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Nutritional and ecoclimatic importance of indigenous and naturalized wild edible plant species in Ethiopia

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ABSTRACT

Wild edible plant species (WEPs) are sources of food, nutrition, and medicine to people. However, often, the nutritional value of WEPs is unknown. This study was conducted to determine proximate and mineral contents of *Balanites aegyptiaca, Cordia africana and Ziziphus spina-christi* fruit. Fruit samples were collected from 10 trees of each species from Northern and Rift Valley region of Ethiopia. Fruit samples from the same species and district were mixed to form a composite sample, then dried, ground to powder and used for chemical analysis. We found a comparable amount of mean crude protein contents in *C. africana* and *B. aegyptiaca*. The fiber content was higher in *B. aegyptiaca* and *Z. spina-christi*. Carbohydrate and energy content were higher in *Z. spina-christi* compared to other study species. We found higher values of calcium in *B. aegyptiaca* and *Z. spina-christi* potassium, iron and zinc contents of *B. aegyptiaca* and *C. africana*, exceeded the value found in *Z. spina-christi* by about 50%. Our findings confirmed that the studied food tree species are potential sources of macronutrients and minerals. Therefore, promoting their sustainable use and increasing their abundance on different landscapes through Agroforestry system is critical to improve food availability and landscape resilience to climate change impacts.

1. Introduction

Globally, malnutrition is among the greatest current societal challenges, causing vast health, economic and environmental burdens (Behrman, 2020). Countries are also experiencing the double burden of malnutrition, where undernutrition coexists with overweight, obesity and other diet-related non-communicable diseases (NCDs) (Akombi, Agho, Merom, Renzaho, & Hall, 2017; Behrman, 2020; WHO, 2017). More importantly, poor diet and the resulting malnutrition are more sever in Sub-Saharan Africa (SSA) and are becoming an increasingly public health problem (Akombi et al., 2017; WHO, 2017) with a basic lack of protein and energy foods and micronutrients (Ritchie & Roser, 2017). In the SSA region, malnutrition-induced stunting prevalence differs across countries, ranging from 7.9% to 57.7%, with a mean of 30% for the region (WHO, 2017). Similarly, the stunting rate across regional states of Ethiopia varies between 22% and 52%, with 44.4% of national level stunting prevalence, which put the country among the top ten countries with a very high stunting prevalence in the world (Akombi et al., 2017; WHO, 2017). Furthermore, one in ten children in Ethiopia is wasted and suffering from acute malnutrition. Hence malnutrition is the leading cause of child illness and death in Ethiopia (CSA-Ethiopia & ICF-International, 2012). Moreover, malnutrition is strongly linked with suboptimal brain development, which diminished cognitive capacity, immune systems, educational performance and economic productivity of nations. Partly, in response to the consequences of malnutrition, SSA countries have developed National Nutrition Programs (NNP) allied to Sustainable Development Goals (SDGs). However, most of SSA countries are still facing a great challenge and lagging, particularly in achieving SDG1 (ending extreme poverty), and SDG2 (ending hunger and all forms of malnutrition) by 2030, where Ethiopia ranked 126th out of 157 countries in progress toward meeting the SDGs (Sachs, Schmidt-Traub, Kroll, Durand-Delacre, & Teksoz, 2017). As a result of the complicated nature of malnutrition and its irreversible consequences, the global society has called for a comprehensive and multi-sectoral approach to

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improving nutrition in developing countries, focusing on agriculture and food systems (Claydon, 2018). To this line, Ethiopia has developed multisectoral NNPs to realize optimal nutritional status for all Ethiopians and to end hunger by 2030, which have tree-centered strategic objectives, such as to create nutrition-sensitive agricultural interventions through agroforestry system, conserve forest areas for wild food sources and conduct research to identify suitable agroforestry tree species (GFDRE, 2016).

Globally, about 30,000 edible plant species currently have a documented use, but only 150–200 have ever been cultivated widely (RBG

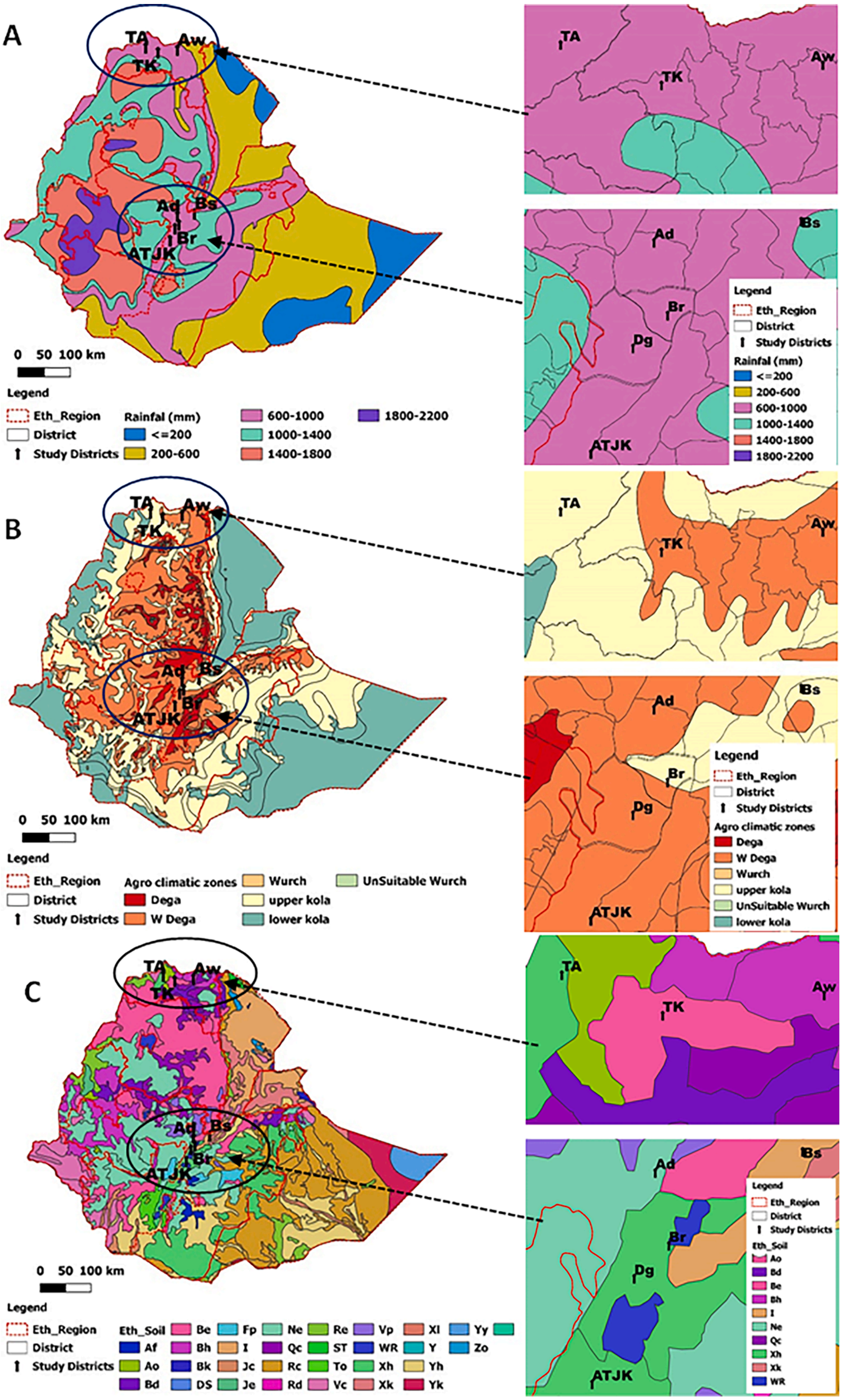

Fig. 1. Characteristics of the study site: Rainfall (A), Agro-ecological (B), and soil properties (C) of the study area. of Ethiopia. In Fig. 1B. Terminologies, Wurch (cold and moist). Dega (cool and humid), Weyna Dega (cool sub-humid), Upper Kola (warm semi-arid), Lower Kola/Berha (hot arid).

Kew 2016). A contemporary industrial agriculture and modern global food systems have exacerbated the disappearance of many wild edible plant species due to over-reliance on crop monocultures of high-yielding, genetically uniform crops (IPES-Food 2016). Today only 12 crops and 5 animal species provide 75% of the world's food (Hunter et al. 2019), indicating that mainstream agricultural and food production systems are not sufficient to satisfy the nutritional and the environmental needs of the community. Thus, wild edible plant species, which may be collected from the wild or grown in traditional production systems with little or no external inputs, could play a potential role in diversifying diets as well as for combating the 'hidden hunger' caused by micronutrient deficiencies (Hunter et al., 2019; Padulosi, Heywood, Hunter, & Jarvis, 2011; RBG Kew, 2016). Therefore, countries in different parts of the world, particularly in SSA, could benefit from wild edible plants (WEPs) resources to achieve their SDGs by 2030 (IPES-Food, 2016). This is because, many countries in SSA region, including Ethiopia, have huge, but underutilized WEP resources, which are rich in available energy, micronutrients and minerals necessary to sustain and support human life (Lulekal, Asfaw, Kelbessa, & Van Damme, 2011; Lykke & Padonou, 2019). Moreover, WEPs have been consumed in several SSA countries for their dietary and medicinal value that may otherwise be scarce, hence they are means of survival for rural communities, especially during times of climate-induced environmental and humanitarian crisis (drought/famine flooding) (Lulekal et al., 2011; Lykke & Padonou, 2019). More importantly, WEPs are naturally adapted to local soils and climates, thus often survive environmental stresses better than introduced species (Zait & Schwartz, 2018). Thus, they should be maintained, improved and optimized through different silvicultural practice, particularly in in resources poor and drier environment, thereby to support the livelihoods of the poor living across inherently fragile and exposed to a range of climate-induced problems (Zait & Schwartz, 2018). Particularly, in Ethiopia, where the majority of the population are depending on the subsistent farming system, protecting and promoting the sustainable use of WEPs in concert with mainstream agricultural innovation efforts could play a substantial role to diversify livelihood income and build household resilience to food insecurity and climate change (GFDRE, 2016). However, little attention has been given to conserve WEPs of Ethiopia, hence facing a danger of loss due to complex environmental and anthropogenic impacts (Lulekal et al., 2011). In addition, information on the nutrient content of indigenous and underutilised food trees is often hard to find, hence, food trees that are rich in nutrient and minerals may therefore be overlooked in agriculture and nutrition development planning, projects and policies. Therefore, the purpose of this study is to investigate and document the nutritional values of WEP resources, thereby understanding the contribution of food trees for household food diet diversification and socio-economic improvement, and environmental protection.

2. Materials and methods

2.1. Study site, socio-economic and climate characteristics of the study regions

This study was conducted in the Northern and Rift Valley region of Ethiopia, considering the wider agroecological niches of the species (Fig. 1A, B). The study districts representing Northern Ethiopia (NE) were Taytay-Adiyabo (TA), Taytay-koraro (TK) and Adwa (Aw). Whereas sites representing the Rift Valley region of Ethiopia (RVE) were Boset (Bs), Bora (Br), Dugda (Dg), Adamitullu-Jido-kombolcha (ATJK) and Adaá (Ad) (Fig. 1A, B). Over 90% of the population in the study districts are heavily dependent on rainfed farming system and are extremely vulnerable to drought and drought related environmental and humanitarian crisis. In general, annual crop, livestock, and forest products are the main sources of income for the farmers in study districts.

Rainfall seasonality across the northern study sites were unimodal, extends from June to September with maximum rain received from June to August (Mokria, Gebrekirstos, Abiyu, Noordwijka, & Braüning, 2017). Based on data from CRU (1901–2018), the annual rainfall ranges from 276 − 883 mm (mean ± SE, 505 (±9 mm), 341–1093 mm (574 ± 12 mm), 293 – 1103 mm (567 ± 13 mm), in Taytay-Adiyabo, Taytay-Koraro and Adwa districts, respectively (Fig. 1A, Supplementary Fig. S1). Across the rift valley study sites, the rainfall is weakly bimodal with a shorter rainy season during the months of April and May, and the long rainy season occurs between the months of June and September (Supplementary Fig. S1). The annual rainfall varies from 697 to 1384 mm (mean ± SE, 837 ± 13 mm), 674–1302 (989 ± 12 mm), 705 – 1561 mm (1112 ± 14 mm); 614 – 1427 mm (957 ± 13 mm) in ATJK, Dugda/Bora, Adaá, and Boset woredas, respectively (Fig. 1A, Supplementary Fig. S1). Fig. 1C shows soil properties of the study areas. For details on dominant soil type in the study area, refer http://www.fao.org/soils-portal/data-hub/soil-classification/fao-legend/key-to-the-fao-soil-units/en/.

2.2. Study species, characteristics, and distribution

For this study, we selected *Balanites eagyptica (Desert date*) (Fig. 2A), *Cordial africana* (Fig. 2B), *and Ziziphus spina-Christi (*Christ's thorn jujube) (Fig. 2C) based on their geographical distribution across all the study sites and commonly used as a source of income, food, nutrition and medicine by the community inhabited the study sites (Lulekal et al., 2011). A detailed description of the study species can be found in the Supplementary Information.

2.3. Fruit sample collection and processing

Fruit samples were collected from 10 individual trees of each species from the study sites. Sample from the same species and district were pooled into one bucket to form a composite sample (Nyanga et al., 2013). The composite samples were washed with tap water, then laid on a plastic flat sheet on the floor of a clean house and left for a week for air drying at room temperature. Then, the whole fruits of *Cordia* and *Ziziphus* were peeled to separate from the stone. Whereas fruit samples of *Balanites* was collected following removing the hard seed coat. All species-specific fruit samples were cut into slices and separately spread on plastic flat-bottomed bowls for drying under room temperature. Finally, dried species-specific composite fruit samples were ground to a fine powder in a mixer grinder and sieved through the mesh and used for proximate and mineral analysis (Supplementary Fig. S5).

2.4. Proximate composition and mineral analysis

Dried and homogenized powdered fruit samples were analyzed for dry moisture, crude ash, crude fiber, crude fat, and crude protein according to AOAC (1990) official methods (AOAC, 1990; Murthy, Joseph, Gaonkar, & Payamalle, 2019). The crude protein was computed using the AOAC 920.152 – method from the sample percentage of nitrogen content as determined by the Kjeldahl procedure multiplied by a factor (6.25) (Nyanga et al., 2013) (Eq. (1)). *The laboratory analyses were conducted at Bless Agri Food Laboratory Services PLC (http://www.blesslaboratory.com/).*

$$\%\mathrm{Crudeprotein} = \%\mathrm{N}x6.25 \tag{1}$$

The crude fiber was calculated using AOAC 978.10 method from the loss in weight on the ignition of dried residue following the digestion of fat-free samples with 1.25% each of sulfuric acid and sodium hydroxide solutions (AOAC, 1990) (Eq. (2)).

$$Crude\ fiber\ (\%) = (\ (W1 - -W2)/W0\ )*100 \tag{2}$$

where: W0 = sample weight; W1 = crucible weight after drying; W2 = crucible weight after ashing.

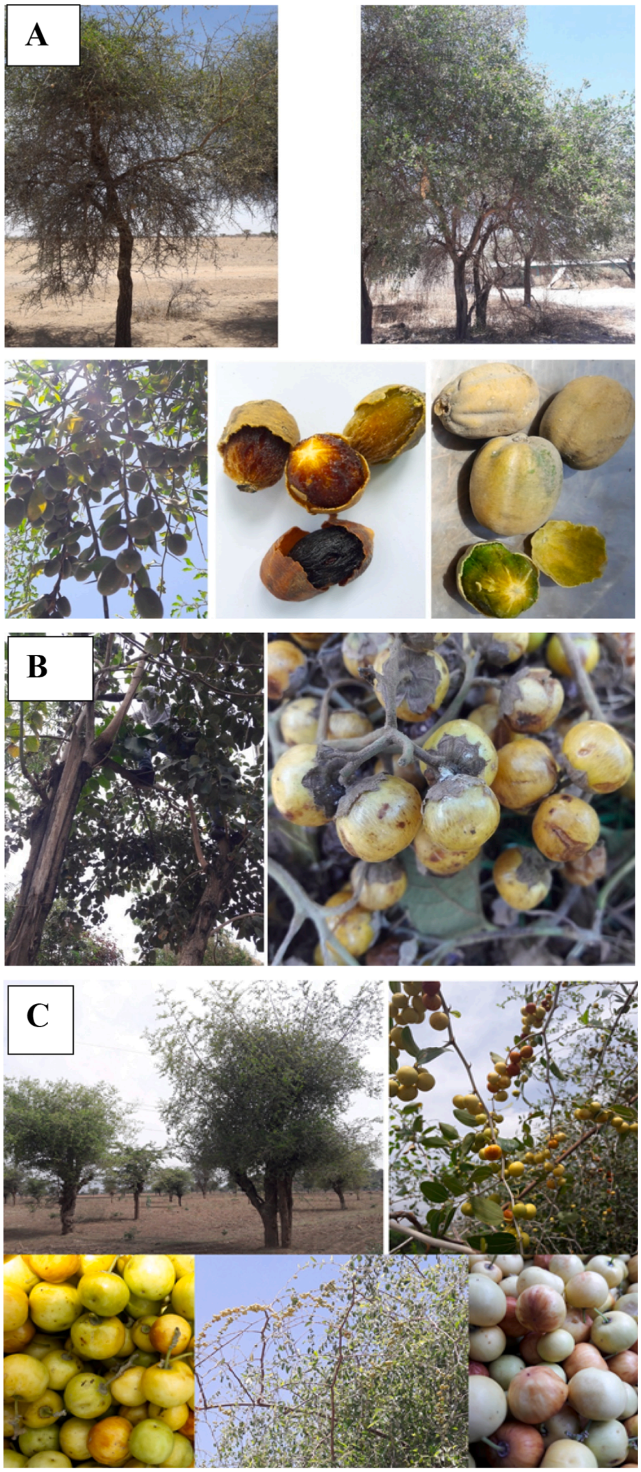

Fig. 2. *Balanites eagyptica* (A), Cordia africana (B) and Ziziphus spina-christi (C) tree with its fruits dispersed in farmlands (*Source: Mulugeta Mokria*).

Crude fat was determined using AOAC 2003.05 method followed by extraction with a Soxhlet apparatus for 70 min using diethyl ether as the extraction solvent. The solvent was evaporated from the extraction flask (aluminum cup), then the amount of fat is calculated from the difference in weight of the aluminum cup before and after extraction (Silvanini et al., 2014)

Moisture content was determined by drying the fruits at 92 °C in an oven until a constant weight was obtained (Method: AOAC 930.04, AOAC 2005) (Eq. (3)).

$$\text{Moisture content}(\%) = \frac{(\text{W1} - \text{W2})\text{X100}}{\text{SW}} \tag{3}$$

where: SW = sample weight. W_1 = the weight of cap and fresh sample, W_2 = the weight of dry sample and cap.

Furnace method (AOAC 940.26) was applied to determined Ash content, by burning in a muffle furnace at a temperature of 550 °C for l hours. Iron (Fe), Zinc (Zn), Copper (Cu), Calcium (Ca) and Potassium (K) were estimated using AOAC official methods AOAC 999. 10 and Atomic Absorption Spectroscopy (AAS). Total carbohydrate was obtained by calculating the difference (Carbohydrate % = 100 – (% moisture + % crude protein + % crude fat + % ash+%crude fiber). Potassium content was estimated by the Flame photometer. Energy content was estimated by multiplying the percentages of crude protein, crude fat and total carbohydrates by 4, 9 and 4 respectively (Kassegn, 2016).

2.5. *Statistical analysis*

Descriptive analysis was conducted to compare the nutritional values of the species across sites and between the three species. We also compared our findings with previous studies done on the same species in other countries of Africa. Based on the literature, values were also compared to other indigenous species of importance, and popular exotic fruit tree species. The mean significance difference of the nutritional composition among WEP across study sites were analyzed using a one-way analysis of variance (ANOVA). The significance of differences between WEPs in mean proximate and mineral composition was tested using the least significant difference test (LSD) with $P < 0.05$. Pearson correlation analyses were conducted to test the relationship between proximate and mineral compositions in each species.

3. Results and discussions

3.1. *Proximate composition of Balanites aegyptiaca, Cordia africana and Ziziphus spina-christi*

This study was done to understand the nutritive value of *B. aegyptiaca, C. africana and Z. spina-christi* species. Using standard procedures, the proximate composition (moisture, crude ash, crude protein, crude fat, crude fiber, carbohydrate, and energy) of the fruit were determined and presented on a dry matter basis (Table 1).

Balanites aegyptiaca contained a higher carbohydrates content compared to protein and fat values (Table 1). It is also a good source of fiber and could cover half of the recommended daily intake (25 g/38 g) for women/men (IOM, 2005). The moisture content of *B. aegyptiaca* obtained in this study is similar with the report from Sudan, but significantly higher in ash, fat, protein, fiber, carbohydrate and energy content and lower in carbohydrate and energy content (Sagna et al., 2014). Our result is comparable for protein (9.57%), fat (0.41%) and ash (9.1%) content reported from a study of this species in Senegal (Sagna et al., 2014). In line with this, *B. aegyptiaca* from Ghana showed higher contents of moisture (18.27%), protein (9.19%), Fat (2.58%), but lower in ash and fiber (Achaglinkame, Aderibigbe, Hensel, Sturm, & Korese, 2019). Compared to other WEPs, the protein content of *B. aegyptiaca* (7.78%) were found considerably higher compared to *Adansonia digitate* (2.5–3.1%), *Grewia tenax* (3.6%), *Sclerocarya birrea* (0.5–0.7%), *Tamarindus indica* (3.6–4.8%), *Ziziphus mauritiana* (0.4–1.2%), and *Dacryodes edulis* (4.6%) (Vinceti et al., 2013) (Supplementary Table S2). In terms of energy content, *B. aegyptiaca* (266 Kcal), contain slightly less compared to *Adansonia digitate* (327–340 Kcal), and *Tamarindus indica* (270–275 Kcal), but greater than energy content in *Sclerocarya birrea* (225 Kcal), *Ziziphus mauritiana* (118 Kcal), while it is comparable with *Dacryodes edulis* (263 Kcal) (Achaglinkame et al., 2019) (Supplementary Table S2).

Cordia africana showed higher carbohydrates content followed by crude ash values (Table 1) and could cover about 46% carbohydrate,

Table 1
Summary results of mean [±SE] macronutrient contents found in *B. eagyptica, C. africana and Z. spina-christi* fruit.

Tree species (WEPs)	MO	CP	CF	CA	CFr	CH	ENG	Region
Balanites aegeyptica	10.31 [±0.67]	6.22 [±0.18]	0.17 [±0.05]	6.90 [±1.43]	14.53 [±3.74]	61.78 [±1.78]	273.17 [±7.72]	NE
Balanites aegeyptica	12.14 [±2.52]	9.34 [±0.69]	0.92 [±0.08]	9.44 [±0.10]	14.60 [±3.11]	53.57 [±1.46]	259.86 [±2.86]	RVE
Overall mean [± SE)	11.22 [±1.36]	7.78 [±0.73]	0.54 [±0.16]	8.17 [±0.88]	14.57 [±2.43]	57.67 [±2.03]	266.52 [±4.93]	
Cordia africana	11.15 [±0.34]	6.64 [±0.55]	0.68 [±0.26]	11.53 [±1.48]	3.56 [±0.27]	66.44 [±1.61]	295.76 [±6.23]	NE
Cordia africana	11.3 [±2.25]	10.30 [±2.60]	0.71 [±0.08]	22.41 [±1.09]	4.30 [±0.64]	50.99 [±4.32]	251.30 [±7.75]	RVE
Overall mean [± SE)	11.21 [±0.92]	8.1 [±1.35]	0.69 [±0.16]	15.88 [±2.58]	3.86 [±0.34]	60.26 [±3.92]	277.97 [±10.88]	
Ziziphus spania-chrsti	8.35 [±0.29]	4.72 [±0.25]	1.05 [±0.25]	4.45 [±0.42]	5.11 [±0.21]	76.31 [±0.82]	333.56 [±4.01]	NE
Ziziphus spania-chrsti	8.14 [±0.25]	5.74 [±0.53]	1.49 [±0.45]	8.10 [±0.83]	5.91 [±0.73]	70.62 [±1.33]	318.86 [±7.13]	RVE
Overall mean [± SE)	8.23 [±0.19]	5.3 [±0.37]	1.3 [±0.29]	6.54[±0.85]	5.56[±0.45]	73.06[±1.35]	325.16[±5.21]	

*The values for Moisture (MO), Crude protein (CP), Crude Fat (CF), Crude ash (CA), Crude fiber (CFr), Carbohydrate (CH) are described in (%g/100 g), energy (Eng) in (Kcal/100 g). Region: NE = Northern Ethiopia, RVE = Rift valley of Ethiopia.

17.6% protein and 15.2% fiber of recommended daily intake (IOM, 2005). Moreover, the proximate composition of *C. africana* from the study site showed lower moister content, higher ash, and closely similar protein content compared to values reported elsewhere i.e. moisture (41–74%), ash (0.1–1.86%) and protein (10.88–12.9%). *Cordia senensis* from Tanzania also showed relatively similar protein contents, ranging from 12.7 to 15.2% and higher fat (1.9%), fiber (17.8%) and energy (318 Kcal), but lower in ash content (Murray, Schoeninger, Bunn, Pickering, & Marlett, 2001). Other species of Cordia (*Cordia myxa*) showed higher contents of moisture, fat, protein, fiber and ash, and lower content of carbohydrate and energy (Murthy et al., 2019). Also, compared to *Cordia obliqua* from India, *C. africana* contains lower moisture content, and a greater amount of protein and ash contents (Gupta & Gupta, 2015). Compared to other types of WEPs, *C. africana* showed comparable values of moisture content with *Adansonia digitata* (10.4%). However, it is considerably lower compared to *Grewia tenax (86%), Sclerocarya birrea Hochst* (85%), *Tamarindus indica (16.8 – 30.6)* (Supplementary Table S2). Protein, fat, and ash content of *C. africana* is great compared to *Dacryodes edulis* and *Ziziphus jujuba Mill*. The carbohydrate and energy content of *C. africana* were less compared to

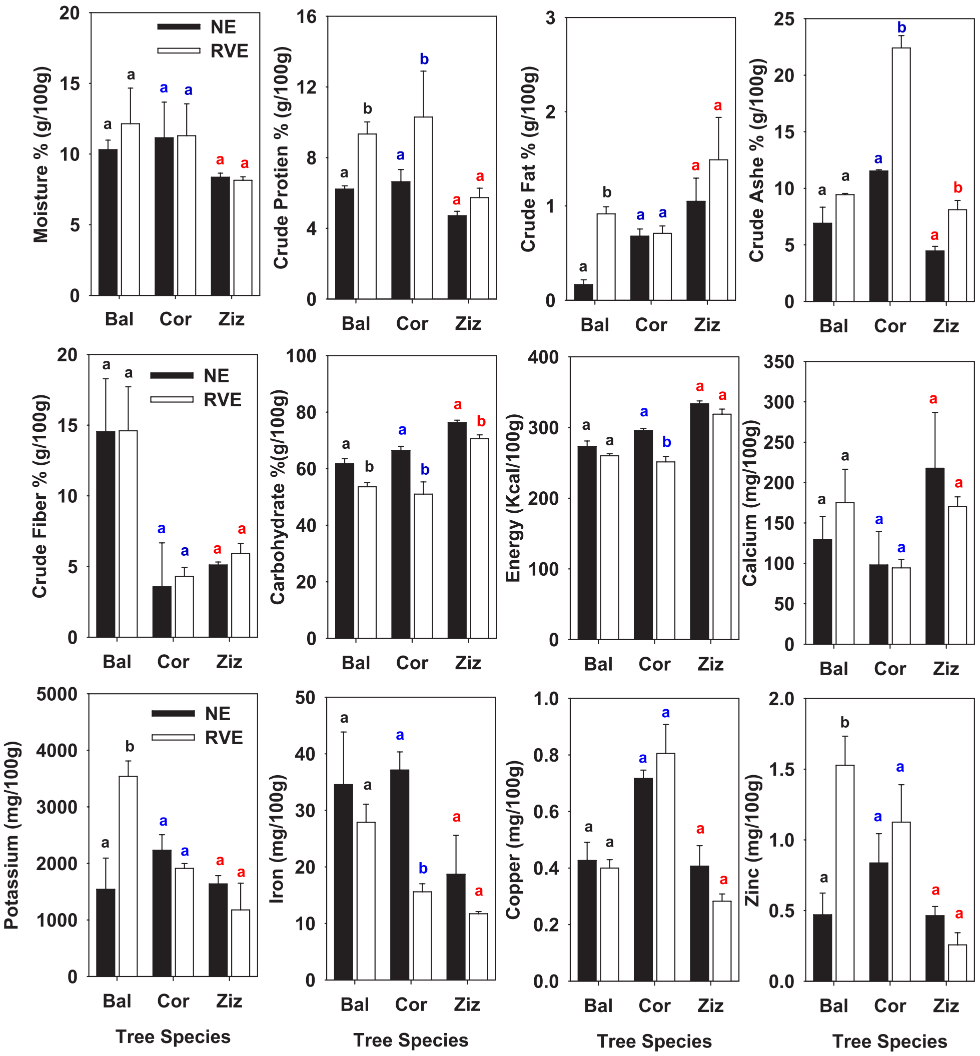

Fig. 3. Proximate composite and nutrient contents of *B. aegeyptica* (Bal), *C. africana* (Cor) and *Z. spina-christi* (Ziz) along an altitudinal gradient, collected from northern and rift valley of Ethiopia. On Fig. 3, NE, RVE refers to Norther and Rift Valley Regions of Ethiopia.

Gardenia erubescens, *Diospyros mespiliformis, and Balanites aegyptiaca* (Supplementary Table S2). Our result confirmed that *C. africana* is an important source of nutrients and minerals important to human health like cultivated edible fruits (Supplementary Table S2). Similar to other study's analyzing the nutritional value of *C. africana,* we found that it is a good source of carbohydrate and as a result, makes its suitable fruit for use in food product development such as jam.

Ziziphus spina-christi contains a higher amount of carbohydrate and energy, followed by moisture, ash, fiber, protein (Table 1). Moisture content in *Z. spina-christi* is by far less compared to a value reported in (Ahmed & Sati, 2018) for *Ziziphus mauritiana* (80.3%) and in (Abdoul-Azize, 2016) for *Ziziphus jujuba* (58.3–76.5%). On the other hand, our finding is comparable with moisture, protein, fat, ash, carbohydrate and energy values reported for *Ziziphus spina-christi, and Ziziphus abyssinica* in Ahmed and Sati (2018) from Sudan. Moreover, carbohydrate (73%) and energy (325 Kcal) contents of *Z. spina-christi* are closely similar to *Gardenia erubescens, Diospyros mespiliformis and Balanites aegyptiaca* (Supplementary Table S2).

3.2. Proximate composition variations across site

B. aegyptiaca, *C. africana* and *Z. spina-christi* showed, in general, a slight variation in proximate composition across sites (Table 1). We have found slightly higher values of protein, fat, and ash in the sample collected from the Rift Valley sites of our study. On the other hand, carbohydrate and energy contents were higher in samples collected from northern Ethiopia (Table 1). Within species, proximate composition variation across sites were found to be partially significant ($P < 0.05$)

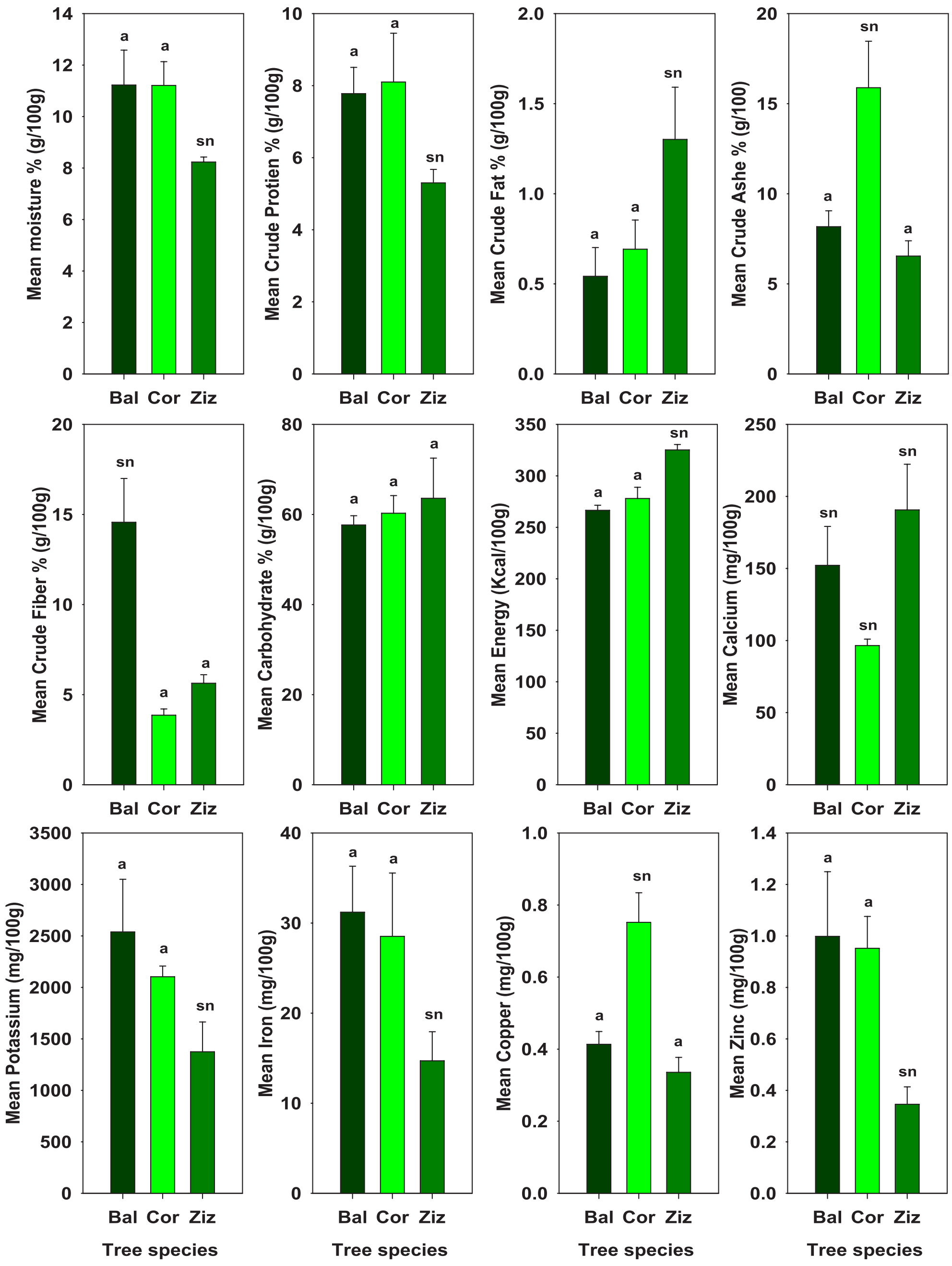

Fig. 4. Differences in nutrient contents between *Balanites aegeyptica* (Bal), *Cordia africana* (Cor) and *Ziziphus spania chrsti* (Ziz). Bars are Standard error (SE). The letter, 'sn' indicates a significant difference among tree species (one-way ANOVA with Tukey's test significant difference at $P < 0.05$). Whereas 'a' indicates no significant difference.

for all the studied WEP species (Fig. 3), indicating that the ecological factors including microclimate, soil properties and environmental conditions might be among influencing factor for the proximate composition of WEPs (Bustrel et al., 2021). This finding is somehow congruent with other studies that have reported a slight variation in fruit proximate contents of *Tamarindus indica* grown in three different agroecological zones of Uganda (Okello, Lamoris, Eilu, Nyeko, & Obua, 2018). Moreover, a significant variations was reported in fruit proximate composition of *Solanum nigrum* cultivated on different soil types (Ogundola, Bvenura, & Afolayan, 2018).

Furthermore, the observed variation in proximate content across sites was not consistent among species (Table 1). For example, crude fiber was slightly higher in the Rift valley of Ethiopia, while Carbohydrate and Energy contents were consistently higher in Northern Ethiopia for all studied species (Table 1). The variation in moisture and crude protein content among the studied species was not statistically significant ($P > 0.05$) (Fig. 4). Fiber (14.57 ± 2.43%) content in *B. aegeyptica*, ash (15.88 ± 2.58%) content in *C. africana*, carbohydrate (73.06 ± 1.35%) and energy (325 ± 5.21%) in *Z. spina-christi*is were found to be significantly different ($P < 0.05$) (Fig. 4). Based on the previous study undertaken, the observed variations in proximate compositions found in this study should be due to a combination of several factors, including provenance, genetic, agroecology, altitudinal differences, species differential responses to external growth influencing factors, season of harvest and harvesting stages among sites/species and sample drying method (Correia et al., 2016; Sibiya, Kayitesi, & Moteetee, 2021; Silvanini et al., 2014). Overall, the results show that these fruits are very important in meeting the protein-carbohydrate deficiency-based malnutrition seen in the society in Ethiopia expressed in the still high level of stunting (Supplementary Table S2). Though not all fruits assessed had high levels of protein, through selection and improvement high protein-containing fruits can be grown and used by the community to meet basic protein-carbohydrate needs (Akombi et al., 2017).

3.3. Mineral compositions of *Balanites aegyptiaca*, *Cordia africana* and *Ziziphus spina-christi*

Balanites aegyptiaca is rich in potassium (K) content, followed by Calcium (Ca) and Iron (Fe) (Table 2). Our findings of Ca, K, and Fe accumulation in *B. aegyptiaca* is significantly higher compared to values reported in Achaglinkame et al. (2019) for the same species. In line with this, *B. aegyptiaca* have higher contents of Ca, K, and Fe compared to other species including *Gardenia erubescens, Diospyros mespiliformis, Sclerocarya birrea* (Achaglinkame et al., 2019; Lykke & Padonou, 2019) (Supplementary Table S3, S4). While a review of findings for other species *Adansonia digitata, Grewia tenax, and Tamarindus indica,* found that they have higher Calcium than the data analyzed for *B. aegyptiaca* from the study site (Supplementary Table S4).

Cordia africana contained higher concentration of potassium (2102.96 mg/100 g), followed by calcium (96.55 mg/100 g) and iron (28.51 mg/100 g) (Table 2). Our finding showed that *C. africana* is rich in K, Ca, Fe, compared to the concertation found in *Cordia obliqua* (K = 1066 mg/100 g, Ca = 62 mg/100 g, and Fe = 5 mg/100 g) (Gupta & Gupta, 2015). Similarly, *Cordia myxa* has also shown lower values of calcium and iron (Murthy et al., 2019) (Supplementary Table S3, S4). Compared with other WEPs, such as *Gardenia erubescens, Diospyros mespiliformis, Sclerocarya birrea Hochst, Ziziphus mauritiana*, *C. africana* fruit (this study), had higher Ca and K content. While, in our study, the zinc values for *C. africana* were lower compared to other fruits such as *Adansonia digitate, Sclerocarya birrea, Diospyros mespiliformis and Balanites aegyptiaca* (Murthy et al., 2019).

Ziziphus spina-Christi contained a higher amount of potassium (Table 2). While, Ca in *Z. spina-christi* were found to be low compared to the result reported for *Z. spina-christi, Z. abyssinica, Z. mauritiana* in (Ahmed & Sati, 2018). Moreover, *Z. spina-christi* has also shown higher Ca, K and Fe compared to *Gardenia erubescens, Diospyros mespiliformis, Tamarindus indica* (Adeola & Aworh, 2015). In general, *Z. spina-Christi* from the study site is also a reliable source of minerals (Supplementary Table S3, S4).

3.4. Species-to-species comparisons and nutrient variability across sites

Our findings showed that *C. africana* fruit contained a higher content of iron and zinc compared to *B. aegyptiaca* and *Z. spina-christi.* Available potassium was recorded lowest in *Z. spina-christi* and highest in *B. aegyptiaca* (Table 2). Among study species, higher calcium content was recorded in *Z. spina-christi* and calcium content was the lowest in *C. africana* (Table 2). Furthermore, the variability of Ca, K, and Fe content of *B. aegeyptica* and *Z. spania chrsti* across sites were more prevalent in sample collected from northern Ethiopia than Rift Valley region (Table 2, Supplementary Table S3). This might also indicate that microclimate and agroecological variation between sites could influence fruit mineral compositions. Similarly, another study has reported significant ($P < 0.05$) differences in mineral composition levels of *Tamarindus indica* fruit across different agroecological zones of Uganda (Okello, Okullo, Eilu, Nyeko, & Obua, 2017) as well as in *Solanum nigrum* cultivated on different soil types (Ogundola et al., 2018). We also found a significant differences ($P < 0.05$) between Ca content in *B. aegeyptica* (152 ± 26.9 mg/100 g), *C. africana* (96 ± 4.4 mg/100 g) and *Z. spania-christi* (190 ± 31.68 mg/100 g). K, Fe and Zn content in *Z. spina-Christi* is significantly ($P < 0.05$) lower compared to other study species. Cu content in *C. africana* is significantly ($P < 0.05$) higher than other studied WEP species (Fig. 4). This variation indicates that knowledge on the mineral contents of WEPs is crucial for selecting mother trees across

Table 2
Summary results of mean [±SE] mineral contents found in in *B. eagyptica*, *C. africana* and *Z. spina-christi* fruit.

Tree species (WEPs)	Calcium	Potassium	Iron	Copper	Zinc	Region
Balanites aegeyptica	129.32 [±8.96]	1541.84 [±552.11]	34.55 [±9.29]	0.43 [±0.06]	0.47 [±0.15]	NE
Balanites aegeyptica	175.12 [±41.41]	3536.24 [±275.58]	27.86 [±3.21]	0.40 [±0.03]	1.53 [±0.21]	RVE
Overall mean [± SE)	152.21 [26.94±]	2539.04 [±510.81]	31.21 [±5.1]	0.41 [0.04±]	1.0 [0.25±]	
Cordia africana	98.01 [±1.14]	2230.58 [±114.69]	37.13 [±8.65]	0.72 [±0.11]	0.84 [±0.01]	NE
Cordia africana	94.37 [±10.69]	1911.52 [±85.43]	15.60 [±1.41]	0.81 [±0.10]	1.13 [±0.27]	RVE
Overall mean [± SE)	96.55 [±4.4]	2102.96 [±103.87]	28.51 [±7.04]	0.75 [±0.08]	0.95 [±0.12]	
Ziziphus spania-chrsti	217.77 [±69.14]	1637.67 [±144.87]	18.70 [±6.86]	0.41 [±0.07]	0.46 [±0.07]	NE
Ziziphus spania-chrsti	170.33 [±11.96]	1176.54 [±471.54]	11.70 [±0.38]	0.28 [±0.03]	0.26 [±0.08]	RVE
Overall mean [± SE)	190.66 [±31.68]	1374.17 [±289.65]	14.7 [±3.23]	0.34 [±0.04]	0.35 [±0.07]	
Recommended Daily Mineral Intake (RDMI)						
Amount (RDMI)	1000	3510	15	2	15	
Balanites aegeyptica	15%	72%	208%	21%	7%	
Cordia africana	10%	60%	190%	38%	6%	
Ziziphus spania-chrsti	19%	39%	98%	17%	2%	

* The values for Calcium, Potassium, Iron, Copper, Zinc were in (mg/100 g). Region: NE = Northern Ethiopia, RVE = Rift valley of Ethiopia (RVE). Sources for RDMI values (https://www.lenntech.com/recommended-daily-intake.htm).

provenances for domestication- improvement programs to ensure highest nutrient contents as a favored trait. We also confirmed that the study species are potential sources for required daily mineral intake (IOM, 2012) and in helping fight malnutrition of these critical nutrients that studies show are lacking in the Ethiopian diet with locally and readily available nutrition in fruits from these trees (Jyotsna & Katewa, 2016; Tewolde-Berhan, Remberg, & Wicklund, 2015).

3.5. Wild edible plants are important sources of nutrient and minerals for human wellbeing

This research further shows that the nutritional value of study species are important sources of nutrients, like more commonly known and cultivated exotic fruit tree species, such as *Apple, Avocado, Guava, Jackfruit, Papaya, Pineapple, Mango, Pomegranate* (Supplementary Table S2 and S4). For instance, the proximate content of exotic spp. (Avocado/Mango/Paya) and study spp. [*B. aegeyptica/C. african/ Z. spania chrsti*] ranges from 0.5–6.0 [5.3–8.1], 0.1–15.4 [0.54–1.3], 0.5–1.6 [6.5–15.8], 0.7–6.8 [3.8–14.5], 8.6–74.6 [57.6–73], and 32–167 [277–325] for crude proteins, crude fats, crude ash, crud fiber, carbohydrate, and energy contents, respectively (for details please refer Supplementary Tables S2 and S4). This suggests that WEPs could potentially contribute to food and nutrition security. Particularly, for SSA region where daily fruit consumption is by far below the recommended daily amount of 200 g per person (Kehlenbeck, Asaah, & Jamnadass, 2013). To this line, our finding showed that, the study species could provide about 10–15%, 39–72%, 98–208%, 17–38% and 2–7% of the recommended daily mineral intake of calcium, potassium, iron, copper, and zinc, respectively (Table 2). WEPs could also play a significant role to maintain household nutrition in many communities, especially during lean seasons, during times of low agricultural production and climate-induced drought (Kehlenbeck et al., 2013). More importantly, since WEPs are drought and heat tolerant, they may play a considerable role in limiting regional desertification processes and mitigating the greenhouse effect while providing economical and nutritional values for millions of poor African farmers (Zait & Schwartz, 2018). The results of this study also substantiate the importance of protecting and sustainable use of such food trees to maintain their future contribution as a reliable source of food, nutrition, and medicine for people depending on subsistent farming systems.

3.6. Associations among nutritive and mineral compositions in wild edible plant species

Significant correlation ($P < 0.05$) were observed in 24.6% (18.5% negative, and 6% positive) for B. *aegeyptica* in 40% (23% positive, and 17% negative) for *C. africana* and in 18.5% (7.7% positive and 10.8% negative) for *Z. spina-Christi,* of the 65 paired comparisons among chemical compositions (Supplementary Tables S5–S7).

4. Conclusions and recommendations

This study presented nutritional composition and macro- and micronutrient contents of *B. aegeyptica, C. africana, and Z. spania-chrsti* collected from different agroecology of Ethiopia. The result showed that fruits from the studied indigenous tree species are potential sources of nutrients and minerals important for the human diet and health. The nutritional values of studied tree species were comparable with reported figures for popular exotic and widely cultivated fruit tree species (e.g., *Avocado, Mango, Papaya*), implying their potential utilization as even food and nutrition supplements and/or complimenting conventional but costly purchased protein, energy, fiber, and fat supplements. They, in turn, being free or relatively cheap and locally available, makes them a good target to help reducing malnutrition in countries like Ethiopia. The data presented are useful and support the effort in developing multi-sectoral national strategic plans for wider domestication and sustainable use of wild edible plants, which in turn help to achieve SDGs (i.e., ending hunger and all forms of malnutrition). We also strongly believe that the current finding must be substantiated by further study of chemical and mineral concentration as well as their test in different forms using large sample size collected from different parts of the country, thereby to select the more preferred, profitable and adaptable to wider ecoclimatic conditions for possible domestication and scaling up of diverse agroforestry systems. Finally, based on the knowledge gained through this study and literatures reviewed, the following recommendations were provided:

- Further studies on the contents of vitamins and heavy metals, as well as antinutrient factor.
- Besides documenting the nutritional contents of WEPs, further investigation on their postharvest storability, food production and intake and commercialization of fruits of WEPs per household is critical to promote and shade light on their contribution to household diet, socioeconomic role, and environmental protection.
- Improve Farmers' knowledge on valuable indigenous tree species through nutritional messaging communication to increase awareness of the nutritional value of WEPs, for healthier diets and nutrition.
- Promote domestication/ improvement programs for such species – through the selection of superior mother trees based on prioritized traits, nutrition, fruit size.
- Conservation of WEPs by use – more widely planted/ naturally managed/ kept landscape for food, nutrition, and possible income opportunities.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Declarations

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Authors' contributions: MM, YG, EB, SM, and EN designed the study, MM and YG collected the sample fruits across the study sites, performed all sample preparation, measurements and carried out a first analysis of the data, which was improved by EB, SM, EN, KMH, NH, and STB. MM, and YG wrote the first version of the manuscript, which was intensively discussed and revised by all authors.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.fochms.2022.100084.

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