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Guidance for optimizing drinking water taste by adjusting mineralization as measured by total dissolved solids (TDS)

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GRAPHICAL ABSTRACT

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ABSTRACT

Dissolved minerals, usually measured as total dissolved solids (TDS), are the major determinant of the taste of tap water. The mineral content of drinking water is largely affected by the source water's mineral content, except where membrane treatment removes minerals which then requires remineralization. The aim of this research is to provide guidance to water utilities about TDS differences that allow consumers to differentiate waters and to determine how changing TDS affects the acceptability of drinking water. Panels of consumers and/or trained professionals performed taste tests to determine their ability to discriminate between two water samples with different TDS. Results reveal that to discriminate between waters based on the taste of TDS, a value of $\approx \Delta TDS > 150$ mg/L is necessary. This provides a baseline target ΔTDS when treating tap water. Panelists provided taste-liking scores, using a 0–10 scale, for individual water samples of varying TDS. Taste-liking scores decreased with increased level of TDS, with an estimated overall rate of −0.23 liking units/100 mg/L TDS. However, there are caveats to this general guidance: specific mineral composition, the direction of change of TDS, the presence of odourants, organic carbon content, temperature, and varying taste abilities and preferences of individual consumers.

1. Introduction

Water utilities actively pursue new engineering treatments, such as advanced oxidation or membrane technologies, to provide safe and satisfying tap water to their consumers. A contemporary challenge to water utilities is to provide safe and acceptable tasting tap water that consumers perceive as constant, when source water quality and/or treatment continually change. In the absence of off-flavours, mineral

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content and consistent aesthetic qualities are the major determinants of both taste and consumer acceptability of their drinking water. Mineral content, usually measured as total dissolved solids (TDS), is also the primary determinant of consumer liking in the absence of unwanted odors [1–4]. Fluctuating water quality in terms of TDS is acknowledged as a source of consumer complaints [5–7].

In the early 21st century, membrane technologies play a crucial role in desalinated water production from seawater, brackish water, and polluted freshwater sources [8,10]. The future for membrane technologies is superb due to continual improvements in membrane materials, process configurations, energy minimization, and reduced membrane fouling and scaling [11–13]. The desalinization process removes most minerals from water, thus requiring remineralization for both corrosion control [14–16] and taste [2,16]. Remineralization is typically accomplished through partial blending with non-membrane treated water or percolating the membrane treated water through limestone ($CaCO_3$).

For desalinated water, taste and aesthetics are among the top-ten post-treatment challenges facing drinking water utilities [16]. With desalinated water, taste is the focus because the types and concentrations of aqueous minerals are the critical determinants of sweet, salty, sour, and bitter tastes in drinking water [1]. While the term “taste” is frequently used to describe the sensation of foods and beverages in the human mouth, “flavour” is the preferred term for this sensation. Flavour describes the entirety of the sensation encompassing taste (e.g., sweet, salty, sour, bitter), odour (e.g., chemical, swampy/septic, earthy/musty), and mouthfeel (e.g., astringent, drying, chalky). The importance of taste, odour, and mouthfeel is recognized in the Drinking Water Taste and Odour Wheel [17] that includes relevant drinking water-related descriptors for all three properties. While minerals are primarily associated with drinking water taste, some minerals also impart mouthfeel (e.g., aluminium produces astringency).

Studies from around the globe have demonstrated the positive contribution that membranes have made to consumer acceptance of their drinking waters. Blends of conventional and membrane-treated waters have more desirable tastes than the corresponding unblended high-TDS waters [2,7,18–20]. On the other hand, some studies have shown that even though consumers are willing to use non-conventional, recycled or desalinated water for household uses such as washing, they are reluctant to drink it even when drinking water standards are met [21,22]. Thus, there is a timely need to understand the taste characteristics of desalinated and remineralized drinking water.

1.1. Purpose

During the last decade, Aigües de Barcelona (AGBAR) and Virginia Tech carried out several projects aimed at evaluating any improvement in the taste of tap water through the use of membrane treatments, and the sensitivity of discrimination of TDS as an aggregate property for evaluating drinking water taste. Some of these projects aimed at defining a range of TDS that are acceptable to the consumer: i.e., a TDS target value (consumer preference) and ΔTDS not perceived for treatment purposes.

The aim of the present work is to review and summarize the results of these individual previous studies from a different perspective. We do not focus on sources, blends or reasons for preference, but rather on just two aspects: the role of TDS as a driving parameter for water liking; and the discrimination ability of trained tasters and consumers as a function of the TDS in the water samples.

2. Methods

2.1. Sensory techniques and panels

Results of triangle and/or scoring tests for liking from twelve works have been reviewed, as shown in Table 1. The triangle test is a difference test to determine the ability to discriminate. It consists of presenting tasters with groups of three samples, two of which are identical and asking the taster to identify the sample that is different. The order of presentation and the proportion of the two samples in the overall experiment are balanced (AAB, ABA, BAA, BBA, BAB, ABB). All the triangle test studies were carried out using the forced choice option: tasters are compelled to indicate one sample as being different. In general, each panelist performed two triangle tests per session with balanced presentation of the two waters. The discrimination between the samples is considered statistically significant if the number of correct answers reaches a critical value that depends on the significance level (α) considered [23]. Scoring test is an effective sensory test in which subjects are asked to rate their overall liking of samples according to a given numerical scale. We used a scale from 0 to 10 with 0 being “extremely dislike” and 10 “extremely like”.

Trained, untrained, “both” and joint panels were used in the studies. “Trained” refers to the Agbar tasting panel [24] which had been trained according to the Flavour Profile Analysis (FPA) method [17]. These panelists were not trained specifically for triangle and scoring tests, but they participated in several studies involving them [24–26]. Therefore, the “trained” panel had significant experience with these tests. “Untrained” refers to volunteer company employees, without any education and training in sensory analysis. “Both” means that trained and untrained panels performed the test in different sessions with data not aggregated but treated separately. “Joint” means that trained and untrained panelists worked together and their data were aggregated into one dataset.

Studies can be found in the literature regarding the importance of training [27,28] and the comparative behavior between professional tasters and volunteers for judging water: flavour assessment of blends of desalinated water [18,19], influence of ions on the taste of water [29,30], and odour thresholds of organic compounds [31,32]. Trained panels show greater sensitivity, but untrained tasters are very useful for estimating the reaction of consumers.

In all the experiments, tasting sessions took place in comfortable rooms that were free of interfering odors. Samples were always coded and tasted from cups at 22–25 °C. Tasters were not allowed to smoke, eat or drink (except water) for one hour before the test. Tasters were not instructed to distinguish between taste and mouthfeel.

2.2. Summaries of projects and data

The twelve studies of triangle and/or scoring tests for liking are shown in Table 1. The scoring test was used as an affective technique to evaluate liking of the water samples. The triangle test was used to assess the ability to discriminate between same waters or blends that were considered especially relevant.

2.2.1. SCENARIOS

Ultrafiltration and reverse osmosis were introduced in 2010 at the Sant Joan Despí drinking water treatment plant (SJD DWTP) to reduce the level of trihalomethanes and improve the organoleptic quality of the finished water. Previously, a deep comparative study (chemical, biological and organoleptic) using different membrane techniques and configurations (ultrafiltration/UF, reverse osmosis/RO, and electrodialysis reversal/EDR) at pilot scale was performed. Taste analyses were done on several blends made up of different ratios of permeates to water from the conventional treatment line. The study revealed a significant taste improvement after membrane treatment, which was perceptible when 30% of the flow was treated by membranes [2].

2.2.2. SWDESAL

After several droughts in Catalonia, the El Prat seawater reverse osmosis (SWRO) treatment plant was commissioned in 2010 to supply the Barcelona metropolitan area with up to 2000 L/s. For an initial estimate of the effects on the taste of supplying a blend of desalinated water and traditional sources, a study was performed using water from

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