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Levels of Chromium in Zimbabwean Foods and Its Importance in Carbohydrate Metabolism

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SUMMARY

Staple foods eaten by Zimbabweans were collected and analysed for their chromium content. Organic matter was destroyed by a wet oxidation procedure using concentrated sulphuric and nitric acids. The food digest was directly aspirated into atomic absorption spectrophotometer (AAS) models Varians AA-1275 and AA-5-275. The remainder of each digest had pentan - 2, 4 dione added to it. The Cr complex formed was extracted in 4 methyl - pentan - 2 - one. Unfortunately no Cr was detected in the extract.

Water, leafy vegetables, naatjies (tangarines), oranges and beverage drink such as fizzy orange cordial and diabetic orange had either no Cr at all or only very low levels. Cr content in some fruits, such as bananas, apples and avocado pears, and in sweet potatoes and mealie-meal was moderate (mean 10,5 + 1,9 mcg) as compared to cheese, groundnuts, cucumbers, maize on the cob, rapoko and meat products, such as liver, which were found to be rich sources of Cr. These ranged from 15,2 to 49,6 mcg/g.

The importance of dietary chromium in the metabolism of carbohydrates is also discussed.

INTRODUCTION

Evidence accumulating during the past two decades has created a considerable degree of interest in the nutritional role of chromium (Cr). A strong link has been observed between chromium and insulin in carbohydrates metabolism.

Cr-deficient animals,[1,2] malnourished children,[3] diabetics,[4,5] patients receiving total parenteral nutrition,[6] and elderly subjects [7] have all been shown to respond to inorganic Cr with improved glucose tolerance. All the supplementation studies on human subjects have

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been done on potentially Cr-deficient groups which exhibited abnormal glucose tolerance. This has led to the hypothesis that Cr is essential for optimum metabolic function of insulin.

That Cr deficiency is implicated in some forms of diabetes mellitus has been demonstrated in several studies. Thus rats fed on a Cr-deficient diet developed a syndrome that was indistinguishable from diabetes glycosuria.[2] Jeejeebhoy *et al.*[6] reported on a patient who developed diabetic symptoms and negative Cr balance after receiving total parenteral nutrition (TPN) for three years. Sargent *et al.* [8] observed a link between Cr and diabetes mellitus in patients with haemochromatosis and diabetes mellitus. Cr is transported in the blood complexed to siderophillin (transferrin)[9] on to which it binds competitively with iron.[10] Sargent *et al.* suggested that iron saturation present in haemochromatosis could inhibit Cr-transfer leading to subsequent loss of chromium and development of diabetes mellitus.[8]

Support for the hypothesis was found by analysis of hepatic chromium concentrations which were found to be higher in controls than in diabetic patients.[11] Genetically diabetic mice injected with glucose tolerance factor (GTF) concentrates from brewer's yeast showed a decrease in non-fasting plasma glucose, triglyceride and cholesterol levels. Doisy *et al.* made the hypothesis that a relative or absolute deficiency of GTF, possibly due to the inability to synthesize it from inorganic chromium, may be a contributing factor in the aetiology of diabetes in genetically diabetic mice.[12]

An insulin-potentiating factor has been named glucose tolerance factor (GTF) by Mertz *et al.*[13] Assays of yeast concentrate that contain biological (GTF) activity have revealed the presence of nicotinic acid, trivalent chromium and glutamic acid to be the possible components of the active factor. It has been postulated that inorganic chromium (III) in the biologically active form of GTF is required for maintenance of glucose utilization by man and animals. The chemical and biochemical properties of chromium and its complexes are useful for an understanding of the biological role of the element.

Cr, atomic number 24, has several oxidation states but only the +3 state is stable in biological systems. Chromium (+3) has a strong tendency to form co-ordination complexes and chelates, as it has $3d^3$ outer electron configuration which leaves two 3d orbitals capable of hydridizing with the 4s and 4p orbitals to yield six spd hybrid orbitals. Several synthetic chromium nicotinic-acid/amino-acid complexes have been shown to possess chemical and biological properties similar to purified yeast extracts.[14]

Evidence for a direct interaction of chromium III (GTF) with insulin has been demonstrated by Evans *et al.*, [15] in which they studied the binding of natural GTF preparation to insulin *in vitro*. Complexes between insulin and GTF were formed and were stable at alkaline pH. These complexes exhibited greater biological activity than either GTF or insulin alone. At cellular level, the interaction probably involves attachment of a chromium complex to cell membrane of sulphydryl groups and insulin disulphide groups.

Lower levels of chromium in foods (the proposed dietary requirements of chromium intake by the National Research Council is 50–200 micrograms/day) are thought to be a consequence of food processing and refining.[16,17,18] Chromium is thus found at high levels in the by-products of refining processes, such as molasses, and very little in the refined sugars.[18] The incidence of glucose intolerance and diabetes is increasing in technologically advanced nations where diets consist of refined and processed foods. Mossop[5] has reported that food preference towards refined carbohydrates by Zimbabweans could partly account for diabetes and atherosclerosis which are becoming more common in Zimbabwe.

This study was undertaken to estimate the levels of chromium (Cr) in foodstuffs available in Zimbabwe. The results, it was hoped, would throw some light on the observations made in technologically advanced nations and on what Mossop has reported.

MATERIALS AND METHODS

Materials

Analytical grade conc. H_2SO_4, conc. HNO_3, saturated solution of ammonium oxalate; pentane - 2, 4 - dione (acetylacetone) general purpose reagent grade for synthesis; $Na_2 SO_3$ (6% $^{W}/v$) analytical grade; standard chromium solution (1 000 ppm) prepared from $K_2 CrO_7$ for atomic absorption spectrophotometry grade and composite standard chromium solutions for calibration were prepared by serial dilution of 1 000 ppm solution. All glassware was soaked in ion-free detergent, rinsed with deionized water, dried, soaked in chromic acid for twenty-four hours and then rinsed in distilled deionized water and dried before use. All samples as used in the study were hydrated, i.e. all units expressed mcg/g wet weight.

Experimental

5,0 ml or 5,0 g of sample organic matter was destroyed by a wet oxidation method modified by the Government Analyst, Harare, using concentrated nitric and sulphuric acid for digestion. A clear solution was obtained and made up to 100 ml with deionized water. About 30 ml of each digest was used for direct aspiration into Atomic Absorption Spectrophotometers (AAS) single-beam Varian AA-1275 series and Varian AA-5-275 series for comparison, because each used different oxidizing flames, namely N_2O/C_2H_2 and Air/C_2H_2. Chromium was extracted from the remainder of the digest using the method similar to that of Jackson *et al.*, and analysed as above.[19]

RESULTS

There was no difference in the readings when either the Varian AA-1275 model or the Varian AA-5-275 model was used to analyse Cr content of the samples that were found to contain high levels. However, at low levels the results for some samples (e.g. white bread, potatoes) were very different (Table I). It can be seen from the results that Cr levels in the foods analysed varied considerably. Levels were found to be high in liver, whole green mealies, cucumber, cheese and groundnuts (Table II). Leafy vegetables, drinking water and refined products were found to contain very low levels of Cr.

Some fruits (for example, naatjies (tangarines), oranges and paw-paws) had lower Cr than bananas, apples and avocado pears which had moderate levels of Cr as shown in Table II. Green maize on the cob appeared to be a very rich source of Cr (29 mcg/kg wet weight) compared to mealie-meal (ground maize) of different grades. The levels of Cr were found to vary also within the different grades of mealie-meal that were on the market in Zimbabwe as shown in Table I. 'Ngwerewere', the highly refined mealie-meal in Zimbabwe, had lower levels than 'Roller Meal', which is less refined. Brown bread had slightly higher levels than white bread.

TABLE I — *Chromium content of cereals, starches and meats analysed*

Product	Chromium contents mcg/g (1)	(2)
Cereals and starches		
Green mealies on cob	29,0	29,0
Mealie-meal (whole)	8,2	8,9
'Roller meal'	4,0	4,9
'Ngwerewere' mealie-meal	2,2	3,9
Brown bread	1,4	2,4
White bread	0,6	1,4
Rapoko (*zviyo*)	15,2	17,4
Sweet potatoes	10,2	8,5
Rice	2,6	3,4
Potatoes	0,8	0,0
Meats and other products		
Beef liver	49,6	46,0
Beef steak	4,4	4,0
Pork chop	3,2	3,5
Tinned beef	9,6	8,5
Boerwoers sausages	9,4	10,4
Beef sausages	14,8	17,9
Beef tripe	5,2	4,5
Cheese	37,2	29,5
Chicken	8,4	9,5
Egg	7,0	7,5
Fish	3,2	2,0

(1) AAS Varian AA-1275
(2) AAS Varian AA-5-275

Different types of meats, i.e. beef, pork, fish and chicken (Table I), were found to contain more Cr than leafy vegetables such as *Brassica napus* (rape), *Brassica unce* (*tsunga*) and *Brassica* (*aleracea*) *capitata* (cabbage), which are commonly eaten vegetables. Beef liver contained the highest quantity per gram of wet weight. Pork chops and fish contained the least amounts in the meat group.

TABLE II — *Foods with high chromium content*

Product	Range (mgm/g)
Vegetables	
Groundnuts	40,4 – 46,4
Cucumbers	32,0 – 34,0
Fruits	
Apples	13,0 – 14,5
Avocado pears	10,4 – 11,4
Bananas	10,0 – 10,4
Meats and dairy products	
Beef liver	46,0 – 49,6
Cheese	37,2 – 39,5
Beef sausages	14,8 – 17,9
Cereals and starches	
Green mealies on cob	29,0
Rapoko	15,2 – 17,4
Sweet potatoes	8,5 – 10,2
Liquids	
Opaque beer	10,8 – 11,5

Drinks such as the carbonated orange, cream soda beverages and diabetic orange were found to contain very low levels of chromium. They contained an average of 0,4 mcg/ml of Cr. Of the drinks analysed, opaque beer was found to contain the highest level of Cr per ml (10,8 – 11,5 mcg/ml).

DISCUSSION

The levels of Cr in most foods are reported to be too low to be detected by direct aspiration of the food digest into the flame atomic absorption of the spectrophotometer.[19,20] In the present study, the levels could be measured by direct aspiration when the sensitivity of the AA-1275 instrument was increased by a 100-fold. The sensitivity of the AA-5-275 flame atomic absorption spectrophotometer could not be increased and so the Cr for some samples could not be picked.

Cr in the 4-methylpentan-2-one extracts could not be detected. There were two possible explanations for this. Firstly, the formation of Cr pentan-2, 4-dione complex is pH dependent, so that a slight alteration in pH would affect complex formation. The optimum pH, for complex formation, is 4,5; and at lower or higher pH, complex formation is reported to be reduced.[19] Thus, measurement of pH of the remaining aqueous solutions revealed the pH to be in the range 2–3. Another possible explanation for the failure to get response could have been due to instability after twenty-four hours.[19]

The difference in the Cr values obtained in this study and those of Schroeder *et al.* could be due to geographical variation of the chromium content of soils of different countries, which might be reflected in plants and animals. The analytical methods used by Schroeder and his colleagues were different from the one used in this study. Samples used in this study were not washed and dried to constant weight at 110 C.[21] Also, the tissue Cr levels of animals can depend on the age of the animal.[22]

TABLE III — *Comparison of results in present study and those of other studies*

Product	Present study Rank	Other studies* Rank
Beef liver	(1)	(1)
Cucumber	(2)	(10)
Apple	(3)	(8)
Chicken	(4)	(2)
Egg (chicken)	(5)	(2)
Beef steak	(6)	(5)
Pork chop	(7)	(4)
Beans	(8)	(9)
Rice	(9)	(6)
Spinach	(10)	(12)
Whole wheat bread	(11)	(6)
Potato (raw)	(12)	(14)
Cabbage	(13)	(11)
Carrots	(14)	(13)

* See reference 21.

From the results obtained it appeared that Cr levels were high in whole green maize, moderate in less refined mealie-meal and very low in the refined mealie-meal. The results obtained support the thesis that nearly all Cr 3+ is removed during refining of foods such as maize.

If Cr is involved in maintaining proper glucose metabolism, adequate dietary intake of Cr, therefore, should be provided to prevent glucose intolerance rather than to reverse or to alleviate the disorder. Effective prevention of Cr deficiency cannot be achieved by supplementing staple food inorganic Cr which does not provide an acceptable substitute for the biologically active glucose tolerance factor occuring naturally in food materials.

Absorption of Cr depends on the chemical form in which it is present: 1 per cent of inorganic Cr is absorbed as against 10–25 per cent of the biologically active organic GTF.[23] Average daily losses of 5–10 micrograms per day of Cr cannot be adequately compensated by intake of inorganic Cr at the 1 per cent absorption rate. Therefore, GTF at a 10–25 per cent absorption rate would have to account for a large proportion of the day's Cr in order to achieve balance. Principal active GTF is present in a variety of foods, including liver, cheese and whole grain. This agreed with the results described in the present study.

It could be argued that dietary correction of carbohydrate disorders should be a therapeutic choice since it elicits fewer adverse effects and non-compliance problems than do drug regimens. Dietary intervention can have practical importance only if Cr deficiency is expected to exist in the population or in the individual. Thus, the elderly, pregant women, diabetics and malnourished infants appear to be at risk of developing or worsening the existing glucose intolerance and so should be considered as candidates for dietary intervention.

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