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Consumer perception of water quality during an off-flavor event in Fortaleza-Brazil

Short title: Water quality and off-flavor perception in a developing country

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ABSTRACT

During a taste and odor episode (2-methylisoborneol) in a reservoir that supplies the Fortaleza Metropolitan Region, Brazil, two surveys were conducted to determine tap water usage behavior as well as the sensory sensitivity towards off-flavors of participants with the same level of education. Most volunteers did not consume tap water, mainly due to safety concerns (57%) and disagreeable organoleptics (21%). The majority of those who did use tap water (73%) did so because of economic reasons and the remainder, because of the use of point-of-use water filtration systems, which rendered the water safer in their perception. The Human Development Index (HDI), as a measure of income, did not influence the rate of rejection. Volunteers from low and medium HDI neighborhoods were as likely to reject tap water as those from high HDI neighborhood. Chlorine-flavor and earthy-flavor were the most perceived off-flavors. Water containing moderate amounts of off-flavor compounds (dilution 1:2 tap/bottled water) was considered “acceptable” by volunteers while water containing low concentrations (dilution 1:5 tap/bottled water) was considered “good”.

Key words | 2-methylisoborneol, chlorine, potable water, taste and odor

INTRODUCTION

Aside from physicochemical and microbiological parameters, water quality can be assessed by its organoleptic properties, otherwise known as aesthetics. The aesthetic qualities of tap water are, commonly, the customers’ only gauge of water safety (Jardine *et al*. 1999; Doria 2010; Dietrich 2006). Amongst those parameters, taste and odor (T&O) in particular is a strong indicator of tap water quality. If water presents with off-flavor and an off-smell customers might deem the tap water unsafe to drink and revert to alternative sources of water, which could be more expensive or higher risk than the rejected tap water. Many compounds can cause off-flavor in tap water, but chief amongst those are three compounds: 2-methylisoborneol (MIB), geosmin, and free chlorine (Mackey *et al*.

2004; Joll *et al*. 2007; Piriou *et al*. 2009). MIB and geosmin are bacteriogenic tertiary alcohols that are poorly removed by most conventional treatment technologies. They confer a musty/earthy taste and odor to the water with a low sensory threshold of around 10 ng.L^{-1} in humans (Webber *et al*. 2015). While many countries and organizations, such as the European Union and the World Health Organization, have guidelines pertaining to off-flavors in water, only Japan has drinking water standards that set a maximum allowable limit for both MIB and geosmin (The Council Of The European Union 1998; Hiroshi, 2005; WHO 2008; NHMRC & NRMMC 2011). Chlorine off-flavor is generally caused by the disinfection process applied in most water treatment plants. Despite chlorine off-flavor being recognized as a cause of rejection of tap water (Doria *et al*. 2009), many countries have regulations about how much free residual chlorine should be maintained in the water reaching consumers (WHO 2008; NHMRC & NRMMC 2011; Ministério da Saúde 2017). Although Brazilian water legislation (Ministério da Saúde 2017) clearly states that water should present with pleasing organoleptics, free chlorine flavor is not considered a relevant off-flavor compound. In fact, according to the legislature, the taste of chlorine is to be taken as a sign of high quality water. The literature presents various concentrations as the threshold for free chlorine perception, lying somewhere between 0.20 and 0.65 mg L^{-1} (Krasner & Barrett 1984; Mackey *et al*. 2004; Piriou *et al*. 2015). This perception amplitude may be connected to regional differences and acceptance of chlorine flavors (Piriou *et al*. 2015).

Little is known about customer behavior and tap water perception in developing countries since different factors may affect tap water acceptance as compared to the developed world. Broad socio-economic differences for example, not present in most developed countries, may lead to different behavior and attitudes. During an off-flavor episode in the Fortaleza Metropolitan Region (FMR) in Brazil, two surveys, using questionnaires, were conducted with undergraduate students at a local public university. The T&O event happened between March and April 2017 affecting approximately 3.5 million consumers. Although the local water company (CAGECE) does not regularly monitor MIB or Geosmin, it reported an unusual high concentration of *Dolichospermum circinale* (around 10^4 cells per mL) in the source water, which may have been the T&O producer. One important question was to elucidate the effects of socio-economic factors on the general attitude towards tap water and the perception of off-flavors maintaining constant the level of education and age whenever possible. This was performed using the Human Development Index (HDI) of the volunteers' neighborhood derived from the latest census of 2015 (IPLANFOR 2015). The Human Development Index (HDI) is a summary measure of average achievement in key dimensions of human development: a long and healthy life, education and standard of living. The HDI is the geometric mean of normalized indices for each of the three dimensions (UNDP, 2016). In summary, the aims of this investigation were to:

- determine the influence of the socio-economic background of the volunteers on the perception of off-flavors and its affecting factors, maintaining the same educational level and age, and;
- determine the general acceptance or rejection of the tap water and the reasons why;
- determine what the tap water was generally used for;
- determine whether the customers are a reliable gauge of the water quality for the water utility.

METHODS

Water analysis

The concentrations of free and combined chlorine in tap and bottled water samples were analyzed using the Standard Method 4500-Cl (F) available at APHA (2012). N,Ndiethyl-p-phenylenediamine (DPD) is used as an indicator in the titrimetric procedure with ferrous ammonium sulphate (FAS). Where complete differentiation of chlorine species is not required, the procedure may be simplified to give only free and combined chlorine or total chlorine. Tap and bottled water were characterized with parameters shown in Table 1, also using methods described in APHA (2012). The geosmin and MIB analysis were performed by pre-concentrating the samples using a headspace technique with solid phase microextraction (SPME), followed by gas chromatography (Thermo Scientific, MA, USA, TRACE 1300 Series GC) coupled to a mass spectrometer (Thermo Scientific, MA, USA, Single Quadrupole MS-ISQ), according to the methodology available in Graham & Haynes (1998). Calibration curves were prepared with concentrations between 4 and 500 $ng.L^{-1}$, using analytical standards (Sigma-Aldrich - Germany).

The FMR is serviced by one reservoir and two water treatment plants employing similar treatment technologies (coagulation, direct filtration, disinfection).

Sensory analysis survey

Two surveys and a flavor test of tap water during an off-flavor episode were performed. The first survey consisted of questions asked regarding water usage and complaint behavior followed by a sensory analysis of four test waters including pure tap water, pure bottled water and two mixtures of the two. The second survey was conducted to elucidate the general attitude towards the tap water and the reasons behind it.

Table 1 | Tap and bottled water physicochemical and microbiological characteristics

Parameter	Tap water	Bottled water	Unit	Method used
Turbidity	1.12	NA	uT	Nephelometry
Apparent Color	10.00	NA	uH	Visual comparison
pH	7,43	6.28	–	Potentiometry/ISE
Alkalinity – hydroxides	ND	ND	mg $CaCO_3$/L	Acid-base titrimetry
Alkalinity – carbonates	ND	ND	mg $CaCO_3$/L	
Alkalinity – bicarbonates	69.19	34.86	mg $CaCO_3$/L	
Total hardness	77.91	12.62	mg $CaCO_3$/L	Titrimetry/complexometry with EDTA
Calcium	12.29	1.62	mg Ca/L	
Magnesium	11.32	2.63	mg Mg/L	Indirect measurement
Conductivity	422	243	uS /cm	Conductometry
Salinity	270	143	mg/L	
Chloride	80.75	27.38	mg Cl^-/L	Titrimetry/argentometry
Sulfate	11.00	1,43	mg SO_4	Spectrophotometry
Sodium	42.00	19.50	mg Na/L	Flame photometry
Potassium	9.00	4.51	mg K/L	
Nitrate	0.04	9.24	mg N-NO_3	Spectrophotometry/Reducing column Cd–Cu
Fluoride	0.74	0.05	mg F^-/L	Potentiometry/ISE
Manganese	0.02	>0.01	mg Mn/L	Spectrophotometry/persulfate
Total Iron	0.16	>0.01	mg Fe/L	Spectrophotometry/orthophenanthroline
Total Coliforms	absence	absence	in 100 mL	Chromogenic substrate
Escherichia coli	absence	absence	in 100 mL	

*ND: Not detected; NA: Not analyzed.

The sensory analysis was carried out by applying a survey (questionnaire) to untrained volunteers, using a modified version (Table 2) of the Flavor Rating Assessment Standard Method 2160C (APHA 2012). The modification was carried out in order to simplify the method and to adapt it to the local conditions. Considerations included simplicity of use by untrained surveyors, low cost, and time constraints. The scale was reduced from 9 to 5 points to allow a quicker throughput, as the questions can be easily read out to the volunteers and the scaling is easier to understand than a higher point scale (Dawes 2008; Bouranta *et al*. 2009). The water samples supplied to the volunteers were tap water, bottled water, and two dilutions (1:5; 1:2) of the same tap water with bottled water.

Samples were then anonymized as: A – bottled water; B – 1:5 dilution; C – 1:2 dilution; D – tap water. For the flavor testing, 50 mL plastic cups were removed from their packaging 1 day prior to use in the sensory analysis to help dissipate residual plastic taste and odor. Cups were filled with approximately 30 mL of the different waters at ambient temperature (~28 ºC) and immediately presented to the volunteer for tasting. The order of sample presentation was randomized following the sequence: ABCD to the first, BCDA to the second, CDAB to the third, and DABC to the fourth subject and then repeating the sequence over again. After tasting a sample, the volunteer was asked to rank the water according to the flavor-rating matrix (Table 2), and the next sample was supplied. After that step, data was recorded in the questionnaire including age, gender, neighborhood of residence, smoking behavior, as well as information about tap water use, complaint behavior, and flavors perceived.

Table 2 | Hedonistic scale used for the simplified Flavor Rating Assessment

Evaluation option	Numerical value
Very good	5
Good	4
Acceptable	3
Poor	2
Very poor	1

Questionnaires

The first questionnaire was subdivided into three sections of questions: "Personal Data", "Water Usage Behavior", and "Complaint Behavior"; followed by a flavor test as described earlier. The "Personal Data" section recorded the participant's age, gender, neighborhood of residence, and smoking habits. The "Water Usage Behavior" section determined whether tap water was used for the following activities: drinking, preparation of tea/coffee, cooking, washing fruit and vegetables, and/or the preparation of ice for beverages. The "Complaint Behavior" section aimed to elucidate to whom the subject was most likely to complain by offering the following options: family, friends, landlord, or the water utility. The second survey was performed to determine reasons for acceptance and rejection of the tap water in the FMR. The survey was subdivided into two sections followed by a flavor test, the first section was "Personal Data" which was identical to the first survey. The second section "Water Acceptance/Rejection" included the options "safety", "taste", "custom", and "other" for the rejection of the tap water and the options "safety", "taste", "cost", and "other" for the acceptance of tap water.

Human subjects

Volunteers were randomly chosen from undergraduate students at a local university campus in Fortaleza, Brazil. For the first study, 308 volunteers were surveyed while for the second study 374 volunteers attended. All lived in the FMR which is supplied by the same water distribution system as the university campus, where the water was sourced from. Verbal consent for the use of data was obtained from all volunteers. No prior training was performed to ensure that the volunteers' replies were representative of the average tap water consumer. The Human Development Index (HDI) of the volunteers' neighborhood, derived from the latest census of 2015 (IPLANFOR 2015), was used since it is considered the most easily available and applicable means for determining socio-economic differences (Ravallion 2012).

Statistical analysis

Generalized linear models (GLM) were applied to investigate whether any of the personal or socio-economic factors determined a heightened sensitivity towards the off-flavor perception in water. The GLM analysis was performed using the "glm function" available in the statistical software *R-statistics*. Binomial and Poisson probability distributions were used to compare the results obtained by the model using each distribution. Adherence tests were performed between the distributions models and the variables before the utilization, obtaining adherent results and allowing the use of these distributions in the model. With GLM, it was possible to predict the probability that a dependent variable (flavor) was related to the independent ones, in this case smoking, age, sex, HDI. The lower the p value, the greater the impact of the independent variable on the perception of taste and odor. In this way, it is possible to rank the importance of each independent variable in flavor perception. More detail about the application of this statistical model can be found in Min & Agresti (2001). For comparison of other survey data found in this research, analysis of variance (ANOVA) was used, considering $p < 0.05$ for significance level.

RESULTS AND DISCUSSION

The first survey consisted of questions regarding water usage, complaint behavior, and sensory analysis. In this survey, 308 volunteers participated, of which 189 were male and 119 were female. The average age was 21.6 ± 5.4 years (Figure 1). Furthermore, 21 participants were identified as smokers. The second survey was conducted to elucidate the general attitude towards the tap water and the reasons behind it. In this survey 374 volunteers were questioned, of which 219 were male and 155 were female. The average age was 22.4 ± 4.9 years (Figure 1).

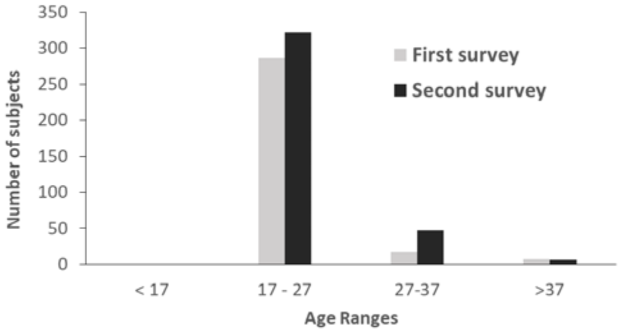

Figure 1 | Age range of subject in the first and second survey.

Water analysis

The focus of this investigation was on organoleptic factors: chlorine and musty/earthy off-flavor. Tap water samples were identified to contain 2-methylisoborneol (MIB). The concentration of MIB in the tap water was determined to be 50 ± 5 ng L^{-1}. Free chlorine concentration was determined to be 0.20 mg L^{-1}, which is close to the odor threshold reported by Krasner & Barrett (1984) and at the minimum level required by Brazilian law (Ministério da Saúde 2017). As the chlorine off-flavor was one of the most identified flavors in the samples, it makes sense that the tested population is quite sensitive to its presence, which may explain the perception by most volunteers at this low concentration, even in the diluted tap water samples. Piriou *et al*. (2015) found that the more sensitive a sample population is to the presence of chlorine off-flavors, the lower the perception threshold is. No other chlorine compounds such as chloramines were detected.

Water usage and complaint behavior

The survey data indicates that only a small portion (11%) of the volunteers used the tap water for drinking (Figure 2). However, almost all volunteers (97%) used it for cleaning fruit and vegetables, about three-quarters (73%) for the preparation of hot beverages and a third (33%) for the preparation of ice for beverages. In most studies that have investigated the reasons behind unwillingness to imbibe tap water, the major concerns of consumers were the safety of the water. This is true even for developed countries like Canada, the United States of America, and France (Doria 2006, 2010; Saylor *et al*. 2011). However, the water usage makes apparent a certain disconnect between the perceived potential dangers to health safety and the use of the tap water to produce ice for beverages and the cleaning of fruit and vegetables. In fact, ingesting fruit cleaned with tap water also means ingesting small amounts of tap water. It must be pointed out that in Brazil consumers have the habit of subjecting vegetables that are going to be consumed raw to a chlorine water bath to remove parasites, especially helminthes (Manuel & Germano 1992;

Amoah *et al.* 2007). In the minds of the consumers this may off-set the perceived safety issue of imbibing even small amounts of tap water on cleaned fruit and salad items.

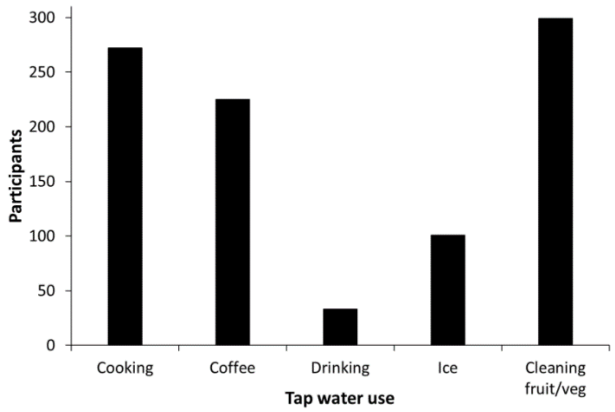

Figure 2 | Tap water use in university students' households in FMR, Brazil.

Volunteers indicated they were more likely to complain about the organoleptic properties of tap water in a social context rather than in a formal one (Figure 3). Of the 308 volunteers, 67% stated they were most likely to complain to family (56%) and their social circle (11%) than formally to their landlord (15%) or the water utility (25%). This is similar to findings by Webber *et al*. (2015), where it was established that South Australian customers were also more likely to complain about water quality in a social context than a formal one. This behavior demonstrates that, in countries like Brazil and Australia, Dietrich's (2006) proposal to utilize the consumer as a "sentinel of water quality" would not work, emphasizing the findings of Webber *et al*. (2015) which state that customer complaints alone are not a good indicator of customer satisfaction.

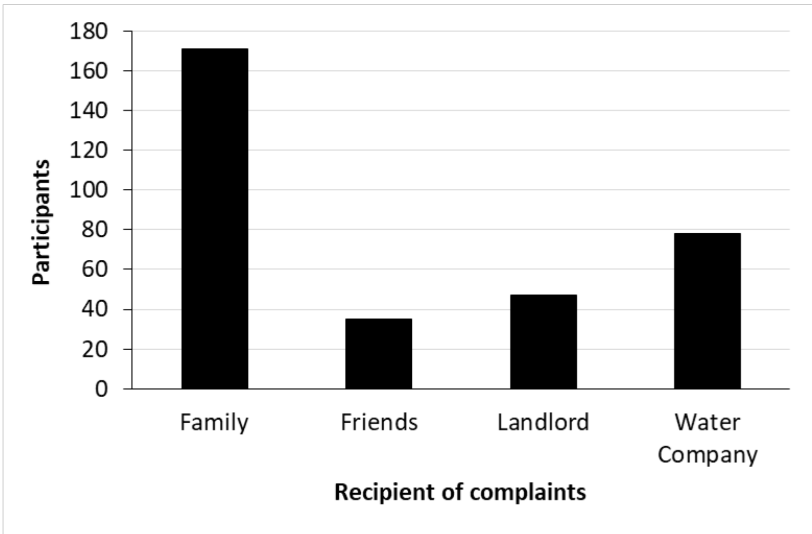

Figure 3 - Complaint behavior regarding organoleptic water quality in the FMR, Brazil.

Reasons for acceptance/rejection of tap water

In the second survey, volunteers were asked whether they consumed tap water for drinking and the reasons why they would or would not. Of the 374 volunteers surveyed, 323 (86%), rejected the tap water (Figure 4). Most of the participants (57%) that rejected tap water did so out of concern for the water's safety. They did not believe that tap water is fit for consumption. This is also the main reason observed in many similar studies in the developed world (Jardine *et al*. 1999; Doria 2006; Doria *et al*. 2009; Dupont *et al*. 2010; Saylor *et al*. 2011).

The perceived concern of the water safety is followed by dissatisfaction with the water's organoleptics as the second reason customers in developed countries reject tap water (Jardine *et al*. 1999; Doria 2006; Saylor *et al*. 2011). This was also the case in the present study where the second most common (21%) reason for rejection of the tap water was disagreeable organoleptics (Figure 4). The concerns with safety and the rejection of the tap water due to unpleasant organoleptics creates a negative feedback loop because, as Jardine *et al*. (1999) established, there is a connection between the water odor and its perceived safety. Dissatisfaction with the water's organoleptics was followed by having the family habit (custom) of only drinking bottled water (19%).

Of the 51 volunteers that consumed tap water on a regular basis, most did so due to economic reasons (70%), followed by “Other reasons”. It is much cheaper to drink tap water than bottled. While this is true for the developed world, it does not appear to be such a significant factor in developing countries (Saylor *et al*. 2011). About a third of those that accepted the tap water (28%) did so because they used a point-of-use water filtration system. The use of a filtration device coupled to the home tap conveys a feeling of security as the customer perceives that the tap water is rendered safer to drink (Dupont *et al*. 2010). Only one participant believed that drinking tap water was safer than consuming bottled water (Figure 4).

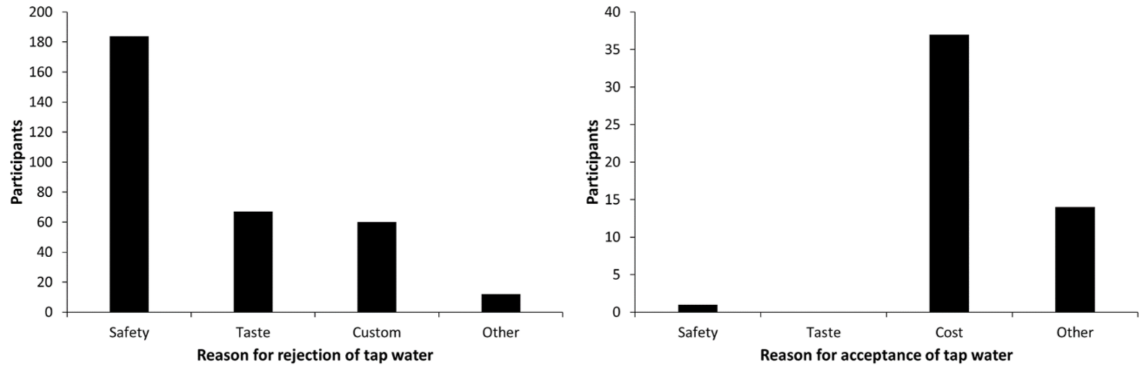

Figure 4 | Reasons for rejection and acceptance of tap water in the FMR, Brazil.

In this survey, the HDI of the volunteers' neighborhood was considered as well. The HDI aggregates the realization of country-level improvements in per capita income and life expectancy (Ravallion 2012). This survey revealed that the rejection of the tap water is universal across the four different HDI categories of "low", "medium", "high", and "very high" (Table 3). Between 83 and 90% across the four categories rejected the water. This is contrary to the results of Sajjadi *et al.* (2016), who found in a survey about water quality perception in Iran that volunteers' acceptance differed greatly across the societal strata. There appears to be no correlation (for α = 5%) between the HDI of the neighborhood that the volunteer lives in and whether the tap water is rejected or accepted.

Table 3 | Acceptance/rejection of the tap water in FMR (Brazil) based on the HDI of the volunteers' neighborhood

Human Development Index	**Accept**	**Tap water reject**	***n***
Low (0–0.549)	36 (16%)	192 (84%)	228
Medium (0.550–0.699)	11 (10%)	97 (90%)	108
High (0.700–0.799)	2 (13%)	13 (87%)	15
Very high (0.800–1)	4 (17%)	19 (83%)	23

Sensory analysis

Both the bottled water and the 1:5 dilution of tap water with bottled water were rated 4 on average, the 1:2 dilution of tap water with bottled water received an average score of 3, while pure tap water received the lowest score on the hedonistic scale with an average of 2. This may indicate that, for the volunteers, tap water with low amounts of off-flavor compounds are still accepted as "good" and that there is no significant difference (for α = 5%) between this water and bottled water. The distribution of the volunteers' rating shows that with 23% of the total ratings distributed between the extremes, “very poor” (9 %) and “very good” (14 %), no complete avoidance of the extremes was observed (Table 4).

Table 4 | Result of the sensory testing of different waters (bottle, tap, mix); (*n*=308)

		Frequency of reply					
	Water	**1**	**2**	**3**	**4**	**5**	**Mean (±std. dev.)**
A	Bottled water	20	29	51	99	109	4 ± 1.2
B	1:5 tap water:bottled water	12	23	110	117	46	4 ± 0.9
C	1:2 tap water:bottled water	23	72	128	72	13	3 ± 0.9
D	Tap water	51	110	117	27	3	2 ± 0.9

Water containing about 10 ± 1 ng L^{-1} of MIB was still considered acceptable. While this value is just within the guidelines value published in Australia and Japan (Hiroshi 2005; NHMRC & NRMMC 2011) it was in accordance with the Brazilian regulations for potable water (Ministério da Saúde 2017). This finding corrolates to the HDI data (Table 5) which shows that volunteers from low HDI neighborhoods (63% of the volunteers) appear less sensitive in perceiving off-flavors. This corroborates the results published by Sajjadi *et al.* (2016), who found that perception of water quality in India depended greatly on the social background of the volunteer.

Table 5 | Indication of off-flavors perceived by volunteers living in neighborhoods with different HDI scores

	Off-flavor perceived (%)		
Human Development Index	**Earthy**	**Chlorine**	***n***
Low (0–0.549)	25	14	195
Medium (0.550–0.699)	37*	43*	92
High (0.700–0.799)	64*	52*	7
Very high (0.800–1)	70	62	14

*Denotes statistical difference from the immediate lower value (α = 5%).

In addition to the flavor rating, volunteers were asked to identify any off-flavors perceived (Figure 5). In the pure tap water sample (sample D), the prevalent flavors identified were “earth” and “chlorine”, followed by “bitter” and “grass”. In the other two samples that contained tap water (samples B and C) “earth” and “chlorine” remained the two most frequently identified flavors. Free chlorine concentration in the tap water sample was determined to be 0.20 mg L^{-1} which is below the perception threshold previously reported in the literature (Krasner 1984; Barrett 1984; WHO 2008; Piriou *et al*. 2015). The results indicated that volunteers could detect chlorine off-flavor at concentrations as low as 0.05 mg L^{-1}. Piriou *et al*. (2015) determined that regional differences in the perception of chlorine off-flavors exist. This low sensitivity may be explained by the fact that bottled water consumers were found to be more sensitive to chlorine flavor than those consumers of tap water (Puget *et al*. 2010). The authors also found that tap water consumers showed a higher liking score for chlorinated solutions and were more inclined to accept chlorine solutions as drinking water. Piriou *et al*. (2015) also observed that customers that are more sensitive to the flavor of free chlorine were less likely to accept perceptible concentrations in the tap water, which may explain the relatively high rejection rate in the present study. It is noticeable, in samples B and C (20 and 50% tap water respectively), that chlorine was perceived more often than earthy off-flavor. This phenomenon was also observed by Piriou *et al*. (2009) who determined that chlorine could mask the presence of the off-flavor compounds MIB and geosmin.

The grassy off-flavor was also identified in all the samples containing tap water. While a grassy off-flavor usually is not considered to be caused by MIB, it was noticed that volunteers were struggling to identify their perception. It is possible that the grassy off-flavor is misidentified since with decreasing amounts of tap water in the samples (D→C→B), the number of times “grass” was perceived decreased as well. Very few volunteers (six) indicated “grass” in the bottled water sample. Water companies have observed that consumer complaints are confusing because they have difficulty describing what they taste and smell. Even in controlled sensory testing it can be difficult to have uniform, accurate, and reasonable answers. (Gallagher & Dietrich 2014; Dietrich *et al*. 2014). According to Burlingame *et al.* (2017), even a trained and experienced panel could not agree on descriptors for river water samples, consistently reporting “grassy” or “earthy”. Phetxumphou *et al.* (2017) used a T&O Wheel to improve geosmin descriptors. According to the authors, geosmin was initially described mostly as dirt, earthy, nothing, soil, bad smell, body odor, and grass. However, with the T&O Wheel, the responses were more consistent – predominantly grassy, earthy, and musty.

The perception of “salt” and “metal” in all samples containing tap water remained at a similar level across samples (24–26 times “salt”; 26–34 times “metal”). In the bottled water sample “metallic” was often perceived and “salt” was perceived 24 times. The “bitter” flavor was most often identified in the tap water sample (sample D; 68 times), in the remaining samples “bitter” was identified with a similar frequency (27–37 times). Teillet *et al.* (2010) suggested three major kinds of taste associated with mineral content: almost bitter and metallic for low mineral content waters, neutral and fresh for medium mineral content waters and for highest mineral content waters. Based on the “kinds of taste” establish by Teillet *et al.* (2010), the results presented in this paragraph suggest that the subjects in this study did not follow the patterns expected when going from a low mineral content (bottled water) to a high mineral content water (tap water). This may indicate that either the subjects needed to be trained for the task, the descriptive attributes should have been better selected or, as suggested by Teillet *et al.* (2010), sensory analysis of water is really a difficult task.

Vingerhoeds *et al*. (2016) examined the differences of flavor between various demineralized drinking waters. The attributes used included flavor intensity and the tastes bitter, sweet, salt, metal, fresh and dry mouthfeel, bitter and metal after-taste, and rough after-feel. They found that lowering mineral content in drinking water from 440 to less than 5 mg L^{-1} shifted the sensory perception of water from fresh towards bitter, dry, and rough sensations. Since the salinity of the tap water in this investigation was 270 mg L^{-1}, the “bitter” and “salty” tastes often perceived may be explained thus. In addition, Vingerhoeds *et al*. (2016) also identified that perceived freshness of waters correlated positively with calcium concentration. The greatest fresh taste was found for water with a TDS between 190 and 350 mg L^{-1}.

Generalized linear models (GLMs) were applied to the survey data using both Poisson and Binominal distribution. It was tested if any of the following factors were important in determining whether off-flavors (“earth” and “chlorine”) were perceived by the volunteers: smoking habit, HDI, gender, and age. Both GLMs determined that none of the above factors displayed a high significance in whether off-flavors were perceived (Table 6). On the other hand, the results indicated that, while not highly significant, the smoking habit of a volunteer had the most influence on the perception of the earthy off-flavor and that the neighborhood HDI influenced whether the chlorinous off-flavor was noticed.

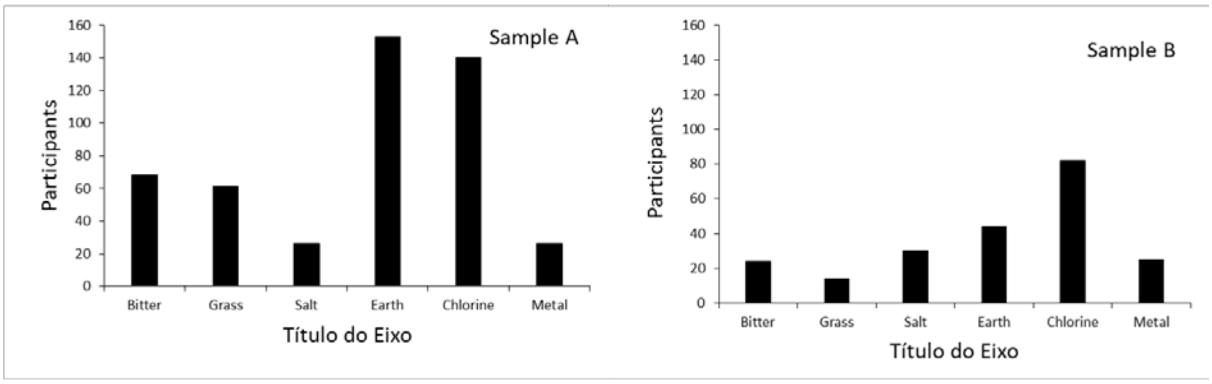

Figure 5 | Results of the sensory testing of different tap and bottled waters in FMR, Brazil. Sample A: bottled water; Sample B: tap water:bottled water (1:5); Sample C: tap water:bottled water (1:2); Sample D: tap water.

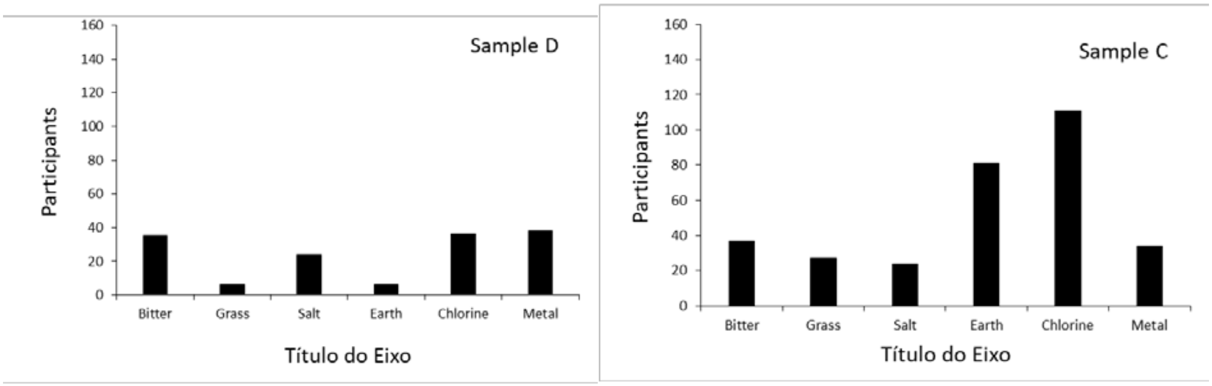

Table 6 | Generalized linear model analysis of the survey data. Using both Poisson and Binomial distribution to determine the most important factor in the perception of earthy and chlorine off-flavors. Bold values represent the factor most likely to affect perception

	Poisson distribution (*p*-value)		**Binomial distribution (*p*-value)**	
Factor	**"Earth"**	**"Chlorine"**	**"Earth"**	**"Chlorine"**
Smoking	0.3725	0.8371	0.216	0.780
HDI	0.5598	0.5792	0.414	0.452
Gender	0.7385	0.9788	0.639	0.972
Age	0.8765	0.9480	0.830	0.930

CONCLUSIONS

During an off-flavor episode (2-methylisoborneol-MIB) in the Fortaleza Metropolitan Region, Brazil, volunteers were subjected to a sensory analysis of tap water, bottled water and mixes of the two. Water usage and complaint behavior, as well as the level of acceptance of the tap water, were investigated. While water was used daily for the preparation of ice for beverages, hot beverages, and for the cleaning of fruit and vegetables it was hardly ever (7%) consumed as a beverage itself. The tap water containing MIB (50 ng L^{-1}) and free chlorine (0.2 mg L^{-1}) was, on average, considered "poor", while bottled water and a mix of 20% tap water with bottled water was considered "good". Statistical analysis with generalized linear models showed that while none of the tested factors was significant in determining whether off-flavors were perceived, the HDI ranked as the most important factor in case of chlorine and as the second most important factor (after smoking) for earthy off-flavors. This research has also shown that customers were most likely to complain in a social context rather than formally. A second survey demonstrated that the major reason for rejection of the tap water was concerns over the safety of the water, followed by disagreeable organoleptic (flavor). The major reason for consuming tap water was economic savings. The HDI of the neighborhood of the participant did not influence whether tap water was rejected or not. This investigation also has demonstrated that:

- Customer complaints may not be a good measure of customer satisfaction;
- Water with low amounts (10 ng L^{-1}) of off-flavor compound MIB and low amounts of free chlorine (0.05 mg L^{-1}) is still rated as "good" and with moderate amounts of MIB (25 ng L^{-1}) and chlorine (0.1 mg L^{-1}) as "acceptable" by customers;
- The greatest hurdles for the consumption of tap water were health and safety concerns (57%) and flavor (21%);
- Although Brazilian legislation has a large set of parameters with strict concentration limits, taste and odor aspects do not seem to be considered as a major consumer gauge influencing water quality perception;
- When decisions need to be made to improve potable water quality and water usage, customers' perception and complains need to be assessed through a more efficient channel of communication;
- Although the water company guarantees that the water distributed to the FMR is safe and potable, only 7% of volunteers used the tap water for drinking. This may suggest that the water utility should communicate better with its customers.

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