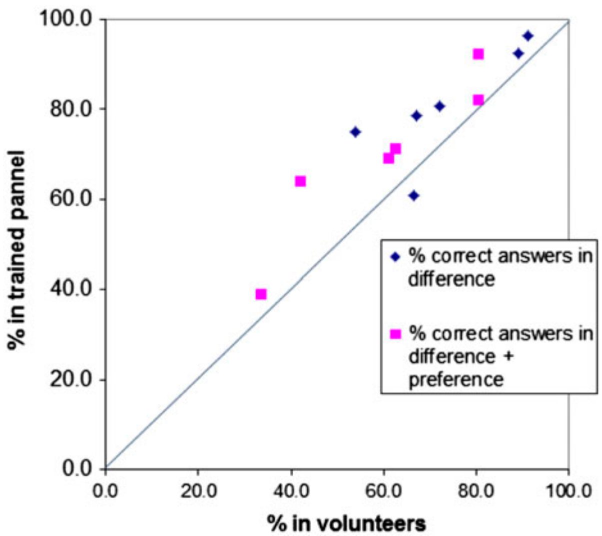

Fig. 4. Percentage of correct answers from the trained panellists (y axis) as a function of the volunteers' percentage (x axis).

("difference") is shown, and in addition, the percentage of tasters who indicated that the blend was the best ("difference + preference") is in agreement with the results obtained from the ranking and scoring tests. All of the points, except for one case, are above the line at 45˚. Therefore, the trained panel exhibited better sensitivity than the volunteers.

3.3. Expansion of the study to some unblended waters

The study of the water blends was structured starting from the expected operating conditions in the regional distribution network. Some changes were indicated during the study by the operations management personnel. Therefore, an expansion of the study was considered, which would include the water from the El Prat SWRO (which could be supplied unblended for a transitory period) and the two types of water produced by the Abrera WTP from conventional treatment or EDR. Ranking and scoring tests were performed in an analogous manner as described above. However, five samples were tasted in each session instead of three (i.e. El Prat SWRO, Abrera-conv and Abrera-EDR as well as the two reference samples (Ter and Llob-Conv)).

Because we intended to perform a combined analysis with the previous results from the blends, only a scoring test was performed. The scale of the ranking test depends on the number of samples, which did not allow for comparison of the results of the two series of experiments. All of the results from the new experiment were normalised in relationship to the mean score of the Ter River water.

The results obtained with the same statistical treatment as mentioned above are shown in Table 5. In addition to the behaviour of the previous blends in Table 4, the EDR water is highly valued, but the unblended SWRO water was not. However, the blends containing SWRO water were highly appreciated.

Fig. 5 shows the scores of the different blends and unblended water samples compared to TDS. The overall trend is that water with increased salinity was less desirable. This result is consistent the effect of TDS on the assessment of the water [4–7,17]. However, other factors can play a significant role in liking water (e.g. pH and mineral composition), which would explain the behaviour of each water sample [5,6,18]. More research is needed on this subject.

Table 5
Mean scores and LSD grouping for blends, unblended waters and references (grey background)

	Sample	TDS (mg/L)	Score
a	EDR	383	6.5
a	Ter	302	6.4
a b	Blend 4	445	6.3
a b	Blend 2	352	6.2
a b	Blend 3	305	6.2
a b	Blend 5	257	6.1
b c	Blend 0	522	5.6
c d	Blend 6	524	5.2
d	SWRO	243	4.7
d	Abrera-Conventional	1077	4.6
d	Blend 1	884	4.2
e	Llob-Conventional	1163	3.3

Note: Water samples with the same letter are not significantly different.

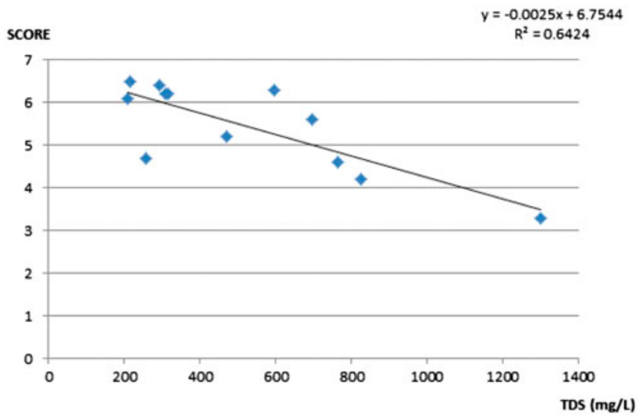

Fig. 5. Variation in the scores as a function of TDS for the different water samples and blends tasted. The solid line is the predicted relationship between both parameters obtained after linear data regression (the equation is also provided).

4. Conclusions

Seven blends of water from membrane treated and conventional sources, as well as three unblended water samples, were assessed using ranking, scoring and triangular tests. Several conclusions can be drawn from the results of the tasting with trained and untrained panellists.

The ranking and scoring results of both panels were similar. These results indicated that the flavour of the blends was significantly better than the water previously distributed in the Llobregat area. Therefore, membrane treatment would positively contribute to consumer perception. This improvement was quite considerable for all of the blends, except for blend 1, which was more moderate. The detection in the improvement is favourable due to the high percentage (75%) of Llobregat water that the blends contained.

In agreement with these results, a multiple comparison test performed on the normalised scores of the aggregated results of both panels resulted in defining a grouping structure of water samples that were significantly different from the others.

With respect to the relationship between TDS and liking, the overall trend is that the taste of water is less appealing when the salinity increases. These results confirm that the assessment of water is primarily determined by TDS even though other factors (pH and mineral composition) can play a significant role in how water tastes. More research is needed on this subject.

Triangle test results for both panels indicated that all of the blends could be differentiated from the Llobregat water, which is produced via conventional treatment. This test was also used to compare the sensitivity of the two panels. The results indicated that better performance was obtained from the trained panel.

Abbreviations and notations

Agbar	—	Aigües de Barcelona
ATLL	—	Aigües Ter Llobregat
Conv	—	conventional (treatment)
EDR	—	electrodialysis reversal
FPA	—	flavour profile analysis
GAC	—	granular activated carbon
Llob	—	llobregat
RO	—	reverse osmosis
SJD	—	Sant Joan Despí
SWRO	—	sea water reverse osmosis
TDS	—	total dissolved solids
WTP	—	water treatment plant

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