Can coca leaves contribute to improving the nutritional status of the Andean population?

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Abstract

Background. *Coca leaves (*Erythroxylum coca*) have been promoted as a food that could address the dietary deficiencies of the Andean population, but this is based on nutrient analyses of a small sample of leaves.*

Objective. *We assessed the nutritional potential of eight samples of coca leaves grown in different regions of Peru.*

Methods. *We used AOAC techniques to measure nutrients, nutrient inhibitors (phytate, polyphenols, oxalic acid, and fiber), and alkaloid concentrations, all expressed per 100 g dry weight (DW) of the ground leaves. Minerals were measured by inductively coupled plasma-mass spectrometry in two independent laboratories.*

Results. *The leaves contained protein, 20.28 g/100 gDW, with lysine as the limiting amino acid; β-carotene, 3.51 mg/100 gDW; vitamin E, 16.72 mg/100 gDW; trace amounts of vitamin D; calcium, 990.18 and 1033.17 mg/100 gDW at two different laboratories; iron, 29.16 and 29.16 mg/100 gDW; zinc, 2.71 and 2.63 mg/100 gDW; and magnesium, 225.19 and 196.69 mg/100 gDW. Cocaine was the principal alkaloid, with a concentration of 0.56 g/100 gDW; other alkaloids were also identified. The results were compared with those for other edible leaves. The nutrient contributions of coca powder (5 g) and bread made with coca were compared with those of normal portions of alternative foods.*

Conclusions. *Two spoonfuls of coca leaf flour would satisfy less than 10% of dietary intakes for schoolchildren and adults for critical commonly deficient nutrients in the diet. Coca leaves do not provide nutritional benefits when eaten in the recommended quantities, and the presence of absorbable cocaine and other alkaloids may be potentially harmful; hence coca leaves cannot be recommended as a food.*

Key words: Coca leaf, Peru, nutrition content, calcium, iron, alkaloids, child malnutrition

Introduction

Coca leaves (*Erythroxylum coca* var *coca*) had mystic and cultural importance in ancient Andean societies. Coca was originally restricted to ceremonial use by the ruling Inka; Spanish colonists were responsible for an increase in production and the extension of use of the leaf throughout the Andes [1–4]. The habit was common among working men, who typically held a bolus of coca leaf and wood ash in the cheek, slowly releasing the cocaine alkaloid responsible for the anti-fatigue effect and suppression of appetite [5–13].

Since the 1970s and increasingly over the past few years, the consumption of coca leaf has been promoted in Peru and Bolivia for its supposed nutritional value, with particular emphasis on the possibility of combating the dietary deficiencies of the Andean region [14-16].

Whereas acute malnutrition (wasting) associated with inadequate caloric intake is rare in Peru, even in the poorest areas [17, 18], stunting is common, especially in rural areas. Population surveys [17] show that overall 29.5% of children under 5 years of age are stunted, with height-for-age less than 2 SD below the World Health Organization (WHO) reference standards [19] for height-for-age, and this number has not significantly changed over the past 5 years [20]. In

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the rural areas of Peru, and especially in the Andean highlands, 43.2% of children under 5 years of age are stunted and 13.1% of women are at obstetric risk, with heights below 145 cm; the corresponding figures for the Amazon region are 32.2% and 11.8%, respectively [17, 18]. Stunting is associated with poverty, unhygienic living conditions, and lower parental education levels, factors that contribute to inadequate dietary quality during the vulnerable intrauterine and early childhood period [18, 21–25]. Stunting is associated with lifelong consequences, such as poor progress in school, lower work capacity, and higher maternal mortality [26]. Stunting is not inevitable; children of rural migrants to large cities, where there is access to a greater variety of foods, are able to realize their growth potential and have markedly lower rates of stunting than their rural counterparts [21].

Anemia, primarily due to iron deficiency, is also a major problem, especially in preschoolchildren and pregnant or breastfeeding women [20]. Anemia results from long-term consumption of diets that are deficient in iron content and/or bioavailability [27–30]. The foods that provide the greatest amounts of easily assimilated iron are animal-source foods such as red meat and offal [31]. Animal-source foods (including meat, poultry, milk, fish, and eggs) are also important sources of other nutrients essential for health that are often lacking in the diet [32, 33], such as calcium, retinol, and zinc.

Calcium is essential for healthy bone formation and immune function, and low dietary intakes during childhood and adolescence are associated with osteoporosis later in life [34, 35]. Dietary zinc deficiency is also common [36] and contributes to stunting, developmental delays [37], and increased rates and severity of diarrhea and pneumonia [38]—the number one killer of children in the Andes [18]. Seasonal or subclinical vitamin A deficiency is also reported in some areas of Peru [18, 39] where intake of retinol or its precursor β-carotene is low or seasonal.

The diet in rural areas of Peru tends to be monotonous, high in carbohydrates, low in fat, and low in animal-source foods [40, 41]. Protein intake is adequate but comes mainly from vegetable sources that have an imbalance of amino acids. The low intake of minerals is exacerbated by the low bioavailability of these nutrients in the diet due to the presence of inhibitors of absorption, such as fiber, phytates, polyphenols, and oxalate.

In 1975, a group from the Harvard University Botanical Museum and the Agricultural Research Service in Beltsville, Maryland, USA, analyzed the nutrient composition of a sample of coca leaves from Bolivia [42] and reviewed previous analyses of coca leaves from Bolivia and Peru [43]. They reported that coca leaves had relatively high contents of energy (305 kcal/100 g), protein (18.9 g/100 g), calcium (1,789 mg/100 g), iron (26.8 mg/100 g), and vitamin A (10,000 IU/100 g) as compared with a selection of other vegetables, although they recognized that in part these high values were accounted for by the fact that the coca leaves were dried and had an average moisture content of 8.5%. The study did not measure inhibitors of absorption of the micronutrients. They also warned that the presence of toxic alkaloids could make the coca leaf undesirable as a source of nutrients [42].

Despite the authors' warning, coca leaf is being promoted as a valuable source of nutrients, and it has even been suggested that it should be included in food-assistance programs as a fortificant on the basis of the results reported by Duke et al. [16].

With the knowledge that has been gained over the past three decades, in conjunction with more advanced technology, more accurate information can now be provided on the composition of coca leaves. Since coca leaf is being promoted for consumption by an inherently vulnerable population for nutritional risk, it was necessary to undertake a more exhaustive study of its nutritional value, taking into account antinutrients and toxic substances.

Materials and methods

Sample provision

We analyzed samples of *Erythroxylum coca* var *coca* from seven different regions of Peru (**table 1**). All regions were river valleys with altitudes less than 1,000 m above sea level. Between 3 and 9 kg of the sun-dried coca leaves ready for traditional use were purchased from local suppliers [44, 45]. In addition, one sample was bought from Mixtura Andina, which sells the product supplied by ENACO as a dried, micropulverized leaf flour.

The leaves were redried and ground to particles less than 0.5 mm in size with homogeneity ensured following Mandel *h* statistics (SGS-Peru, Callao). Moisture content was determined according to AOAC method 930.04:2000 [46]. These oven-dried ground samples were stored in the dark in plastic bags in a controlled environment at 15° to 24°C with less than 60% moisture content before being shipped at ambient temperature to the laboratories for analysis.

Analyses

Biochemical analyses were performed by various independent private, governmental, and university laboratories in Peru, France, England, Sweden, Canada, and the United States. We consulted well-known commercial analytic laboratories and researched the published literature to identify laboratories with the capability of and experience in analyzing minerals, vitamins, potential inhibitors of micronutrient absorption, and

TABLE 1. Proximate analysis of coca leaf samples from different regions of Peru

Sample	Source	Moisture content at purchase (%)	Moisture content after drying (%)[a]	Crude fiber (g/100 g dry wt)	Fat (g/100 g dry wt)	Ash (g/100 g dry wt)	Protein (g/100 g dry wt)	Energy (kcal/100 g dry wt)[b]
1	San Francisco, Provincia de la Mar, Ayacucho	15.89	11.97	15.65	5.96	5.58	19.74	345.34
2	Shupte, Provincia de Leoncio Prado	12.82	9.06	15.36	6.76	5.04	19.91	351.88
3	Provincia de Tocache, San Martín	13.32	9.42	16.17	5.53	6.56	17.24	336.72
4	Valle Paucartambo, Cusco	14.23	9.84	15.56	5.29	5.69	21.51	341.61
5	Aguaytia, Ucayali	14.32	9.85	16.45	7.13	5.42	18.96	348.31
6	Valle del Monzón, Provincia Huamalies, Huánuco	13.93	9.52	15.36	6.61	5.39	21.12	350.35
7	Inambari, Puno	14.88	11.47	14.91	5.30	6.04	22.24	342.26
8	ENACO S.A.	8.03	4.63	14.24	6.35	5.46	21.51	353.36
Mean ± SD		13.43 ± 2.37	9.47 ± 2.21	15.46 ± 0.69	6.12 ± 0.70	5.65 ± 0.47	20.28 ± 1.65	346.23 ± 5.76

a. Moisture content of samples as used in analyses.
b. Calories measured by bomb calorimetry.

alkaloids in leaf matrices. The final selection was also based on the ability of the laboratories to import and handle controlled substances.

Proximate analysis

Proximate analysis was performed at SGS-Peru, Callao, according to the following current AOAC protocols. Crude fiber was measured according to AOAC 930.10:2000 [46], ether extract according to AOAC 930.09:2000 [46], ash according to AOAC 930.05:2000 [46], and protein according to AOAC 978.04:2005 [47]. Energy was measured at the Instituto de Investigación Nutritional, La Molina, Peru, with the use of a bomb calorimeter according to standard methods [48].

Mineral analyses

Trace element mineral analysis was performed by inductively coupled plasma-mass spectrometry (ICP-MS) at two independent laboratories using the same methodology: Central Science Laboratory-UK (CSL, York, UK) and the Toxicology Division of the National Public Health Institute of Quebec (INSPQ, Ste-Foy, Canada). Magnesium, calcium, iron, zinc, arsenic, selenium, cadmium, mercury, and lead were measured at CSL, York, UK; nitric acid digestion in quartz high-pressure closed vessels was followed by microwave heating prior to quantification by ICP-MS. Reference materials NIST 1515 apple leaves, NIST 1547 peach leaves, and NIST 1573 tomato leaves were used for comparison.

Vitamin analyses

Vitamin A (retinol and β-carotene), vitamin C (ascorbic acid), vitamin D (cholecalciferol), and vitamin E (tocopherols) were analyzed by high-performance liquid chromatography (HPLC) (Aquanal Pessac, France) according to French Norms NF EN 12823-1 and 2 [49, 50], EN 14130 [51], NF EN 12821 (2001) [52], and NF EN 12822 (2001) [53], respectively.

Amino acids

The amino acid profile was evaluated by ion-exchange chromatography using ninhydrine derivation according to AOAC 982.30 and 985.28 [54]. A separate tryptophan analysis was performed by HPLC following alkaline hydrolysis AOAC 982.30 and 988.15 [46] (Aquanal, Pessac, France).

Potential inhibitors of mineral bioavailability

Soluble and insoluble fiber. Fiber was analyzed according to AOAC method 991.43 [46] (Aquanal, Pessac, France).

Phytic acid and oxalic acid. Phytic acid and oxalate were analyzed at Chalmers University of Technology, Göteborg, Sweden. For both analyses, dried samples were extracted with 0.5 M HCl, followed by three series of 30 minutes of ultrasonic lysis and centrifugation at 10,000 × *g* for 5 minutes. Inositol phosphates were separated with ion-exchange chromatography and quantified according to the method described by Carlsson et al. [55]. The same extract was used for total quantification using anion-exchange chromatography as described by Normén et al. [56].

Polyphenols. Evaluation of polyphenols was performed at CSL (York, UK) by the Folin-Ciocalteau reaction, in which 2.0 g of sample was brewed in 250 mL of boiling water for 4 minutes followed by decantation and centrifugation. After addition of Folin-Ciocalteau reagent and sodium carbonate, the samples were incubated at 20°C for 2 hours with shaking. Total phenols were calculated from absorbance reading at 750 nm, as gallic acid equivalents (GAE). A composite of all samples was used as a quality control sample.

Alkaloids. Alkaloids were assayed at the Québec National Public Health Institute (INSPQ), Ste-Foy, Canada. The alkaloids of the coca leaf were measured by gas chromatography–mass spectrometry (GC-MS) after soxhlet extraction: 1 g of powdered leaves was weighed precisely into a 250-mL volumetric flask and 100 mL of methylene chloride was added. The flask was then refluxed in a soxhlet apparatus for 24 hours. At the end of this period, the volume of solvent remaining in the flask was measured precisely, transferred to a 100-mL tube, and kept at 4°C until analysis. An aliquot of the soxhlet extract was then further diluted 1/10 in chloroform containing deuterated cocaine as the internal standard, and a small portion was injected into GC-MS.

Results

Eight samples of *Erythroxylum coca* var *coca* were analyzed. **Table 1** shows the moisture content of the leaves as purchased and the moisture content after redrying in preparation for the analyses. The samples were stored and shipped in this condition. Leaves, as purchased, varied in moisture content from 13% to 16%, except for the sample bought as a powder, which had a moisture content of 8%. The results of the proximate and all other analyses, except when specified, are expressed per 100 g dry weight (0% moisture content); **table 1** shows those results. The protein content varied from 17% to 22%, with an average of 20.28 ± 1.65 g/100 g dry weight.

Proteins vary in the extent to which they provide amino acids that cannot be synthesized in the body and are therefore necessary in the diet. These are referred to as indispensable amino acids. The quality of a protein depends on the relative content or balance of amino acids; a high-quality protein satisfies both the nitrogen requirement and all the essential amino acid requirements with the minimum amount of protein [57]. Animal-source proteins, such as cow's milk or whole hen's egg, are considered high-quality proteins. To estimate protein quality, the amino acid content may be compared against a requirement scoring pattern. **Table 2** shows the amino acid contents of coca leaves compared with the Food and Nutrition Board of the Institute of Medicine (FNB/IOM) 2002 amino acid scoring pattern for use in all children 1 year of age or older [57]. In this way, the amino acid score for a particular food is calculated by comparing the amino acid content of the food in milligrams per gram of protein to the requirement pattern, and limiting amino acids can be identified as those having a ratio less than 1 [58]. Thus, lysine is the limiting amino acid with a

TABLE 2. Amino acid contents of coca leaves and amino acid score

Amino acid	Amino acid content (g/100 g leaf)[a]	Amino acid content (mg/g protein)[b]	Requirement scoring pattern (mg/g protein requirement)[c]	Amino acid score[d]
Histidine	0.418 ± 0.040	20.611	18	1.145
Isoleucine	0.728 ± 0.072	35.897	25	1.436
Leucine	1.323 ± 0.147	65.237	55	1.186
Lysine	0.801 ± 0.095	39.497	51	0.774
Methionine	0.337 ± 0.036	16.617		
Cysteine	0.200 ± 0.020	9.862		
Methionine + cysteine	0.537 ± 0.057	26.479	25	1.103
Phenylalanine	0.790 ± 0.094	38.955		
Tyrosine	0.570 ± 0.073	28.107		
Phenylalanine + tyrosine	1.360 ± 0.167	67.061	47	1.427
Threonine	0.711 ± 0.076	35.059	27	1.298
Tryptophan	0.265 ± 0.034	13.067	7	1.867
Valine	0.902 ± 0.096	44.477	32	1.390

a. Mean ± SD of 8 samples, amino acid concentration in 100 g dry weight ground coca leaf.
b. Mean of 8 samples, amino acid mg/g protein.
c. Requirement scoring pattern for amino acid requirements for children 3 to 10 years of age.
d. Amount of amino acid in 1 g protein (mg)/amount of amino acid in requirement pattern (mg) [57].

TABLE 3. Mineral contents of coca leaf samples (mg/100 g dry weight)[a]

Sample	Calcium			Iron			Zinc			Magnesium		
	Laboratory		Mean	Laboratory		Mean	Laboratory		Mean	Laboratory		Mean
	1	2		1	2		1	2		1	2	
1	1,009.32	1,135.98	1,072.65	28.06	28.40	28.23	2.84	3.41	3.13	245.48	227.19	236.34
2	955.47	1,000.66	978.07	12.54	23.09	17.82	2.50	2.20	2.35	195.18	175.94	185.56
3	964.45	993.60	979.03	41.07	40.85	40.96	2.21	1.99	2.10	196.40	165.60	181.00
4	812.67	831.85	822.26	71.21	54.35	62.78	2.60	2.33	2.47	255.10	210.74	232.92
5	960.51	1,053.8	1007.16	13.87	14.42	14.15	2.93	2.88	2.91	176.48	155.30	165.89
6	1,135.61	1,105.22	1120.42	28.63	28.74	28.69	2.65	2.54	2.60	180.37	154.73	167.55
7	1,019.65	1,095.67	1057.66	18.07	20.33	19.20	3.03	2.94	2.99	362.59	316.38	339.49
8	1,063.75	1,048.55	1056.15	19.82	23.07	21.45	2.90	2.73	2.82	189.89	167.77	178.83
Mean ± SD	990.18 ± 94.15	1,033.17 ± 95.23	1011.67[b]	29.16 ± 19.39	29.16 ± 12.77	29.16[b]	2.71 ± 0.27	2.63 ± 0.46	2.67[b]	225.18 ± 6.27	196.71 ± 5.50	210.95[b]

a. Adjusted to 0% moisture content.
b. Mean of the means.

score of 0.774.

High concentrations of vitamins such as vitamin A and minerals such as calcium and iron are claimed for coca leaves. Analysis revealed a mean content of 3,510 µg of β-carotene in 100 g of dry leaf. This represents 292.50 µg of retinol activity equivalent [59]. Five of the eight leaf samples contained small amounts of vitamin D, 3.12 µg/100 g dry weight. Vitamin E (α-tocopherol) content was very variable, with a mean of 16.72, a standard deviation of 9.01, and a range of 3.63 to 29.57 mg/100 g dry weight. **Table 3** shows the contents of key minerals for all samples analyzed in two separate laboratories. The results are very similar from both laboratories, which used ICP-MS with similar methods. As expected, there was variation between the samples from different geographic areas. Low contents of other minerals were found, adjusted to dry weight and expressed as micrograms or milligrams per kilogram of dry leaf because of the low content, were as follows: copper 9.92 mg/kg, mercury 0.19 µg/kg, and lead 0.42 µg/kg. These mineral contents are of no nutritional or toxicologic importance, and the intakes from coca leaf in edible amounts would be well below the Provisional Tolerable Weekly Intakes and the Provisional Maximum Tolerable Daily Intakes for these minerals [60]. Selenium was present in concentrations too low for accurate measurement in laboratory 1, where the concentrations in four samples were below the detectable limit. The results from laboratory 2 showed a selenium content that varied from 0.333 to 1.435 mg/kg, with a mean of 0.800 ± 0.365 mg/kg corrected to dry weight. Five grams of coca leaf would provide only 7% of the daily requirements of selenium [61].

Bioavailability is a measure of the amount of a nutrient in a food that is absorbed and available for physiological purposes. The bioavailability of essential minerals such as iron, zinc, and calcium is reduced in plant sources: the reduction may be just as significant as a lack of the nutrients in the food in determining nutrient deficiencies in populations mainly dependent on plant staples. **Table 4** shows the results of analyses of inhibitors of absorption in the coca leaves.

TABLE 4. Potential inhibitors of nutrient absorption in coca leaf

Inhibitor	Concentration (g/100 g dry weight)[a]
Insoluble fibers	38.02 ± 1.86
Soluble fibers	2.83 ± 0.81
Oxalic acid	2.09 ± 0.10
Phytic acid	0.29 ± 0.21
Polyphenois	3.78 ± 0.34

a. Mean ± SD of 8 samples.

Table 5 shows the alkaloid results for the leaves. We measured only five of the alkaloids present in coca leaves [62]. Cocaine was the principal alkaloid, with a concentration of 0.56 mg/100 g dry weight; the others were present in small amounts.

Discussion

We analyzed the contents of seven samples of leaves from *Erythroxylum coca* var *coca,* the variant of the coca plant that is most commonly cultivated in the Andean region, plus a commercially processed coca flour sold as a nutritional supplement. Our objective was to assess the possible role of coca leaves in addressing dietary deficiencies in the Andean population when used, as has been suggested, as a nutrient supplement or added to processed food such as bread.

Our study contributes new information on nutrient contents and the presence of other constituents of the leaves that may affect bioavailability. Although chewing coca has been studied for its physiological and

TABLE 5. Alkaloid contents of coca leaf samples (g/100 g dry weight)

Sample	Anhydroecgonine methyl ester	Ecgonine methyl ester	Cocaine	*trans*-Cinnamoylcocaine	*cis*-Cinnamoylcocaine
1	0.02	0.26	0.58	0.07	0.10
2	0.02	0.14	0.54	0.02	0.04
3	0.01	0.29	0.50	0.07	0.10
4	0.01	0.23	0.70	0.04	0.08
5	0.01	0.12	0.58	0.03	0.06
6	0.03	0.06	0.54	0.03	0.06
7	0.02	0.10	0.60	0.02	0.05
8	0.02	0.26	0.44	0.03	0.06
Mean ± SD	0.02 ± 0.01	0.18 ± 0.09	0.56 ± 0.08	0.04 ± 0.02	0.07 ± 0.02

toxicological effects, there have been no studies on the bioavailability of nutrients from this form of ingestion, and this is the first report of potential inhibitors of mineral bioavailability in coca leaves. It is important to consider bioavailability, as it may be a more important factor than dietary content in determining dietary adequacy. This is especially important for many minerals. Inhibitors of absorption contained in foods influence the absorption of nutrients not only from the same foods but also from other foods that are eaten at the same time.

Dietary intakes of iron and zinc are low in the Andes [40], and deficiencies of these micronutrients are considered important contributors to the high prevalence of stunting and anemia. Calcium intakes are also very low.

The iron content was 29.16 mg per 100 g of coca leaf dry powder (the value from both laboratories was the same), which is 38% lower than the earlier reported value [42]. We did find variability between the samples from different areas, ranging from 12.54 to 71.21 mg/100 g dry weight. These differences may be due to differences in the growing conditions of the coca plants, the age of the leaves, contamination from soil and other materials, or the methods used in the two studies. Genetic variability may also play a role. Taking into consideration the mean value, coca powder used in flour at a concentration of 5% would contribute only about 1.45 mg of iron in 100 g of flour or 0.8 mg in a serving of two bread rolls, which is only 10% of the daily recommended intake for children [59].

Bioavailability of iron is a complex problem because of the effect of the food matrix on its absorption. Facilitating and inhibiting substances may be present and influence bioavailability. The content of ascorbic acid, a well-known enhancer of iron absorption, seems very low in these sun-dried coca leaves, yet inhibiting factors that would negatively affect iron absorption are present in substantial quantities. For example, the phytic acid content is high enough to be of concern. The phytic acid content varied among the eight samples; this was expected, since the phytate content varies with the phosphorus content in the soil, and the leaves were collected at various locations. The average phytic acid content was 0.3%, which is lower than that in cereal grains (1% to 2%) but higher than that in spinach (0.01% to 0.07%) [63].

Coca leaves also have significant amounts of polyphenols. We found 3.8 g/100 g based on dry weight and 66 mg per serving of infusion (data not shown) as gallic acid equivalents. It is difficult to interpret the data on polyphenols, since not all types of phenolics have the same effect on iron absorption [64]. When iron absorption was measured from various beverages containing different types of polyphenols, a 50% to 70% reduction of iron absorption was found with 20 to 50 mg of total polyphenols as catechin equivalents [65], which translates into 22 mg of gallic acid (based on molar concentrations) [64]. When the powder form of coca leaf is added to a food product at the 5% level, the amount of polyphenols (76 mg) is similar to that in one serving of infusion.

The zinc content is low in coca leaves compared with that in the other leaves listed in **table 6**. Consuming bread with 5% added coca leaf powder contributes only 0.1% of the daily requirement for children. Zinc bioavailability is not influenced by most of the factors

TABLE 6. Concentrations of minerals in coca leaf compared with other leaves (mg/100 g dry weight)[a]

Leaf	Calcium	Iron	Zinc	Magnesium
Coca	1,015.5	29.2	2.7	210.9
Parsley	1,629.7	108.6	5.2	276.4
Bay	882.0	45.5	3.9	126.9
Coriander	1,344.1	45.8	5.1	748.7
Oregano	1,697.5	47.4	4.8	290.8
Dried spinach	1,151.2	31.5	6.2	918.6.
Alfalfa	445.7	13.4	12.8	376.0

a. Data for coca are the mean results of tests of eight samples from two laboratories. Data for other leaves are from the US Department of Agriculture [69].

that affect iron absorption. The phytate-to-zinc ratio is an important determinant of zinc absorption; it was found to be 1.1, which is below the critical value of 15 [66]. The low content of zinc rather than its low bioavailability means that coca leaf cannot be considered a useful source of this essential mineral.

Our analyses indicate lower calcium concentrations than those reported by Duke et al. [42]. This might be due to different growing conditions of the plants, and we did find some variability between the leaves collected from different regions. This is expected and may be due to intrinsic genetic variability between plants, variation in growing conditions such as soil, age of the leaves, storage conditions, and exposure to light and heat before being purchased. Nevertheless, all our samples had calcium contents much less than the values reported by Duke et al. They reported 1,647 mg/100 g (corrected to dry weight) for calcium in the Bolivian sample measured and 2,272 mg/100 g (corrected to dry weight) for the Peruvian samples previously analyzed by Machado et al. [43], as compared with the 990 to 1,033 mg/100 g dry weight reported here. Differences in analytic technique as well as the potential for variability mentioned above may account for these differences; however, we measured these critical minerals in two independent carefully selected laboratories in different countries and obtained very similar mean contents of calcium, iron, and zinc, with less than 5% variability, a result that increases confidence in the standard of the analyses. This amount of calcium would provide less than 5% of the daily recommended intake for children. We found significant amounts of oxalic acid (2.1%) in the coca leaves, which would be expected to affect the bioavailability of calcium and reduce even further the calcium available from the leaves. The extent of this effect should be measured in studies of bioavailability.

The magnesium content of coca leaves was very comparable to the previously reported value (211 vs. 233 mg) [42], although there was a greater variability in measurements, with laboratory 2 reporting values on average 13% lower than laboratory 1. The amount of magnesium in bread flour made with 5% of added coca leaf powder would contribute only 4.5 mg of magnesium, significantly lower than the daily dietary reference intake of 240 mg [59]. Although magnesium bioavailability has not been not well studied in humans, a recent study reported that magnesium availability was lower from spinach meal (27%) than from kale meal (37%), a difference that was attributed to differences in oxalic acid content [67]. In that study, the molar ratio of oxalic acid to magnesium was 1.33. In the current study, the molar ratio was found to be 2.56, and we can expect much more reduction in absorption.

We also analyzed the vitamin contents of the coca leaves. As expected in plant foods, β-carotene but not retinol was detected in our analyses. Current evidence suggests that the conversion ratio of β-carotene from green leaves to retinol equivalents is greater than 10:1; estimates vary from 10:1 to 26:1 [68]. We have used a value of 12:1 [69]. Compared with other sources, the amount of vitamin A provided by foods including coca leaf would be small.

Only small amounts of vitamin D were detected in some of the leaf samples. The amount obtained from suggested intakes of coca leaf would represent 2% of the daily requirement of 5 mg of α-tocopherol [59]. Vitamin D is mainly made in the skin when it is exposed to ultraviolet sunlight, a process that takes place throughout the year at high altitudes; thus, vitamin D deficiency is not considered a problem for children and adults in the Andes.

In contrast to Duke et al. [42], no vitamin C was detectable in any of our leaf samples. It is probable that our samples were exposed to sunlight, as is usual in the traditional drying process, and that this reduced the vitamin C content. Duke et al. [42] did not provide details of the source of the leaves; they may have been picked straight from the plant, avoiding exposure to sunlight and preserving the vitamin C. Vitamin C deficiency is not a nutritional problem in the Andean highlands of Peru and Bolivia, where potatoes, an excellent source of vitamin C, are an important constituent of the diet [70].

Finally, it has been suggested that coca leaves might be a useful source of dietary protein. We report a similar protein content to that reported by Duke et al. [42] at around 20 g/100 g dry weight. Eating 5 g of coca leaf per day would provide only 1 g of protein, less than 3% of a schoolchild's requirement [57]. We were also able to analyze amino acid contents and to document that protein quality based on amino acid score is limited by lysine content. To satisfy 100% of all the essential amino acid requirements, it would be necessary to eat 30% more of coca leaves by weight than of an animal-source food such as egg or milk. The protein quality based only on amino acid score does not include an adjustment for protein digestibility. The protein efficiency ratio of coca leaf protein is inferior to that of casein [71], so that taking protein digestibility into account, we would expect an even lower protein digestibility-corrected amino acid score (PDCAA) [58].

Dietary protein quality may also be assessed in studies in protein-deprived growing animals. Such studies [71–73] showed that animals fed coca leaf as a source of protein lost weight [72], and that when coca leaf constituted more than 5% of the diet, the animals died and were found to have grossly abnormal livers on autopsy [73]. Negative effects were documented even when the coca leaves were dealkalinized [74–76]. Rats and rabbits fed coca leaf for extended periods also failed to grow and showed abnormalities of the liver, kidney, uterus, and heart [76]. Although some of these animal studies are unable to determine whether these effects are due to the poor quality of the protein or to other substances in the leaves, the results indicate that coca leaves cannot be considered a good source of protein.

The toxic content of coca leaves is a concern and represents a potential risk to the consumer. In his review of the nutritional value of the coca leaf, Duke expressed concern about the alkaloid content of the leaves [42]. The principal alkaloid is cocaine, whose stimulant, anorexic, addictive, and psychological properties have been extensively reviewed [45, 62, 77–81]. In addition to the psychological effects, cocaine ingestion by oral, inhalation, or intravenous administration causes increased heart rate, vasoconstriction, and hypertension [78, 79]. Deaths from overdose are most commonly due to cardiac effects or stroke [79]. The coca leaves evaluated in this study contained an average of 0.5% cocaine, which is similar to previously reported concentrations [82–84]. This would mean that there was 15 mg of cocaine in two bread rolls made with flour containing 5% coca leaves.

Although it was once thought that cocaine was not absorbed from the gastrointestinal tract, bioavailability studies show that consumption of coca leaves either as powder or tea, or held in the cheek and sucked, results in absorption of cocaine with pharmacological effects [45, 85–89], and cocaine and its metabolites can be measured in the blood [85, 89] and urine [88].

At least 18 alkaloids belonging to the tropanes, pyrrolidines, and pyridines have been reported in coca leaves [62]. We measured only anhydroecgonine methyl ester, ecgonine methyl ester, cocaine, *trans*-cinnamoylcocaine, and *cis*-cinnamoylcocaine. The results are shown in **table 5**. Cocaine was present in the highest concentration of any alkaloid in all the samples. Normally viewed as metabolites of cocaine, especially when found in the blood or urine of users, the other alkaloids have been much less studied than cocaine. The cinnamoylcocaines have anticholinergic activity [62] and cardiovascular sympathetic action. Liver toxicity has also been reported [73].

Additionally, benzylecgonine and ecgonine ethyl ester may be generated by nonmetabolic chemical conversions. When coca leaf samples were exposed to aqueous methanol extraction and the extracts were concentrated with heat, nearly all the cocaine was transformed to benzylecgonine and ecgonine ethyl ester, as shown by high-performance thin-layer chromatography and confirmed by mass spectrometry (J. McChesney, personal communication, 2007). It is probable that similar transformations of cocaine to these potentially liver-toxic degradation products occur during incorporation of coca flour into bread dough and baking into rolls. Given the toxicity of these alkaloids, it is essential that more is learned about production of these degradation compounds under extreme heat before coca leaf flour is included in products that will be cooked.

An additional important adverse effect of eating coca leaf is its anorexic properties. Appetite suppression following chewing coca leaves is well recognized, and as reported in several anthropological texts [12, 13], the ability to reduce hunger has been one of the most prized properties of the leaves. Detailed studies have been conducted in rats and monkeys demonstrating that a reduction of food intake occurs when coca extracts or purified cocaine are administered orally [90–92]. This documented appetite suppression of cocaine preparations would seem to be contraindicated in youngsters, especially schoolchildren.

Our objective was to assess whether coca leaf could make a nutritionally significant contribution to the diet of the Andean population and whether this benefit could outweigh the potential adverse effects. With this in mind, our results have to be considered in the context of the contribution of critical nutrients from coca leaf in the amounts suggested for consumption as a food as compared with alternative foods.

Several shrub or tree leaves are reported to contain relatively high contents of minerals [93], so we have compared the mineral contents of coca leaves with those of other leaves [69] that are normal constituents of the human diet in Peru and Bolivia (**table 6**). Overall, coca leaves show no significant advantage in terms of critical mineral contents. Parsley, for instance, has more than three times as much iron as coca leaves, and bay, coriander, and oregano have 50% more iron. Oregano has more than 50% higher calcium content and 70% higher zinc content than coca leaves. Alfalfa has almost five times as much zinc as coca leaves.

It has been suggested that 5% coca leaf be added to bread flour for use in public nutrition programs [16]. Coca flour is also sold as a nutritional supplement with a recommended intake of 2 spoonfuls (5 g) added to soups or drinks. Using our results, we have calculated the expected nutrient contribution of coca flour in these preparations compared with other normal portion sizes of foods that are available alternatives to increase the dietary intakes of micronutrients that are deficient in the diet of the rural population of Peru and Bolivia. We have calculated that school-aged children consuming two wheat bread rolls of 30 g each would consume 3 g of coca leaf flour. Fortification of wheat flour with iron, folic acid, and B vitamins is mandatory in Peru, and we have taken this into consideration in the calculations. The results are shown in **table 7**. In no case does coca flour contribute more than 10% of the daily requirements for this age group.

Conclusions

So should coca leaf be advocated as a food? Apart from the issue of safety arising from the toxic alkaloid content and its anorectic effect, we found that coca leaves have no nutritional advantage over other leaves, such as

TABLE 7. Amounts of nutrients in bread with added coca leaf compared with amounts in usual portions of foods eaten by Peruvian children 9 years of age or older

Nutrient	RDI[a]	2 rolls with coca[b]	Bread	Coca leaf (8% humidity)	Coca leaf powder (2 spoonfuls)[c]	Fresh milk with sugar	Whole egg	Chicken liver	Cheese[d]	Oily fish (jurel)	Quinoa	Amaranth	School meal program[e]	Fortified cereal (papilla)[f]
Portion size (g)[g]		60	57	3	5	250	60	45	15	60	60	60	140	45
Energy (kcal)[h]		184.2	174.6	9.6	15.9	189.2	83.4	56.3	34.5	76.8	224.4	226.2	594.8	203.0
Protein (g)	34.0	5.6	5.0	0.6	0.9	7.4	7.7	8.1	2.4	13.1	8.2	8.1	13.5	6.6
Calcium (mg)[i]	1,300.0	48.9	21.0	27.9	46.5	258.9	18.0	5.0	101.1	18.0	33.6	141.6	480.0	306.0
Iron (mg)*i*	8.0	2.7	1.9	0.8	1.3	0.9	0.7	3.9	0.3	1.1	4.5	4.5	10.0	5.0
Zinc (mg)[i]	8.0	0.5	0.4	0.1	0.1	0.9	0.6	1.5	0.4	0.4	2.0	1.9	6.0	3.0
Vitamin A (µg RE)	500.0	0.0	0.0	8.1	16.1	71	115	2,774.3	70.8	9.6	0.0	0.0	800.0	444.4
Vitamin D (µg)	5.0	0.0	0.0	0.0	0.1	0.3	0.6	0.3	0.3	ND	1.5	ND	ND	ND
Vitamin E (mg TE)	9.0	0.7	0.2	0.5	0.9	0.2	0.6	0.4	0.2	0.8	ND	ND	ND	ND

ND, no data; RDI, Recommended Dietary Intake; RE, retinol equivalent; TE, alpha-Tocopherol equivalent

a. From www.nap.edu.
b. The amount of nutrient in 60 g of French bread with wheat flour fortified with micronutrients, as required by Peruvian law, plus addition of coca leaf flour at 5%. Humidity,8% (ENACO sample).
c. Recommended amount (2 spoonfuls = 5 g) for commercial micropulverized coca leaf flour (Laboratorios Kaita del Peru S.A.C., Lima).
d. Fresh soft cow's milk cheese.
e. One daily portion of national school meal program
f. One daily ration of national program for complementary food for at risk groups (PACFO)
g. Portion size based on direct weight and observational studies in families in Peru (Instituto de Investigación Nutricional).
h. RDI is not provided for energy, as it depends on activity. Values are given for comparison only.
i. Mean of the mean values from laboratories 1 and 2.

oregano, parsley, or coriander. In addition, the presence of inhibitors may limit bioavailability of micronutrients and reduce even further any nutritional potential of the coca leaf. In the amount recommended for consumption of coca leaf powder or the amount that would be eaten if coca leaf was included as part of a school breakfast program, coca leaf would have no significant nutritional benefit. Some proponents advise eating much larger amounts, up to 100 g, but such quantities not only would be unpalatable and difficult to consume but would contain considerable amounts of cocaine, with all the known harmful effects of this alkaloid.

The diet of the people of the high Andes is deficient in many ways, and the effects of this poor dietary quality are of concern. Intakes of iron, calcium, and zinc are particularly low, and their deficiencies have serious health consequences. Efforts are needed to find ways to improve these diets, but eating coca leaves or adding them as a nutrient fortificant does not contribute to improving the nutritional quality of the diet, introduces an appetite suppressant that is counterproductive, and exposes the population to toxic substances that are associated with short- and long-term health risks.

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