Relationships between Concentrations of Sodium, Potassium, and Chlorine in Unsalted Foods

Philip A. Helmke* and Denise M. Ney

Department of Soil Science and Department of Nutritional Sciences, University of Wisconsin—Madison, Madison, Wisconsin 53706

Instrumental neutron activation analysis was used to determine the concentrations of sodium, potassium, and chlorine in 167 samples of unsalted foods representing 112 different foods and 6 commercial beverages. The results of regression analysis show that the concentrations of chlorine in foods cannot be predicted accurately from the concentrations of sodium and potassium. Comparison of the results to those in published data bases shows excellent agreement for potassium; however, the data bases contain values of sodium and chlorine that are excessively high for some foods. The very low detection limits of neutron activation and the relative freedom from contamination make it an excellent technique for the simultaneous analysis of sodium, potassium, and chlorine in foods. Many of the values for chlorine reported here are the first published values for chlorine concentrations in food.

INTRODUCTION

The concentration of chlorine in food is often assumed to be correlated with the concentration of sodium. This is a reasonable assumption when sodium chloride is a food additive, but the supporting evidence for this assumption in uncooked, unadulterated, primitive foods is equivocal. The primary evidence for the correlation of chlorine and sodium concentrations in food is based on a statistical analysis of the British nutrient data base (Paul and Southgate, 1978) that showed more than two-thirds of the overall variation of the chlorine concentration in unadulterated foods were linked to the sodium concentration (Yarbrough Al-Bander et al., 1988). The primary nutrient data base used in the United States, the *Composition of Foods* series, does not include data on the chlorine content of foods (USDA, 1976–1991).

Conclusions about the relationships between nutrients in food, based on statistical analysis of compiled nutrient data bases, are limited by inconsistencies inherent in such compilations. For example, the British data base is compiled from published sources that used a variety of analytical procedures to determine sodium and chlorine concentrations. The various elements were often determined by different investigators, and the values for sodium and chlorine were often determined on different samples. The values thus reflect interlaboratory biases and regional and seasonal differences in the composition of the food samples.

There is an increased need for an accurate data base for the chlorine concentration of foods because of the critical role of chlorine in the correction of hypokalemic alkalosis (Kassirer et al., 1965) and the role of the chloride ion as a determinant in sodium-dependent hypertension. Sodium appears to induce hypertension only in conjunction with the chloride anion (Whitescarver et al., 1984; Kurtz et al., 1987). Amelioration of hypertension by increased potassium intake has been suggested (Luft, 1989). The large data base for sodium and potassium concentrations in foods suggests that diets low in sodium tend to be high in potassium. These biological interactions among sodium, potassium, and chlorine make it important to have accurate data regarding their concentrations in foods.

Table I. Concentrations of Sodium, Potassium, and Chlorine Determined in NBS Reference Materials[a]

	sodium, $\mu g\ g^{-1}$	potassium, $\mu g\ g^{-1}$	chlorine, $\mu g\ g^{-1}$
	Orchard Leaves 1571		
NBS values	82 ± 6	14700 ± 300	700[b]
this study	86 ± 5	14100 ± 400	760 ± 70
this study	88 ± 6	14500 ± 500	830 ± 90
	Bovine Liver 1577A		
NBS values	2430 ± 130	9960 ± 70	2800 ± 100
this study	2400 ± 30	10200 ± 400	2750 ± 90

[a] Analytical uncertainties for values determined in this study represent one standard deviation based on counting statistics. [b] Value is not certified.

The concentrations of sodium, potassium, and chlorine are difficult to determine in unadulterated foods because these elements, especially sodium and chlorine, are often present at very low concentrations and samples are susceptible to contamination during preparation for analysis. An investigation into the covariance of these elements in foods is done optimally if the element concentrations are determined simultaneously by the same analytical technique on single samples. Neutron activation analysis is an excellent method for the simultaneous determination of these three elements because the limits of detection are less than the microgram per gram level (DeSoete et al., 1972). The potential for contamination is minimized with neutron activation analysis because no sample pretreatments are required.

The objectives of this research are to determine the relationships between the concentrations of sodium, potassium, and chlorine in unadulterated and minimally processed foods; to demonstrate the applicability of neutron activation for the analysis of sodium, potassium, and chlorine in foods; and to extend the data base for the chlorine content in foods.

EXPERIMENTAL PROCEDURES

Samples of food were purchased from local supermarkets. Most items represented major national brands. Salt-free products of processed foods, juices, etc., were included. Fruits, vegetables, and meats were fresh except dried beans, peas, etc. Foods representative of a typical diet and the major food groups were selected. A total of 167 samples representing 112 different foods and 6 commercial beverages were analyzed. A limited number

---

* Author to whom correspondence should be addressed.

0021-8561/92/1440-1547$03.00/0

Table II. Concentrations of Sodium, Potassium, and Chlorine in Unsalted Foods[a]

food	code[b]	sodium		potassium		chlorine	
		μmol g^{-1}	$\pm 1\sigma$	μmol g^{-1}	$\pm 1\sigma$	μmol g^{-1}	$\pm 1\sigma$
apple, Granny Smith	675	0.17	0.02	50	2	0.038	0.002
apple, Granny Smith	675	0.09	0.02	23	2	0.1	0.1
apple, Red Delicous	675	0.3	0.03	26	2	0.28	0.07
applesauce	677	0.068	0.007	15.0	0.6	0.051	0.008
apricots	682	0.15	0.01	68	3	0.16	0.02
apricots	682	0.08	0.01	72	4	0.09	0.02
banana	693	0.68	0.04	77	2	27.	1
banana	693	0.1	0.01	108	2	26.3	0.8
banana	693	0.02	0.02	87	3	20.5	0.3
barley, pearled	11-2	1.99	0.07	70	3	30.9	0.6
beans, Great Northern		0.76	0.06	509	9	3.2	0.2
beans, Great Northern		0.11	0.02	390	50	3.3	0.3
beans, Great Northern		0.09	0.04	410	20	3.0	0.2
beans, green	562	0.28	0.05	78	3	4.1	0.3
beans, green	562	0.04	0.03	100	6	23.1	0.9
beans, kidney		0.05	0.01	350	10	4.9	0.2
beans, lima	565	0.11	0.02	420	7	2.0	0.1
beans, pinto		0.13	0.02	420	20	3.7	0.2
beef	237	24.8	0.3	92	4	15.6	1
beef	237	23.3	0.3	94	4	14.5	0.8
beef, ground	247	25.4	0.3	81	4	16.0	0.8
beef, veal liver	371	27.7	0.3	77	3	24.2	0.5
beets	574	16.7	0.2	88	3	26.2	0.9
broccoli	576	22.0	0.3	90	4	16.4	0.8
broccoli	576	38.7	0.5	84	4	10.1	0.8
Brussels sprouts	578	8.8	0.1	72	2	5.8	0.3
cabbage	584	0.62	0.04	84	3	4.3	0.1
carrots	587	31.92	0.02	40	3	10.2	0.8
carrots	587	42.6	0.4	97	4	20.4	0.5
carrots, home garden	587	5.3	0.1	121	4	10.7	0.3
cauliflower	591	4.03	0.02	85	3	3.8	0.4
cauliflower	591	11.1	0.2	68	3	4.7	0.3
cauliflower	591	13.9	0.2	21	1	4.6	0.3
celery	594	6.6	0.1	92	3	46	1
celery	594	5	0.1	92	2	45.9	0.8
cherries	699	0.09	0.02	62	2	0.24	0.06
cherries	699	0.08	0.01	62	2	0.14	0.02
chicken, breast	316	25.6	0.3	84	4	16.1	0.5
chicken, breast	316	24.7	0.3	83	4	15.3	0.5
chicken, thigh	317	27.5	0.3	81	3	19.8	0.5
chicken, thigh	317	26.9	0.4	84	4	18.5	0.6
coffee, instant, Folgers	872	9.1	0.3	1000	20	14	1
corn, whole		0.06	0.01	88	2	10.7	0.4
corn, whole		0.039	0.009	82	2	12.8	0.4
cornmeal		0.018	0.009	37	2	12.6	0.4
cornmeal		0.03	0.01	47	2	12.9	0.3
cucumber	597	0.16	0.02	25.9	0.9	3.3	0.2
cucumber	597	0.26	0.03	44	3	9.5	0.3
eggplant		0.46	0.04	55	2	8.0	0.3
eggs, whole (6)	165	62.5	0.6	38	2	48	2
endive	598	17	0.3	66	3	12.4	0.6
fish, lake trout		20.1	0.3	59	3	15.3	0.4
fish, ocean perch	438	33.8	0.4	72	4	35.4	0.8
fish, ocean perch	438	34.3	0.4	85	4	28.3	0.9
fish, rainbow trout		24.5	0.4	104	5	16.8	0.8
flour, white, unbleached	10	0.19	0.04	32	2	12.5	0.5
flour, white, bleached	12	0.34	0.06	36	2	25.9	0.5
flour, whole wheat	9	0.72	0.08	105	5	16.0	0.8
flour, whole wheat	9	0.54	0.07	82	4	16.1	0.6
garlic		8.3	0.1	144	5	18.0	0.4
grape, red	737	1.36	0.05	82	5	1.24	0.08
grape, Thompson	738	0.64	0.03	62	2	1.0	0.1
grapefruit	740	0.32	0.02	54	3	1.1	0.1
juice, apple		2.02	0.05	28.4	0.7		
juice, apple		2.61	0.02	23	1	1.4	0.2
juice, cranberry		0.56	0.03	4.4	0.2		
juice, cranberry		0.72	0.02	4.9	0.4	0.74	0.07
juice, cranberry		0.51	0.03	5.4	0.6	0.7	0.1
juice, grape		0.87	0.05	28	1	0.6	0.1
juice, grape		0.69	0.04	35.7	0.9		
juice, grape		0.64	0.03	27	1	0.62	0.08
juice, grapefruit	879	0.43	0.03	32	1	1.21	0.07
juice, orange drink, Hi-C		0.97	0.02	10.8	0.3		
juice, orange, 100% nat	885	1.75	0.05	43	1	2.4	0.1
juice, orange, from conc		0.71	0.02	43	1	0.97	0.05
juice, prune		2.74	0.07	4.8	0.7	0.7	0.1

Table II (Continued)

food	code[b]	sodium		potassium		chlorine	
		μmol g^{-1}	±1σ	μmol g^{-1}	±1σ	μmol g^{-1}	±1σ
juice, tomato		5.1	0.1	56	2	15.2	0.4
juice, tomato		2.8	0.1	61	2		
kashi, breakfest cereal		1.7	0.1	87	5	18	1
kiwi		0.72	0.05	82	3	13.9	0.4
lettuce, green leaf	606	8.2	0.2	57	2	16.2	0.4
lettuce, iceberg	606	3.0	0.1	172	6	39	2
lettuce, red leaf	606	8.4	0.2	62	3	32.6	0.6
lettuce, romaine	606	4.71	0.01	134	3	26.8	0.5
macaroni	11-53	0.55	0.08	59	3	14.6	0.6
melon, cantaloupe	762	8.0	0.1	70	2	5.8	0.2
melon, honeydew	764	4.9	0.1	61	2	10.2	0.4
milk, human, 6 months	138	3.93	0.09	11.0	0.9	8.3	0.5
milk, skim	131	16.7	0.3	35	2		
milk, skim	131	17.1	0.2	40	2	27.3	0.5
milk, 2%		17.7	0.3	41	3	28.2	0.5
milk, whole	124	16.2	0.2	37	1		
milk, whole	124	15.7	0.2	37	2	24.1	0.8
milk, whole	124	16.1	0.2	36	2	25.7	0.4
mushroom, select w/stem	609	1.48	0.07	101	6	16.2	0.3
mushrooms, white	609	1.71	0.07	101	3	31.8	0.9
nuts, almonds	822	0.23	0.04	163	6	1.5	0.2
nuts, peanuts	835	0.27	0.06	168	6	2.4	0.2
nuts, pecans		0.6	0.1	87	5	3.6	0.6
nuts, walnuts	839	2.6	0.1	89	4	7.1	0.2
oat bran		0.875	0.001	119	5	8.9	0.6
oat bran		0.98	0.09	117	5	10.3	0.5
oatmeal	17	0.7	0.1	98	5	11	1
oatmeal	17	0.86	0.08	89	4	10.0	0.6
oats, whole grain		1.1	0.1	100	4	17.8	0.6
oats, whole grain		1.9	0.1	82	4	8.6	0.6
okra	612	1.00	0.08	69	3	20.6	0.7
onion, green	616	8.8	0.2	66	4	17.7	0.5
onion, green	616	8.8	0.1	31	2	10.8	0.8
onion, yellow	613	1.1	0.2	44	1	4.8	0.3
orange	773	0.019	0.005	41	2	0.71	0.04
orange	773	0.10	0.02	43	1	0.97	0.09
parsley	617	38.0	0.4	157	5	43	1
peach	779	0.24	0.02	90	2	1.23	0.07
peach	779	0.032	0.008	43	1	0.30	0.04
pear	785	0.14	0.02	43	3	0.20	0.06
pear	785	0.13	0.02	27.8	0.9	0.05	0.01
peas, black-eyed		0.51	0.05	310	20	3.4	0.1
peas, split	628	0.77	0.07	270	10	12.8	0.3
peas, split	628	0.83	0.08	234	5	13.7	0.3
peas, split	628	1.03	0.08	260	10	16.4	0.3
pepper, green	634	0.073	0.007	7.6	0.6	1.5	0.1
pepper, green, home garden	634	0.07	0.01	39	2	1.7	0.2
plum	793	0.006	0.006	30	1	0.16	0.02
plum, Grand Rosa	793	0.01	0.01	48	3	0.8	0.1
popcorn		0.04	0.02	73	3	11	0.6
pork, dark	303	28.3	0.4	95	4	15	1
pork, light	303	17.7	0.3	96	4	11.3	0.9
potato, red	639	0.53	0.04	106	3	23	1
potato, red	639	3.1	0.1	109	3	20.5	0.5
potato, red	639	2.83	0.09	110	3	26.8	0.7
potato, Russet, w/o skin	639	0.364	0.009	91	5	3.6	0.3
potato, Russet, w/o skin	639	0.26	0.04	69	4	5.7	0.3
potato, white, home garden	639	0.11	0.02	132	4	7.6	0.2
pumpkin, canned	653	0.14	0.02	53	2	2.2	0.2
radish	654	2.16	0.09	112	4	11.9	0.8
radish	654	4.7	0.1	73	4	8.2	0.6
rice, brown		0.46	0.07	62	4	7.7	0.3
rice, white	19	0.28	0.04	20	2	6.4	0.2
rice, white	19	0.23	0.03	27	2	7.9	0.2
rice, wild		2.07	0.07	74	3	5.4	0.2
Shredded Wheat, breakfast cereal	11-148	1.34	0.09	83	3	14.4	0.3
Shredded Wheat, breakfast cereal	11-148	0.9	0.1	90	5	16.1	0.6
soybean curd, tofu		14.4	0.2	50	2	8.4	0.6
soybeans, yellow		0.08	0.02	464	8	2.4	0.5
spinach, leaf raw		42.8	0.4	100	3	40.8	0.9
squash, butternut		0.06	0.03	119	4	11.8	0.4
squash, zucchini		0.01	0.01	90	3	14.8	0.4
squash, zucchini		0.03	0.02	56	2	9.4	0.4
sunflower seeds		0.09	0.02	154	5	7.9	0.6
tomato	666	1.25	0.05	48	3	11	0.2
tomato, cherry	666	1.11	0.04	35	1	4.5	0.3

Table II (Continued)

food	code[b]	sodium		potassium		chlorine	
		μmol g^{-1}	±1σ	μmol g^{-1}	±1σ	μmol g^{-1}	±1σ
tomato, roma, home garden	666	0.47	0.04	68	2	10.0	0.2
wheat bran	11-5	0.8	0.1	390	20	13.3	0.9
wheat bran	11-5	1.5	0.2	450	20	16	1
wheat germ	11-34	1.5	0.3	260	20	25	4
wheat, whole		0.46	0.03	87	3	10.1	0.4
tea and water							
tea, Eng Breakfast		1.5	0.2	430	40	21	6
tea, green		1.9	0.2	380	20		
tea, leached Eng Breakfast		2.2	0.3	220	10		
tea, leached green		2.9	0.6	90	30		
tea, liq Eng Breakfast		0.21	0.02	4.3	0.7	0.40	0.05
tea, liq green tea		0.18	0.02	7.3	0.9	0.60	0.05
water, tap, Madison, WI		0.13	0.01			0.1	0.1
water, tap, Madison, WI		0.190	0.006			0.15	0.03
carbonated beverages							
7-Up, aluminum can		4.2	0.1			0.8	0.1
7-Up, plastic bottle		4.01	0.06			0.50	0.05
7-Up, plastic bottle		3.93	0.07				
Coca-Cola		1.45	0.03			15.9	0.8
Coca-Cola		1.06	0.2			16.2	0.8
Coca-Cola		1.43	0.03			4.05	0.09
Coca-Cola Classic		1.40	0.06			3.1	0.3

[a] The analytical uncertainties represent one standard deviation based on counting statistics. [b] The code number identifies foods compiled by Paul and Southgate (1978) and Holland et al. (1988).

of items per food sample was prepared for each analysis because the major objective of this study was to determine the interrelationships between sodium, potassium, and chlorine within foods and not the average composition of foods representative of the United States diet.

Samples of fresh produce were prepared for analysis by dissecting and removing cross-sectional samples from six or more items. A stainless-steel scalpel was used to cut the samples, but all other materials that contacted the foods were polyethylene. All containers and materials that contacted the samples were carefully washed with deionized water or reagent-grade methanol followed by deionized water. Approximately equal-sized subsamples were combined to produced a composite sample. A full bag of dried beans (456 g) and similar products were ground in a Wiley mill to pass a 0.425-mm (no. 40 mesh) screen prior to analysis.

Neutron Activation Analysis. In preparation for analysis, about 1.0 g of each composite sample was weighed and heat sealed into a 6.3-mm-i.d. × 6-cm-long polyethylene tube. Pure solutions of NaCl, KCl, and NBS bovine liver and orchard leaves were similarly packaged for standards and check samples, respectively. A piece of solid polyethylene rod, 6.3-mm diameter × 5-mm length, was placed in the bottom of the polyethylene tubes that received pulpy samples, such as meats, fruits, etc., so that the sample could be easily pushed out of the tube after neutron irradiation by ejecting the plug with a rod. The samples and standards were irradiated for 10 min in the University of Wisconsin Nuclear Reactor at a thermal neutron flux of 9×10^{12} n·cm^{-2} s^{-1}. The samples were grouped to have similar sodium and chlorine concentrations to minimize variations in detector dead time. The samples and appropriate standards were irradiated in groups of 18 tubes. After irradiation, the samples and standards were transferred to 5-mL polyethylene vials for radioassay. Small amounts of water were used to ensure quantitative transfers when needed.

Each sample and standard was counted for 5 min using high-resolution Ge(Li) detectors and a multichannel analyzer (Tracor Northern Model TN-11). The isotopes and their γ-ray emission lines (MeV) used analytically were: ^{38}Cl, 1.61 and 2.16; ^{24}Na, 2.75 and 1.37; and ^{42}K, 1.516. The results were calculated as given in Helmke (1982).

Statistical Analysis. Multiple linear regression was the primary tool of analysis using PROC REG SAS (SAS Institute, 1987). Regression analysis was done using data on all foods except commercial beverages (n = 156), and then by sorting foods into major food groups: fruits (n = 43); vegetables (n = 44); small grains (n = 29); legumes (n = 12); meat, fish, milk, and egg (n = 22); and nuts and mushrooms (n = 6). Separate analyses were performed with the dependent variable as concentration of chlorine and the independent variable as concentration of sodium, concentration of potassium, and concentration of sodium and potassium. A number of second-order regression equations were also examined. Each term in the regression models was assessed for significance, and adjusted r^2 values were used to compare the amount of variation accounted for by the different regression models. In some cases, the second-order regression equations gave a larger adjusted r^2 value than first-order regression equations; however, the biological significance of these relationships is unclear. Values obtained by neutron activation analysis for sodium, chlorine, and potassium concentrations in individual foods were also compared by regression analysis with values for similar foods in the British nutrient data base (Paul and Southgate, 1978; Holland et al., 1988).

RESULTS AND DISCUSSION

The concentrations of sodium, potassium, and chlorine determined in NBS reference materials are given in Table I. The results generally agree within the reported analytical uncertainties. The results show that neutron activation analysis is very appropriate for the analysis of these elements in foods.

The concentrations of sodium, potassium, and chlorine in foods are given in Table II. The analytical uncertainty associated with each value represents one standard deviation analytical uncertainty based on counting statistics (Koons and Helmke, 1978) or 1%, whichever is greater. The codes identifying individual foods are those used in the British data base. Replicate analyses represent separate composite samples prepared from different suppliers or distributors.

The concentrations of chlorine and sodium in unsalted, unadulterated foods are weakly correlated (r^2 = 0.27, n = 156, $P < 0.0001$) when chlorine is regressed against sodium for all foods analyzed excluding commercial beverages. However, within individual food groups (Figure 1), only the food group that contained animal products (meat, milk, fish, and eggs) showed a significant correlation between chlorine and sodium concentrations, r^2 = 0.49, $P < 0.001$; the vegetable and legume food group showed a weak but significant correlation between chlorine and sodium concentrations, r^2 = 0.15, $P < 0.01$. Compared to other food

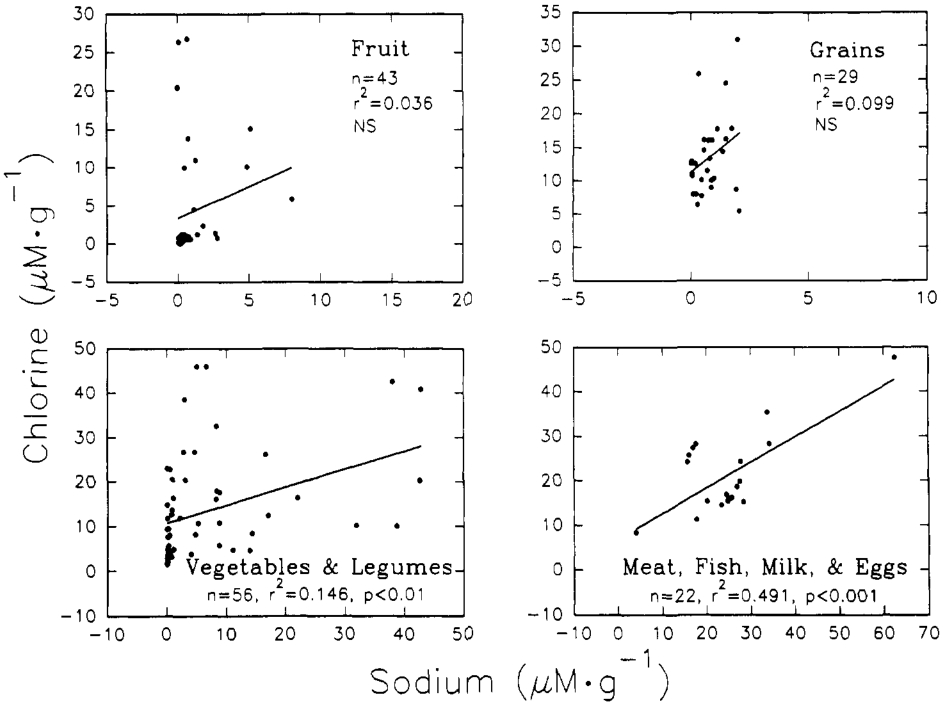

Figure 1. Concentration of chlorine as a function of sodium in four food groups. The equations for the only significant linear regressions are for meat, fish, milk, and eggs, Cl = 0.57Na + 6.97; and for vegetables and legumes, Cl = 0.40Na + 10.8.

groups that contained plant food sources, the animal products showed the greatest ranges of sodium (Na = 4–62 $\mu mol{\cdot}g^{-1}$) and chlorine (Cl = 8–48 $\mu mol{\cdot}g^{-1}$) concentrations. The correlation of chlorine and sodium in animal products is reasonable given the biological regulation of sodium and chlorine in extra- and intracellular fluids. Plants do not maintain similar strict regulation of sodium and chlorine in fluids, and the concentration of these ions may vary depending on soil and water conditions. However, even for animal products the correlation of chlorine with sodium concentration accounts for less than half of the variation, and thus, sodium concentration cannot be used to accurately predict the chloride content of individual unsalted foods.

The correlation between the concentrations of chlorine and potassium in foods was not significant ($P = 0.90$) when the regression model included all foods. Although, the food groups with higher potassium contents—fruits (K = 4–108 $\mu mol{\cdot}g^{-1}$), vegetables (K = 8–172 $\mu mol{\cdot}g^{-1}$), and legumes (K = 234–509 $\mu mol{\cdot}g^{-1}$)—showed significant, although somewhat weak, associations between chlorine and potassium content, $r^2 = 0.29$–0.43, $P = 0.01$–0.001. The regression of chlorine versus potassium was not significant ($P = 0.13$–0.39) for animal products (K = 11–104 $\mu mol{\cdot}g^{-1}$) or small cereal grains (K = 20–454 $\mu mol{\cdot}g^{-1}$).

The value of r^2 for chlorine concentration vs sodium plus potassium concentrations in all foods ($Cl = a + bNa + cK$, $r^2 = 0.26$) was similar to the value for regression of chlorine vs sodium for all foods ($r^2 = 0.27$, $n = 156$, $P < 0.001$). The coefficient for the potassium term in the first case was not significant. This suggests that when a group of foods with a wide range of chlorine, sodium, and potassium concentrations are combined, the contribution of potassium, relative to the sodium concentration, contributes little to the prediction of chlorine concentration. For individual foods groups the same regression equation for chlorine concentration vs sodium plus potassium concentrations was significant for animal products ($r^2 = 0.73$), legumes ($r^2 = 0.60$), fruits ($r^2 = 0.34$), and vegetables ($r^2 = 0.34$). Thus, for specific food groups inclusion of both sodium and potassium in the regression model improved the prediction of chlorine concentration. In summary, it is impossible to accurately predict chlorine concentrations in individual unsalted foods based on sodium or potassium concentrations given the large variation in the relationships between sodium, potassium, and chlorine concentrations in foods.

The generally good agreement between the values reported in the British nutrient data base (Paul and Southgate, 1978; Holland et al., 1988) for sodium ($r^2 = 0.47$, $n = 110$), potassium ($r^2 = 0.79$, $n = 116$), and chlorine ($r^2 = 0.44$, $n = 86$) and those obtained in this study demonstrate the applicability of neutron activation analysis for the determination of these elements in foods (Figure 2).

The slope of the line for the potassium concentrations shows the expected value of 1.00, which indicates excellent agreement. The poorer agreement for sodium (slope = 0.55) and chlorine (slope = 0.61) is suspected to occur because the concentration of potassium (5–509 $\mu mol{\cdot}g^{-1}$) is much higher in most foods than the concentrations of sodium (0.01–62 $\mu mol{\cdot}g^{-1}$) and chlorine (0.04–48 $\mu mol{\cdot}g^{-1}$). Many of the values for sodium and chlorine reported by Paul and Southgate (1978) and Holland et al. (1988) were near the detection limits of the techniques employed and thus more susceptible to contamination and other errors. The slopes of the lines for sodium and chlorine in Figure 2 are much less than the expected value of 1.0 because several of the values reported by Paul and Southgate (1978) and Holland et al. (1988) are large compared to the values measured in this research. For example, the chlorine values for wheat bran of 42.3 $\mu mol{\cdot}g^{-1}$ (item 11-2 Holland et al., 1988) and for brown rice of 64.9 $\mu mol{\cdot}g^{-1}$ (item 11-35 Holland et al., 1988) were 4–8 times greater than the values determined in this study. The limit of detection of neutron activation analysis is much lower than those of most of the techniques used in the compiled data.

Knowledge of the sodium, potassium, and chlorine content of food may be useful for the correction of hypokalemic alkalosis, a common medical complication of diuretic therapy used for the treatment of hypertension. Potassium chloride (25–50 mmol of $K{\cdot}d^{-1}$) is often pre-

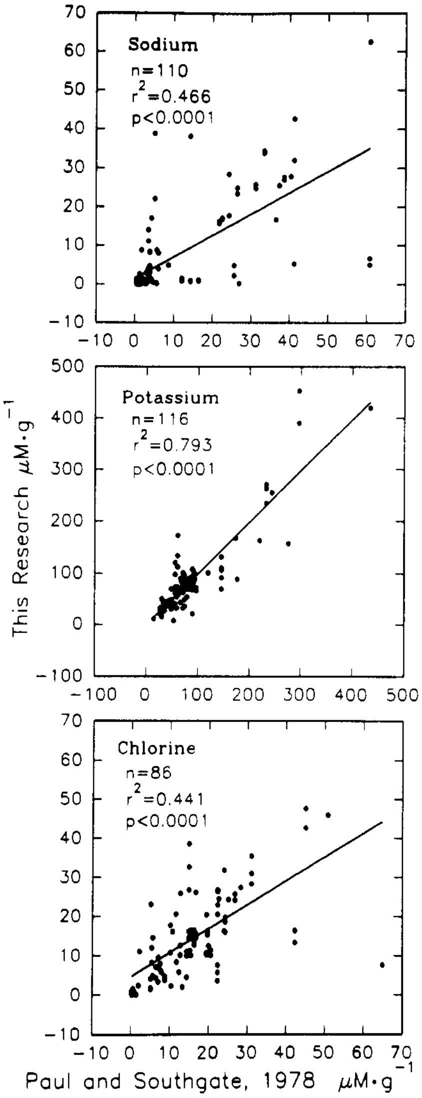

Figure 2. Concentrations of sodium, potassium, and chlorine as a function of the parallel values in compiled data bases (Paul and Southgate, 1978; Holland et al., 1988). The equations from the linear regressions are $Na_{TR} = 0.55Na_{PS} + 1.45$; $K_{TR} = 0.99K_{PS} - 1.21$; $Cl_{TR} = 0.61Cl_{PS} + 4.64$.

scribed for patients with diuretic-induced hypokalemia, although it is very unpalatable. Foods low in sodium content but relatively high in potassium and chlorine contents may be effective replacements for potassium chloride salts (Kassirer et al., 1965; Miller et al., 1979). The current data identify foods that contain relatively large amounts of potassium and chlorine and negligible amounts of sodium. A survey of the data in Table II indicates several foods meet these criteria. For example: 1 banana (120 g and 100 kcal) provides 0.03 mmol of Na, 11 mmol of K, and 3 mmol of Cl; 1 tomato (135 g and 25 kcal) provides 0.12 mmol of Na, 8 mmol of K, and 1.4 mmol of Cl; and Shredded Wheat cereal (50 g and 180 kcal) provides 0.06 mmol of Na, 4.6 mmol of K, and 0.75 mmol of Cl.

ACKNOWLEDGMENT

We appreciate the assistance of Kris Bork in preparing the samples for analysis. Support of this research by the College of Agricultural and Life Sciences, University of Wisconsin—Madison, and by Hatch Projects 2606 and 3096 is gratefully acknowledged.

LITERATURE CITED

DeSoete, D.; Gijbels, R.; Hoste, J. *Neutron Activation Analysis*; Wiley-Interscience: New York, 1972; pp 531–566.

Helmke, P. A. Neutron Activation Analysis. In *Methods of Soil Analysis*, 2nd ed.; Page, A. L., et al., Eds.; ASA/SSSA: Madison, WI, 1982; Part 2, pp 67–84.

Holland, B.; Unwin, I. D.; Buss, D. H. *Cereals and Cereal Products*, The Third Supplement to *McCance and Widdowson's The Composition of Foods*, 4th ed.; Royal Society of Chemistry: London, 1988.

Kassirer, J. P.; Berkman, P. M.; Lawrenz, D. R.; Schwartz, W. B. The Critical Role of Chloride in the Correction of Hypokalemic Alkalosis in Man. *Am. J. Med.* **1965**, *38*, 172–189.

Koons, R. D.; Helmke, P. A. Neutron Activation Analysis of Standard Soils. *Soil Sci. Soc. Am. J.* **1978**, *42*, 237–240.

Kurtz, T. W.; Al-Bander, H. A.; Morris, R. C., Jr. "Salt-sensitive" Essential Hypertension in Men: Is the Sodium Ion Alone Important? *N. Engl. J. Med.* **1987**, *317*, 1043–1048.

Luft, F. C. Dietary Sodium, Potassium and Chloride Intake and Arterial Hypertension. *Nutr. Today* **1989**, *24*, 9–14.

Miller, S. A.; Roche, P. A.; Srinivasan, P.; Victor, V. Chloride and Potassium-rich Foods. *Am. J. Clin. Nutr.* **1979**, *32*, 1757–1758.

Paul, A. A.; Southgate, D. A. T. *McCance and Widdowson's The Composition of Foods*, 4th rev. ed.; Elsevier/North Holland Biomedical Press: London, 1978.

SAS Institute. *SAS User's Guide*: *Statistics*, ver. 6, 6th ed.; Statistical Analysis Press: New York, 1987.

USDA. *Composition of Foods*, Handbook 8; USDA: Washington, DC, 1976–1991; series 8-1 to 8-19.

Whitescarver, S. A.; Jackson, B. A.; Couthrie, G. P., Jr.; Kotchen, T. A. Salt-sensitive Hypertension: Contribution of chloride. *Science* **1984**, *223*, 1430–1432.

Yarbrough Al-Bander, S.; Nix, L.; Katz, R.; Korn, M.; Sebastian, A. Food Chloride Distribution in Nature and Its Relation to Sodium Content. *J. Am. Diet. Assoc.* **1988**, *88*, 472–475.

Received for review March 23, 1992. Accepted June 1, 1992.

Registry No. Na, 7440-23-5; K, 7440-09-7; Cl_2, 7782-50-5.