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Nutritional potential of underutilized edible plant species in coffee agroforestry systems of Yayu, southwestern Ethiopia

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Abstract Ethiopia is confronted with the paradox of hosting hundreds of edible plants and having high food and nutritional insecurity. Meals are mainly made up of staples and often lack of protein and micronutrients. Therefore, a large section of the population, particularly children and women, are malnourished. We hypothesize that wild edible plant species can contribute to fulfil the micronutrient demands of local people. Hence, we assessed the nutritional potential of underutilized edible plant species growing in understories of coffee agroforestry systems of southwestern Ethiopia. An ethnobotanical household survey (n = 300) documented the edible existing plants; and a promising subset of them (n = 12) was analysed for nutrient and antinutritional factor content in the lab. All 12 species, except fruits, have higher calcium, iron and zinc contents compared to regularly cultivated crops. Vitamin C was high in *Syzygium guineense* (330.72 mg/100 g edible parts or EP) and *Rubus apetalus* (294.19 mg/100 g). Beta-carotene ranged from 9.2 to 75 µg retinol activity equivalent (RAE) / 100 g 25 among all species, but was exceptionally high in *Rubus apetalus* (161.7 µg RAE/100 g). Concerning the antinutritional factors, phytate content varied from 31.06 to 601.65 µg/100 g, being lower in *Dioscorea prehensilis* (31.06 µg/100 g) and *D. alata* (90.17 µg/100 g) compared to *Carissa spinarum* (601.65 µg/100 g) and *Solanum nigrum* (536.48 µg/100 g). Thus, we conclude that the assessed underutilized species are potential sources of dietary nutrients locally needed, and are notable *Amaranthus graecizans*, *Portulaca oleracea* and *Dioscorea cayenensis* as providers of Ca, Fe and Zn, and the fruit *Rubus apetalus* of provitamin A.

Keywords Diet diversity · Underutilized food plants · Nutritional potential · Antinutritional factors

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Introduction

The global food system depends on only a few species. Nowadays, about 70–90% of all vegetable calories consumed by humans are derived from rice, wheat, maize, sugar, sorghum, millet and cassava (Pimentel et al. 2007), while in the past about 7000 plant species were regularly cultivated, mostly for food (Frison and Padulosi 1999). The main reason for the decline is the rise of modern agriculture (Khoury et al. 2014), which has affected the cultivation of indigenous vegetables, fruits, and other food plants (Khoury et al. 2014). This process is continuing, as there is little attention to local, traditional, and (semi)wild species (Grivetti and Ogle 2000).

In Africa, several species of high nutritional value are customarily cultivated or consumed. E.g., *Adansonia digitata, Balanites aegyptiaca, Ziziphus mauritiana, Boscia senegalensis* and *Cassia obtusifolia*, are key suppliers of the pro-vitamins A, B2 and C (Becker 1983), *Amaranthus viridis* and *Hibiscus sabdariffa* are important providers of protein, fatty acids, iron (Fe), magnesium (Mg), calcium (Ca) and zinc (Zn) (Sena et al. 1998). In Ethiopia, the nutritional importance of safflower (*Carthamus tinctorius*), tef (*Eragrostis tef*), noug (*Guizotia abyssinica*), and enset (*Ensete ventricosum*) is broadly acknowledged. Nevertheless, 38% of the Ethiopian children under 5 years suffer from chronic malnutrition (stunting or low weight-for-age), and 22% of the women of the reproductive age are undernourished, and therefore predisposed to have children of low birth weight and height, and of having high risk of disease and even death, situation that is exacerbated in rural areas (CSA and ICF 2016).

This critical situation of rural Ethiopia is due to several reasons, e.g., limited food availability and accessibility, inappropriate child feeding practices, deficient norms regarding food safety, limited access to health care, etc. (Beyero et al. 2015), but the unbalanced diet seems to be among the most important. Although staple crops such as tef (*Eragrostis tef)*, enset (*Ensete ventricosum*), maize (*Zea mays*), wheat (*Triticum aestivum*), yam (*Dioscorea* spp.), etc. are widely cultivated and consumed (Fentahun and Hager 2009), the consumption of vegetables and fruits is limited. Even when farmers grow these, they are sold to supplement the household income and not for self-consumption. Consequently, diets are often deficient in protein and micronutrients, such as Fe, Ca and vitamin A (Sheehy et al. 2019; Baye et al. 2019). In rural Ethiopia the risk of vitamin A deficiency reaches 60.3% and of iron 86.3% (Seyoum et al. 2018).

The evidence suggests that nutrition-sensitive agriculture interventions can have a positive impact on dietary diversity (FAO 2017), and that growing various foods diversify the diets and improves the nutritional status of individuals. In this regard, an important alternative are the underutilized, semi-domesticated, wild crop species. Underutilized plant species are those whose cultivation has been neglected due to various constraints, e.g. require traditional management, are suited to specific environments, need laborious processing, are subject of poor grading and packaging, their taste is unfamiliar, their nutritional properties are unknown, and even are subjects of social taboos (Padulosi et al. 2013; Cernansky 2015). Underutilized species have long been part of local cultures and traditions in many parts of the world. For instance, about 300 million people collect products from the forests (Bharuch and Pretty 2010) that regularly include fruits, leafy vegetables, nuts, seeds and edible oils (Belcher et al. 2005). These species support diet diversification and address seasonal food and nutritional gaps by what is called "hidden harvest" (Pol 2002, Power et al. 2015). Furthermore, they are bonded to the land uses different to agriculture (e.g. forests), and come under pressure as their habitats deteriorate through agricultural expansion (Senbeta et al. 2010). Thus, many of these underutilized species, along with the traditional knowledge about their cultivation and use, are being lost at an alarming rate. Moreover, despite their value and contribution to the global food basket, underutilized species are often excluded from official statistics in terms of their economic value (Bharuch and Pretty 2010).

In Ethiopia, over 200 wild and semi-domesticated edible plant species have been documented (Fentahun and Hager 2009; Senbeta et al. 2010; Lulekal et al. 2011). Notable is the prevailing negative connotation bonded to their use (Fentahun and Hager 2009), which is related to the homogenization of eating habits that exclude them, the lack of information about their nutritional value, and the limited knowledge on their production and postproduction (Balemie and Kebebew 2006). The underutilization and marginalization of these species may also be attributed to the lack of scientific knowledge on their nutritional and antinutritional properties, which is the *raison d'être* of this study: to identify, characterize and determine the nutritional content of selected underutilized edible plants in agroforestry systems of southwestern Ethiopia.

Materials and methods

This study combined various methods, which included households surveying, experts interviews, botanical characterization and biochemical laboratory analyses, which were ensembled to provide a comprehensive view on the local underutilized species.

Study site

This study was undertaken in the Yayu area of southwestern Ethiopia, from May to December 2016. The area comprised of six *Woredas* (districts), out of which four, namely Chora, Doreni, Hurumu and Yayu, were selected for sampling. The Yayu area is regarded as having the highest forest cover in Ethiopia (Tulu 2010). It is characterized by a rolling topography, dissected by two major rivers: Geba and Dogi. The elevation ranges from 1140 to 2562 m above sea level and the area extends from 08°00′42′' to 08°44′23″ N and 35°20′31″ to 36°18′20″ E (Gole et al. 2003). The annual temperature varies between 12.7 °C and 26.1 °C on average, and the mean annual precipitation is 2100 mm, oscillating from year to year from 1400 to 3000 mm (Gole et al. 2008).

Comprising 167,000 ha and about 320,000 inhabitants (CSA 2007), the Yayu area overlaps with the *Yayu Coffee Forest Biosphere Reserve* established by UNESCO in 2011 (Fig. 1). This is one of the last remaining montane rainforests containing wild *Coffea Arabica* (Gole et al. 2009). Hence, it plays a significant role in natural and cultural conservation, and also for the local economy. Yayu rural households depend greatly on coffee cultivation. More than 60% of the population depends financially on coffee production and coffee-related activities, such as its collection, processing and trade (Gole et al. 2008). Other predominant crops are khat (*Catha edulis*), maize (*Zea mays*), sorghum (*Sorghum bicolor*) and tef (*Eragrostis tef)*.

Species identification, selection and sampling

This research was a subset of a major study on the roles of agroforestry systems on human nutrition. Data collection applied a multistage systematic sampling. The proximity of a household to the forest (core biosphere reserve) and market (urban agglomeration) were the extremes that defined the sampling sites. Accordingly, eight sites/*Kebeles* (lowest administrative unit) in four *Woredas* (district-equivalent) were selected (Callo-Concha et al. 2019; Jemal et al. 2018). Three hundred households (n = 300) were randomly selected, and an ethnobotanical survey implemented to identify and document all edible plant species, and the householders' practices, opinions, perceptions and preferences towards these. Three successive subsettings were implemented, considering: (i) all useful species growing in agroforestry plots, (ii) all edible species, by consulting knowledgeable individuals, and (iii) the species available at the time of the sampling (seasonal availability) (Jemal 2018).

Key informants (n = 40), were interviewed to identify the species usefulness and widespread cultivation. Field assessments, guided by local agronomists and botanists, were conducted to identify and characterize the species in the field. This has helped us to validate the preferences of the interviewees and document the most liked ones. We also contrasted our list with a specialized database (Fern and Fern 2014), to refine the information accuracy. In the case of unknown species, a voucher specimen was taken to the National Herbarium of Ethiopia for final identification. From the general interviews, the 12 most commonly recalled were selected for further analyses (see Table 1).

Although the main goal was to identify wild edible plants and analyze their biochemical content that determine the nutritional quality, we also collected some socioeconomic information, which included the species current use status, mode of preparation and consumption, type of management, and other uses.

Nutrient content analyses

Sample preparation

In the field, samples of about 500 g of main edible parts, e.g., leaf, stem, tuber, root or fruits, were stored in an icebox to be transported to the laboratory. Leaf samples were washed and chopped to a uniform size. Tubers were peeled, washed and cut into small pieces, which later were pulverized. Fruit pulp was washed and separated from the seeds. These were oven-dried at 60 °C until reaching constant weight, and grounded to fine powder. Samples were then labelled in plastic bags and stored at room temperature. Similarly,

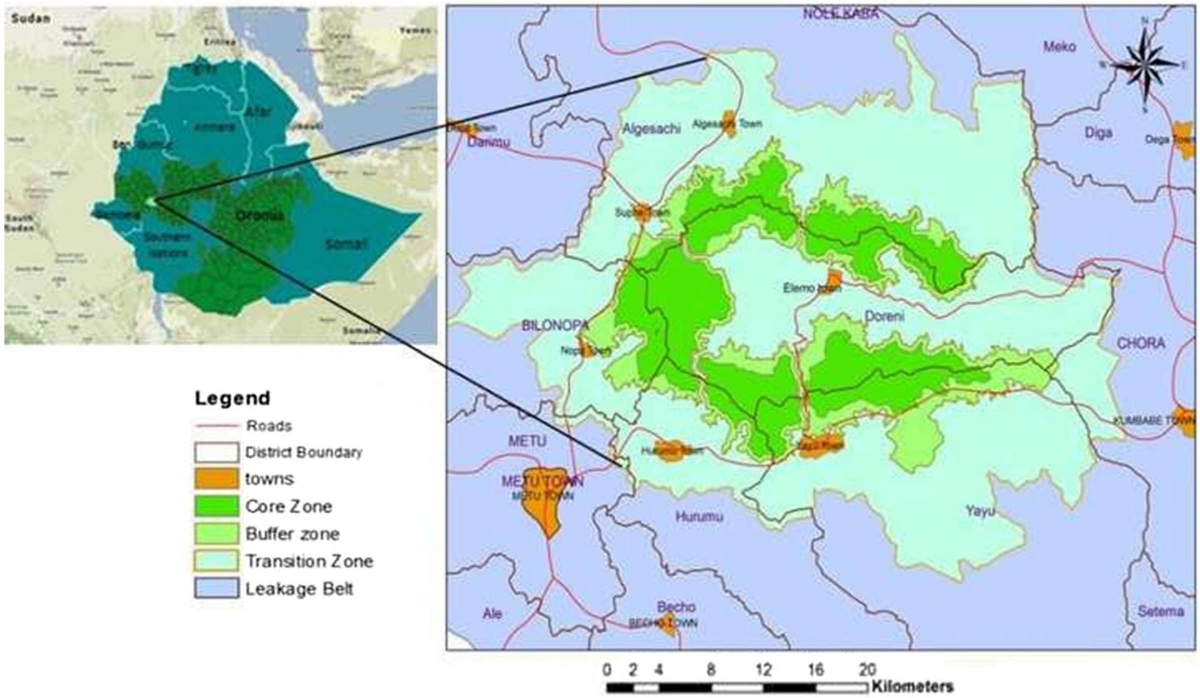

Fig. 1 Location of the Yayu Coffee Forest Biosphere Reserve; *Source*: Adapted by the Authors from Gole et al. (2009)

Table 1 Characterization of the 12 shortlisted edible plant species

Species	Local name (Afaan Oromo)	Common name	Edible part
Amaranthus graecizans L.	Liima	Short-tepalled pigweed	Green leafy vegetable
Solanum nigrum L.	Obxi	Black nightshade	Green leafy vegetable
Hypolepis sparsisora (Schrad.) Kuhn.	Giixo	False bracken	Green leafy vegetable
Portulaca oleracea L.	Meteri	Hogweed	Green leafy vegetable
Dioscorea alata L.	Boyna	Purple yam	Root/tuber
Dioscorea cayenensis Lam. (yellow)	Buri	Guinea yam	Root/tuber
Dioscorea prehensilis Benth. (white)	Buri	Yam	Root/tuber
Ficus sycomorus L	Harbo	Sycamore fig	Fruit
Rubus apetalus Poir.	Gora	Raspberry	Fruit
Syzygium guineense Wall.	Bedesa	Water berry	Fruit
Tristemma mauritianum J F Gmel.	Bedesa	Tristemma	Fruit
Carissa spinarum L.	Agamsa,	Bush plum	Fruit

Note Abbreviation in the species name represented its botanical author. L.: Carl Linnaeus (1707–1778); Kuhn.: Friedrich Adalbert Maximilian Kuhn (1842–1894); Lam.: Jean-Baptiste Lamarck (1744–1829); Benth.: George Bentham (1800–884); Poir.: Jean Louis Marie Poiret (1755–1834); Wall.: Nathaniel Wolff Wallich (1786–1854) and J F Gmel.: Johann Friedrich Gmelin (1748–1804)

depending on the analyses, all freshly prepared samples were labelled and stored in a deep freezer (−20 °C). Proximate food composition, vitamins and antinutritional factors analysis was performed at Jimma University, Ethiopia, and the minerals content was analyzed at the University of Bonn, Germany.

Minerals and vitamins content determination.

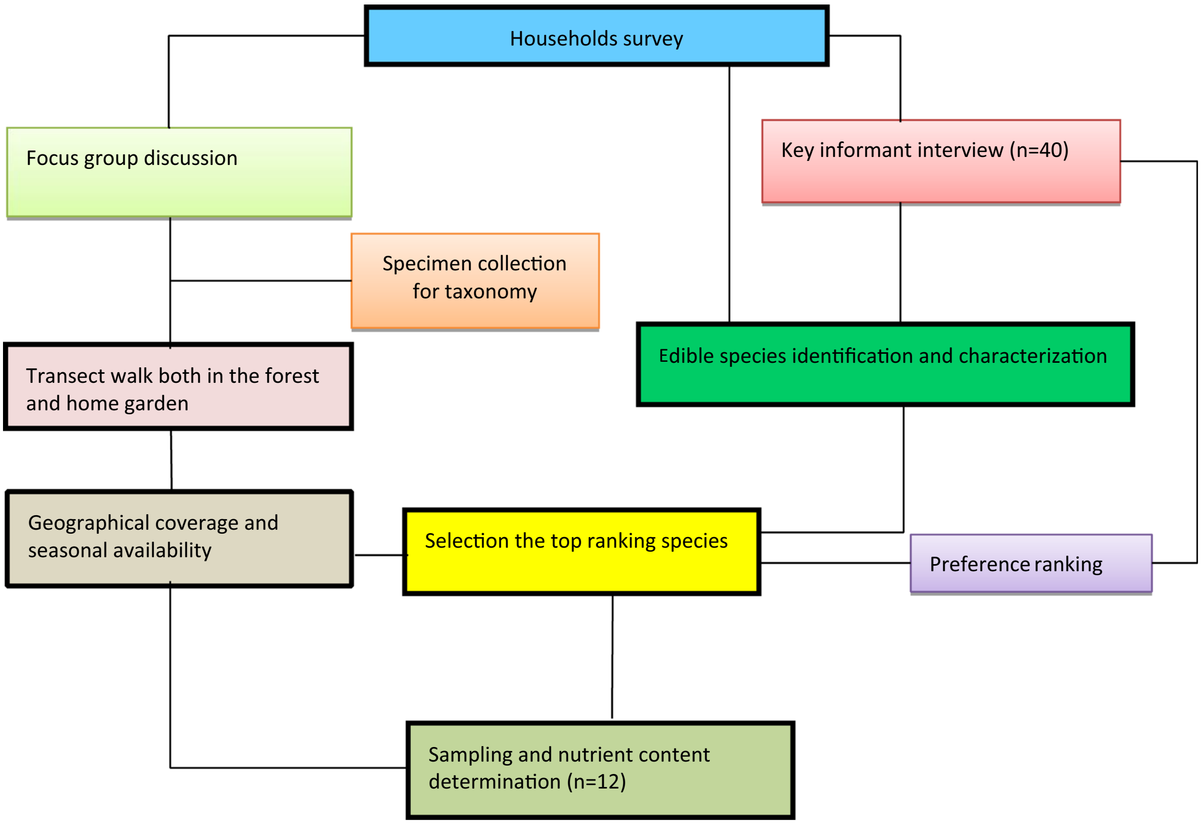

Fig. 2 Process of selection of underutilized edible species

The mineral concentrations were determined in accordance with the methods of the Association of Official Analytical Chemists (AOAC 2003). The total beta-carotene content was determined by spectrophotometry using the method described by Sadler et al. (1990) with a few modifications. Ten gram of the samples were placed in a 125-ml flask, and 100 ml of hexane–acetone-ethanol (50:25:25), and extraction solvent containing 0.1% BHT was added to the flask. This was wrapped in aluminium foil and agitated for 10 min on a wrist action homogenizer (PLTYRON®2500E, Switzerland). The solution was then mixed with 1 g $CaCl_2.2H_2O$ and gently shaken for 30 min by a mechanical shaker. After adding 15 ml distilled H_2O, the solution was shaken again for 15 min. The organic phase containing beta-carotene was separated from the water phase using a separation funnel and filtered through 0.45-µm membrane filters.

Sample handling, homogenization and extraction were performed under low light and at 4 °C to minimize photo-isomerization and oxidation of carotenoids. Each sample was analyzed three times (n = 36) and an average value calculated. The beta-carotene content in the sample and beta-carotene standard (Sigma Aldrich) were estimated from absorbance read at 450 nm using spectrophotometry (UV–Vis spectrophotometer, T80 China). The beta-carotene content was calculated using a regression equation after the analysis of the standard curve and expressed as µg RAE per 100 g edible portion. Vitamin C content was determined by iodometric titration using the method described by Sowa and Kondo (2003).

Antinutritional factors content determination

The colorimetric assay of phytate was determined using spectrophotometry following the method applied by Vaintraub and Lapteva (Vaintraub and Lapteva 1988). Tannin was determined using spectrophotometry based on the Maxson and Rooney method (Maxson and Rooney 1972). The oxalate content was determined with permanganate titration as described in the method (Ukpabi and Ejidoh 1989).

Data analysis

Each experiment was executed in triplicate. Descriptive statistics for mean values and standard errors were calculated for minerals, vitamins and antinutritional factors content determination and comparison. One-way analysis of variance (ANOVA) and *t*-test were applied, and the least significance differences (LSD) post-hoc test implemented to compare the means. Calculations were done by the R-software, specifically by the agricolae package (Free Software Foundation Inc. USA).

Results and discussion

Underutilized edible species

Ninety-four (94) edible plant species were identified and their use documented. They belong to 79 genera and 41 families. The most abundant genera are Moraceae and Rutaceae (8 species each), Poaceae (7), Fabaceae (6), Solanaceae (5), Brassicaceae and Rosaceae (4 species each) and Dioscoraceae, Zingiberaceae and Meliaceae (3 species each).

It was recorded that most of the 94 species identified, are casually picked and consumed mostly while doing agricultural and forestry-related and by searching for traditional medicines. In lesser extent when community members enter to the forest for purposes such as collecting materials for farm tools, preparing charcoal, gathering construction materials and hunting. However, they also reported a current decrease in collection of forest foodstuff, which does not mean an abandonment but rather tells on their importance as repository during shortage of other agricultural products: '*This forest* [Yayu] *is our food bank, whenever necessary I go to the forest and collect fruit for myself and family, so I keep on watching the forest*' (*Kochina Geba Village*, *30/05/2016)*. However, it was also pointed out that the rapid conversion of forest to farmland and the decreasing productivity of forests poses challenges to local peoples, thus some of them have started to collect some of these species and transplanted in their home gardens. Another common practice is to purposefully leave some edible species, for instance regarding valuable trees species that provide shade but also produce fruits.

From a list of preferred 25 edible species, either under cultivation or (semi)domesticated, the 12 available during the study period were taken for nutritional analysis. The 12 shortlisted species belong to fruits, vegetables and roots and are consumed as fruit, leaf and tuber, respectively. Fruits are found in agroforestry multistorey systems, while vegetables and roots mostly occur in homegardens and the later receives occasional management (Table 1).

Green leafy vegetables grow in a large part of southwestern Ethiopia during the rainy season, and often are consumed to help to bridge the food shortage gap when the staple crops are not yet harvested (Uusiku et al. 2010). That is the case of *Amaranthus graecizans*, *Solanum nigrum*, *Hypolepis sparsisora* and *Portulaca quadrifida,* that are mostly available between July and September, and therefore are called "ye kiremt migboch" (summer foods in Amharic language) (Stellmacher and Kelboro 2015); although may also be cultivated during the dry season through supplemental irrigation (Senbeta et al. 2010). Fruits and tubers, on the other hand, are abundant in the dry season, when are consumed raw and sometimes processed, e.g. as juices. In terms of management, fruits such *as Carissa spinarum and Syzygium guineense* are not cultivated regularly but collected instead. Tubers like *Disocorea prehensilis*, a wild yam growing in the understory of coffee forests, has not been widely acknowledged as food stuff, but we have found to be rich in key nutrients. Still, most of these species are also consumed in other parts of the country. For example, edible fruit bearing species such as *Ficus sycomorus* and *Syzygium guineense* in Derashe and Kucha districts of southern Ethiopia (Balemie and Kebebew 2006).

Energy and micronutrients

The leaves of *Amaranthus graecizans, Hypolepis sparsisora*, *Portulaca oleracea* and *Solanum nigrum* hold the highest content of protein: 17.95, 18.43, 15.62 and 19.26 g/100 g dry EP, respectively. Similar results have been reported for other green leafy vegetables in other parts of Africa. For instance, the amount of protein obtained in *Amaranthus gaecizans* is comparable with values reported from Mali and northern Senegal, that range from 17.92 to 23.2 g/100 g dry EP (Becker 1983; Akubugwo et al. 2007). In addition, Venskutonis and Kraujalis (2013), have conducted an extensive review on *Amaranthus spp* and found out that its protein content in leaves vary from 14 to 30 g/kg FW g in the wild, and among cultivars, values that are consistent with our results.

The identified green leafy vegetables were also rich in Ca, Fe and Zn. *A. graecizans* (2065 mg/100 g dry EP) had the highest Ca content, while *S. guineense* the lowest (65 mg/100 g dry EP). Values in the remaining species varied in the range of 75–1225 mg/100 g dry EP. Similarly, Fe and Zn contents varied significantly among the fruit- and leafy vegetable-provider species ($p \leq 0.05$), but the Fe content was higher in leafy vegetables and tubers. The highest Fe content was found in *A. graecizans* (91.29 mg/100 g dry EP) followed by *D. cayenensis* (46.78 mg/100 g dry EP) and *P. oleracea* (44.51 mg/100 g dry EP). Furthermore, we found significantly high amounts of Zn (6.51 and 4.33 mg/100 g dry EP) in *R. apetalus* and *P. oleracea*, respectively (Table 2).

A precedent study showed that mature leaves of *P. oleracea* contain particularly high amounts of Ca, Fe and Zn (Uddin et al. 2012), and also omega-3 fatty acid, α-tocopherol, ascorbic acid, β-carotene and glutathione are abundant in shoots (Wenzel et al. 1990), considering it a source of minerals, vitamins and antioxidants for functional foods and nutraceutical applications (Wenzel et al. 1990). This evidence suggests, that the consumption of *A. graecizans D. cayenensis* and *P. oleracea* could substantially address the persistent iron deficiency in the Yayu, where 96.4% of women at productive age lack in their diets during shortage season (Jemal 2018).

The beta-carotene content varied significantly among species, in the range of 110 – 1940 µg/100 g fresh EP (9.2 – 161.67 µg RAE /100 g fresh EP, considering the latest conversion factor). The species with the highest content was *R. apetalus* (161.67 µg RAE/100 g fresh EP), likely associated with its yellow pigment (as we applied the spectrophotometric method, there is a limitation in differentiating beta-carotene from other carotenoids and chlorophyll). Hence, we have estimated that 100 g of *R. apetalus* can provide nearly 50% of the daily recommended vitamin A required by children, 23% to female adults and 21% to pregnant women of the recommended dietary intake. Similarly, 100 g of fresh leaves of A. graecizans (75 µg RAE/100 g EP) would contribute 20% of the recommended intake of vitamin A for children, 13% for females, and 11% for pregnant women (NIH 2018).

The vitamin C content also varied significantly among species in the range between 126.88 and 330.72 mg/100 g fresh EP, being higher in the fruits of *S. guineense* (330.72 mg/100 g fresh EP) and *R. apetalus* (294.19 mg/100 g fresh EP), and in *A. graecizans* (Table 2). The obtained values agree with those reported for sub-Saharan Africa and India (Stadlmayr et al. 2013). In the case of tubers of *D. cayenensis* and *D. prehensilis*, although their vitamin C content is high, their dietary contribution is difficult to calculate, as vitamin C content is greatly affected by temperature (Hernández et al. 2006). In this line, reductions in vitamin C due to cooking have been reported in *Amaranthus spp.* (65%), dried *V. amygdalina* (61%), and almost 100% in dried *A. digitate* (Yadav and Sehgal 1995; FAO 1990).

Antinutritional factors

Antinutritional factors are compounds intrinsic to the composition of species that limit the utilization of nutrients by humans and animals that consume them (Soetan and Oyewole 2007). High phytate content inhibits the bioavailability of minerals (FAO and WHO 2001). In the shortlisted species, the phytic acid content varied significantly from 31.06 µg/100 g fresh EP (*D. prehensilis)* to 601.65 µg/100 g fresh EP (*C. spinarum)*. Values were especially low in tubers: *D. alata*, *D. cayenensis* and *D. prehensilis*, whose content ranged between 31.06 and 96.48 µg per 100 g fresh EP (Table 2). These values are lower to the ones reported in Nepal for similar species (Wanasundera and Ravindran 1994). Similarly, the phytate content in *S. nigrum* (536 µg/100 g EP) are slightly lower compared than the values obtained in a similar study conducted in Nigeria (Akubugwo et al. 2007). As Ca and phytates determine the bio-availability and absorption of Fe. The benefits of iron-rich green vegetables and fruits in preventing anaemia depend not only on the intake itself, but also on the presence of ascorbic acid, which contributes to its absorption. According to the daily recommended calcium intake for all age groups (800–1200 mg), a 50 g of fresh

Table 2 Minerals, Vitamins and Antinutritional factors content of 12 edible plant species (per 100 g EP)

Species	Calcium	Iron	Zinc	Vitamin C	β- carotene	Phytate	Tannin	Total Oxalate
	(mg)	(mg)	(mg)	(mg)	(mg)	(μg)	(μg)	(mg)
A. graecizans	2065 ± 195.0^{a}	91.29 ± 0.75^{a}	3.81 ± 0.13^{d}	180.70 ± 19.67 ^{cd}	0.90 ± 0.14^{b}	418.75 ± 10.86^{d}	405.40 ± 75^{e}	4.22 ± 1.41^{a}
C. spinarum	130 ± 10.00^{f}	4 ± 0.53^{f}	1.33 ± 0.05^{i}	256.55 ± 9.66^{b}	0.14 ± 0.02^{f}	601.65 ± 1.11^{a}	1313. ± 89^{c}	0.84 ± 0.28^{e}
D. alata	75 ± 5.00^{f}	12.83 ± 0.00^{e}	2.20 ± 0.08 ^{g}	131.06 ± 25.60^{e}	0.51 ± 0.06^{d}	90.17 ± 4.87 ^{h}	ND	2.46 ± 0.35^{bc}
D. cayenensis	1225 ± 25.00^{b}	46.78 ± 0.75^{b}	3.83 ± 0.00^{d}	259.33 ± 47.50^{b}	0.22 ± 0.02^{f}	96.48 ± 6.72 ^{h}	837.41 ± 130^{d}	2.81 ± 0.00^{b}
D. prehensilis	80 ± 10.00^{f}	12.82 ± 2.26^{e}	2.33 ± 0.00 ^{g}	296.15 ± 33.58^{ab}	0.11 ± 0.02^{f}	31.06 ± 1.65^{i}	ND	2.81 ± 0.28^{b}
F. sycomorus	321.17 ± 2.93^{e}	14.69 ± 0.71^{de}	4.95 ± 0.17^{b}	179.58 ± 37.64 ^{cd}	0.18 ± 0.02^{f}	372.79 ± 68.80^{e}	1963 ± 241^{b}	1.83 ± 0.42 ^{cd}
H. sparsisora	760 ± 10.00^{f}	28.29 ± 0.38^{d}	3.16 ± 0.03^{a}	197.99 ± 12.78^{c}	0.16 ± 0.01^{f}	155.80 ± 1.11^{f}	ND	1.83 ± 0.42 ^{cd}
P. oleracea	785 ± 145.00^{c}	44.51 ± 8.30^{b}	4.33 ± 0.10^{c}	191.02 ± 15.83^{c}	0.35 ± 0.03^{e}	227.30 ± 18.32^{f}	ND	2.32 ± 0.21^{bcd}
R. apetalus	150.00 ± 20.00^{c}	18.48 ± 1.13^{c}	6.51 ± 0.08^{f}	294.19 ± 41.90^{ab}	1.94 ± 0.19^{a}	218.80 ± 6.30^{f}	ND	2.11 ± 0.42^{bcd}
S. nigrum	585.00 ± 5.00^{d}	24.14 ± 3.02^{c}	1.60 ± 0.08 ^{h}	126.88 ± 13.44^{e}	0.75 ± 0.57^{c}	536.48 ± 10.85^{b}	756.03 ± 139^{d}	1.41 ± 0.28^{de}
S. guineense	65 ± 5.00^{f}	24.90 ± 3.02^{c}	1.38 ± 0.25^{i}	330.72 ± 27.81^{a}	0.13 ± 0.03^{f}	480.15 ± 7.67^{c}	3973.75 ± 422^{a}	1.69 ± 0.84^{cde}
T. mauritianum	275 ± 25.00^{e}	24.90 ± 2.26^{c}	3.56 ± 0.03^{e}	136.64 ± 12.77^{de}	0.15 ± 0.04^{f}	225.31 ± 21.86^{f}	315.91 ± 90^{ef}	2.53 ± 0.28^{bc}

ND not determined; *Values followed by different lower-case letters are significantly different at $P \leq 0.05$ (Fisher test of Least Significance Difference, LSD) leaves of Amaranthus could provide a daily Ca requirement.

Tannins are also undesirable in high levels, as by interacting with proteins, starch and digestive enzymes, reduce the nutritional value of foods (Chung et al. 1998). Tannins content was the highest in the fruits of *S. guineense* (3.97 mg/100 g fresh EP) followed by *F. sycomorus* (1.96 mg/g fresh EP). However, out of the 12 species analysed, in 5 species no tannins were detected, but in the other 7 the content varied significantly ($p < 0.05$) from 3.15 mg/ g EP (*T. mauritianum*) to 3.97 mg/ g fresh EP (*S. guineense*) (Table 2). These low values might also be consequence of the freezing, as long freezing periods were reported to reduce the tannin content in some vegetables (Aregahegn et al. 2013). Its value in *C. spinarum* (1.31 mg/g 100 g fresh EP) was consistent with Ambika et al. (2015).

The oxalate content also varied significantly ($p < 0.05$) from 0.84 – 4.22 mg/100 g fresh EP, the highest were found in the leaves of *A. graecizans* and the fruits of *C. spinarum* (Table 2). In the case of *Dioscorea* spp. (2.46—2.81 mg/100 g), was found to be lower compared to values in other reports (Wanasundera and Ravindran 1994; Bhandari and Kawabata 2004). However, variations in oxalates content differ by cultivar, planting and harvesting conditions; and it is also known that their detection may vary depending on the analytical techniques applied. Nevertheless, all green vegetables and tubers analysed are consumed cooked, which reduces the levels of phytates, tannins and oxalates. For example, *S. nigrum* loses its bitter taste after cooking (personal experience).

Finally, Ca, Fe and Zn contents, as well as the calorific value, were the proxies used to compare the nutritional potential of underutilized species against commonly cultivated crop species. Almost all green vegetables identified provide significantly less energy compared to popular crops species like tef (*Eragrostis tef*), maize (*Zea mays*), sorghum (*Sorghum bicolor*), bean (*Phaseolus vulgaris* L.) and enset (*Ensete ventricosum*), with the exception of yam (*D. cayenensis*), whose energy values are similar to tef, maize and enset. However, regarding protein, mineral and vitamin contents, the species analysed have shown higher values compared to the species commonly consumed. Some underutilized species showed up to tenfold higher content of Ca, as it is the case of the leaves of *A. graecizans,* when compared to tef seeds. Similarly, *Portulaca oleracea* is considered a weed plant by many people in Ethiopia, but its leaves and stems contain high amounts of Fe, Zn and vitamin C, e.g. twice the amount of Fe in maize. Indigenous fruits such as *C. spinarum* and *S. guineense* were observed to provide higher energy values than commonly consumed exotic species, such as mango (*Mangifera indica*) and papaya (*Carica papaya*).

In Jemal (2018) assessment of Yayu rural householders' diets, iron happened to be the most critical nutrient, notably low in women in reproductive age and children under five years old; furthermore, the situation tends to worsen in the food scarcity seasons, leading to potential chronic deficiencies (Jemal 2018). Such a situation is not exclusive to Yayu, but reported country wide (CSA and WFP 2014). Our findings state that in terms of vitamin provisions some of the underutilized plants can be a promising alternative, for example *R. apetalus*, capable to hold up to 10 times more beta-carotene than mango (Table 3).

Conclusions

It is documented that most households in Yayu face food shortages during the rainy season (June–August). We stand that the detected underutilized species can contribute to bridging this food shortages gap, and some of them, like fruits produced during the dry season (January-April), also can help to improve the overall quality of householder diets.

Among the found species, leafy vegetables, such as *Amaranthus graecizans*, *Portulaca oleracea* and *Solanum nigrum,* have proved to be good sources of protein and minerals (Ca, Fe and Zn). While other species were reported to be good sources of provitamin A (*Rubus apetalus*) and vitamin C (*Syzygium guineense*), at the same time that contain relatively low amounts of antinutritional factors. Furthermore, it was found that the nutritional values of the analysed species is comparable and sometimes higher than the ones of conventionally cultivated crops, e.g. *Portulaca oleracea* provides more dietary Fe than maize.

This study shows that an increase in the food and nutrition standards of Yayu inhabitants are feasible and, more importantly, depends almost exclusively of the householders themselves. However, the use of these underutilized edible species require of additional research and development. Key aspects include:

Table 3 Nutrient content values of the identified underutilized species against values of popular crop species in Yayu per 100 g dry edible portion

Edible plant species	Energy	Calcium	Iron	Zinc	Vitamin C	Vitamin A
	(kcal)	(mg)	(mg)	(mg)	(mg)	RAE (µg)
A. graecizans	141.99	2065	91.29	3.81	180.7	150.00
Tef (*Eragrostis tef*) (uncooked)[1,2]	(178, 367)	(86.0, 180.0)	(50.20, 7.63)	(1.10, 3.63)	0.0, NA	(5.20, 0.0)
P. oleracea	97.2	785	44.51	4.33	191.02	58.33
White maize (*Zea mays* L.) (whole grain)[1,2]	(192.0, 365	(10.50, 7.0)	(22.80, 2.71)	(1.23, 2.21)	0.0,	(3.60, 0.0)
S. nigrum	106.1	585	24.14	1.60	126.88	125.00
Sorghum (*Sorghum bicolor*) grain)[1,2]	(171.0, 359)	(10.40,12)	(6.30, 3.14)	(0.84, 1.63)	0, 0.8	(34.6, 0.0)
D. cayenensis	182.96	1225	46.78	3.83	259.33	36.67
Enset (*Ensete* ventricosum) (baked)[1,2]	(178, NA)	(71.3, NA)	(2.80, NA)	(0.42, NA)	(0.00)	(0.00)
Field bean (*Phaseolus vulgaris*) (seed)[1,2]	(162, 29)	(72.70, 17)	(2.40, 0.81)	(1.10, 0.40)	(0.0, 38.7)	(3.50, 0.0)
Avocado raw (*Persea americana*)[1,2]	(121, 160)	(19,12)	(1.4, 0.55)	(NA, 0.64)	(18, 10)	(530, 7)
S. guineense	244.54	65	24.90	1.38	330.72	21.67
C. spinarum	252.3	130	4	1.33	256.55	23.33
Mango (*Mangifera* indica)[1,2]	(60, 60)	(24, 11)	(1.2, 0.16)	(NA, 0.09)	(42, 36.4)	(3200, 54)
R. apetalus	151	150	18.48	6.51	294.19	323
Papaya[1,2]	(32, 43)	(21, 20)	(0.6, 0.25)	(NA, 0.08)	(42, 60.9)	(950, 47)
Banana (*Musa* spp.)[1,2]	(88, 89)	(9, 5)	(1.4, 0.26)	(NA, 0.15)	(9, 8.7)	(120, 3)
Coffee (*Coffea* arabica)[1,2]	(384, 353)	(416, 141)	(7.7, 4.41)	(NA, 0.35)	-	-

NA: data not available; '-' not determined; [1]FAO- Food composition table for use in Africa (FAO and EHNRI 1998); [2] USDA-National nutrient database (USDA 2018)

Note Nutrient compositions for staple foods are given for unprocessed foods, while fruit species are considered as raw, ripe, edible parts. Energy value in calories (FAO report), and kcal (USDA nutrient database)

harvesting, postharvest processing, storage, preparation, bioavailability and marketing, not only to improve the food safety and quality, but also to minimize waste and promote their effective and sustainable use.

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Declarations

Conflicts of interest The authors have declared no conflict of interest.

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