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Nº 14039

Reprinted from
Food Additives & Contaminants, Vol. 14 (2), 1997

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Food Additives and Contaminants, 1997, Vol. 14, No. 2, 115–126

Purity of food cooked in stainless steel utensils

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(Received 16 February 1996; revised 27 May 1996; accepted 12 June 1996)

An extensive programme of cooking operations, using household recipes, has shown that, apart from aberrant values associated with new pans on first use, the contribution made by 19% Cr/9% Ni stainless steel cooking utensils to chromium and nickel in the diet is negligible. New pans, if first used with acid fruits, showed a greater pick-up of chromium and nickel, ranging from approximately $\frac{1}{20}$ *to* $\frac{1}{3}$ *and* $\frac{1}{20}$ *to* $\frac{1}{2}$ *of the normal daily intake of chromium and nickel respectively. This situation did not recur in subsequent usage, even after the pan had been cleaned by abrasion. A higher rate of chromium and nickel release in new pans on first use was observed on products from four manufacturers and appears to be related to surface finish, since treatment of the surface of a new pan was partly, and in the case of electropolishing, wholly effective in eliminating their initial high release.*

Keywords: stainless steel, nickel and chromium pick-up and determination, surface treatment, cooking utensils, foodstuff.

Introduction

There are general legislative requirements that food should be free from harmful constituents, especially those that might result from treatments given to crops or livestock, or those that might be introduced in subsequent processing of food for sale or in its preparation for the table (Directive 89/109/EEC, Council Regulation 315/93). From time to time, concern is expressed over the possibility of pick-up of metals and their compounds from utensils used in the cooking of food in the kitchen (Rasmussen 1983), and their possible adverse effects on human health and food quality.

Both in industry and domestically, the grade of stainless steel most commonly used for the processing and preparation of food is UNS (Unified Numbering System) 30400 containing 19% Cr/9% Ni. Reports in the literature show that release of small amounts of chromium and nickel is possible when certain foods or simulated foods are processed in S30400 utensils.

The chromium intake from the diet and water varies considerably between regions; typically, levels lie within the range 50–200 μg/day (*Environmental Health Criteria 61* 1988). Some 0·5–3% of the intake is retained and is an essential requirement in humans for maintenance of normal glucose metabolism. Cases of chromium deficiency resulting in impaired glucose tolerance have been reported, which have been corrected by addition of chromium (as $CrCl_3.6H_2O$) to the daily diet. Although not always effective, doses of chromium as high as 10 mg/day have been used for this purpose. Organic complexes of chromium may also be used.

When considering the toxicity of chromium it is essential to distinguish between the hexavalent and trivalent forms (Fairhurst and Minty 1989). In animals, doses of soluble hexavalent chromium compounds greater than 10 mg/kg diet adversely affect the gastrointestinal tract and kidneys, whereas dietary toxicity has not been reported for trivalent chromium even when administered in amounts of up to 1 g/day (*Environmental Health Criteria 61* 1988). Hexavalent chromium has been reported to occur in the corrosion products when stainless steels react with serum but not with saline solution (Merritt and Brown 1984). The hexavalent form of chromium is unstable in the presence of organic matter at the pH levels found in foods (1·9–9·0) and hence it is reasonable to assume that any chromium derived from the reaction of food with stainless steel will be in the trivalent state.

The average human daily intake of nickel is approximately 200 μg (Thomas *et al.* 1974, Nielsen and Flyvholm 1983, Smart and Sherlock 1987), and although the essentiality of nickel in the diet of animals such as sheep, goats, rats, chickens has been proven (Nielsen *et al.* 1975, Anke *et al.* 1980) as has its essentiality in plants (*AG News* 1992)—the ubiquitous nature of nickel makes it difficult to establish its essentiality in the human diet. However, a nickel dietary requirement for humans of 50 μg/kg of diet has been proposed (Nielsen 1982).

The toxicity of nickel was reviewed by Nielsen (1977) who concluded that abnormally high levels of oral nickel salts are required to overcome homeostatic mechanisms that control nickel metabolism. Nickel toxicity in humans via the oral route occurs only in extreme and unusual circumstances. One such occurrence was of workers in an electroplating plant who accidentally drank water contaminated with nickel-plating solution. The nickel doses (as nickel sulphate and chloride) in workers with symptoms (nausea, giddiness, vomiting, headache, lassitude) were estimated to range from 0·5 to 2·5 g. All subjects recovered rapidly and without evident sequelae (Sunderman *et al.* 1988).

It is not possible to acquire skin sensitization to nickel by the ingestion of nickel compounds, but a number of investigators (Christensen and Moller 1975, Kaaber *et al.* 1978, Jordan and King 1979, Cronin *et al.* 1980) have shown that ingested nickel can cause exacerbation of hand eczema in patients who are already sensitized to nickel. Although only a minority of patients react to oral doses below 1250 μg of nickel (as nickel sulphate) (Menné and Maibach 1991), it has been concluded that a reduction of the dietary intake of nickel may benefit some nickel-sensitive patients (Kaaber *et al.* 1978, Nielsen and Flyvholm 1983; Veien *et al.* 1987, 1993). Special low nickel diets have been devised for such patients; these diets sometimes include a recommendation to avoid acid fruits cooked in stainless steel utensils.

In contrast, it has been found that oral exposure to nickel prior to sensitization results in a reduced frequency of nickel hypersensitivity. That conclusion was reached from a survey (Van Hoogstraten *et al.* 1991) of persons who had oral contact with dental braces containing nickel at an early age prior to ear piercing—a common cause of nickel sensitization. The effectiveness of nickel ingestion as a means of inducing tolerance to sensitization by nickel was subsequently established experimentally (Van Hoogstraten *et al.* 1993).

Most experiments on pick-up of nickel or chromium from stainless steel utensils have been conducted using acid solutions, ostensibly simulating real foods. Generally organic acids have been used (acetic, citric, maleic, oxalic) or chloride solutions at or near boiling point (Christensen and Moller 1978, Brun 1979, Rasmussen 1983, Kuligowski and Halperin 1992, Tupholme *et al.* 1993). However, it is well known (Truman 1976, Sedriks 1979, Audouard 1993) that considerable variability in performance can be shown by stainless steels in such conditions depending upon the transition from passive (surface protected by chromium oxide film) to active (unfilmed) states during the test period, which in turn is dependent upon the concentration of the acid, the presence of chlorides and other contaminants, particularly those of an oxidizing or reducing character. The situation is will exemplified by results obtained in oxalic acid at pH 4 (Tupholme *et al.* 1993) where nickel pick-up was below the level of detection, and those at pH 2 (Koerner and Haberle 1991) where nickel pick-up exceeded 3 mg/l. Evidently, results from tests in simulated foods need to be treated with caution and require careful interpretation.

Tests involving real foods demand more exacting experimental techniques and consequently are much less numerous. One investigation (Brun 1979) compared nickel contents of fruits cooked in enamel or stainless steel utensils and found significant pick-up from the stainless steel. Conversely a more recent investigation (Vrochte *et al.* 1991) of actual cooking operations using other foods showed that the nickel and chromium contents of spinach, sauerkraut and rhubarb, cooked in 19% Cr/9% Ni stainless steel saucepans were within the normal range of values found in these foods in the raw state. Flint and Packirisamy (1995) have also reported low pick-up of nickel by foods cooked in stainless steel utensils.

The present investigation was made with the aim of determining the pick-up of chromium and nickel in foods that are aggressive, or potentially aggressive, to stainless steel and which were prepared using typical household recipes. Preliminary experiments had indicated that new pans on first use could behave erratically and particular attention was paid to this aspect by examination of (a) pans from different manufacturers, (b) the effects of surface treatments, and (c) pans that had been in domestic use.

Experimental procedure

The following determinations were made:

(a) The naturally occurring levels of chromium and nickel and pH of all the matrices tested (table 1).
(b) The pick-up of chromium and nickel by rhubarb cooked in new S30400 stainless steel pans from manufacturer M1. Tests were performed in triplicate and a sequence of 20 cooking operations was undertaken. Further determinations were made after abrasion of the test surfaces using either plastic or steel wire wool abrasives (figure 1).
(c) The pick-up of chromium and nickel by apricots cooked in new S30400 stainless steel pans from manufacturer M1. Tests were performed in duplicate and a sequence of 16 cooking operations was undertaken. Further determinations were made after abrasion of the test surfaces using either plastic or steel wire wool abrasives (figure 2).
(d) The pick-up of chromium and nickel by other foodstuffs of an aggressive nature cooked in new S30400 stainless steel pans from manufacturer M1. These tests were performed in duplicate and sequences of five cooking operations were undertaken (figures 3 and 4).
(e) The pick-up of chromium and nickel by rhubarb cooked in new S30400 stainless steel pans from manufacturers M2, M3 and M4. Sequences of five cooking operations were undertaken (figure 5).
(f) The pick-up of chromium and nickel by rhubarb cooked in new S30400 stainless steel pans from manufacturer M1 after the various surface treatments described in table 2.
(g) The pick-up of chromium and nickel by rhubarb cooked in a glass beaker containing specimens of unfabricated S30400 stainless steel with two different surface finishes (table 2).
(h) The pick-up of chromium and nickel by rhubarb cooked in pans that had been in domestic use for some years.
(i) The pick-up of chromium and nickel by 5% acetic acid boiled in a pan from manufacturer M1, that previously had been used for 18 cooking operations with apricots. The test conditions used were those employed by Kuligowski and Halperin (1992).

Materials

Stainless steel saucepans of 1·6 litre capacity, 160 mm diameter made by manufacturer M1 were purchased from a London store. Before and between testing the pans were washed in demineralized water with gentle cleansing using a soft sponge and dried using tissues. Similar sized pans to the same specification as the M1 pans were obtained either by purchase or as gifts from manufacturers M2, M3 and M4. The four manufacturers were of German, French, Norwegian and US origin.

Of the two used pans tested, one was of North American manufacture and had been in domestic use for 35 years, whilst the other, of Belgian manufacture, had been in domestic use for 5 years. Two specimens of unfabricated S30400 stainless steel were obtained from a steel producer who supplies sheets to fabricators of kitchen utensils.

The following ingredients were purchased in bulk and sampling techniques were performed to ensure minimum variation within each ingredient of the samples tested:

(a) rhubarb
(b) dried apricots
(c) ingredients for the preparation of lemon marmalade (Patten 1973)
(d) ingredients for the preparation of green tomato chutney (Watts 1989)
(e) potatoes

Once prepared, all perishable ingredients were stored frozen (−18°C to −22°C), whilst the non-perishables were stored at room temperature.

Demineralized water was used to wash all samples and distilled water was used for all cooking operations.

Cooking procedures

Care was taken at all stages to avoid contamination of the test samples. Where possible plastic utensils were used. A domestic gas cooker was used for all cooking operations.

Rhubarb. Sliced rhubarb (250 g) and 30 ml of distilled water were placed in the pan, brought to the boil and simmered for 15 min. The surface area of pan exposed to the mixture was 0·025 m^2.

Apricots. Dried apricots (250 g) were placed in 500 ml of distilled water and allowed to soak for 16 h in the pan. The soaked apricots and water were

brought to the boil and simmered for 15 min. The surface area of pan exposed to the mixture was 0·040 m^2.

Lemon marmalade. The juice, peel, pips, flesh and pith of the lemons (450 g) were separated. The juice was refrigerated until required for use. The lemon peel was cut into strips and placed in the pan with 568 ml of distilled water and a nylon bag containing the pips, flesh and pith. The contents of the pan were allowed to soak overnight (16–18 h), then the pan was heated strongly for 5 min, covered, and the contents simmered for 1 h. The nylon bag was removed prior to the addition of the refrigerated lemon juice and 450 g of sugar. The contents of the pan were stirred for 3 min with heating to dissolve the sugar prior to being heated strongly and brought to the boil with stirring (3 min), the heat was reduced and the contents of the pan were allowed to boil gently without stirring for 4 min (Patten 1973). The surface area of pan exposed to the mixture was 0·049 m^2.

Green tomato chutney. The prepared fruit and vegetables were placed in the pan with sultanas, sugar, salt and pepper. Vinegar (250 ml) was added and the pan was gently heated for 3 min to dissolve the sugar. Grated ginger and mustard seeds were placed in a nylon bag and put into the pan. The pan was covered and the liquid gently simmered for 2 h (Watts 1984). One quarter of the recipe weight was used. The surface area of pan exposed to the mixture was 0·044 m^2.

Potatoes. Three potatoes (approximately 470 g) were peeled, rinsed with demineralized water, dried with tissue and cut into 30–40 g cubes. Four hundred g of these potato cubes, 2 g of salt and 400 ml of distilled water were placed in the pan, brought to the boil and simmered for 20 min. The salt was added before the water as this gives maximum possibility for attack on the stainless steel. The surface area of pan exposed to the mixture was 0·039 m^2.

Once cooked, all samples were transferred to plastic boxes for cooling prior to the measurement of pH, weighing and homogenization in a blender. All cooked samples were stored frozen (−18°C to −22°C) until required for analysis.

Except in the case of potatoes, all analyses were made on the homogenized liquid + solid material. For potatoes, analyses were made separately on the solid homogenized potato and on the water used to boil the potatoes.

Field blanks were performed to assess if there had been any contamination during sample homogenization. Blank wheat starch solutions were taken through the blender both before and after the homogenization of test samples. The starch solutions were analysed for chromium and nickel.

Determination of chromium and nickel

Prior to the determination of chromium and nickel, all samples were wet oxidized using a combination of concentrated acids (Analytical Methods Committee 1960). Weights of samples taken for digestion ranged from 2 to 50 g depending on the moisture content of the samples. All digests were made up to 100 ml and were analysed by atomic absorption spectrometry (AAS). The instrument used was a Perkin Elmer 2100 with a heated graphite analyser (HGA700). Measurements of chromium and nickel were made at wavelengths of 357·7 nm and 231·7 nm respectively. National Institute of Standards and Technology (NIST) certified reference materials were run with every assay to check the accuracy of the analysis. For NIST oyster tissue (1566a), at the 95% confidence level the levels were:

Element	*Certified level*	*Observed level*
Chromium	1·46 ± 0·46 mg/kg	1·56 ± 0·32 mg/kg
Nickel	2·25 ± 0·44 mg/kg	2·15 ± 0·55 mg/kg

Also, with every assay, reagent blanks were taken through the analytical procedure to check for contamination during the measurement stage. The limit of detection of the analytical method, calculated on 3 standard deviations (99% confidence limit) of reagent blank responses from successive assays was calculated to be 30 μg/kg for chromium and 10 μg/kg for nickel. In the calculation of the results in standard food portions (Crawley 1988), the limits of detection were scaled down by the appropriate factor.

Calculation of pick-up

It was necessary to obtain reliable figures for the chromium and nickel contents of each food in order

to determine if any pick-up had occurred during the cooking operation.

For rhubarb and apricots, 10 raw samples were selected at random and analysed. For lemon marmalade, green tomato chutney and potatoes five ingredient sets of each were selected at random and cooked in glass pans.

The average chromium and nickel contents were calculated for each food and used as the base levels for calculation of pick-up values (table 1). The Student's *t* distribution was used to reflect the amount of uncertainty around the 'true levels' of chromium and nickel occurring naturally in the foods tested. The following formula was used:

Confidence Limits,

$$\text{CL} = \text{Mean} \pm t \times \left(\frac{\text{Standard Deviation}}{\sqrt{\text{No, of samples}}}\right)$$

where t is the appropriate tabulated value from Student's t table. For example, nickel in rhubarb:

$$\text{CL} = 39 \pm 2{\cdot}26 \times (7{\cdot}41/\sqrt{10}) = 39 \pm 5{\cdot}3 \text{ μg/kg}$$

i.e. 95% of all results should lie between 33·7 and 44·3 μg/kg.

Experimental results

The field blank studies demonstrated that no detectable contamination of the test samples occurred during sample homogenization.

The levels of chromium and nickel in uncooked rhubarb and apricots, glass-pan-cooked lemon marmalade, green tomato chutney and potatoes are given in table 1. All values fell within or were close to the range of chromium and nickel contents of these foods reported in the literature (Thomas *et al.* 1974, Smart and Sherlock 1987). The pH values of both cooked (in stainless steel pans) and 'uncooked' foods are also given in table 1.

A check analysis, by X-Ray fluorescence (XRF), on an M1 pan gave results of 18·18% Cr, 9·44% Ni and values for minor elements which were also within the S30400 stainless steel specification.

The levels of chromium and nickel in rhubarb cooked in the S30400 pans in the initial sequence of 20 cooking operations are shown in figure 1. The results are expressed in terms of standard food portions (Crawley 1988). It is evident that new pans can release some chromium and nickel but that after two operations the pick-up is drastically reduced to levels close to, and ultimately below, the naturally occurring levels of chromium and nickel in the test samples of uncooked rhubarb. Abrasion of the pan surface, following the sequence of 20 operations, generally had little effect.

New pans, when first used for the stewing of apricots, also released some chromium and nickel (figure 2) but, in contrast to rhubarb, some pick-up remained measurable even on continued use. Abrasion of the pan surface, following 16 cooking operations, caused a reduction in chromium and nickel pick-up with one exception for chromium.

Table 1. Naturally occurring chromium and nickel contents and acidity of foods tested.

Foodstuff	Mean chromium content (μg/kg)	Mean nickel content (μg/kg)	pH before cooking	pH after cooking in glass	pH after cooking in stainless steel
Rhubarb	< 30	39 ± 5·3	3·5 $n = 10$	—	3·5 $n = 60$
Apricots	54 ± 3·7	111 ± 6·1	3·7 $n = 10$	—	3·6 $n = 36$
Lemon marmalade	< 30	76 ± 20·7	—	2·6 $n = 5$	2·8 $n = 10$
Green tomato chutney	40 ± 8·7	30 ± 8·7	—	3·3 $n = 5$	3·5 $n = 10$
Potatoes: boiled potato water only	< 30	< 10	—	5·8 $n = 5$	5·8 $n = 10$
homogenized cooked potatoes	< 30	12 ± 5·6[a]	—	5·9 $n = 5$	5·9 $n = 6$

n is the number of samples analysed for pH.
The chromium and nickel content is based on 10 samples of raw rhubarb and apricots, and five samples (cooked in glass) for each of the other categories.
[a] Although two of the results were below the limit of detection, they were used at their maximum value to calculate a confidence interval.

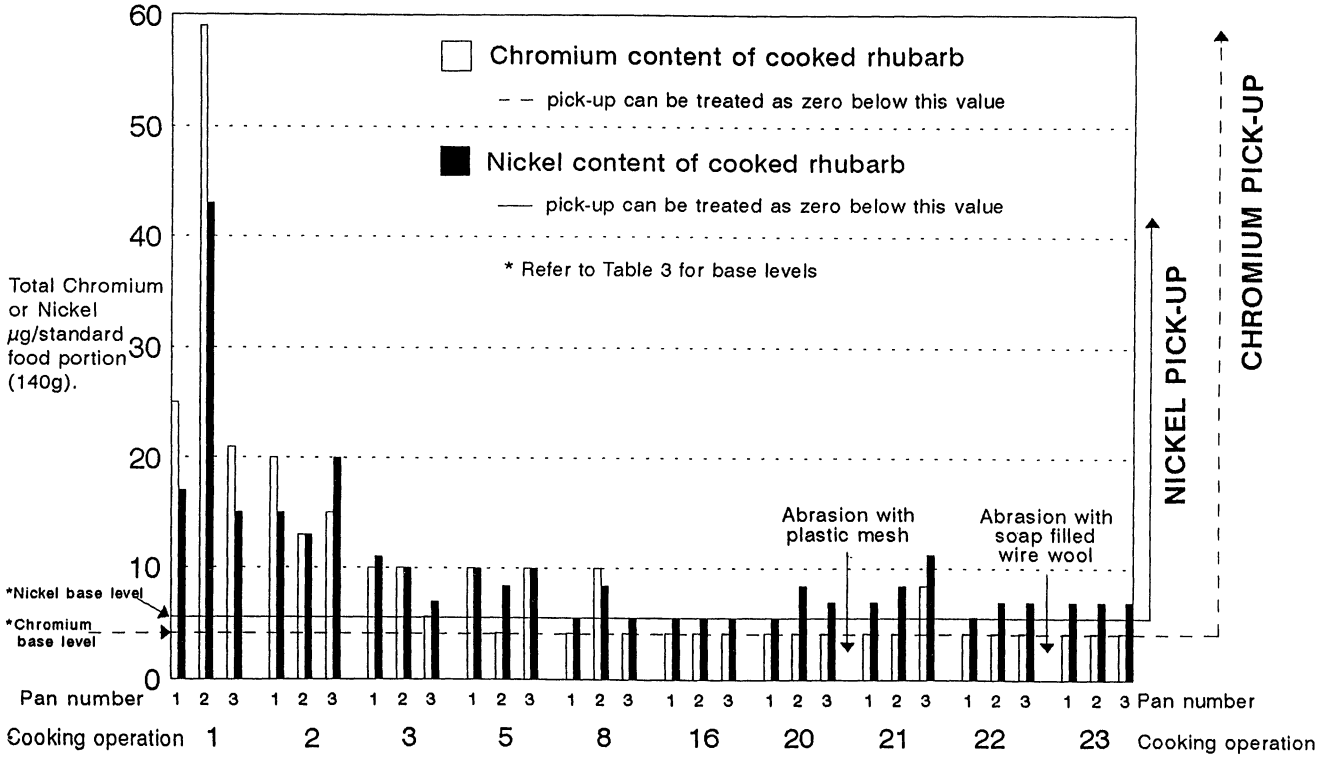

Figure 1. Total chromium and nickel in rhubarb cooked in new M1 stainless steel saucepans.

In the preparation of lemon marmalade and green tomato chutney, the pick-up of chromium and nickel was nil or just detectable, even in the new pans on first use, a somewhat surprising observation in view of their greater acidity compared with that of rhubarb and apricots. In one case, some slight pick-up was detected in the salt water used to boil potatoes but this pick-up was not observed in the potatoes (figures 3 and 4).

The greater release of nickel and chromium from new pans when first used for the cooking of rhubarb was observed on pans from four different manufacturers located in four different countries using steel from different sources (figure 5). Some difference was apparent in the pick-up from the pans from the various manufacturers, but replication between pans from the same manufacturer was also poor. Of possible significance in that it might help in providing an explanation for the high results on first use, is the observation that for pans from manufacturers M1 and M3 the pick-up of chromium exceeded that of nickel, with one exception, whereas for pans from manufacturers M2 and M4 the reverse was true. In subsequent cooking operations pick-up was reduced and the difference in manufacturers' products disappeared.

Prior surface treatment of new pans from manufacturer M1 was effective to varying extents in reducing the initial release of chromium and nickel that occurred on first use in the cooking of rhubarb (table 2). Electropolishing was the most effective treatment and reduced pick-up to levels close to the naturally occurring levels of chromium and nickel in raw rhubarb.

The specimens of unfabricated S30400 steel gave very little pick-up of chromium or nickel when cooked with rhubarb and no significant effect of surface finish was observed (table 2). It should be noted that in this experiment the specimens were not subject to the effects of heat transfer.

In the case of the used pans, the 5-year-old pan did not give any detectable pick-up of chromium or nickel when used for cooking of rhubarb but some pick-up was apparent in the 35-year-old pan in a similar circumstances. This pan was of thinner construction

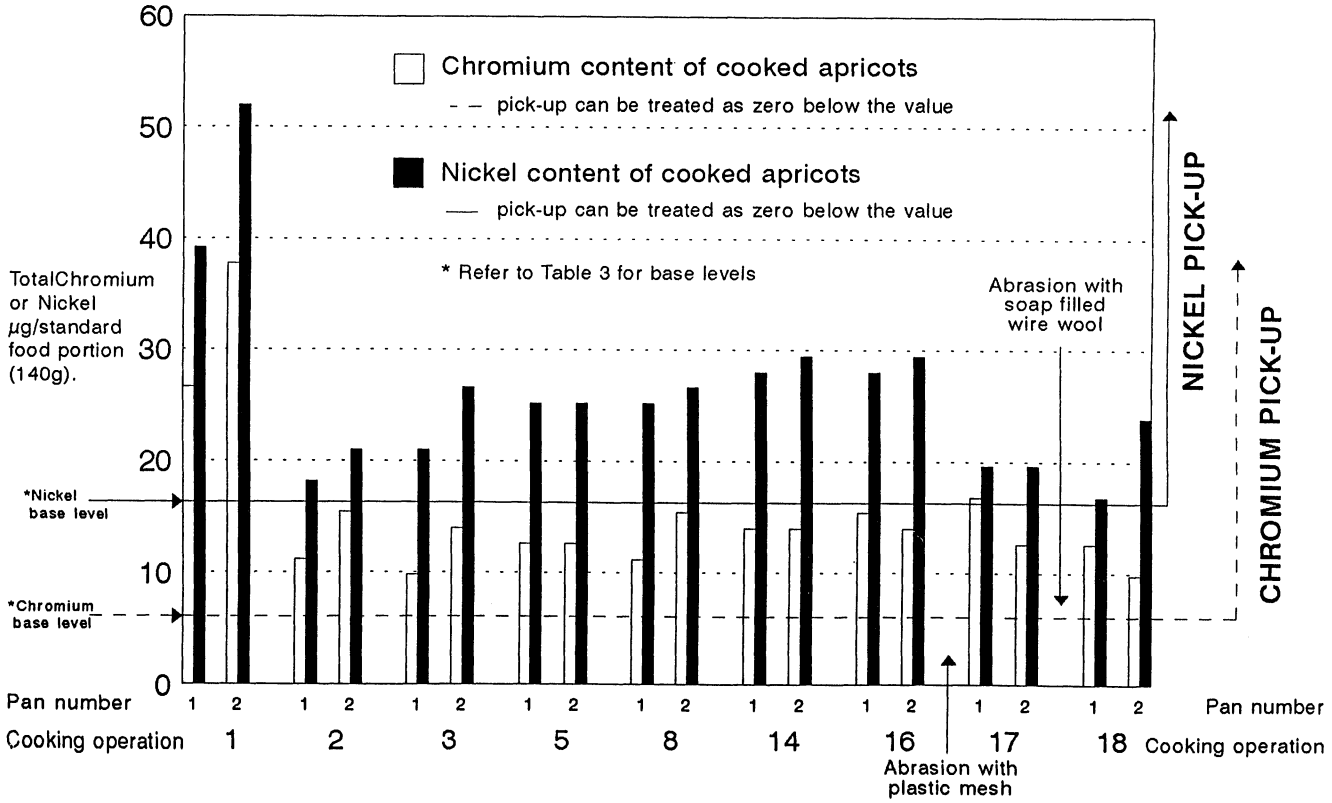

Figure 2. Total chromium and nickel in apricots cooked in new M1 stainless steel saucepans.

Table 2. The effect of surface treatment of S30400 stainless steel on the chromium and nickel content of rhubarb.

Type of surface treatment	Total chromium (µg/kg)	Total nickel (µg/kg)
New stainless steel saucepan, first use (as received)	Mean = 202[a] $n = 12$	Mean = 296[a] $n = 12$
New stainless steel saucepan M1, after:		
(a) mild abrasion using stainless steel 'reviver'	90	80
(b) treatment with HNO_3/HF	250	90
(c) electropolishing	40	60
(d) ultrasonic cleaning	90	70
New stainless steel saucepan, after five cooking operations	49[a] $n = 12$	66[a] $n = 12$
Unfabricated stainless steel piece—2A finish	< 30	60
Unfabricated stainless steel piece—2B finish	80	80

2A finish: bright annealed—a cold rolled reflective finish retained through annealing.
2B finish: cold rolled, softened, descaled and lightly rooled on polishing rollers.
From table 1: the mean chromium content in raw rhubarb is < 30 µg/kg and the mean nickel content in raw rhubarb is 39 ± 5·3 µg/kg.
[a] The average of 12 pans (three pans from four manufacturers).

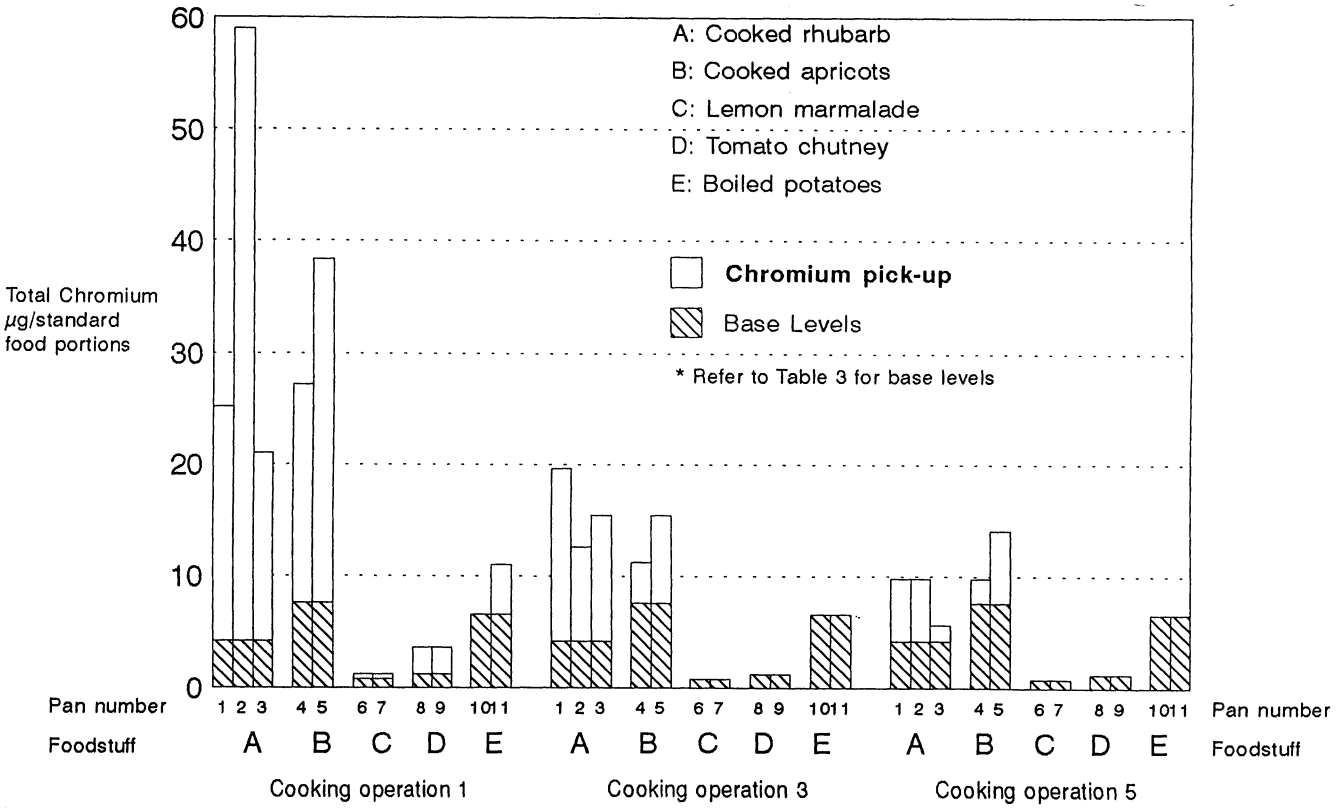

Figure 3. Total chromium in various foodstuffs cooked in new M1 stainless steel saucepans.

than other pans tested and thus is likely to have operated at a higher temperature in the cooking process.

No pick-up of chromium or nickel was detected in the 5% acetic acid which had been boiled in a pan previously used for cooking apricots. This observation is in accord with the result obtained in the preparation of green tomato chutney.

Discussion

The results of the investigation show that the pick-up of chromium and nickel by foods cooked in stainless steel utensils was, in most cases, negligible being either nil or of a very low value despite the special selection of a range of foods likely to provide media aggressive to stainless steels. The low levels of pick-up of chromium and nickel even in acid fruits, are particularly evident when expressed as the content in standard portions (table 3) (Crawley 1988).

The results have established that it is possible for new pans if *first used* with some acid fruits, to give rise to some pick-up of chromium and nickel. In the worst cases, the initial pick-up of nickel in the fruit could reach an amount that, if ingested repeatedly, might be significant to a nickel-hypersensitized person suffering from hand eczema. However, in subsequent cooking operations that pick-up was reduced to such low values that in a standard portion the amount was of little consequence in comparison with the content of chromium or nickel occurring naturally in the food (table 3). The observation in relation to first use is important in that it provides a possible explanation for the high level of pick-up reported by Brun (1979).

An initial high pick-up of chromium and nickel was also observed in one of two samples of salted water used for boiling potatoes. Unlike the fruits, neither sample of potatoes picked up the chromium and nickel leached into the salted water.

Table 3. Total chromium and nickel in standard food portions arising from the use of new S30400 stainless steel saucepans.

Foodstuff	Standard portion in g[a]	Mean base levels of Chromium (μg/std portion)[b]	Total chromium (μg/standard portion)						Mean base levels of Nickel (μg/std portion)[b]	Total nickel (μg/standard portion)					
			First cooking operation			Fifth cooking operation				First cooking operation			Fifth cooking operation		
			Pan 1	Pan 2	Pan 3	Pan 1	Pan 2	Pan 3		Pan 1	Pan 2	Pan 3	Pan 1	Pan 2	Pan 3
Rhubarb	140	<4·2	25	59	21	9·8	<4·2	9·8	5·5	17	43	15	9·8	8·4	9·8
Apricots	140	7·6	24	35	—	13	13	—	16	39	52	—	25	25	—
Lemon marmalade	25	<0·8	1·3	1·3	—	<0·8	<0·8	—	1·9	<1·9	2·5	—	<1·9	<1·9	—
Green tomato chutney	30	1·2	3·6	3·6	—	<1·2	<1·2	—	0·9	2·1	1·8	—	<0·9	<0·9	—
Potatoes	220	<6·6	<6·6	11[c]	—	<6·6	<6·6	—	2·6	4·4	4·4[c]	—	<2·2	6·6	—

[a] Crawley (1988).
[b] These values are from table 1, scaled appropriately for the size of a given standard portion.
[c] The water after boiling contained 150 μg of chromium and 100 μg of nickel per litre.

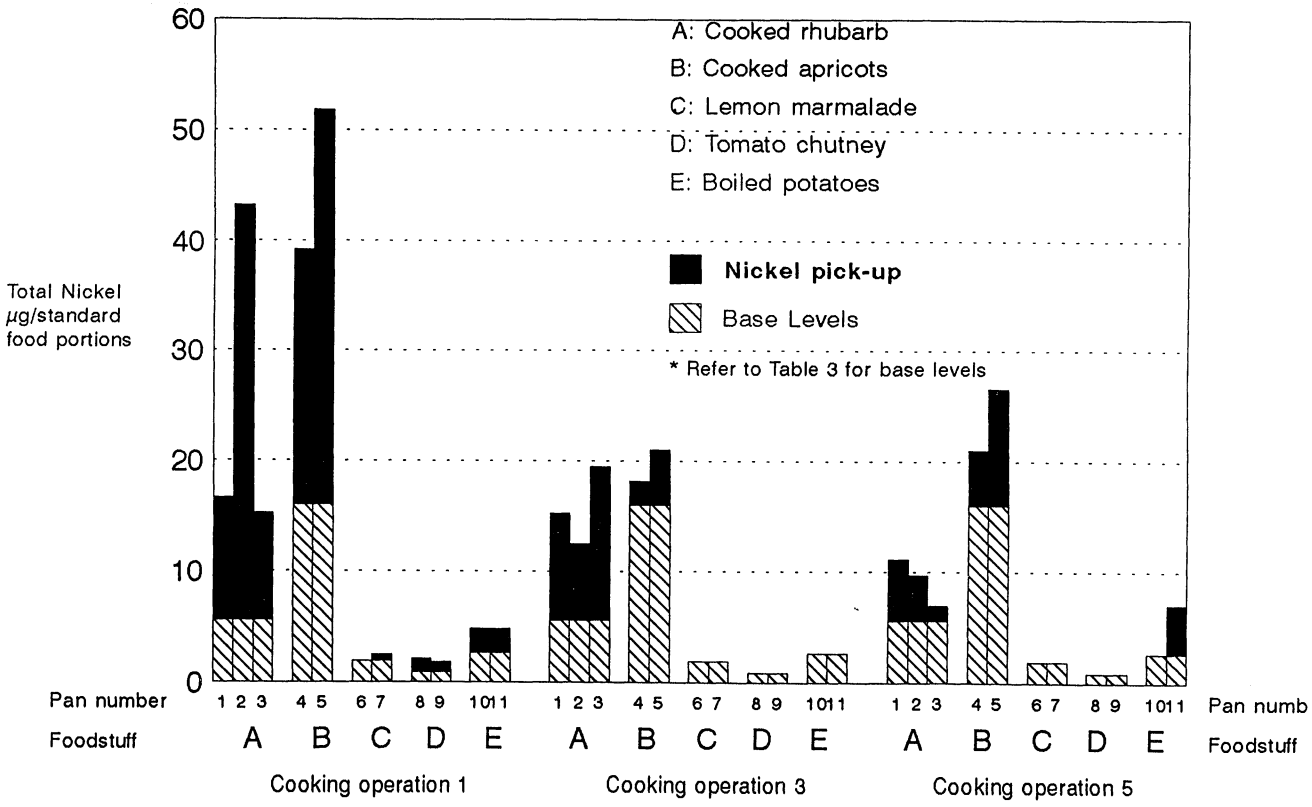

Figure 4. Total nickel in various foodstuffs cooked in new M1 stainless steel saucepans.

The results from the pan that had been in domestic use for 5 years supports the experimental work on new pans, in that no metal pick-up could be detected in the cooked rhubarb. This was not the case for the 35-year-old pan, although the pick-up was small. This pan had suffered some misuse in service and, being of thinner construction, boiling occurred more vigorously, which could provide an explanation for the

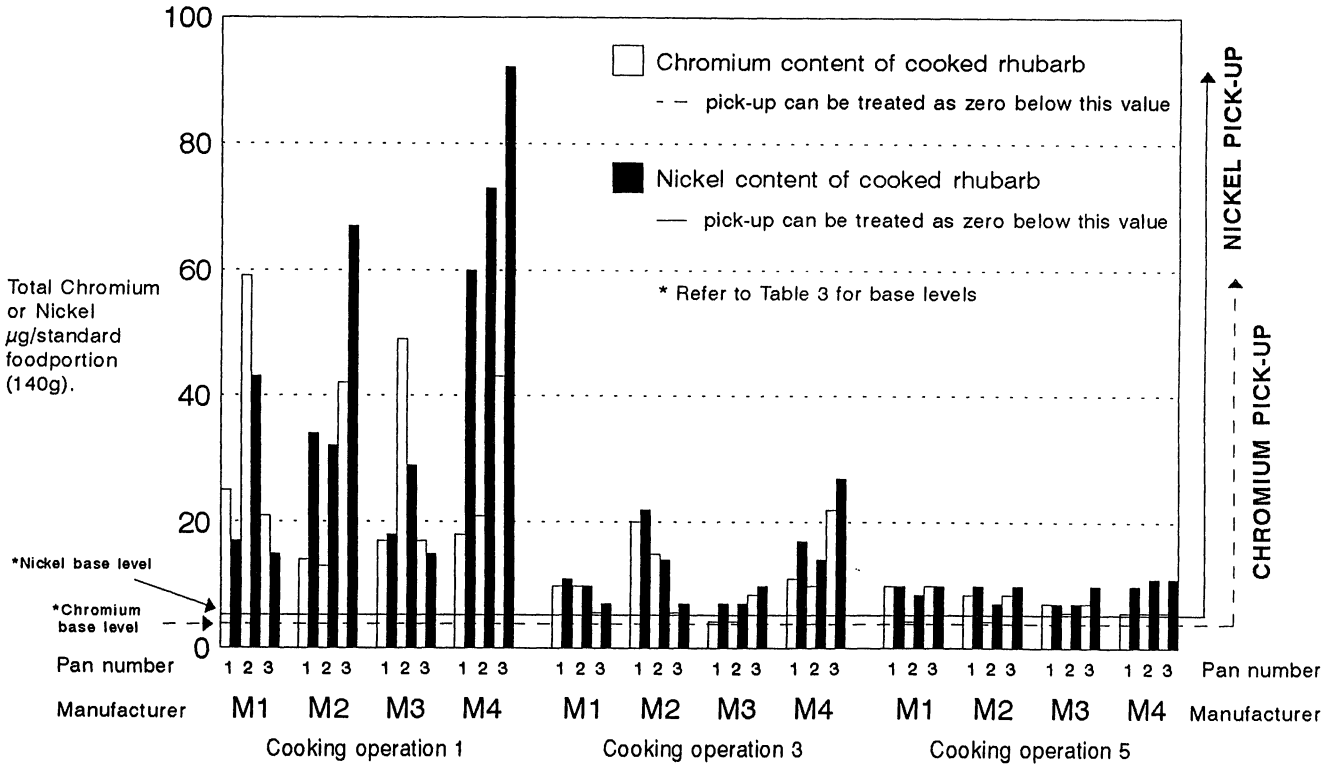

Figure 5. Total chromium and nickel in rhubarb cooked in new stainless steel saucepans made by different manufacturers.

higher levels of chromium and nickel pick-up measured. In an earlier, exploratory investigation, metal pick-up by rhubarb cooked in pans that were 12, 16 and 21-years-old were below the limit of determination (0·2 mg/kg) by the analytical techniques available at that time.

The high values for metal pick-up on first use with acid fruits were observed for pans from four different manufacturers based in four different countries using steel from different sources. This must be assumed to be due to the fabrication process since (a) they did not recur when the used pan surface was abraded; (b) they were eliminated or much reduced by surface treatment of the new pan before use; (c) they were not observed on the steel prior to fabrication; and (d) they were generally not observed in used pans.

It is considered probable that in the final polishing process some entrapment of polishing detritus or of oxidized steel occurred in the surface. The detritus was then released by the slight corrosion that occurred in the first cooking operation in acid fruits. Such entrapment would be likely to vary from pan to pan and occur to different extents according to the manufacturing process. It will be observed in figures 1–5 that, indeed, replication of results in the first cooking operation in an acid fruit was poor, whereas subsequently replication was much improved and became closer with continuing usage of the pan. Furthermore, although pans from all manufacturers gave a higher metal pick-up on first use, there were some differences between pans from the various factories, notably in the chromium to nickel ratio of the pick-up values. The differences could be a reflection of the variation in polishing practices, especially in the type of polishing compound used.

In all experiments the ratio of chromium to nickel in the pick-up was less than 2:1—the ratio of the metals in the steel. It may be supposed that the acids occurring in fruits react preferentially with nickel.

The ingestion of chromium at the levels occurring in foods is considered of benefit to human health. The significance of nickel ingestion to contact dermatitis has been reviewed (Menné and Maibach 1991, Burrows 1992, Moller 1993). Ingestion, of nickel has been shown to be of benefit to persons not sensitized to nickel in providing some immunity from subsequent

sensitization (Van Hoogstraten *et al.* 1991). However, some persons already sensitized and who suffer from hypersensitivity to nickel may experience a reduction in activity of dermatitis by adopting a low nickel diet (Veien *et al.* 1993).

Nevertheless, it is abundantly clear from the results of this research that the use of stainless steel cooking utensils does not provide a source of dietary chromium or nickel of any significance, as postulated by Kuligowski and Halperin 1992.

Apart from the rare circumstance of first use of a new pan with some acid fruits, the amount of nickel that may be picked up is small in comparison to naturally occurring levels of nickel in foods and is insufficient to be of relevance, even to persons wishing to adopt a low nickel diet.

Acknowledgements

I. Lumley, G. Holcombe, P. Lawrance, K. Ogunbayode, K. Lee and J. Parker of the Laboratory of the Government Chemist are thanked for their scientific advice and technical support. Thanks are due to Anopol Ltd for undertaking the electropolishing and acid pickling of the stainless steel pans and to Branson Ultrasonics for the ultrasonic cleaning.

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