Effects of Various Cooking Processes on the Concentrations of Arsenic, Cadmium, Mercury, and Lead in Foods

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The effects of cooking processes commonly used by the population of Catalonia (Spain) on total arsenic (As), cadmium (Cd), mercury (Hg), and lead (Pb) concentrations in various foodstuffs were investigated. All food samples were randomly acquired in local markets, big supermarkets, and grocery stores of Reus (Catalonia). Foods included fish (sardine, hake, and tuna), meat (veal steak, loin of pork, breast and thigh of chicken, and steak and rib of lamb), string bean, potato, rice, and olive oil. For each food item, two composite samples were prepared for metal analyses, whose levels in raw and cooked (fried, grilled, roasted, and boiled) samples were determined by inductively coupled plasma−mass spectrometry (ICP−MS). The highest concentrations of As, Hg, and Pb (raw and cooked samples) were mainly found in fish, with a clear tendency, in general, to increase metal concentrations after cooking. However, in these samples, Cd levels were very close to their detection limit. In turn, the concentrations of metals in raw and cooked meat samples were detected in all samples (As) or only in a very few samples (Cd, Hg, and Pb). A similar finding corresponded to string beans, rice, and olive oil, while in potatoes, Hg could not be detected and Pb only was detected in the raw samples. In summary, the results of the present study show that, in general terms, the cooking process is only of a very limited value as a means of reducing metal concentrations. This hypothetical reduction depends upon cooking conditions (time, temperature, and medium of cooking).

KEYWORDS: Arsenic; cadmium; mercury; lead; food; cooking processes

INTRODUCTION

Metals are natural components of the earth's crust, which are present in air, soils, and waters (*1−3*). However, certain elements can be also environmental pollutants, particularly in areas with high anthropogenic pressure (*4, 5*). While metals such as cobalt (Co), chromium (Cr), iron (Fe), manganese (Mn), or zinc (Zn), among others, are essential for humans, elements such as arsenic (As), cadmium (Cd), mercury (Hg), and lead (Pb) have no beneficial effects, and there is no known homeostasis mechanism for them in humans (*6*). Although the adverse health effects of a specific metal depend upon the concentration in the media, chronic exposure to elements such as As, Cd, Hg, and Pb can cause toxic effects at relatively low levels (*6*). Metals can enter the human body mainly through inhalation and ingestion, with the diet being the main route of human exposure for non-occupationally exposed individuals (*7−9*). It must be taken into account that, although metals can change their chemical form, they cannot be degraded or destroyed. Therefore, the assessment of the health risks of metals via dietary intake is an issue of special interest (*10, 11*).

During the period 2000−2002, we determined the levels of various chemical pollutants in various groups of foodstuffs purchased from Catalonia (Spain). Dietary intake of the pollutants, including As, Cd, Hg, and Pb, was also estimated for various age and gender groups of the population of that country. Because the highest levels of most metals and organic pollutants were mainly detected in fish and shellfish (*12−15*), in 2005, we extended the initial number of analyzed edible marine species. The levels of As, Cd, Hg, and Pb were measured in 14 species of fish and shellfish most consumed in Catalonia (*16*). To the well-known toxic effects of As, Cd, Hg, and Pb in humans, it must also be added that the European Commission (EC) has recommended some restrictions concerning the consumption of marine species (especially predatory species, which accumulate Hg over a long lifetime) (*17*). This is

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particularly important for children, pregnant women, and breast-feeding mothers.

To determine the temporal variation in the total dietary intake of As, Cd, Hg, and Pb by the population of Catalonia, in addition to the species of fish and shellfish already examined (16), foodstuffs belonging to the remaining 10 food groups assessed in our previous (2000−2002) survey were again analyzed in 2006 (18). According to the Food and Agriculture Organization/World Health Organization (FAO/WHO) (18), the basic approaches that can be used to determine the intake of a food contaminant are (1) total diet study, (2) duplicate diet method, (3) and diary study, which combines data for specific contaminants in food with individual (or household) consumption data. In our previous surveys, total diet study (TDS) was the approach used. Although a number of studies have shown that cooking practices can modify the levels of chemical contaminants in foods, in our studies, we did not take into account any potential effects of cooking. Moreover, most of the reported surveys were focused on organic pollutants, such dioxins and furans, polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), pesticides, etc. (19−26), with those focused on metals being much more limited (20, 27−29). Therefore, the main purpose of the present study was to evaluate the effects of traditional cooking processes (fried, grilled, roast, and boiled) in Catalonia on the concentrations of As, Cd, Hg, and Pb in various foods.

MATERIALS AND METHODS

Sampling. In July−August 2007, food samples were randomly purchased from local markets, big supermarkets, and grocery stores of Reus (Catalonia, Spain). Samples included fish (sardine, hake, and tuna), meat (veal steak, loin of pork, breast and thigh of chicken, and steak and rib of lamb), string bean, potato, rice, and olive oil. For each food item, two composite samples were prepared for metal analyses. Each composite sample consisted of a minimum of 10 individual units. The effects of cooking processes on the levels of As, Cd, Hg, and Pb in foods were analyzed in a total of 68 composite (22 raw and 46 cooked) samples, which included 680 individual samples. Only edible parts of each food item were included in the composites.

Cooking Processes. Cooking processes were carried out in either a kitchen gas (fried, grilled, and boiled) or an electric convection oven (roast). These processes are the most used cooking practices by the population of Catalonia (30). Extra virgin olive oil (0.4°) was used for cooking, while Ultrapure water was employed to wash and/or cook. For frying, pans of Teflon (30 cm in diameter) were used. The quantities of oil for frying, as well as the time of cooking, varied depending upon the type and quantity of food (400−1000 mL of oil and from 4 min 1 s to 16 min 4 s). Frying was the process used for sardine, hake, tuna, veal, pork, chicken, lamb, and potato. For the grilled fish and meat, oil was not added and the time of cooking ranged between 5 min and 7 min 3 s. On the other hand, hake, string bean, potato, and rice samples were added to boiling water (2−3 L) in stainless-steel pots (25 cm in diameter). The times for the boiling process were 27, 22, 14, and 29 min, respectively. For the roasted process, hake samples, to which 40 mL of olive oil were added, were cooked in the oven for 100 min. For chicken samples, the time was 80 min, with 80 mL of oil being employed. Finally, to evaluate the effects of cooking on metal levels in olive oil, samples of 250 mL of this product were cooked at different temperatures, for 4 (E1) and 8 (E2) min. Data on the amount of the respective food samples, as well as the initial and final temperatures, which were measured with Laser Testo 830-T2 (Lenzkirch, Breisgau-Hochschwarzwald, Baden-Württemberg, Germany), and varied in function of the respective cooking process, are summarized in **Table 1** (average value of the two composite samples for each food item).

Analytical Procedure. The levels of As, Cd, Hg, and Pb were determined after previous digestion of the food samples. About 0.25 g of homogenized sample was predigested with 4 mL of 65% nitric acid (Suprapur, E. Merck, Darmstadt, Germany) plus 4 mL of 30% hydrogen

Table 1. Characteristics of the Cooking Processes[a]

		food sample (g)	oil for cooking (mL)	amount of water used (L)	cooking times	initial T^a (°C)	final T^a (°C)
sardine	raw	1500					
	fried	1648.5	800		6 min 3 s	137.8	72.9
	grilled	1670			7 min	227.6	67.0
hake	raw	700					
	fried	1421	500		5 min 5 s	119.4	46.8
	grilled	1201			6 min 32 s	224.3	44.6
	roast	1435	40		100 min	187.0	80.5
	boiled	1052.5		3	27 min	167.0	71.8
tuna	raw	700					
	fried	1103	600		6 min 2 s	121.4	63.9
	grilled	812			5 min	231.4	56.7
veal steak	raw	700					
	fried	887.5	600		5 min	182.0	84.5
	grilled	991			6 min 15 s	252.6	51.1
loin of pork	raw	700					
	fried	757	400		4 min 1 s	31.8	61.0
	grilled	718.5			5 min	48.8	51.7
chicken	raw	700					
	fried	995	500		9 min	174.0	66.0
	grilled	997.5			7 min 3 s	221.5	62.6
	roast	1707.5	80		80 min	170.0	87.5
lamb	raw	700					
	grilled	772.5			6 min 15 s	46.3	46.2
	fried	854.5	625		5 min 5 s	31.6	55.4
string bean	raw	700					
	boiled	800		3	22 min	52.8	72.3
potato	raw	700					
	fried	700	1000		16 min 4 s	118.0	122.5
	boiled	700		2	14 min	96.0	71.8
rice	raw	700					
	boiled	715.5		3	29 min	68.0	63.8
olive oil (mL)	raw	250					
	E1	250			4 min	29.3	205.5
	E2	250			8 min	29.4	267.2

[a] Values are the average of each two composite samples. The initial T^a is the temperature of the liquid or surface cooking before adding the food, while the final T^a is the temperature of the food after cooking.

peroxide (Suprapur, E. Merck) in TFM vessel Teflon with a Milestone Start D microware digestion system, heated up to 210 °C for 85 min. After cooling, solutions were filtered and made up to 25 mL with ultrapure water. The accuracy of the instrumental methods and analytical procedures was checked by duplication of the samples. Analytical-grade reagents were used for blanks and calibration curves. Quality control of the methodology was assured by analyzing a certified reference material (Lobster hepato/pancreas, NRC Canada, TORT-2, Ottawa, Ontario, Canada). For sets of every eight samples, a procedure blank and spike sample, involving all reagents, was run to check for interference and cross-contamination.

The concentrations of As, Cd, Hg, and Pb were determined by inductively coupled plasma−mass spectrometry (ICP−MS, Perkin-Elmer Elan 6000, Woodbridge, Ontario, Canada) (10, 31). Rhodium was used as an internal standard. Replicate measurements were performed. The limits of detection (LOD, fresh weight) were the following: As, 0.100 μg/g; Pb, 0.017 μg/g; Hg, 0.007 μg/g; and Cd, 0.002 μg/g. Recovery rates for the elements analyzed under the different experimental conditions ranged between 87.0 and 103.0%.

Data Analysis. Results were statistically evaluated using the statistical software SPSS 15.0. The Levene test was applied to study the equality of variances. The statistical significance of differences was assessed by applying the Student's test. A probability of 0.05 or lower ($p < 0.05$) was considered as significant.

On the other hand, the self-organizing map (SOM) procedure developed by Kohonen was used to accomplish two main objectives: (1) to establish pattern similarities between metals and (2) to study the influence of the cooking processes on metal levels. SOM is an unsupervised artificial neural network based on data mining. The Kohonen neural network consists of two layers: the input layer, connected to a vector of the input data set, and the output layer (map), which is an array of nodes (also called neurons) (32). The weight

Table 2. Metal Concentrations in Cooked Foods (μg/g of Fresh Weight)[a]

		As	Cd	Hg	Pb
sardine	raw	2.086	ND	0.034	0.043
	fried	2.906	0.002	0.051	0.060
	grilled	3.281	0.002	0.028	0.043
hake	raw	0.939	ND	0.142	0.014
	fried	1.284	ND	0.121	0.015
	grilled	1.379	ND	0.199	0.018
	roast	1.062	ND	0.123	0.019
	boiled	1.013	ND	0.166	0.043
tuna	raw	1.566	0.003	0.355	0.054
	fried	1.620	0.002	0.421	0.059
	grilled	1.628	0.002	0.369	0.031
veal steak	raw	0.284	0.002	0.012	0.084
	fried	0.140	ND	ND	0.014
	grilled	0.181	ND	ND	0.018
loin pork	raw	0.303	0.002	ND	ND
	fried	0.277	ND	ND	0.025
	grilled	0.212	ND	ND	ND
chicken	raw	0.110	ND	ND	ND
	fried	0.128	ND	ND	0.015
	grilled	0.092	ND	ND	ND
	roast	0.131	ND	ND	ND
lamb	raw	0.186	ND	ND	ND
	fried	0.121	ND	ND	ND
	grilled	0.173	ND	ND	ND
string bean	raw	0.217	ND	ND	ND
	boiled	0.184	ND	ND	ND
potato	raw	0.167	0.007	ND	0.023
	fried	0.136	0.012	ND	ND
	boiled	0.102	0.008	ND	ND
rice	raw	0.159	ND	ND	ND
	boiled	0.237	0.002	ND	0.016
olive oil	raw	0.050	ND	ND	ND
	E1	0.119	ND	ND	ND
	E2	0.181	0.003	ND	0.015

[a] Calculations were performed assuming ND = $^1/_2$LOD when at least one composite sample was detected. ND = not detected. LOD: As, 0.100 μg/g; Cd, 0.002 μg/g; Hg, 0.007 μg/g; Pb, 0.017 μg/g.

associated to each node or neuron in this two-dimensional lattice is adjusted to cluster the original information. The map can also be divided into so many *c* planes (component planes) as data variables, representing the variable contribution to each node in the map (*10, 33*).

RESULTS

The concentrations of As, Cd, Hg, and Pb in the 68 samples (22 raw and 46 cooked) analyzed in the present study are shown in **Table 2**. In general terms, the highest levels of As, Hg, and Pb were found in fish. It is in agreement with the results of previous studies also performed in Catalonia, in which a number of food items were analyzed for metal content (*14, 16, 34*). In general, fish (sardine, hake, and tuna) species showed a clear tendency to increase metal concentrations after cooking. Arsenic concentrations in cooked fish were higher than those found in raw fish. Sardine presented higher As concentrations when grilled than when fried (3.28 and 2.91 μg/g, respectively), with both values being higher than those observed in raw sardine (2.09 μg/g). In hake, the highest As concentrations were noted when this species was grilled (1.38 versus 1.28, 1.06, 1.01, and 0.94 μg/g, when fried, roasted, boiled, or raw, respectively). Cadmium was not detected in hake, while in sardine, the highest concentration of this element was found after cooking. In contrast, raw tuna showed higher Cd levels than the cooked samples. However, in all of these samples, Cd levels were very close to the LOD. With respect to Hg levels in fish, these were increased when samples were fried (0.05 μg/g for sardine and 0.42 μg/g for tuna). Hake samples were an exception because grilled was the cooking practice producing the greatest Hg

concentration (0.20 μg/g). It is important to note that frying and roasting decreased the levels of Hg in hake. With regard to Pb, the concentrations in sardine and tuna were lower in grilled samples in contrast to grilled hake, where the Pb level was increased. In turn, frying sardine, hake, and tuna meant an increase in Pb concentrations: 0.06, 0.02, and 0.06 μg/g, respectively. Anyhow, it is important to note that all of the above differences between raw and cooked fish were not statistically significant ($p > 0.05$).

Metal concentrations in meat decreased after cooking, being the differences statistically significant for As ($p < 0.05$) (**Figure 1**). For steak veal and lamb, the lowest As levels corresponded to fried samples (0.14 and 0.12 μg/g, respectively), while in pork, the lowest As level was found in the grilled sample (0.21 μg/g). In turn, As concentrations in chicken were rather similar between all cooking processes, being higher in roasted (0.13 μg/g) and lower in grilled (0.09 μg/g) samples. Cadmium could be only detected in raw samples (0.002 μg/g) of veal and pork, while Pb was detected in all veal samples, as well as in fried pork and chicken.

The remaining food items, string bean, potato, rice, and olive oil, presented concentrations of As between 0.05 and 0.24 μg/g, which depended upon the specific food item and/or the respective cooking process. For string bean and potato, boiling decreased As concentrations, showing statistically significant ($p < 0.01$) differences with respect to the raw or fried (only potato) samples. In rice and olive oil, the cooking process and the increase of temperature enhanced As concentrations (0.24 versus 0.16 μg/g in rice; 0.12 μg/g for E1 and 0.18 μg/g E2 versus 0.05 μg/g in raw olive oil). A similar effect of cooking was also noted for Cd and Pb levels in rice and olive oil samples. With respect to potatoes, the highest Cd concentration was observed in fried samples, while Pb could be only detected in the raw samples (0.02 μg/g). Finally, Hg levels in all of these food items were under the detection limit. The different cooking processes did not cause any statistically significant difference ($p > 0.05$).

Although metal levels in most samples were below the LOD, SOM showed a clear relationship between metals and groups of foodstuffs (**Figure 2**). High concentrations of As, Hg, and Pb were observed in fish, with the highest As levels corresponding to sardine. Tuna also showed high of concentrations of Hg and Pb. For Cd, the group of miscellaneous foods (string bean, potato, rice, and oil) presented higher levels of this element, especially in potato.

DISCUSSION

In recent years, a number of surveys have determined the concentrations of metals in foods from different countries. A summary of the results can be found in **Table 3**. However, most of these surveys reported the levels of chemical contaminants on an uncooked basis, with information on the potential influence of the cooking processes on metal concentrations in foodstuffs being particularly scarce. It is known that cooking may, in certain conditions, change the amount of chemical pollutants in foods (*19–26*). With respect to metals, it has been reported that, although cooking may reduce their contents, some foods can also absorb metals if the cooking water is contaminated (*28*).

In relation to the effects of cooking practices on As levels in foods, a notable number of the studies found in the scientific literature have been focused only on rice. In Bangladesh, an As-endemic area, Bae et al. (*35*) assessed the effect of boiling on the amount of As retained in cooked

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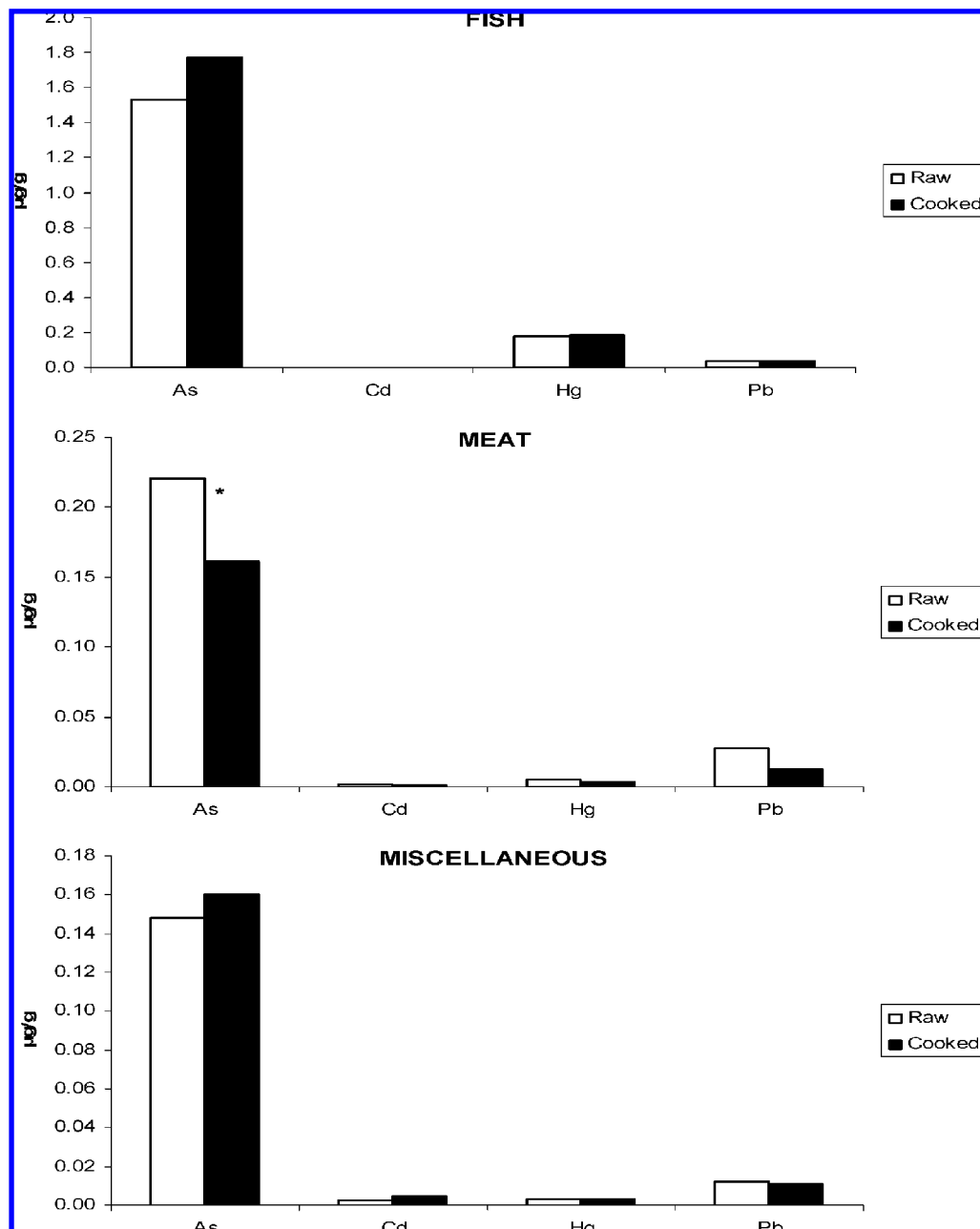*J. Agric. Food Chem.*, Vol. 56, No. 23, 2008 **11265**

Figure 1. Concentrations of As, Cd, Hg, and Pb in fish, meat, and miscellaneous foods (raw or cooked samples). An asterisk indicates significant differences at $p < 0.05$.

rice. The concentration of As in cooked rice was higher than that in raw rice and absorbed water combined, suggesting a chelating effect by rice grains or a concentration of As because of water evaporation during cooking or both. In another study performed in that country, Rahman et al. (*29*) observed that cooking of As-contaminated rice with As-contaminated water increased its concentration in cooked rice. However, Sengupta et al. (*36*) showed that preliminary washing until clear did remove 28% of the rice As. The results were not influenced by water source (tube well, dug well, pond, or rain), the cooking vessel (aluminum, steel, glass, or earthenware), or the absolute weight of rice or volume of water. These authors concluded that use of low-As water in the traditional preparation of As-contaminated rice could reduce the ingested burden of As (*36*). Laparra et al. (*27*) determined the levels of total and inorganic As in rice cooked with As-contaminated water, the bioaccessibility of As^{III} and As^{V} after simulated gastrointestinal digestion,

and the extent of As retention and transport by Caco-2 cells used as a model of intestinal epithelia. Cooking significantly increased inorganic As contents. After simulated gastrointestinal digestion, the bioaccessibility of inorganic As reached 63−99%, with As^{V} being the main species found. All of the above results show that, in As endemic areas with subsistence rice diets, the contribution of inorganic As from cooked rice should be considered in the assessment of arsenic health risks (*37*).

With respect to other foodstuffs, Devesa et al. (*38*) analyzed total and inorganic contents in cooked seafood products consumed in Spain during the period July 1997−June 1998: hake, meagrim, small hake, anchovy, Atlantic horse mackerel, sardine, bivalves, crustaceans, squid, and salted cod. Various cooking treatments were used (grilling, roasting, baking, stewing, boiling, steaming, and microwaving). The results were compared to those found previously in the same products raw. In grilled sardine, As levels ranged between
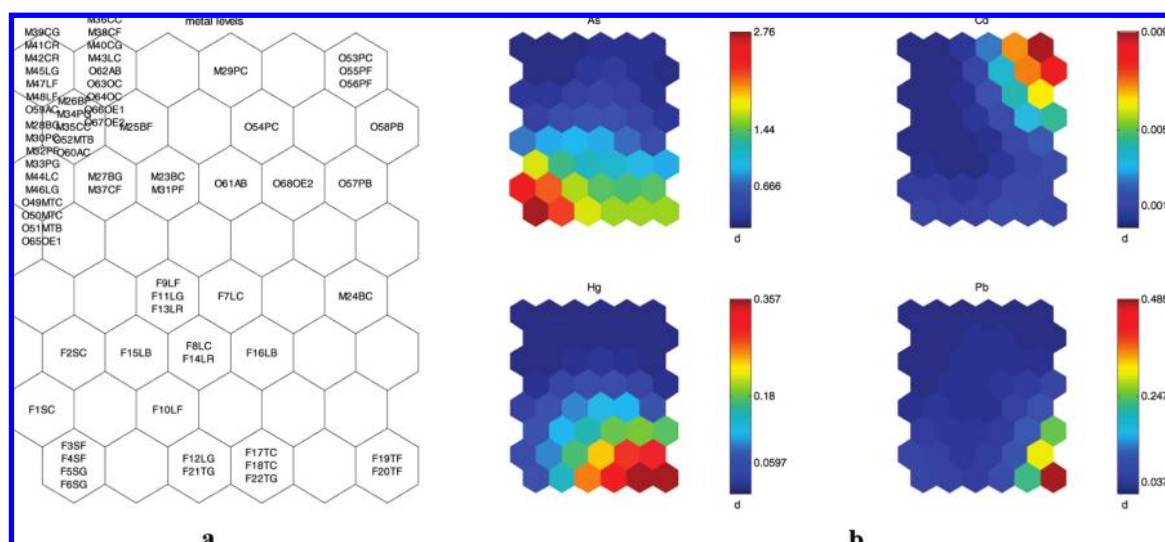
Figure 2. Kohonen's SOM (a) and *c* planes (b) for the levels of 4 elements in 68 samples (22 of fish, 26 of meat, and 20 of miscellaneous foodstuffs). Foodstuff: F, fish; M, meat; and O, miscellaneous. Number: number of samples. Samples: S, sardine; L, hake; T, tuna; B, veal steak; P, loin pork; C, chicken; L, lamb; MT, string bean; P, potato; A, rice; and O, olive oil. Cooking procedures: C, raw; F, fried; G, grilled; R, roast; and B, boiled.

Table 3. Summary of As, Cd, Hg, and Pb (μg/g) Levels in Foodstuffs from Previous Surveys

		As	Cd	Hg	Pb	city, country	notes	reference
fish	raw	0.372	ND		0.278	Adana, Turkey	sea bass filets	40
	raw	2.645	0.013	0.047	0.22	Huelva, Spain		50
	raw	1.351	0.277	0.005	0.005	Santiago, Chile	fish and shellfish	51
	raw				0.367	Canary Islands, Spain		49
	fried	2.66	ND		0.277	Adana, Turkey	sea bass filets	40
	grilled	0.398	ND		0.284	Adana, Turkey	sea bass filets	40
	roast	0.324	ND		0.224	Adana, Turkey	sea bass filets	40
sardine	raw	3.53–3.94	0.002–0.01	0.07–0.09	0.01–0.08	Catalonia, Spain		16
	grilled	5.8–29.1				Basque Country, Spain	dry weight	38
hake	raw	3.22–4.55	0.01	0.12–0.29	0.01–0.13	Catalonia, Spain		16
	grilled	4.4–17.4				Basque Country, Spain	dry weight	38
	roast	3.7–10.0				Basque Country, Spain	dry weight	38
	boiled	3–3.8				Basque Country, Spain	dry weight	38
tuna	raw	0.516	0.009	0.296	0.021	Huelva, Spain		50
	raw	0.99–1.25	0.01–0.02	0.38–0.58	0.01–0.02	Catalonia, Spain		16
meat	raw	0.034	0.006	ND	0.112	Santiago, Chile		51
	raw		0.014			Canary Islands, Spain	read meat	52
loin of pork	raw		0.003	tr	0.01	Perugia, Italy		42
	raw	0.002	0.013	0.237	0.067	Huelva, Spain		50
	raw		0.0055		0.005	Tenerife, Spain		41
chicken	raw		0.003	ND	0.022	Perugia, Italy		42
	raw	ND–0.018	0.003–0.022	0.02–0.03	0.025–0.056	Huelva, Spain		50
	raw		0.0017		0.007	Tenerife, Spain		41
	roast		0.0024	ND	0.023	Perugia, Italy		42
lamb	raw		0.0012		0.0014	Tenerife, Spain		41
miscellaneous	raw	0.007	0.004	ND	0.031	Santiago, Chile		51
string bean	raw	0.022				Chiu Chiu, Chile		53
	boiled	0.007–0.057				Chiu Chiu, Chile		53
potato	raw		0.003	ND	0.01	Perugia, Italy		42
	raw	0.015	0.015	0.003	0.004	Huelva, Spain		50
	raw	0.021				Chiu Chiu, Chile		53
	raw	0.006	0.008	ND	0.03	Santiago, Chile		51
	raw				0.001	Canary Islands, Spain		49
	fried		0.003	ND	0.019	Perugia, Italy		42
	fried	0.03				Chiu Chiu, Chile		53
	boiled	0.004–0.011				Chiu Chiu, Chile		53
rice	raw	0.203–0.540				West Bengal, India		36
	raw	0.14	ND	ND	ND	Tarragona, Spain		10
	boiled	0.25–2.82				Valencia, Spain		27
olive oil	raw	0.002	ND	0.001	0.004	Huelva, Spain		50
	raw	0.003	ND	ND	ND	Santiago, Chile	fats and oils	51
	raw				0.001	Canary Islands, Spain		49

5.8 and 29.1 μg/g (dry weight), while As levels in anchovy were 2.6–38.2 μg/g (dw). As in the present study, grilled samples showed the highest As concentration in sardine. It

was noted that after cooking there was a significant increase in the concentration of total As for salted cod and bivalves and in the concentration of inorganic As for bivalves and

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squid. Lee et al. (*39*) reported levels of 0.28 µg/g of As in stir-fried anchovy. In our previous studies (*34*), As concentrations in raw samples of sardine and tuna were similar to those found in the present survey, while the current As concentration in hake was lower.

With regard to Cd, a number of previous data show that the concentrations of this element in raw, roast, grilled, and fried samples of white fish samples were under the detection limit (*16, 40*). With regard to meat raw samples, in the present study, Cd concentrations were similar to those previously found by other authors (*14, 41*). Alberti-Fidanza et al. (*42*) reported that Cd content in raw and cooked foods showed slight differences. Recently, Amiard et al. (*4*) showed that bioaccessibility was significantly lowered for Cd after cooking a total of seven species of mollusks from France, U.K., and Hong Kong, including clams, mussels, oysters, scallops, and gastropods. In different organs of fish, Atta et al. (*43*) observed a decrease of Cd, Cu, Pb, and Zn concentrations after steaming or baking. During thermal processing, the application of heat hastens protein degradation and loss of weight and water, and therefore, chemical contaminants may also be affected by the heat applied (*44−46*).

With respect to Hg, Morgan et al. (*47*) assessed the effects of commonly used cooking techniques (including pan-frying, deep-frying, baking, boiling, and smoking) by Native Americans on widely consumed fish species, such as walleye and lake trout. Whitefish livers were also selected for the study. Mercury concentrations (wet weight basis) in pan-fried, baked, and boiled walleye fillets and deep-fried and baked whitefish livers were 1.1−1.5 times higher than those in the corresponding raw portions. In lake trout, Hg concentrations were 1.5−2.0 times higher in cooked portions than in the raw portion. However, total Hg levels were constant before and after cooking, indicating that the concentration effect was caused by weight (moisture and fat) loss. Burger et al. (*20*) analyzed the Hg content in fillets from largemouth bass collected from a contaminated lake on the Savannah River Site, SC. Samples were randomly assigned to a raw or fried treatment (the commonly used local cooking method). The fried fillet was further divided in half for a breaded or nonbreaded treatment. Mercury levels averaged 0.44 µg/g (wet weight) in raw fish, 0.63 µg/g in fried, breaded fish, and 0.76 µg/g in fried, unbreaded fish. The maximum concentration was 1.5 µg/g in raw fish (1.9 µg/g in cooked fish). Deep-frying with and without breading, resulted in a weight loss of 25 and 39%, while Hg levels increased by 45 and 75%, perhaps because of the breading and absorption of oil. To have a general idea of the impact of various procedures for cooking the fish on the Hg amount, recently, Gremiachikh et al. (*48*) measured Hg concentrations in smoked perch and manufactured and homemade canned salt- and fresh-water fishes. The absolute content of Hg in fish was unchanged during cooking, and it did not depend upon the procedure and duration of cooking. In the current survey, the Hg concentrations of blue fish species (sardine and tuna) presented a similar behavior in the cooked samples, while in hake, certain cooking processes (grilled and boiled) caused an increase of Hg levels. On the other hand, Alberti-Fidanza et al. (*42*) did not detected Hg in meat samples, which is in agreement with the results of the present study.

Finally, some previous investigations indicated that grilling is the cooking process causing a higher increase on the concentration of Pb in food (*40*). However, the current results indicate that frying, roasting, and boiling were the processes

causing the highest Pb concentrations. In recent studies, Pb levels in (sardine, hake, and tuna) raw samples showed values between 0.01 and 0.13 µg/g (*16*), which are similar to those of the present investigation. Rubio et al. (*49*) found a level of 0.37 µg/g of Pb in raw samples of fish (sardine and tuna). However, the effect of cooking on metal levels was not investigated by these authors. Alberti-Fidanza et al. (*42*) reported that Pb levels were higher in meats cooked on a hot plate because of Pb released from the plate. The highest Pb amount was observed in raw sausages, whereas a high variability was observed in grilled sausages (*42*). In our raw meat samples, Pb concentrations were similar to those reported by other authors (*14, 41*).

In summary, the results of this study comparing the influence of several cooking processes on metal levels in various foodstuffs can potentially be useful as a simple guide for the selection of food cooking for preparing a healthy diet with a low content of toxic metals. However, in fact, it would only be of particular interest to reduce metal contents in fish, because in general terms, it seems that the cooking process is only of very limited value as a means of reducing metal concentrations. Anyhow, the reduction depends upon cooking conditions (time, temperature, and medium of cooking).

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