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# Determination of Some Toxic and Essential Metal Ions in Medicinal and Edible Plants from Mali

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Plants are used in different ways in Mali, among those as medicine and as food. The monitoring of metals in the plants is of great importance for protecting the public from the hazards of possible toxic effects and also for informing the population about the nutritional value of the plants. The concentrations of some toxic and essential metal ions were surveyed in seven medicinal and edible plants from Mali. Dry ashing of the plant material and subsequent use of atomic absorption spectrophotometry were the analytical methodologies used. Iron, manganese, and zinc were found in high concentrations in some of the plants, i.e., 1.4 and 1.5 mg/g iron in *Cuminum cyminum* and *Bombax costatum*, respectively, 243 $\mu$g/g manganese in *Hibiscus sabdariffa*, and 62.8 and 67.1 $\mu$g/g zinc in *Spilanthes oleracaea* and *B. costatum*, respectively, whereas cobalt and cadmium were not detected in any of the plant material studied. The other ions detected, Cr, Ni, Pb, and Cu, were present in minor amounts, in the ranges of 2.2−17.2 $\mu$g/g for Cr, 1.6−8.1 $\mu$g/g for Ni, 0.7−5.2 $\mu$g/g for Pb, and 2.4−17.1 $\mu$g/g for Cu. From a toxicological point of view, none of these plants would be harmful for the user by taking in the plant material in the traditional manner, which is preparing an infusion of the plant using amounts not adding up to those necessary to reach a harmful level of the metal ions detected. The plants *B. costatum* and *C. cyminum* could be of interest as sources for iron for humans in the case of too low of a level of hemoglobin.

**KEYWORDS: Malian medicinal plants; edible plants; toxic metal ions; nutritional metal ions**

## INTRODUCTION

The chemical constituents in plants, including metal ions, are partially responsible for their medicinal and nutritional properties as well as the toxic ones. The metals also play an important role in the plants themselves, e.g., for the formation of bioactive constituents in medicinal plants. As trace elements, they play an important role in the plant metabolism and biosynthesis as cofactors for enzymes. These trace elements are also important metabolic products for the plant cells (*1*). By accumulating metals in both the root and the above-ground tissue, plants can transfer heavy metal pollutants from soils into the food chain, and this accumulation is one of the most serious environmental concerns of the present day, not only because of the phytotoxicity of many of these metals to the crops themselves but also because of the potential harmful effects that toxic metals could have on animals and human health. The monitoring of heavy metals in crops and other food is therefore of great importance in protecting the public from the hazards of these metal ions.

Some metals are also essential nutrients (zinc, iron, copper, chromium, and cobalt) and only become toxic at high concentrations, while others (lead and cadmium) have no known beneficial properties and are hence exclusively toxic (*2*). However, all elements in high concentrations may become detrimental to organisms. The nutritional role of elements and the essentiality of trace elements as well as their biochemical and pathological significance to human and animals are well-known. There is a general agreement that metals may react directly with DNA. The large number of nucleophilic centers in nucleic acids implies a high affinity for metals. The most serious interaction between metals and DNA is, probably, cross-links between the DNA strands as was noticed after exposure to $Cu^{2+}$, $Zn^{2+}$, $Co^{2+}$, and $Mn^{2+}$ (*3*). Ions such as $Ni^{2+}$ and $Cd^{2+}$ can react with the phosphate groups as well as with the bases of DNA. Nickel has been reported to induce a variety of DNA lesions. These include both DNA strand damage, as well as DNA protein cross-links. Nickel has been shown to inhibit DNA synthesis following either in vitro or in vivo exposure (*4*).

**Important Biological Factors of the Metal Ions Studied.** *Chromium.* According to Barceloux (*5*), trivalent chromium is a trace metal necessary for the normal metabolism of cholesterol, fat, and glucose. Chromium deficiencies in the diet produce

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elevated circulating insulin concentrations, hyperglycemia, hypercholesterolemia, elevated body fat, decreased sperm counts, reduced fertility, and shortened life span. Hexavalent chromium is a skin and mucous membrane irritant as well as a powerful oxidizing agent. It is recognized by the International Agency for Research on Cancer and by the U.S. Toxicology Program as a pulmonary carcinogen.

*Cobalt.* Cobalt is an essential element in humans necessary for the formation of vitamin B12 (hydroxycobalamin), which catalyzes reactions, such as the synthethesis of methionine, the metabolism of purines and folates, and the formation of methylmalonic acid in succinic acid. However, excessive administration of this trace element may cause goiter and reduced thyroid activity. Exposure to cobalt has been associated with the development of cardiomyopathy (*5*).

*Copper.* Copper poses problems for all life forms. It is needed for a number of essential enzymes including superoxide dismutase (SOD), cytochrome *c*-oxidase, lysyloxidase, and ceruloplasmin, but the ion is potentially toxic because it is a potent generator of free radicals (*6*). Copper plays a role in common neurological conditions such as Alzheimer's disease, the Prion disease, Wilsons's disease, and amylotrophic lateral sclerosis (*6*). Copper toxicity is ascribed to the induction of reactive oxygen species in the Fenton type reactions causing breaks of DNA strands, as well as damage to membranes and mitochondria (*7*).

*Lead and Cadmium.* Lead and cadmium are widely dispersed in the environment. These elements have no beneficial effects in humans. Although toxicity and the resulting threat to human health of any contaminant are, of course, a function of concentration, it is well-known that chronic exposure to Cd and Pb (*9*, *10*) can cause adverse effects.

Lead is known to induce a broad range of physiological, biochemical, and behavioral dysfunctions in laboratory animals and humans (*8*). Lead alters antioxidant activities by inhibiting the functional SH group in several enzymes such as ALAD, SOD, catalase, glutathione peroxidase, and glucose-6-deshydrogenase. Lead-induced oxidative stress contributes to the pathogenesis of lead poisoning by disrupting the delicate pro-oxidant/antioxidant balance that exists within mammalian cells (*9*, *10*).

Cadmium is a potent cell poison, which causes different types of damage, including cell death or increase in cell proliferation. Oral exposure to cadmium may result in adverse effects on a number of tissues (*11*). Cadmium also affects the nervous system, and neurogical disorders such as learning disabilities and hyperactivity in children may occur. In neuronal cells, cadmium induces oxidative stress, which produces protein damage and subsequently neurodegeneration. It is also known to enhance the production of free radicals in the brain and to interfere with the cellular defense mechanism against oxidation.

*Iron.* Iron is vital for almost all living organisms, participating in a wide variety of metabolic processes, including oxygen transport, DNA synthesis, and electron transport. High concentrations of iron may lead to tissue damage, as a result of the formation of free radicals. Disorders of iron metabolism are among the most common diseases of humans, encompassing a broad spectrum of diseases with diverse clinical manifestations ranging from anemia to iron overload and, possibly, to neurodegenerative conditions (*12*).

*Manganese.* Manganese is present in metalloproteins, such as pyruvate carboxylase, and in the cytoplasmic glial enzyme, glutamine synthetase. Deficiencies of manganese produce severe skeletal and reproductive abnormalities in mammals. High doses of manganese produce adverse effects primarily on the lungs and on the brain (*5*). Manganese can stimulate several signal transduction pathways known to be responsible for apoptosis and also induces caspase-dependent apoptosis in PC12 cells (*13*).

*Nickel.* Nickel is an essential element for several animal, particularly for the regulation of lipid content in tissues and synthesis of phospholipids. On the basis of animals studies, nickel is probably involved in the action of biotin, folate, and vitamin B12. Nickel-containing enzymes include carbon monoxide dehydrogenase, methyl coenzyme M reductase, hydrogenase, and urease. Nickel compounds bind a variety of enzymes, including hepatic microsomal enzymes as well as enzymes that catalyze carbohydrate metabolism and the transport of ions across membranes. $Ni^{2+}$ crosses cell membranes via calcium channels and competes with $Ca^{2+}$ for specific intracellular receptors (*5*).

*Zinc.* Zinc is an integral component of a wide variety of different enzymes in which it plays catalytic, structural, and/or regulatory roles. Zinc also appears to have an important role in biomembrane structure and function. The earliest detectable feature of zinc deficiency in infants is usually a decline in growth velocity. Appetite may be impaired. With more severe depletion, changes in mood are marked with irritability and lethargy. Impairment of the immune system, especially T-cell function, has been linked to increased susceptibility to infection (*14*). Zinc intoxication can produce either lung or intestinal tract manifestations. Zinc also plays an important role in various cell processes including DNA synthesis, normal growth, brain development, behavioral response, reproduction, fetal development, bone formation, and wound healing (*15*).

Zinc is a neurotoxin in vitro when present in high concentrations. Cultured mouse cortical neurons became swollen and granular within 15 min of exposure to 300−600 $\mu$M zinc, and the cells were completely destroyed after 24 h (*16*). Using cell cultures, Kim et al. observed zinc-induced swelling of cell bodies and mitochondria. Zinc-induced cytotoxicity has been linked to an inhibition of DNA and RNA, synthesis, compromised cellular protein metabolism, and $Ca^{2+}$ antagonism (*17*). Wilhelm et al. (*18*) found that inhibition of GSSH reductase is an early event after cellular zinc exposure. Inhibition occurs about 0.5−2 h after the beginning of the exposure; therefore, it precedes GSH depletion or GSSR increase.

Although some individuals are primarily exposed to metal ions in the work place, for most people, the main route of exposure to these toxic and nutritional elements is through the diet. Dietary intake is important as shown above, to obtain sufficient minerals of benefit to human health. Herbs are used for many purposes, and the ultimate objective of their use is a positive interaction with the biochemistry of the body. The herbs may be used in various forms as food, medicines, and cosmetics or as aromatics, and their active constituents must be absorbed by the body for giving the required benefits. Once they are absorbed in the blood stream, they circulate and influence our whole system; included in these compounds are the metal ions.

There are numerous published procedures for the determination of the mineral content in plants (*19*). In most of them, the inorganic ions are first converted to a soluble form either by extracting the plant tissue with a suitable solvent or by removing the organic fraction by oxidation, leaving the inorganic ions for subsequent analysis. Oxidation of the organic fractions is achieved either by heating the tissue to a high temperature in air and dissolving the remaining mineral ash in dilute acid or by digestion in strong oxidizing acids, leaving the organic ions in solution. The ions can then be determined by the usual analytical procedures, e.g., atomic absorption spectrophotometry (AAS).

In the present study, the mineral contents of some plants frequently used both for eating and as medicinal plants in Mali are determined. To understand the importance of the plants studied, their use, possible medicinal effect, and the contents responsible for these are described, as this is also relevant for the plants used in Mali.

**Description of the Plants Studied and Their Uses in Traditional Medicine and as Food.** *Bixa orellana L. (Bixaceae).* This is an abundantly branched shrub or small tree about 5 m high, with showy pink or white flowers and brown, bristly bivalved fruit in pods bearing numerous red seeds within. The fruit pulp is used in West Africa as a febrifuge and an astringent for dysentery and against kidney diseases. A decoction of the leaves is taken to stop vomiting and as a gargle for sore throat. The most interesting aspect of the plant lies in the use as a dye. The plant has been entered in commercial cultivation for the production of a dye, which is used mainly in the food industry and for coloring dairy products such as butter, cheese, margarine, edible oils, etc. (*20*). The seeds studied in this paper are chewed.

*Bombax costatum Pellegr. (Bombacaceae). B. costatum* is a common tree in West Africa. The bark and the roots are recognized as having diuretic properties. The leaves have emollient properties, and a warm bath in a decoction of the leaves may be taken for feverish patients, especially children. They are also prescribed with other plants for blenorrhoea (*20*). In Mali, the sepal of the flower is used to make a sauce used in food.

*Corchorus tridens Lam (Tiliaceae). C. tridens* is a woody herb or a low shrub of the grassy savanna from Senegal to Nigeria and is widespread in tropical Africa, India, and Australia. The leaves are commonly used to make soup in the whole region, including Mali. The leaves are ground and made into a sauce (*20*), and the plant is also thought to be an important source of iron (*21*).

*Cuminum cyminum L. (Umbelliferae).* The seeds of cumin are one of the most important spices in the world, including Mali (*22*, *23*). In indigenous medicine, cumin seeds have since long been considered as a stimulant and a carminativum and are used for various therapeutic purposes. They are also used in veterinary medicines (*23*). The essential oil of cumin seeds prevents butter from deterioration and improves its acid value. It has an antihydrolytic value and is better than conventional synthetic antioxidants. The oil of cumin also possesses antimicrobial effects (*24*) and has been shown to induce antiinflammatory activities in rats (*25*).

*Detarium microcarpum Guill. & Perr. (Cesalpiniaceae).* According to Burkill (*20*), *D. microcarpum* is a shrub or a tree up to 10 m high with a twisted stem and spreading crooked branches, growing in the dry savannah woodland from Senegal across the region in the sub-Sahara zone to Nigeria, and into Sudan. The wood is dark brown, tough, and hard. The leaves are eaten as a vegetable. The fruit is edible and frequently eaten in Mali. The plant enters into local pharmacopoeias for treating numerous ailments, and different parts (bark, roots, and leaves) are used for diarrhea, dysenteries, hemorrhoids, leprosy, syphilis, blenorrhoea, rheumatism, impotence, sterility, fungal infection, and biliousness.

*Hibiscus sabdariffa* L. (Malvaceae) is an annual herb that may be 2 m or higher, the stems are globorous, and the lowers leaves are ovate with the upper leaves being 3–5 palmately lobed. The flowers are auxiliary or in terminal racemes, the petals are white with a reddish center at the base of the staminal column, the calyx enlarges at maturity, and the fruit is fleshy and bright red. It is called roselle in English and l'Oiselle in French. The calyces are used to make cold and hot beverages in many of the tropical and subtropical countries.

In folk medicine, it is reported that *H. sabdariffa* has the following properties: antiseptic, aphrodisiac, astringent, resolvent, cholagogue, digestive, and stomachic (*26*). Roselle is also a folk remedy for abscesses, heart ailments, and hypertension. Hibiscus tea has been shown to lower the blood pressure in patients with essential hypertension (*27*). The bitter root is used as an aperitif and a tonic (*28*). The flowers are also used as an herbal tea in Mali.

*Moringa oleifera* Lam (Moringaceae) is indigenous to northwestern India and has been introduced into Mali. The tree is valued mainly for the tender pods, which are esteemed as a vegetable. Flowers and young leaves are also eaten as vegetables. A paste of the leaves is used as an external application for wounds. The leaves are a rich source of essential amino acids. Decoctions and extracts made from the leaves are used in native medicine (*29*). Pal et al. (*30*) have reported that the methanol fraction of *Moringa* leaf extract possesses antiulcer activity against induced gastric lesions in rats. The pressed juice of the fresh leaves shows strong antibacterial activity. The flowers of *M. oleifera* are also considered to possess medicinal value as a stimulant, aphrodisiac, diuretic, and cholagogue, and they have also been reported to contain flavonoid pigments such as quercetin, caempferol, rhamnetin, isoquercitin, and caempferitrin (*29*). Ghasi et al. (*31*) have found that administration of the crude leaf extract of *M. oleifera* along with a high-fat diet decreased the high-fat diet-induced increase in serum, liver, and kidney cholesterol levels. Esttrella et al. (*32*) reported that *M. oleifera* leaves increased breast milk production day from the third postpartum day to the fifth among mothers who delivered preterm infants. Siddhuraju et Becker (*29*) found that the methanol and ethanol extracts of the leaves showed the highest antioxidant activities in the $\beta$-carotene–linoleic system. Various types of antioxidant compounds such as ascorbic acid, carotenoids, and phenolic substances (quercetin and kaempferol) are present in moringa leaves. They are used as food in Mali.

*Spilanthes oleracea* Jacq. (Compositae) (*Spilanthes acmella* L. var. *oleracea* Clarke), also called the toothache plant, is an annual herb belonging to the family Compositae, the tribe of Heliantheae, and the subtribe Ecliptinate. It has yellow flower heads. Spilanthol is considered one of the most active constituents and was isolated from *S. oleracea* Jacq. in 1903; other N-isobutylamides have also been isolated from *Spilanthes* species (*33*). The hexane extract of *S. acmella* var. *oleracea* is able to induce generalized convulsion in rats (*34*). *S. oleracea* is one of the ingredients of Malarial, an improved traditional medicine of Mali used for the treatment of malaria.

As seen, these plants are important for food and as medicinal agents in Mali, and for this reason, it is important to investigate the contents of various minerals in these plants. The purpose of this communication is to determine the amounts of certain essential and toxic minerals in the plants described above that are frequently used by the population in Mali in order to find out if they contain metal ions in amounts that could be toxic in the normal doses used for food or medical purposes.

## MATERIALS AND METHODS

**Materials.** *B. orellana* Linn. (Bixaceae), *B. costatum* Pellegr. (Bombacaceae), *C. tridens* Lam. (Tiliaceae), *C. cyminum* Linn. (Umbelliferae), *D. microcarpum* Guill. & Perr. (Cesalpiniaceae), *H.*

**Table 1.** Ash Content in 100 g of Plant Materials (g)[a]

| plant material | average ± SD |
|---|---|
| *B. costatum* sepals | 7.5 ± 0.4 |
| *B. orellana* flowers | 4.35 ± 0.04 |
| *C. cyminum* fruit | 13.7 ± 0.3 |
| *C. tridens* leaves | 9.3 ± 0.1 |
| *D. microcarpum* fruit with epicarp | 2.35 ± 0.01 |
| *D. microcarpum* fruit without epicarp | 2.32 ± 0.01 |
| *H. sabdariffa* flowers | 9.4 ± 0.6 |
| *M. oleifera* leaves | 7.40 ± 0.04 |
| *S. oleracea* flower heads | 9.0 ± 0.2 |

[a] The results are given as an average of three replicates. SD, standard deviation.

*sabdariffa* L. (Malvaceae), *M. oleifera* Lam. (Moringaceae), and *S. oleracea* Jacq. (Compositae) (*S. acmella* L. var. *oleracea* Clarke) were all collected in Mali in December 2002. The plants were identified by Prof. Drissa Diallo at the Department of Traditional Medicine where specimens of all the plants are deposited in the herbarium according to an alphabetical system. The plant materials were air-dried at room temperature and then ground prior to extraction.

**Decomposition Procedure.** The dry ashing of the plant material was carried out using a programable electrical furnace (Naberterm). One gram of material was accurately weighed in a silica crucible and placed in the furnace at room temperature. The temperature was raised continuously to 750 °C for 2.5 h and was held at that temperature for 3 h. The crucible was removed from the furnace and cooled to room temperature.

**Analysis of the Ash by Flame Atomic Spectrometry.** A 0.5 g amount of ash (accurately weighed) was dissolved in 5.0 mL of concentrated nitric acid until the evolution of gases had stopped. Thirty milliliters of water was added to this mixture, and the content was filtered through an acid-washed filter paper (Schleicher and Schill, Rundfilter, Germany) into a 50 mL volumetric flask. The filter and precipitate were washed with water and filled to volume. For some elements, i.e., for those that might be present in higher concentrations, further dilution might be necessary.

The concentrations of the elements were determined using a Varian AA 50B Atomic Absorption Spectrometer equipped with the appropriate lamp for the respective element using an air−acetylene flame. The concentrations of the solutions were calculated and displayed by the instrument based on the measurements of four different concentrations of standard solutions of the element in question. The standard solutions were made by appropriate dilutions of multielement standards containing 500 $\mu$g/mL of $Co^{2+}$, $Mn^{2+}$, $Ni^{2+}$, and $Zn^{2+}$; 1000 $\mu$g/mL of $Pb^{2+}$ and Cd; 200 $\mu$g/mL of $Cr^{2+}$; 250 $\mu$g/mL of $Cu^{2+}$; and 1000 $\mu$g/mL of $Fe^{2+}$ supplied by Holger Teknologi (Norway). Each sample was analyzed in triplicate, and the results are given in $\mu$g/g dry plant material ± relative standard deviation (RSD) (%) if not otherwise stated.

## RESULTS AND DISCUSSION

**Mineralization.** The mineralization method used to obtain ashes has been shown to exert a significant influence on the determination of minerals from plant materials. There is a risk of losses during ashing, due to volatilization or insolubilization of mineral elements. In preliminary studies, 1 g of each sample was incinerated at 560 and 750 °C for 3 h. At 560 °C, the recovery was lower than at 750 °C.

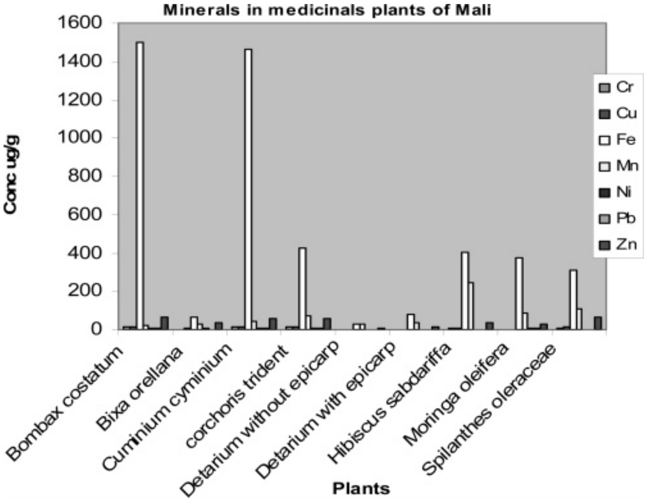

**Figure 1.** Comparison of the minerals present in different medicinal and edible plants of Mali.

The 750 °C ashes were dissolved in 5.00 mL of $HNO_3$ in a 150 mL beaker on a water bath (95−100 mL) and compared with the same samples not heated. No difference was observed between the not heated and the heated samples. Consequently, ashing at 750 °C for 3 h without dissolution by heating was selected. A longer time will be required if the dry material weighs more than 2 g.

**Ash Content.** The ash contents are shown in **Table 1**. The samples are measured in triplicate, and the results are presented as means ± SD. All results are less than 10%, which is well within the limit given for medicinal plants in various pharmacopoeias.

**Minerals and Traces Elements.** All determinations were performed in triplicate, and data were reported on a dry material basis as average values ± %RSD. **Table 2** and **Figure 1** show the Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn contents in $\mu$g/g of dry plant material.

Plants absorb metal ions from the soil through the roots. The uptake of metals by plants is influenced by various factors, including type of plant, nature of soil, climate, and agriculture practices. The concentration of heavy metals is not uniformly distributed throughout the plant. In general, the roots contain the highest levels of heavy metals, followed by vegetative tissue, which in turn has higher concentrations than seeds or grains (*2*). The monitoring of toxic metals is very important in developing countries where plants are used as foods or as medicine and should probably also be monitored in the

**Table 2.** Concentration Levels of Minerals in Raw Materials of Plants ($\mu$g/g Materials Dry Plant ± % RSD)

| | Cd | Co | Cr | Cu | Fe[a] | Mn | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|
| *B. costatum* flowers | ND | ND | 17.2 ± 2.2 | 11.9 ± 0.5 | 1.5 ± 0.3 | 22.4 ± 1.2 | 4.5 ± 0.4 | 5.2 ± 2.6 | 67.1 ± 0.7 |
| *B. orellana* seeds | ND | ND | 10 ± 1.2 | 7.4 ± 0.7 | 0.06 ± 1.4 | 30.5 ± 1.3 | 5.4 ± 0.8 | 0.9 ± 1.8 | 34.8 ± 1.0 |
| *C. cyminum* seeds | ND | ND | 13.7 ± 1.7 | 10.9 ± 0.7 | 1.4 ± 0.1 | 40.9 ± 1.3 | 6.8 ± 0.9 | 4.1 ± 5.3 | 54.6 ± 0.4 |
| *C. tridens* leaves | ND | ND | 11.2 ± 1.2 | 13.0 ± 0.7 | 0.4 ± 0.9 | 74.4 ± 0.8 | 3.7 ± 0.8 | 4,6 ± 3.9 | 55.7 ± 0.9 |
| *D. microcarpum* fruit without epicarp | ND | ND | 0.7 ± 1.0 | 3.2 ± 0.5 | 0.03 ± 0.9 | 30.1 ± 0.8 | 1.6 ± 2.0 | 0,46 ± 1.2 | 9.2 ± 1.3 |
| *D. microcarpum* fruit with epicarp | ND | ND | 2.3 ± 2.7 | 3.5 ± 0.9 | 0.08 ± 2.4 | 39.4 ± 0.5 | 1.8 ± 0.2 | 0.70 ± 3.9 | 13.9 ± 0.8 |
| *H. sabdariffa* flowers | ND | ND | 5.9 ± 4.6 | 5.6 ± 0.4 | 0.4 ± 1.0 | 243.0 ± 1.6 | 3.1 ± 3.2 | 1.8 ± 1.9 | 37.3 ± 1.3 |
| *M. oleifera* leaves | ND | ND | 2.2 ± 7.1 | 2.4 ± 0.6 | 0.4 ± 0.9 | 88.8 ± 0.4 | 8.1 ± 0.9 | 3.7 ± 1.0 | 29.6 ± 1.1 |
| *S. oleracea* flower heads | ND | ND | 9.0 ± 4.1 | 17.1 ± 0.6 | 0.3 ± 1.0 | 107.7 ± 1.1 | 3.6 ± 1.2 | 3.5 ± 0.6 | 62.8 ± 0.8 |

[a] Values for iron are in mg/g. ND, not detected.

developing countries as well. The heavy metal contents of our study were in the descending order of Fe > Mn > Zn > Cu > Ni > Pb. Cd and Co were not detected at all.

A total of nine elements (Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn) were analyzed for the powdered medicinal and edible plants samples by AAS. **Table 2** gives the mean concentration of various metal ions in the plants. The metal concentrations were based on the dry weight of the plant. From the study, it was revealed that except for Cd and Co, all of the metals are accumulated to greater or lesser extents by all of the plants. High levels of iron, manganese, and zinc were detected in all samples.

The levels of iron are very high in some of the plants, e.g., 1.5 mg/g in *B. costatum* flowers, 1.5 mg/g in *C. cyminum* seeds, 0.4 mg/g in *C. tridens* leaves, 0.4 mg/g in *H. sabdarriffa* flowers, 0.4 mg/g in *M. oleifera* leaves, and 0.3 mg/g in *S. oleraceae* flower heads. The iron levels vary totally between 0.03 mg/g in *D. microcarpum* fruit and 1.5 mg/g in *B. costatum* flowers. The tolerable upper limit of iron is 45 mg corresponding to 30 g of *Bombax* flowers per day (*35*).

The level of manganese is high in *H. sabdariffa* flowers, 0.2 mg/g; *S. oleracea* flower heads, 0.1 mg/g; *M. oleifera* leaves, 0.08 mg/g; *C. tridens* leaves, 0.07 mg/g; *C. cyminum* fruits, 0.04 mg/g; and *D. microcarpum* fruits, 0.04 mg/g. The recommended dietary allowance of 2−5 mg $Mn^{2+}$ per day is 10-fold the upper levels found per gram in these plants.

High levels of zinc as well were found in *B. costatum* flowers (0.07 mg/g), *S. oleracea* flower heads (0.06 mg/g), *C. tridens* leaves (0.06 mg/g), and *C. cyminum* fruits (0.05 mg/g). The WHO permissible limit of zinc in foods of 6 mg/100 g is well above these values.

Lead, nickel, and chromium were all present in low amounts in the plants studied as compared to the other metals in all of the plants. The level of lead is between 0.5 $\mu$g/g in *D. microcarpum* fruits and 5 $\mu$g/g in *B. costatum* flowers. These values were below the WHO permissible limit in foods, which is 10 $\mu$g/g (*36*).

The level of chromium is between 2 $\mu$g/g in *M. oleifera* leaves and 0.17 $\mu$g/g in *B. costatum* flowers. These values were well below the FDA recommended daily intake of chromium for foods and feeds, which is 0.12 mg/g (*36*).

The copper level is between 2 $\mu$g/g in *M. oleifera* leaves and 17 $\mu$g/g in *S. oleracea* flower heads. These levels are below the WHO permissible limits in foods, which is 4 mg/100 g (*37*).

According to Barceloux (*5*), nickel is a compound generally recognized as safe when used as a direct ingredient in human food and also is not a cumulative toxin in animals and in humans. The level of nickel in our study (2−8 $\mu$g/g) is below the average breast-fed infant consumable amount [5−15 $\mu$g/g Ni/day in the milk (*5*)].

It is evident from the data that the medicinal and edible plants of Mali included in the present study could be a source of essential elements (Fe, Zn Cu, Ni, and Mn) as well as heavy toxic metals (Pb), but no studies related to this aspect were known when the project started. In our study, all of the values are below the WHO permissible levels and may not constitute a health hazard for consumers. However, because the elemental contents of plants depend on many factors like geoclimatic conditions, anthropogenic activities such us chemical industries, plant species, and parts used, it becomes absolutely essential to ensure the quality of the plant material and detect the presence of contaminants if they are meant for human consumption. The environmental impact of heavy metals as such, as well as their health effects, is a source of major concern. Heavy metal contamination of crops and its effects on growth of plants are also a great threat. On the basis of this, it was a positive result that none of the plants growing in Mali that were investigated in this study contained high levels of toxic metals.

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