THE EFFECT OF WATER IMPURITIES ON THE FLAVOR OF BREWED COFFEE[a,b]

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Coffee is one of the most popular beverages in the United States. The per capita consumption is approximately 13 pounds and the total consumption about two billion, one hundred million pounds. The average coffee drinker consumes three and one-half cups each day or more than 1,250 cups each year.

Coffee has attained its eminent position simply because it tastes good. As a result of much painstaking effort and experience, growers and manufacturers have created the varieties, blends of varieties, roasts and grinds of coffee that yield brews highly acceptable to consumers.

The final step, that of preparing the extract, is a crucial one. Although it is not difficult to make a cup of good coffee, lack of knowledge, indifference, carelessness, and circumstance often act separately or together to prevent the consumer from receiving the full measure of enjoyment that the growers and the manufacturers have struggled so diligently to achieve.

Circumstance, certainly, plays an important role in the success or failure of coffee making. For example, an essential component of coffee is water. Unfortunately, the water we drink and use in the preparation is not simply H_2O, but a complex solution containing many different chemical compounds. The complexity of the solution varies greatly according to the region of origin, the type of storage, the treatment it receives, and many other factors. A vast knowledge concerning types and composition of water supplies throughout the country has become available over the years but relatively little is known about the effect of water impurities on the flavor of beverage coffee.

The object of the present study was to determine what effects impurities normally present in water might induce in brewed coffee.

EXPERIMENTAL

A survey of literature sources and correspondence showed that water supplies are described in terms of some 16 chemical components. These are silica, iron, manganese, calcium, magnesium, sodium, potassium, carbonate, bicarbonate, sulfate, chloride, fluoride, nitrate, dissolved solids, calcium carbonate hardness, and non-carbonate hardness. While this study was in progress an excellent review of the composition and other characteristics of public water supplies became available *(4)*. This publication confirmed our previous choice of components to be studied.

The experimental approach included a determination of taste thresholds for individual components in distilled water according to the method described by Harrison and Elder *(1)* and modified by Lockhart and Stanford *(3)*.

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A series of solutions varying in concentration with respect to a single component was prepared. Sodium bicarbonate was used as a source of bicarbonate ions; sodium carbonate, carbonate ions; sodium chloride, chloride ions; potassium chloride, potassium ions; potassium acetate, potassium ions; sodium acetate, sodium ions; magnesium sulfate, magnesium ions; sodium phosphate dodecahydrate, phosphate ions; calcium chloride dihydrate, calcium ions; and ferric sulfate as a source of ferric ions. All chemicals used were of analytical reagent grade. The water was distilled first from a tinned still and then from an all-glass still. All concentrations were prepared in terms of parts per million (p.p.m.) and after preliminary trials were selected so that the odd sample in any test would be identified correctly by more than 33% but less than 100% of the judges.

Each solution and distilled water as a control were presented to members of a taste panel for their differentiation. The experimental design was a randomized triangle test. The solutions, in 25-ml. portions, were served in identical coded beakers. Each set of three consisted either of one sample of distilled water and two of component or two of distilled water and one of component. Combinations were presented randomly and judges were never given any information about the component or the nature of the combination. They were asked only to select the odd sample.

Each taste panel was composed of 18 or more members selected from the departmental staff. Both men and women participated. Some were smokers; others were not. All had previous experience in judging food quality, in threshold testing, and in other flavor studies. Panels were varied in composition.

The tests were conducted in mid-morning and mid-afternoon, at least one hour after meals and in a room designed for work of this kind.

The data obtained from the individual tests are recorded in Table 1. Included in this table are results in terms of percentage correct identifications of the odd sample, and percentage above chance.

As a threshold value became known, a water containing a concentration of the component equal to the threshold value was made up and used for the preparation of coffee beverage. At the same time a control beverage was prepared with distilled water. Triangle difference tests were presented to panels in the manner described above. If the panel could not differentiate the odd sample with statistical significance, the component concentration was increased stepwise until the panel was able to make a significance differentiation. In some cases hedonic scale scores *(5)* were also recorded.

The coffee used was one selected from several as an acceptable brand. It was a Silex-grind type and vacuum-packed in one-pound cans. Silex vacuum coffee makers were employed in the preparation of brews. The brew was prepared generally in 10-cup quantities. The proportion of coffee to water was one standard measure (equivalent to two level tablespoons) per six ounces of cold water. The water was measured into the lower bowl of the maker and heated to boiling. At this point the upper bowl containing the coffee was inserted into the lower. After the water had risen into the upper bowl, the suspension was stirred for 30 seconds and held on the hot plate for a total of 2 minutes. The maker was removed to a cool surface to bring the extract down into the lower bowl as rapidly as possible. This generally required less than one minute.

The coffee was maintained at a temperature of approximately 180°F. (82°C.) until served. It was served in 25-ml. portions. Small amounts of cream and sugar were permitted if the beverage were normally consumed with these optional ingredients. No coffee was held for longer than 30 minutes; fresh beverage was prepared as required.

Data relating to the ability of panels to detect added components in coffee are presented in Table 2.

RESULTS AND DISCUSSION

The data obtained from experiments on threshold testing of ions in water solution were plotted on logarithmic probability paper according to the method of Harrison and Elder *(1)*. A line was drawn visually through the points for each set and the concentration corresponding to a probability of 50% above chance taken as the threshold value. A typical result from the calcium data is shown in Figure 1. A summary of the

TABLE 1

Data for the measurement of taste thresholds of ions in water solution

Ion	Conc. p.p.m.	Separations		Percentages	
		Total	Correct	Correct	Above[1] chance
HCO_3^-	125	20	8	40.0	9.5
	250	20	9	45.0	17.5
	500	20	11	55.0	32.5
	1000	20	15	75.0	62.5
$CO_3^=$	31	20	13	65.0	47.5
	62	20	14	70.0	55.0
	125	20	16	80.0	70.0
	250	20	18	90.0	85.0
Cl^-	75	20	11	55.0	32.5
	125	20	12	60.0	40.0
	250	20	15	75.0	62.5
	500	20	14	70.0	55.0
Ca^{++}	62	20	9	45.0	17.5
	125	20	13	65.0	47.5
	188	20	17	85.0	77.5
	250	20	18	90.0	85.0
Fe^{+++}	1	20	7	35.0	2.5
	2	20	7	35.0	2.5
	4	20	8	40.0	9.5
	8	20	10	50.0	25.0
	12	20	15	75.0	62.5
$PO_4^{\equiv}$	10	20	7	35.0	2.5
	50	20	13	65.0	47.5
	100	20	12	60.0	40.0
	150	20	13	65.0	47.5
	250	20	16	80.0	70.0
Mg^{++}	50	20	8	40.0	9.5
	75	20	10	50.0	25.0
	100	20	15	75.0	62.5
	125	20	14	70.0	55.0
K^+ in KCl	250	20	12	60.0	40.0
	500	20	15	75.0	62.5
	625	20	16	80.0	70.0
	750	20	17	85.0	77.5
K^+ in KAc	340	20	9	45.0	17.5
	400	20	10	50.0	25.0
	500	19	11	57.9	35.0
	600	19	12	63.2	44.7
	750	20	16	80.0	70.0
Na^+	75	20	9	45.0	17.5
	100	20	12	60.0	40.0
	150	20	12	60.0	40.0
	200	20	16	80.0	70.0

[1] Calculated from formula: % above chance is equal to 3/2 (% observed—% expected).

TABLE 2

Data relating to the effect of ions on the flavor of coffee beverage

Ion	Conc. p.p.m.	Separations		Hedonic scores[1]	
		Total	Correct	Control	Test
$CO_3^{=}$	55	20	5	5.5	6.3
	100	20	8	3.9	6.0
	125	20	16[2]	4.2	5.0
HCO_3^-	1000	20	16[2]	5.3	5.0
Cl^-	225	40	12	4.8	5.6
	250	20	7	3.5	4.3
	300	20	4	5.0	4.0
	400	20	12[2]	4.3	5.0
Mg^{++}	110	20	9	....	....
	200	20	12[2]	....	....
K^+	340	20	9	....	....
	375	20	9	....	....
	410	20	11[2]	....	....
Fe^{+++}	10	18	11[2,3]	....	....
Ca^{++}	125	20	10	....	....
	250	20	8	....	....
	300	20	11[2]	....	....

[1] Calculated from correct separations only.
[2] 11 or more correct separations, significant, $p < 0.05$.
[3] See discussion on effect of iron in coffee.

threshold concentrations and concentrations giving detectable effects in coffee beverage is shown in Table 3. These results have been calculated in terms of both ions contributed by the salt because different thresholds were obtained for several ions due to the nature of the accompanying ions.

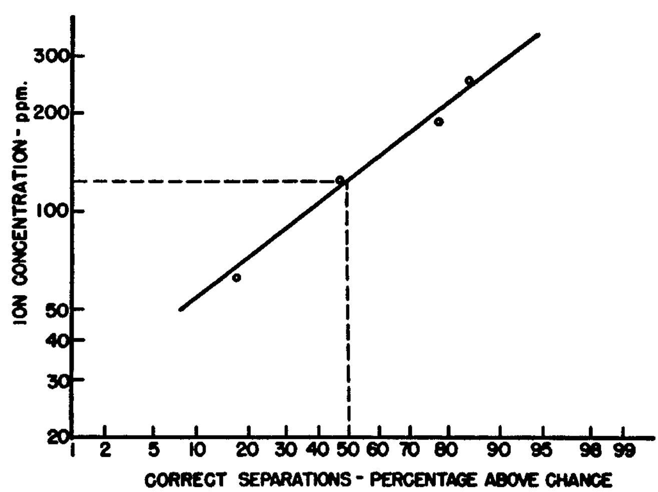

Figure 1. Threshold determination of calcium ion in distilled water. Triangle test. Concentrations of calcium against percentage of correct separations above chance.

TABLE 3

Threshold concentrations of ions in water solution and concentrations in coffee beverage

Ion	Threshold in water p.p.m.	Concentration detectable in coffee beverage p.p.m.
$NaHCO_3$		
Na^+	290	377
HCO_3^-	770	1000
Na_2CO_3		
Na^+	34	96
$CO_3^=$	44	125
Na_3PO_4		
Na^+	75	....
$PO_4^{\equiv}$	105	....
NaAC		
Na^+	140	....
Ac^-	360	....
NaCl		
Na^+	135	258
Cl^-	210	400
KCl		
K^+	340	410
Cl^-	310	450
KAc		
K^+	680	....
Ac^-	1020	....
$CaCl_2$		
Ca^{++}	125	300
Cl^-	222	530
$MgSO_4$		
Mg^{++}	100	200
$SO_4^=$	400	800
$Fe_2(SO_4)_3$		
Fe^{+++}	10	10
$SO_4^=$	25	25

In these cases one must hesitate to say that either of the paired ions is exerting an effect unsupplemented by some effect of the other. For example, five of the salts contained sodium. In combination with bicarbonate the concentration of sodium at threshold was highest, 290 p.p.m. It was lowest, 34 p.p.m. in combination with carbonate. Concentrations in other combination were not higher than 140 p.p.m. It is impossible to say that differentiation of the sodium bicarbonate solutions from water is due either to sodium or bicarbonate. In all probability the action of these ions is supplemental. On the other hand, one can infer that the differentiation of sodium carbonate solutions from water is due almost entirely to the presence of the carbonate ion. In the threshold solutions of carbonate and bicarbonate the ratio of sodium concentrations is approximately 1:9. A similar analysis might be made of the results that are shown for compounds containing potassium, chloride, acetate, and sulfate ions.

As might have been expected, in those instances in which coffee beverage was prepared with water containing ions at or near their threshold concentrations, no detectable difference in flavor was observed. Increases in concentration ranging from 20% in the case of ions in potassium chloride to 180% in the case of ions in sodium carbonate were required to induce effective changes in the taste of the beverage.

Iron is a special case. Preparation of coffee with iron at 10 p.p.m. yielded a beverage that was differentiated not because of flavor changes but because of changes in color or appearance particularly when cream was added. Although this point has not been investigated, it may be conjectured that the iron combines with polyphenolic components of the extract to produce typical greenish colors. A more detailed qualitative study of this effect indicated that when iron is added to coffee with cream at levels not exceeding 4 p.p.m. the mixtures have a normal appearance if not compared against controls containing no iron. At levels between 4 and 7 p.p.m. there might be some question about acceptability. At levels above 7 p.p.m. a very definite unpleasant greenish cast was readily perceptible. When mixtures containing iron are compared side by side with those containing none, differences are apparent even at an iron concentration of one p.p.m.

Because of limitations associated primarily with panel composition and bias, no attempt was made to determine precisely the relative acceptability, like or dislike, for the members of a pair of coffees when significant differences were obtained. The general observation, however, is that the presence of ions aids in the preparation of a more acceptable brew. Previous evidence *(2)* which still requires confirmation has also indicated that this may be so.

The major objective of this study was to determine whether concentrations of ions at levels normally found in public water supplies have an effect on the flavor of brewed coffee. Table 4 compiled from data recently available *(4)* shows the ion composition of typical water supplies throughout the country. An effort was made to locate areas having water supplies that contained high concentrations of specific ions because no supply contained high concentrations of all ions. Many of the areas have supplies that contain relatively low concentrations of all ions. The bicarbonate appeared to be the ion present in all waters in highest concentrations. A very high value for this ion was 336 p.p.m. This value is well below that found for the threshold (770 p.p.m.) and should not affect the taste of coffee beverage. Iron and carbonate, although having the lowest threshold values, are found in almost negligible concentrations in water supplies. A high concentration of iron was 0.56 p.p.m., found in Sarasota water. It cannot have any effect on the taste of water or coffee and should not produce detectable color changes. Occasionally, as in the case of sulfate, sodium and chloride, there are concentrations high enough to be taste factors. For example, in the Sarasota water the concentration of sulfate is reported as 817 p.p.m. and that for sodium, 530 p.p.m. These values are higher than those for the corresponding thresholds in water and the detectable limit in coffee beverage. In the Galveston water the concentration of chloride is reported as 422 p.p.m. Again this value is higher than threshold for water and the

TABLE 4

Analyses of water supplies used by large cities in the United States

Component	Boston, Mass.	New York, N. Y.	Chicago, Ill.	Los Angeles, Calif.	San Francisco, Calif.	Indianapolis, Ind.	Cleveland, Ohio	St. Louis, Mo.	Kansas City, Kan.	Galveston, Texas	Sarasota, Fla.	Pittsburgh, Pa.
Iron	0.10[1]	0.03	0.09	0.04	0.02	0.11	0.12	0.01	0.01	0.0	0.56	0.3
Calcium	4.0	13.0	39.0	25.0	1.1	67.0	39.0	23.0	75.0	30.0	14.0	60.0
Magnesium	0.4	4.3	10.0	5.0	1.4	20.0	7.3	9.7	22.0	9.7	0.3	18.0
Sodium	1.8	3.0	3.3	34.0	0.1	6.2	8.7	33.0	59.0	351.0	530.0	49.0
Potassium	0.7	1.4	0.7	4.0	....	1.6	1.3		5.6		16.0	
Carbonate	0.0	0.0	0.0	2.0	0.0	0.0	0.0	13.0	0.0	0.0	0.0	0.0
Bicarbonate	7.0	36.0	132.0	138.0	7.0	206.0	103.0	20.0	237.0	336.0	161.0	17.0
Sulfate	5.6	20.0	23.0	23.0	1.6	67.0	30.0	109.0	172.0	1.0	817.0	248.0
Chloride	3.4	5.8	7.2	17.0	1.0	10.0	20.0	17.0	29.0	422.0	168.0	58.0

[1] All data given in p.p.m.

detectable limit in coffee. However, these are isolated conditions and although important locally, affect only small groups of beverage consumers. Large cities either secure their supplies from sources that are naturally quite pure or finish raw waters by methods that remove or reduce materially concentrations of ions to innocuous levels.

It may be concluded, therefore, that except for local conditions and isolated cases, the inorganic components of water supplies studied to date should not affect the taste of brewed coffee. There remains still the problem of determining by similar techniques the effect of dissolved gases, such as ammonia, sulfides and chlorine, and in addition, organic materials that may form an important odor fraction of the dissolved solids. This work is now in progress.

SUMMARY

Taste thresholds of a number of inorganic ions found in public water supplies have been measured. Coffee prepared with water containing individual ions at threshold levels could not be differentiated from coffee prepared with distilled water. Coffee prepared with water containing higher concentrations of ions could be differentiated. The levels at which differentiation was possible were found.

Except for some minor local supplies, the concentrations of inorganic components studied should not affect the taste of brewed coffee.

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