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ORIGINAL PAPER

Contribution of Leafy Vegetable Sauces to Dietary Iron, Zinc, Vitamin A and Energy Requirements in Children and Their Mothers in Burkina Faso

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Abstract Improved leafy vegetable (LV) sauces, with amaranth, sorrel, and Ceylon spinach/spider plant leaves were formulated from traditional recipes to assess their potential use for food-to-food fortification in iron, zinc and vitamin A in the diet of young children and their mothers in Burkina Faso. Improvement was based on an increase in LV proportion and a decrease in mineral absorption inhibitors. An increase in iron content of up to 3 mg/100 g was obtained in some improved sauces in which dried fish was replaced by chicken liver, and vitamin A content was about 40 times higher than in traditional sauces. Fractional dialyzable iron was low in all sauces. Intakes of sauce were measured to assess their acceptability and no significant difference was found between traditional and improved formulations. The mean intakes of sauces were 66±40 g for young children and 166±65 g for their mothers. Amaranth or Ceylon spinach/spider plant sauces, consumed with the cereal based paste "tô" twice a day, would contribute 80 to 86 % of children's estimated average requirement (EAR) of iron and to 90 to 170 % of EAR of vitamin A but their contribution to zinc and energy needs would remain low.

Keywords Food-based approaches · Iron bioaccessibility · Micronutrient deficiency

Abbreviations

DM	Dry matter
EAR	Estimated average requirement
LV	Leafy vegetable

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Introduction

Inadequate dietary intakes and diseases are considered to be the immediate causes of maternal and child undernutrition among low-income populations in developing countries [1]. The foods eaten by these populations are poor in micronutrient-dense foods, because their plant-based diets mainly comprise cereals, starchy roots, tubers and legumes and lack diversity [2]. Monotonous cereal and legume based diets contain mainly non-haem iron along with high concentrations of non-haem iron chelators such as phytate, polyphenols, fibers, and low concentrations of absorption enhancers (animal tissue, ascorbic acid). This results in low micronutrient bioavailability and often in iron deficiency anemia [2]. Low income populations mostly cannot afford animal source foods with high quality proteins, which are rich in bioavailable iron and zinc and devoid of mineral chelators. Vegetables are often cheaper and are sustainable dietary sources of vitamins, trace elements and other bioactive compounds [3–5], which is an obvious advantage over cereals and legumes. Among vegetables, dark green leafy vegetables are commonly consumed by many populations in southern countries as part of their diet, by adults and children who share the same family meal, thereby improving the nutrient quality of cereal based diets [6] and making starchy staple foods more palatable [7]. Recently, more attention has been paid to wild or underused vegetables [8, 9].

In food based strategies, four proposals have been put forward to help reduce iron and vitamin A deficiencies [2]: (i) increasing the production and availability of foods that are rich in these nutrients, (ii) increasing consumption of these foods, (iii) making these micronutrients more bioavailable through combinations of foods, and (iv) breeding new varieties of plants that contain larger amounts and more bioavailable micronutrients. Combining the first three food-based

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strategies proposed above, also called food-to-food fortification [2], the objective of this study was to determine if improved leafy vegetable (LV) sauces with increased micronutrient content and reduced concentrations of mineral-chelating factors could be used for this purpose. We focused on iron, zinc and vitamin A in the diet of young children and their mothers who traditionally share the same family meal in Burkina Faso. Leaves of sorrel (*Hibiscus sabdariffa*), amaranth (*Amaranthus cruentus*), Ceylon spinach (*Basella alba*) and spider plant (*Cleome gynandra*) were chosen because they are already widely consumed, already contain high concentrations of some micronutrients and are available in markets. The acceptability of improved LV sauces eaten with tô, a cereal based thick paste, was assessed by measuring the quantity consumed by young children and their mothers, respectively, during meals in Ouagadougou. Iron bioaccessibility in improved sauces was also assessed. These results were then used to decide if the consumption of these improved LV sauces should be promoted in nutrition education programs to fight micronutrient deficiencies.

Materials and Methods

Formulation of Sauces

For each of the four types of leaf selected, standardized recipes for traditional LV sauces were formulated based on recipes, ingredients and proportions traditionally used in Burkinabè households (Table 1) [10]. Improvement of traditional recipes mainly meant increasing the quantity of LV they contained and decreasing the quantity of ingredients rich in chelating factors. In some cases, improved sauces were formulated by replacing fish powder by chicken liver (on a DM basis). Dry matter contents of 18 and 20 % were targeted in traditional and improved sauces, respectively. Six improved recipes were compared to two traditional recipes: one with low LV content (amaranth) and one with high LV content (sorrel), both with high chelating factors.

Table 1 Composition of traditional and improved sauces on a dry matter basis

Sauces	Traditional		Improved		
	Amaranth	Sorrel	Amaranth	Sorrel	C. spinach-spider plant*
	(g/100 g DM)				
Sorrel leaves	–	23.5	–	25.0	–
Amaranth leaves	14.2	–	24.0	–	–
Ceylon Spinach leaves	–	–	–	–	22.0
Spider plant leaves	–	–	–	–	8.0
Fish powder (/chicken liver)	15.3	6.8	17.0	16.0	16.0
Fresh tomato	2.8	3.4	5.4	3.6	3.0
Onion	5.6	7.8	6.0	7.0	6.0
Groundnut paste	26.2	25.8	16.0	9.0	13.7
Tomato purée	3.2	2.4	6.0	4.5	3.0
Groundnut oil	16.8	12.0	13.0	18.0	13.0
Soumbala	6.1	3.4	4.0	3.0	5.0
Bouillon Cube	2.9	3.4	2.8	2.9	2.9
Salt	6.3	7.0	5.0	5.0	5.0
Potassium carbonate	0.6	1.0	0.8	1.0	0.4
Garlic	–	2.2	–	2.2	2.0
Fresh onion leaves	–	1.1	–	1.1	–
Parsley	–	0.3	–	1.7	–
Total	100	100	100	100	100

*C. spinach-spider plant=Ceylon spinach-spider plant

Materials

Batches of amaranth, sorrel, Ceylon spinach (C. spinach) and spider plant leaves were purchased in a local market in Ouagadougou. They were carefully washed several times and dewatered for immediate use or frozen for storage and dispatched to the laboratory in Montpellier for analyses. Other ingredients (see Table 1) were purchased in a local market and kept refrigerated until use. Chicken livers purchased from a local butcher were cleaned, immediately separated into aliquots, and frozen. The aliquots were defrosted just before the sauces containing liver were prepared. A 100 kg batch of whole maize grains (*Zea mays*) was purchased from a local market in Ouagadougou for the preparation of the "tô" cereal paste. The grains were carefully washed several times, dewatered and sun dried before milling. The flour was stored in closed bags in a ventilated room and a portion was also sent to Montpellier where it was kept refrigerated until required for tô preparation.

Measurements of Intake Amounts of Sauces and tô

Subject Recruitment Intake amounts were measured in Wapassi, a poor outer suburb of Ouagadougou. After approval of the investigation by Wapassi municipal councilors, 12 children aged from 12 to 18 months and their mothers, who were used to eating tô plus traditional sauces were selected. An informed consent form was signed by the legal representatives of the children (usually their parents) after the purpose of the study had been explained to them.

Preparation of LV Sauces and tô Seven different sauces were prepared: the traditional sorrel sauce as control and six improved sauces with limited amounts of groundnut paste and soumbala and either fish or liver, based on sorrel, amaranth or a mixture of C. spinach and spider plant leaves. One type of sauce (2 kg) was prepared in the village canteen in the morning of each day of intake. The amount of each ingredient was measured by local cooks who were trained to use the following standardized processing method: the onions were fried, and fresh tomatoes, tomato puree and a small quantity of tap water were added. The mixture was cooked for 10 min. Dried fish, coarse salt and pounded potash, stock cube and soumbala, a legume-based condiment, were then added and cooking continued for 18 min. Chopped fresh and washed leaves, groundnut paste, other ingredients (Table 1) and water were added and the mixture was cooked for further 15 min (see diagram in additional material 1). The total weight of the sauce was adjusted with water to reach the targeted dry matter content. Six kg of maize based thick tô paste was prepared with a DM content of 17 % according to the traditional recipe used in Burkina Faso [11].

Measurement of Food Intakes Sauces and tô were served separately in sufficient quantities to allow *ad libitum* consumption. Intakes were measured by weighing the plate containing tô and the bowl containing the sauce before and after consumption by the children and their mothers, separately. The mothers were asked not to eat anything themselves and not to feed their child for 1 h before the test meals. Mothers fed their child and themselves as usual, using their hand. Seven sauces were tested on seven consecutive days in a random order.

Characterization of the Nutritional Value of Sauces

Preparation of Blanched Leaves, LV Sauces and tô Frozen leaves of sorrel, amaranth, spinach and cleome were boiled for 15 min in Volvic™ mineral water just before laboratory analysis. Two hundred grams of sauce and 65 g of tô were prepared following the same processing method as in the field study, using Volvic™ water instead of tap water and frozen leaves. The sauces were pureed in a Robot-Marie blender (Moulinex, Ecully, France).

DM, Iron and Zinc Contents, and Iron Bioaccessibility were determined as previously described [11], using freshly blanched leaves or freshly cooked sauces. Measurement of *DM* contents was preceded by oven drying at 105 °C to constant weight; *iron* and *zinc* by extraction with a closed-vessel microwave digestion system and analysis by flame absorption spectrometry. *Iron bioaccessibility*, defined as the fraction of iron that is released from its matrix into the gastrointestinal tract and thus becomes available for intestinal absorption was determined using an appropriate *in vitro* procedure [12]. Samples were homogenized with ultrapure water to obtain a DM content of 9–10 %. After gastric digestion, intestinal digestion occurred in tubes containing dialysis bags. Dialyzable iron diffused into these bags containing PIPES (piperazine-N,N'-bis-[2- ethanesulfonic acid] sodium salt) buffer at a concentration that enabled the pH to stabilize at 6.7. The contents of the dialysis bags are hereafter referred to as dialysates. The digested mixtures remaining in the tubes were centrifuged at 10,000×*g* for 15 min at 4 °C to separate the insoluble and soluble iron fractions in the pellet and supernatant, respectively. Thus, the sum of dialyzable, soluble non-dialyzable (SND) and insoluble fractions should be equal to the total amount of iron in the sample before digestion. Each fraction was calculated on the basis of the total iron recovered at the end of the digestion:

$$\text{Dialyzable Fe \%} = C_D(W_D + W_S)/(C_D W_D + C_S W_S + C_I W_I) \times 100 \quad (1)$$

$$\text{SND Fe \%} = W_S(C_S - C_D)/(C_D W_D + C_S W_S + C_I W_I) \times 100 \quad (2)$$

$$\text{Insoluble Fe \%} = W_I(C_I)/(C_D W_D + C_S W_S + C_I W_I) \times 100 \quad (3)$$

where C_D, C_S and C_I are iron concentrations (µg/100 g) and W_D, W_S and W_I are the weights (g) of the dialysate, supernatant, and pellet, respectively. The iron contents of each fraction were analyzed as described above at least in triplicate. Results are expressed as a percentage (fractional iron) of the total iron in the food.

Sauce and tô Composition in iron, zinc, phytate, vitamins A and C, and total polyphenol (PP) was calculated using data compiled either from the Malian food composition database [13] or from results of analyses carried out in our laboratory using the methods detailed above [11] and the method of Georgé [14] for PP.

Statistical Analysis biochemical analyses were performed in triplicate. Results are expressed as average values±standard deviations (SD). Univariate analysis of variance (ANOVA) was used to compare iron bioaccessibility in the blanched leaves and in the sauces. To adjust for the subject effect, ANOVA for repeated measures was used for the statistical analysis of intake measurements. When appropriate, Tukey's tests were used to separate the means at 5 % significance level. Statgraphics software version 5.1 was used in both cases.

Results and Discussion

Formulation of Improved Sauces

The sauces were improved in steps by (i) increasing the proportion of LV, (ii) increasing their DM content to 20 %, (iii) decreasing the proportion of ingredients rich in mineral-chelating factors *i.e.*, groundnut paste and the soumbala condiment and finally by (iv) replacing fish powder by an equivalent amount of liver on a dry matter basis (Table 1). The sensory characteristics of the sauces and their acceptability by the mother and child were the main constraints for their nutritional improvement. Thus, the increase in the percentage of leaves in the improved sauces was limited to a maximum of 24–30 % DM, depending on the plant species. We also set the dry matter content of improved sauces at 20±0.5 g of DM/100 g instead of the values of around 16 % in traditional sauces. Higher DM content is hard to target as it would require considerably longer cooking to evaporate enough water to concentrate the sauce, which would have a negative effect on their sensory properties. At the same time, groundnut paste or the soumbala condiment, which is rich in chelating factors like phytates, were reduced: groundnut paste was reduced from 26 % of DM to 7 and 16 % of DM in the improved sauces and soumbala was reduced from 6 % of DM in the traditional amaranth sauce to 3 and 5 % of DM in the improved sauces. Unlike most studies, our study focused not only on the fresh or cooked leaves [15, 16], but on the complete dishes in the form they are consumed in Africa, hence including the effects of mixing the leaves with other ingredients and of food processing.

Micronutrients and Chelating Factors

Table 2 lists the concentrations of micronutrients and chelating factors (phytate and polyphenols) of the sauces used in the feeding trial. In the case of the amaranth sauce, the composition of the traditional variant (which has lower LV content, but higher fish powder and groundnut oil content) is given for reference purposes only: compared to the traditional sorrel sauce, the traditional amaranth sauce had an 10 % lower iron content, a 20 % lower zinc content, a 36 % lower vitamin A content, a 40 % lower vitamin C content, a similar phytate content, but a 90 % lower polyphenol (PP) content. In the improved amaranth sauce with more LV and less groundnut paste, the LV increased the iron, vitamin A and C contents, while the reduction in groundnut paste reduced the phytate content.

Thus, in the improved sauces with limited groundnut paste based on sorrel, amaranth or C. spinach-spider plant, iron content was 2.5 mg/100 g (Table 2). The improvement of sorrel, amaranth and C. spinach-spider plant sauces by reducing the amount of groundnut paste (and in the case of amaranth increasing the amount of LV) increased total iron content by 25 % compared to the traditional sorrel sauce. There was no variation in zinc content between traditional and improved sauces due to the low zinc content of the leaves. Phytate content was reduced by respectively 47, 21 and 29.5 % in sorrel, amaranth and C. spinach-spider plant sauces, thanks to the major decrease in the proportion of groundnut paste in their formulation. The improved sauces had the same vitamin A content (in the case of sorrel and amaranth), or double the amount (in the case of C. spinach-spider plant). Using the standard retention coefficient [17], the improved sauces had the same estimated vitamin C content (in the case of sorrel and amaranth), or 94 % more (in the case of C. spinach-spider plant) (Table 2). Yet, the estimated vitamin C content was low compared to requirements in all sauces, as observed previously [5]. The polyphenol content of the sauces depended on the type of leaves, and was 4–9 times higher in the sorrel based sauces than in the other sauces. This high PP content is likely to negatively affect the bioavailability of the non-haem iron in dishes made with sorrel (and to a lesser extent with C. spinach-spider plant) [18]. Sauces made with liver instead of fish powder had a more than 30-fold increase in vitamin A content, and 20–80 % more vitamin C. Replacing dried fish by liver in the sorrel, amaranth and C. spinach-spider plant "liver sauces"

Table 2 Micronutrient, chelating factors and energy contents of traditional and improved sauces (calculated taking the contribution of each ingredient into account)

Sauces or tô	Iron mg / 100 g of sauce or tô	Zinc mg	Vit A µg RAE	Vit C* mg	Phytate mg	PP mg	Energy kcal
Traditional amaranth	1.8	0.4	65	11	36	9	88
Improved amaranth	2.5	0.5	122	21	27	14	87
Amaranth + liver	3.0	0.8	3900	24	27	14	89
Traditional sorrel	2.0	0.5	102	18	34	80	82
Improved sorrel	2.5	0.6	113	21	18	93	91
Sorrel + liver	2.9	0.8	3682	25	18	93	92
Improved C. spinach – spider plant	2.5	0.7	236	35	24	23	87
C. spinach – spider plant + liver	3.0	0.9	3791	38	24	23	88
Tô	0.8	0.1	0	0	41.0		63

*Coefficient of retention for vitamin C: 0.6 [17], PP=polyphenols, vit A=vitamin A, vit C=vitamin C, RAE=retinol activity equivalent led to a modest further increase in iron of at least 0.4 to 0.5 mg per 100 g of sauce (a 45 % increase compared to the traditional sorrel sauce), and to an appreciable increase in zinc content of 0.3 mg per 100 mg of sauce (a 60–80 % increase compared to the traditional sorrel sauce). Including liver instead of dried fish led to a huge (16 to more than 30-fold) increase in vitamin A content, which reached more than 3000 µg RAE (retinol activity equivalents) /100 g DM. This implies that to prevent going over the upper limit of vitamin A requirements, liver should not be added to the sauce every day, but not less than once a week.

Intake Amounts of Sauces by Children and Their Mothers and Contribution to EARs

Mean intakes of LV sauces by the children and their mothers were respectively 66 and 166 g with huge inter-subject variations, as shown by the high SD and min-max values (Table 3). No significant differences were observed between the different sauces in this small sample (12 children each with their mother). We consequently cannot reject the hypothesis that all the sauces formulated had the same overall level of acceptability, which was comparable to that of the traditional sorrel sauce. These levels of consumption, which would be doubled if eaten twice a day, appear to be almost adequate for mothers, knowing that for adults, a supply of 200 g of vegetables/capita/day is recommended [6] based on minimum vitamin A and C requirements. Intakes of tô by both children and mothers were also highly variable. One child ate very little sauce and tô, and several times refused to eat any *tô* at all. The ratio of sauce to tô was 1:1.3 for the children and 1:2.3 for their mothers, showing that the children ate a larger proportion of the sauces. Or conversely, considering that a sauce is designed to help swallow the tô, the children ate a smaller proportion of the tô with the sauce.

Mean contribution to EAR of iron ranged from a low 22 % for both the children and their mothers in the case of the traditional sorrel sauce plus tô, to a high value of 47 % for children and 42 % for their mothers, respectively in the case of the amaranth liver sauce plus tô (Fig. 1). The latter combination could ensure 94 and 84 % of EAR iron coverage in children and their mothers, respectively, if such a meal is eaten twice a day. The first partial improvement in the formulation of the sorrel and amaranth sauces and of the tô led to a 3 and 14 % and to a 3 and 10 % increase per meal in the mean EAR coverage of iron for the children and their mothers, respectively. The increase was higher in the amaranth sauce thanks to the lower original proportion of leaves used in the traditional sauce. The dishes including sauces with liver and tô had a 4 % higher mean coverage of EAR of iron compared to the sauce made with dried fish. Whatever the sauce, our results were below those obtained previously [15] in which the iron content measured in four underused LV ranged from 96.5 to 107.2 mg/100 g DM, resulting in 40–50 % contribution to the daily iron requirements in one serving. Whatever the sauce, the contribution to EAR of zinc of children was about half that of iron and did not exceed 18 % in the improved sauces. For the children, the highest contribution to EAR of zinc, 19 and 21 %, were obtained with sauces containing liver. Conversely, for the mothers, contribution to the EAR of zinc was almost the same as that of iron, ranging from 22 % in sorrel sauce to 38 % in the C. spinach-cleome sauce with liver. This difference is due to the mean daily iron and zinc requirements: whereas iron requirements are much higher for mothers than for 1–3 year old children (29.2 *vs*. 9.2 mg iron /day), they are only a little different for zinc (7.4 *vs*. 6 mg zinc /day) [19]. The

Table 3 Mean intakes of LV sauces and cereal-based "tô" paste by young children (n=12) and their mothers (n=12) in Ouagadougou

		Children						Mothers					
		Sauces			tô			Sauces			tô		
	DM (%)	Intake ± SD (g)	min	max	Intake ± SD (g)	min	max	Intake ± SD (g)	min	max	Intake ± SD (g)	min	max
Traditional sorrel	18	56±32	11	113	70±46	2	151	179±87	90	386	342±100	158	494
Sorrel	20	71±36	13	131	98±76	0	286	156±57	59	281	379±132	130	533
Sorrel + liver	20	68±30	21	103	88±60	0	175	154±66	70	293	403±154	144	612
Amaranth	20	70±36	4	141	93±70	10	245	180±64	58	306	433±116	144	580
Amaranth + liver	20	55±33	13	122	76±70	10	261	175±36	119	223	409±83	291	540
C. Spinach-spider plant	20	58±32	16	115	66±54	0	180	155±41	92	218	338±99	174	478
C. Spinach -spider plant + liver	20	81±68	4	201	97±86	0	242	159±94	48	424	331±105	140	516
Mean		66±40			84±66			166±65			377±117		
p		0.07						0.75					

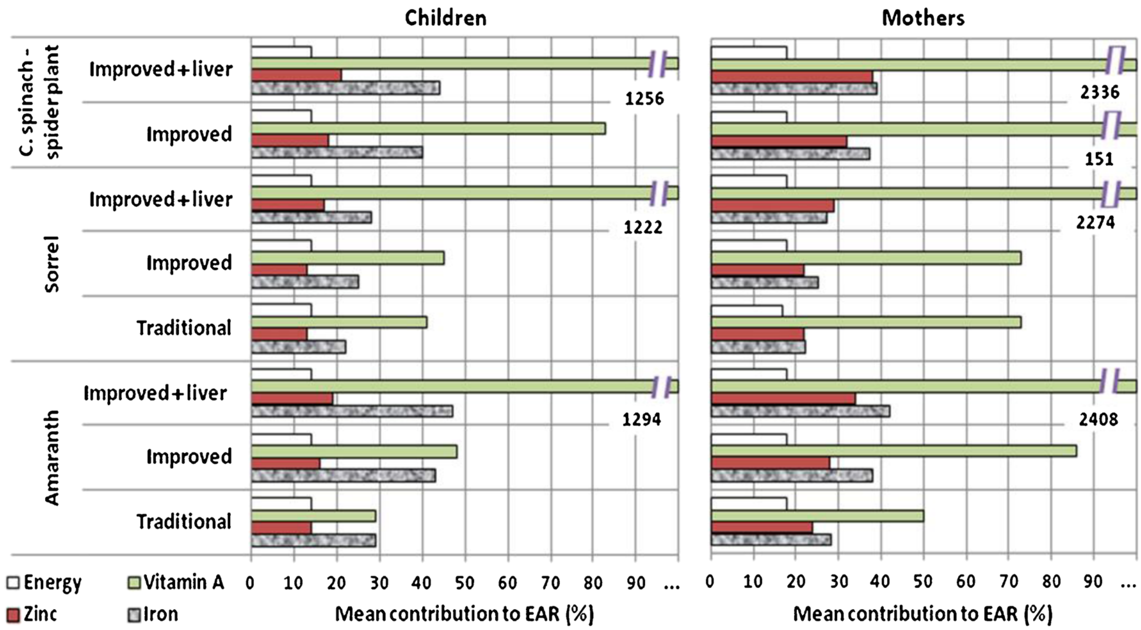

Fig. 1 Mean contribution of a whole meal composed of different LV sauces plus tô to covering EAR of iron, zinc, vitamin A and energy requirements of children (n=12) and their mothers (n=12), calculated using the values listed in Table 3 as mean intakes and taking the low bioavailability of iron (5 %) and zinc (15 %) into account. EAR values for iron, zinc, vitamin A and energy were respectively (mg/day or kcal/day for energy) 9.2, 6.0, 200 and 900 for children, and 29.2, 7.4, 270 and 2000 for mothers. [19]

regular consumption of LV may help prevent zinc deficiency in both children and their mothers [8]. Sauces containing dried fish are good providers of provitamin A: whatever their formulation, the mean contribution to EAR of provitamin A for children ranged from 29 % with the traditional amaranth sauce, to 83 % with the C. spinach-spider plant sauce, and to much more (almost twice as much) for their mothers. Sauces containing liver contributed to more than 15–25 times more EAR of vitamin A than the sauces containing dried fish. These findings are in good agreement with the results of another study reporting that LV contain provitamin A and iron and are valuable ingredients in diets for moderately malnourished children [6]. The mean contribution to EAR of energy per meal remained low whatever the sauce: 14 % for children and 17–18 % for their mothers. Their daily diet should then be further diversified with others foods rich in energy-dense nutrients.

Bioaccessibility of Iron in Leaves and Sauces

The total iron content of amaranth leaves was significantly higher than that of the other leaves tested (Table 4).

Table 4 Iron bioaccessibility in blanched leaves and LV sauces prepared in the laboratory

Fe	n	Total Fe (mg /100 g DM)	Dialysable Fe (%)	SND Fe	Insoluble Fe	Dialysable Fe (µg /100 g of sauce)	SND Fe	Insoluble Fe
Leaves								
Sorrel	7	58.6±11.0 [b]	11.0±5.2 [b]	10.3±4.8 [b]	78.8±3.3 [b]	131±44 [a]	140±91 [b,c]	1018±206 [b]
Amaranth	11	73.9±10.4[a]	4.1±2.9 [c]	10.1±2.6 [b]	85.7±5.1 [a]	150±98 [a]	379±88 [a]	3272±601 [a]
C. Spinach- spider plant	6	34.2±4.6 [c]	17.3±4.5 [a]	6.2±2.6 [c]	76.6±3.5 [b]	147±46 [a]	53±24 [c]	642±70 [b]
Sauces								
Traditional sorrel	7	19.0±0.9 [c]	6.8±2.1 [a]	3.4±1.8 [d]	89.7±1.0 [a]	209±69 [b]	104±56 [e]	2725±110 [b]
Improved sorrel	5	17.0±0.7 [c]	6.8±1.3 [a]	4.1±0.6 [d]	89.0±0.8 [a,b]	231±36 [b]	141±25 [e]	3020±137 [b]
Traditional amaranth	6	14.8±3.7 [c]	3.2±0.8 [b,c]	10.8±1.7 [a,b]	86.0±2.4 [b,c]	73±9 [c]	249±25 [d,e]	2047±570 [b]
Improved amaranth	17	27.3±5.3 [b]	5.3±3.2 [a,b]	8.3±2.1 [c]	86.4±3.7 [b,c]	275±146 [b]	448±117 [c]	4735±998 [a]
Imp. amaranth + liver	6	33.2±0.7 [a]	7.1±0.6 [a]	13.2±2.0 [a]	79.7±2.3 [d]	470±38 [a]	875±113 [a]	5300±243 [a]
Imp. C. spinach-spider plant	4	30.6±19.2 [a,b]	5.3±1.3 [a,b]	10.3±0.4 [b,c]	84.4±1.5 [c]	357±277 [a,b]	635±409 [b]	5117±3158 [a]

Results are means of n measurements±standard deviation; for the same product (leaves or sauces), values in one column with different superscript letters are significantly different (p<0.05). SND Fe=soluble non dialyzable iron

Amaranthus species are known to be rich in iron [20]. Sorrel leaves had two times higher iron content than C. spinach-spider plant leaves. The percentage of dialyzable iron varied significantly depending on the type of leaves, and was the highest, around 17 %, in C. spinach-spider plant leaves, and the lowest, around 4 %, in amaranth leaves. The absolute amount of dialyzable iron per 100 g EP was similar in sorrel, amaranth and C. spinach-spider plant leaves. In all leaves, 77 to 86 % of iron was insoluble.

In LV sauces, total iron contents were highest in the sauces made with amaranth, particularly when liver was added, and those made with C. spinach-spider plant, with iron contents of around 30 μg/100 g DM of sauce. These total iron contents are 1.4–2.4 times higher than those calculated from available food composition tables (Table 2). Even if iron content varies considerably depending on the agronomic and climatic environment [3], we hypothesize that despite careful washing of the leaves, some of the total iron contents reported in this paper are contaminant iron from the soil. Due to processing into sauces, fractional dialyzable iron was increased to 5.3 and 7.1 % for amaranth. In the sorrel based sauces, the fraction decreased to 7 % (from 11 % in the leaves). The highest dialyzable iron contents were measured in the amaranth-liver and the sorrel sauces. The highest soluble non-dialyzable iron contents were measured in the amaranth-liver sauce and in the C. spinach-spider plant sauce. The percentage and concentration of insoluble iron were higher in the sauces than in the leaves. Liver supplied a little more iron to the sauces but its main advantage, which was not revealed by measuring dialyzability, may be improving iron bioavailability thanks to the presence of animal proteins [3].

Conclusion

Consumption of LV could significantly contribute to covering iron and vitamin A requirements, but we observed a major difference between leaves depending on their nature and on the way they were processed, as shown by the difference in micronutrient content and bioaccessibility between blanched leaves and cooked leafy vegetable sauces. Iron content in leaves could be further increased by improving cultural practices. Combined with animal source food, which could also provide a little more of the zinc lacking in LV, the consumption of amaranth, sorrel or spinach-cleome sauces can be recommended for food-to-food fortification and equally as part of the food diversity strategy to combat micronutrient deficiencies.

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Conflict of Interest The authors declare that they have no conflict of interest.

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