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Evaluation of the comprehensiveness and reliability of the chromium composition of foods in the literature ★

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Abstract

In the early 1960s, trivalent chromium Cr^{3+} became recognized as an essential trace element due to its potential metabolic and cardiovascular benefits. No comprehensive chromium database currently exists; thus a thorough review of the literature was conducted to examine the availability and reliability of chromium data for foods. A number of key issues were identified that challenge the feasibility of adding chromium to a food and nutrient database. Foremost, dietary chromium data reported in the literature prior to 1980 cannot be relied on because of problematic analytical issues before that time. Next, paucity of data emerged as an issue that could impede database completeness. Finally, large variation in reported chromium content of foods may render disputable representative chromium values. This variation has been speculated to originate from differences in growing and particularly processing foods. Furthermore, contamination of chromium from laboratory equipment and/or materials is possible and also believed to contribute to the variation observed in reported values. As a result, database developers must carefully consider the availability and reliability of information on the chromium composition of foods when deciding whether to incorporate chromium into or exclude it from a nutrient database.

Keywords

Chromium; Chromium variability; Food composition; Commonly consumed foods; Food and nutrient database; Literature review; Analytical methods; Contamination issues; Data availability

1. Introduction

Chromium was identified as a component of biological tissues in the late 1940s but it was not until the mid-1950s that scientific evidence suggested that this trace mineral might have biologic activity. The work of Mertz and Schwarz in 1955 and 1959 led to coining the term “glucose tolerance factor” or GTF and to identifying Cr^{3+} as the active ingredient of GTF. Since then, a multitude of studies have emerged, suggesting that chromium may play an important role in metabolic and lipid disorders. One of the foremost significant studies supporting its essentiality emerged in 1977 when Jeejeebhoy et al. reported that chromium supplementation through Total Parenteral Nutrition (TPN) dramatically improved glucose regulation in a patient who had developed glucose intolerance characteristics. This study provided valuable information for establishing the first U.S. dietary recommendations for chromium. The Estimated Safe and Adequate Daily Dietary Intake (ESADDI) was set at 50–

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200 µg/day for adults by the Food and Nutrition Board in 1980 (Food and Nutrition Board, 1980). The most recent dietary recommendations set for chromium in the U.S. were issued in 2001 as Adequate Intake (AI) of 25–35 µg/day for adults (Food and Nutrition Board and Institute of Medicine, 2001).

Despite various key studies that helped acknowledge the biochemistry of chromium and its role in nutrition, controversies have surrounded this trace mineral, including its essentiality, its exact role in glucose regulation, and the potential benefits of chromium supplementation, all of which have been refuted by many scientists (Nielsen, 1996; Vincent and Stallings, 2007). Inadequacies in quantifying chromium concentrations in foods have undermined the methodological integrity of some studies on the topic, thereby contributing to the uncertainty.

There are several analytical methods used to detect chromium in foods, beverages, and other biological samples: Neutron Activation Analysis (NAA), Mass Spectrometry (MS), Atomic Emission Spectrometry (AES), and Atomic Absorption Spectrometry (AAS). Each of the spectral methods is coupled with a different atomization process before mass or atomic emission/absorption measurements can be performed. Graphite Furnace Atomic Absorption Spectrometry (GFAAS) has been the preferred technique for determining chromium concentrations in biological samples since it became commercially available in 1968 (Veillon and Patterson, 1999; Willis and Stevens, 1988; Wolf, 1982). However, the validity of values derived from this method prior to 1978 is believed to be poor due to analytical issues. First, standard reference material certified for chromium analysis was not available to use for calibration and refinement of analytical and contamination control methods (Kumpulainen, 1988, 1992). Second, inaccurate background correction resulted in unreliable measurement of chromium content in biological samples (Veillon and Patterson, 1999). Since the elucidation and correction of these analytical problems, additional studies have evaluated the chromium composition of various foods.

Chromium is present in foods in all food groups. This poses a challenge for database developers who wish to incorporate chromium into their databases because analytical values are needed for an array of foods if a high level of database completeness for the nutrient is to be achieved. It is speculated that external factors, specifically growing and processing, affect the chromium content of foods. This may also be a hurdle for database developers because multiple analytical values for individual foods may be needed to evaluate the appropriateness of inclusion of representative chromium composition values for foods. The objective of this study was to evaluate the availability and reliability of analytical data on the chromium composition of foods reported in the literature between 1980 and 2007. The evaluation was framed around the needs of food and nutrient databases in which representative values for an array of foods are needed.

2. Material and methods

In 2007, a comprehensive literature search was performed to identify articles published between 1980 and 2007 that provided analytical data on the chromium composition of foods. Only literature sources with analytical chromium values published after 1980 were selected due to the methodology and apparatus problems that arose prior to that time. The search engines Google, AGRICOLA, OVID, and PubMed were utilized to identify articles. Search terms utilized included the following key word and phrases: chromium; chromium a trace mineral; chromium in food; chromium content of foods; chromium composition of foods; chromium analysis in foods; chromium database; chromium food and nutrient database. Journal articles identified through the search engines were reviewed to confirm that original chromium composition values for foods were provided within these sources.

Also; the reference lists in the articles were reviewed to identify additional sources of chromium composition values for foods.

Journal articles identified through the search process just described were used to record the following information in Excel spreadsheets for each food for which an analytical value was provided: food name, food description (if available), chromium value(s), and analytical method. After data abstraction was completed the food items in the spreadsheets were classified into major food categories (e.g. fruit, vegetable, meat). Using data in the spreadsheets, frequencies were calculated with respect to variables such as analytical method and number of values available for various food groups and specific food items.

Unpublished sources of chromium values such as U.S. and non-U.S. databases that contain data on the chromium composition of foods were not included in this review because several of these databases were not readily available due to subscription requirement. Also, there were several barriers to reviewing values included in databases that NCC could readily access. First, documentation on the source of chromium values was sometimes lacking or given in a language other than English. Second, these databases were not complete for chromium composition data. Third, the analytical method used was generally not specified. Finally, some of these databases included values from the published papers selected for this review. Since unpublished values were not included in this study, the number of analytical values available for various food categories may be somewhat underestimated.

In order to determine the extent to which chromium data for foods are available, various analyses were conducted. First, information on the most commonly consumed foods in the U.S. within common food categories was tabulated based on data from the United States Department of Agriculture Food Supply Series and the National Health and Nutrition Examination survey (Bachman et al., 2008; Economic Research Service (ERS), 2010). Next, the number of analytical chromium values was tallied for each food in the rankings.

To evaluate the extent to which chromium values are available for foods typically included in food and nutrient databases, an attempt was made to identify a chromium value for each of the approximately 2600 core foods in the University of Minnesota Nutrition Coordinating Center (NCC) Food and Nutrient Database. Core foods in this database are single ingredient foods (e.g. beef, apple, honey) and basic multi-ingredient foods (e.g. bread, sausage, cereal). The core foods in the database are used to create nutrient composition values for multi-ingredient foods. Because the core foods serve as building blocks, it is important to assign valid and reliable values to these foods, and keep missing values to a minimum.

The process of identifying chromium values in the literature for core foods involved first aiming for identifying directly matching food items from the list of those with analytical values. If the process of direct matching was possible, unit conversion of the chromium value(s) of the analyzed foods was performed as needed so that all values assigned to core foods were in μg of chromium per 100 g of food. After the direct matching and unit conversion processes were completed, an attempt was made to impute values for core foods in which a chromium value for one form of the food was assigned via direct matching. With this imputation process, the chromium value for a food in one form is applied to other forms of the same food. For example, the same chromium value could be assigned to both raw and cooked broccoli if only one chromium value was available for either form of the food. The chromium values for canned and other processed foods were excluded from this imputation process because scientific evidence indicates that these particular foods have higher chromium content than fresh foods as a result of leaching from stainless steel equipment used in processing (Anderson and Kozlovsky, 1985; Kumpulainen, 1992).

To examine the reliability of available chromium values, the mean, standard deviation, median, and range were calculated for foods for which multiple chromium values were available.

3. Results and discussion

A total of 51 articles published between 1980 and 2007 were identified. These articles included dietary chromium analyses performed in 20 different countries. The frequencies at which the various analytical methods were used to analyze foods reported in the articles were as follows: 2% NAA, 24% ICP-AES (Inductively Coupled Plasma Atomic Emission Spectroscopy), 11% ICP-MS (Inductively Coupled Plasma Mass Spectroscopy), 38% GFAAS (Graphite Furnace Atomic Absorption Spectroscopy), 15% FAAS (Flame Atomic Absorption Spectroscopy), 2% other, and 8% of studies used AAS but the source of energy for atomization was not clearly stated to provide a specific classification. Table 1 specifies the analytical method(s) used in each of the 51 articles reviewed.

3.1. Comprehensiveness

Across the articles reviewed, a total of 1382 chromium values were reported for 856 foods. The discrepancy in these two numbers is due to the fact that certain food items were analyzed more frequently than others, resulting in publication of more than one chromium value. For example, there were 48 chromium values available for asparagus out of a total of 243 total values for the vegetable group. The food group with the most values was the vegetable group whereas the fat group had the least data (see Fig. 1 for distribution of analytical chromium values by food group).

Table 2 shows the number of analytical chromium values available in the literature for the most commonly consumed protein sources, fruits and fruit juices, vegetables, milk and dairy products, grains, and fats in the U.S. Multiple analytical values were available for most of the commonly consumed foods.

Fig. 2 shows the proportion of core foods in NCC Food and Nutrient Database that could be assigned a chromium value by direct match and the proportion of core foods for which a chromium value could be imputed via the procedure described earlier. In total, 39% of the core foods could be assigned a chromium value via direct matching or imputation. With 61% of core foods lacking chromium values, substantial additional information on the chromium composition of foods and imputation would be required if missing values were to be kept to a minimum in the database.

3.2. Reliability

Table 3 lists means, standard deviations, medians, and range chromium values for the most commonly consumed foods in the U.S. for which two or more analytical values were identified in the literature. For many of the foods listed, the range in chromium values was very wide which was reflected in large standard deviations for many foods and sizeable differences between the means and medians. This variability appeared across the food groups examined. The large variation in analytical chromium values observed for many foods raises concerns regarding the potential representativeness of chromium values assigned to foods in a food and nutrient database. If nutrient values assigned to foods in a database are not close to representing the typical nutrient content of foods, the usefulness of the database for many applications may be seriously undermined. As an example, an individual's dietary chromium intake estimated using chromium values included in a food and nutrient database may be over or under-estimated if the actual chromium content of

foods consumed by the individual deviate greatly from the representative chromium values assigned to foods in the database.

Variation in nutrient content of foods is not a novel concept. In fact, food composition studies have documented that all the following factors may affect the nutrient composition of foods: geographic variation in soil mineral content, seasonal factors, plant cultivar, and manufacturing processes (Greenfield and Southgate, 2003; Pedro et al., 2006). In the case of chromium, external contamination from processing sources are believed to contribute to the amount of chromium present in foods to such an extent that different types and lots of foods have resulted in chromium concentrations with wide variation (Anderson et al., 1992; Offenbacher and Pi-Sunyer, 1983). Furthermore, analytical conditions that do not optimize for chromium analysis have been documented to amplify analytical values, as this trace mineral is ubiquitous, even in the laboratory setting (Anderson and Kozlovsky, 1985; Kumpulainen, 1992). In the past, it was suggested that laboratory methods used in published studies may not have addressed these contamination issues (Veillon and Patterson, 1999). The variation in chromium values seen in Table 3 for commonly consumed foods is consistent with the notion that contamination issues may be persistent in some laboratory analyses. However, the variation could also be attributable in whole or part to other factors such as manufacturers' processing of foods.

4. Conclusion

Our evaluation of the comprehensiveness and reliability of chromium composition values for foods in the literature revealed two main impediments to assigning representative chromium values to foods in a comprehensive food and nutrient database. First, analytical chromium data is available for many commonly consumed foods, but overall, a relatively limited number of foods have been analyzed. Second, the large variation in the chromium content of individual foods originally identified by Anderson et al. (1992) remains an issue. Although the first challenge (limited availability of analytical values) may potentially be overcome if analyses are conducted for foods lacking analytical data, the second issue (large variation in analytical values) may be insurmountable. While laboratory contamination could potentially be minimized by refining analytical control methods, the variation due to other factors such as differences in soil chromium content and processing equipment reflect true variation in the chromium composition of foods in the food supply. Assigning representative chromium values to foods in a food and nutrient database may not be appropriate in this context. If representative values are assigned it may be important to acknowledge the limited usefulness of these values for estimating dietary chromium intake of individuals.

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Fig. 1.
Number of chromium values identified in the literature for various food groups.

Fig. 2.
Percentage of foods in NCC Food and Nutrient Database for which a chromium value can be assigned using direct matching or imputing.

Table 1
Summation of the research studies and their corresponding analytical methods identified for this investigation.

NAA	ICP-AES	ICP-MS	GFAAS
Singh and Garg (2006)	Baucells et al. (1989) ^c	Ashton et al. (2005)	Anderson and Bryden (1983)
	Bhattacharjee et al. (1998) ^c	Ayaz et al. (2006)	Anderson et al. (1992)
	Eitenmiller et al. (1985)	Bibak et al. (1998a)	Anderson et al. (1988)
	Ikem and Egiebor (2005)	Bibak et al. (1998b)	Bratakos et al. (2002)
	King et al. (1990)	Bibak et al. (1999)	Cabrera et al. (1996)
	Lisiewska et al. (2006)	Brunborg et al. (2006)	Cabrera-Vique et al. (1997)
	Ozcan (2004)		Garcia et al. (1999)
	Pedro et al. (2006)		Garcia et al. (2000)
	Pegg et al. (2006)		Gyori and Prokisch (1999)
	Porter and Jones (2003)		Kovacs et al. (2007)
	Ragaei et al. (2006)		Krzsik et al. (2008)
	Sika et al. (1995)		Mateos et al. (2003)
	Vlieg et al. (1991)		Miller-Ihli (1996)
			Raczajka et al. (2005)
			Stoddard-Gilbert and Blincoc (1989)
			Tinggi et al. (1997)
			Van Schoor et al. (1986)
			Vos and Hovens (1986)
			Wilplinger et al. (1995)
			Wrobel et al. (2000)
FAAS	Other	Method not clearly stated ^b	
Amaro-Lopez et al. (1997a)	Schmitt and Weaver (1982) ^a	Anderson et al. (1990)	
Amaro-Lopez et al. (1997b)		Chandrasekar and Deosthale (1993)	
Baucells et al. (1989) ^c		Leterme et al. (2006)	
Bhattacharjee et al. (1998) ^c		Roussel et al. (2007)	
Farre and Lagarda (1986)			
Giri et al. (1990)			

NAA	ICP-AES	ICP-MS	GFAAS
Nabhan et al. (1985)			
Puchyr and Shapiro (1986)			

- ^a Analytical method involved radionuclides detection.
- ^b AAS used but source of energy for atomization not clearly stated to provide a specific classification.
- ^c Reference listed twice as study used more than one analytical method.

Table 2

Commonly consumed foods and the number of analytical chromium values available from the literature.

Commonly consumed foods (descending order) ^a	Number of analytical values
Protein sources, include meat, poultry, fish, eggs, nuts	
Beef	8
Chicken	7
Pork	9
Eggs	13
Peanuts	1
Turkey	2
Fish and shellfish	82
Fruits and fruit juices	
Orange juice	5
Apple	13
Banana	7
Apple juice	2
Strawberries	3
Watermelon	1
Orange	7
Raisins	1
Peach	4
Vegetables	
Potatoes	20
Canned tomatoes	2
Head lettuce	3
Dry edible beans	34
Romaine and leaf lettuce	4
Onion	10
Tomato	4
Cabbage	5
Carrot	13
Celery	7
Milk and dairy products	
Mozzarella cheese	0
Cheddar cheese	0
2% milk (fluid)	0
Whole milk (fluid)	4
Nonfat dry milk	0
Skim milk (fluid)	5
1% milk (fluid)	0
American natural cheese	0

Commonly consumed foods (descending order) ^a	Number of analytical values
Ice cream	3
Yogurt	11
Grains ^b	
Ready-to-eat cereals	156
Nonwhole grain yeast bread	6
Whole grain yeast bread	4
Hot cereals	13
Popcorn	0
Nonwhole grain based desserts	10
Pizza	3
Pasta and pasta dishes	3
Mexican mixed dishes	0
Crackers	1
Fats	
Salad and cooking oils	7
Shortening	0
Butter	7
Margarine	5
Edible beef tallow	0

^aBased on ERS USDA 2008 Average daily per capita MyPyramid equivalents from the U.S. food availability, adjusted for spoilage and other waste.

^bRanking from Bachman et al. (2008).

Commonly consumed foods and their corresponding analytical chromium values ($\mu\text{g}/100\text{ g food}$) available from the literature, only foods with two or more values are reported.

Table 3

Commonly consumed foods (descending order) ^A	n	Mean	Median	Range	SD
Protein sources, include meat, poultry, fish, eggs, nuts					
Beef: meat, beef, ground beef	3 <i>a,f,r</i>	168.390	9.000	1.280-494.890	282.784
Chicken: chicken breast	2 <i>b,f</i>	8.300	-	0.600-16.000	10.889
Pork: ham	3 <i>u,r,b</i>	2.144	2.230	0.003-4.200	2.100
Eggs: egg, whole, cooked	6 <i>u,c,b,r,t,h,f</i>	2.252	0.455	0.001-10.000	3.883
Peanuts: peanut butter	2 <i>c,b</i>	2.800	-	1.800-3.800	1.414
Fish and shellfish: shrimp	3 <i>l,f,v</i>	15.800	21.000	0.400-26.000	13.569
Fruits & fruit juices					
Orange juice	5 <i>r,c,a,b,i</i>	0.523	0.403	0.100-0.910	0.366
Apple	7 <i>u,b,q,d,r,f,j</i>	8.212	3.250	0.002-39.733	14.163
Banana	7 <i>u,c,r,b,h,m,j</i>	4.856	0.800	0.001-16.420	6.766
Apple juice	2 <i>i,c</i>	0.155	-	0.010-0.300	0.205
Strawberries	3 <i>r,h,q</i>	1.652	0.970	0.787-3.200	1.343
Orange	7 <i>u,c,b,h,t,r,j</i>	4.900	1.700	0.001-25.500	9.200
Peach	2 <i>f,h</i>	6.200	-	5.000-7.400	1.697
Cantaloupe	3 <i>u,g,D</i>	4.334	5.000	0.001-8.000	4.041
Vegetables					
Potato: potato, peeled, raw	4 <i>q,t,e,h</i>	1.098	0.570	0.300-2.950	1.252
Head lettuce	3 <i>c,a,b</i>	0.511	0.132	0.100-1.300	0.684
Dry edible beans: pinto beans	2 <i>p,D</i>	58.000	-	28.000-88.000	42.426
Romaine and leaf lettuce	4 <i>u,f,h,r</i>	11.045	5.745	0.001-32.690	14.694
Onion, fresh	4 <i>h,t,j,s</i>	51.018	34.200	1.670-134.000	59.300
Tomato, fresh	7 <i>u,c,r,b,h,f,j</i>	8.178	0.700	0.003-46.100	17.027
Cabbage	4 <i>q,h,f,s</i>	16.595	7.890	0.600-50.000	22.917

Commonly consumed foods (descending order) ^A					n	Mean	Median	Range	SD
Carrot					6 ^{b,q,r,h,i,n}	3.246	1.737	0.400-9.000	3.532
Celery					3 ^{b,f,n}	5.100	7.000	0.300-8.000	4.187
Milk & dairy products									
Whole milk (fluid)					3 ^{a,c,h}	1.069	0.200	0.097-2.910	1.595
Skim milk (fluid)					4 ^{u,o,h,f}	0.946	0.892	0.001-2.000	1.062
Yogurt					4 ^{u,r,f,h}	1.540	1.570	0.001-3.020	1.698
American cheese ^C					3 ^{c,o,b}	2.137	2.000	1.400-3.010	0.814
Grains^B									
Ready-to-eat cereals: Kellogg's Raisin Bran					3 ^{c,a,o}	11.567	13.200	8.000-13.500	3.092
Nonwhole grain yeast bread: white bread					6 ^{u,c,o,f,h,k}	9.066	4.720	0.003-30.450	11.596
Whole grain yeast bread: whole wheat bread					6 ^{u,o,h,w,f,k}	14.883	10.500	0.008-38.200	15.660
Hot cereals: Nabisco quick prepared cream of wheat					3 ^{aD}	7.167	8.600	3.900-9.000	2.836
Fats									
Butter					6 ^{c,f,r,o,b,f}	2.726	0.679	0.300-13.000	5.042
Margarine					4 ^{r,b,o,f}	1.914	0.309	0.040-7.000	3.393

^aAnderson et al. (1988).

^bAnderson et al. (1992).

^cAshton et al. (2005).

^dBaucells et al. (1989).

^eBibak et al. (1999).

^fBratakos et al. (2002).

^gEitenmiller et al. (1985).

^hFarre and Lagarda (1986).

ⁱGarcia et al. (1999).

^jGiri et al. (1990).

- k* Gyori and Prokisch (1999).
- l* King et al. (1990).
- m* Leterme et al. (2006).
- n* Lisiewska et al. (2006).
- o* Miller-Ihli (1996).
- p* Nabhan et al. (1985).
- q* Racajaska et al. (2005).
- r* Roussel et al. (2007).
- s* Singh and Garg (2006).
- t* Stoddard-Gilbert and Blincoe (1989).
- u* Tinggi et al. (1997).
- v* Vos and Hovens (1986).
- w* Wilplinger et al. (1995).
- A* Based on ERS USDA 2008 Average daily per capita MyPyramid equivalents from the U.S. food availability, adjusted for spoilage and other waste.
- B* Ranking from Bachman et al. (2008).
- C* Ranking data not available for this cheese in ERS USDA files but food included in the table as chromium values were available.
- D* Different values from same study.