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Indigenous food ingredients for complementary food formulations to combat infant malnutrition in Benin: a review

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Abstract

This paper reviews indigenous Beninese food resources as potential ingredients for complementary infant foods with the aim to develop affordable formulations for low-income households in each agro-ecological zone of the country. Potential ingredients were selected on their documented nutritional value. The selected foods encompass 347 food resources, namely 297 plant products from home gardens or collected from natural vegetation and 50 animals, either domesticated or from the wild. The compiled data reveal that the distribution of the available food resources was unbalanced between agro-ecological zones. Only a few animal ingredients are obtainable in northern Benin. Most resources are seasonal, but their availability may be extended. A high variation was observed in energy and nutrient contents. Antinutritional factors were identified in some resources, but processing techniques were reported to reduce their presence in meals. In general, ingredients from local tree foods (*Adansonia digitata*, *Parkia biglobosa*) were adequate as sources of nutrients for complementary infant foods. Based on this review, local foods for the development of complementary food formulas for Beninese infants and children may be selected for each agro-ecological zone. The approach used is exemplary for other sub-Saharan African countries in need of complementary infant foods.

Supporting information may be found in the online version of this article.

Keywords: local food resource; infant food; standards; nutritional value; Benin

INTRODUCTION

Infant and young child malnutrition is a major public health concern in developing countries. The contribution of early childhood malnutrition in infant morbidity and mortality has been demonstrated worldwide.[1–6] Malnutrition of infant and young children results mainly from poor feeding practices such as complete absence or inadequacy in macronutrients and micronutrients of complementary feeding.[4,7]

In the West African subregion, where infant and child malnutrition remains important among both urban and rural communities, improvements in the processing of traditional complementary foods and ensuring their adequate nutritional value are set as priorities. Home fortification with multiple micronutrients powder has been recommended as an efficient food-based approach for reducing malnutrition and micronutrient deficiencies among populations depending on plant-based diets. However, this approach has not been sufficiently experimented, especially in poor and rural settings. More sustainable and indigenous improvements could be achieved by wisely combining locally available foods that complement each other in a way that the new pattern of nutrients created by this combination can meet the requirements for infants.[8] Clearly, the use of local food resources for infant and young children's food formulations is strongly encouraged.[9,10] The basic step for achieving such a goal is the inventory and screening of available resources consumed by local communities to enable the selection of the most suitable products for designing appropriate nutritional food formulae.

In Benin, as in most developing countries, low-income groups remain dependent on available indigenous plant and animal resources to ensure their food security. These resources vary according to agro-ecological zones,[11,12] leading to a diversity in diet and nutritional profiles. On the one hand, commercial complementary foods available in the country, especially infant flour,

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are often cereal based.[13] Most of cereal-based complementary foods fail to meet the Codex Alimentarius standards,[14] except for energy density (4000 kcal kg^{-1} dry flour) or protein content (150 g kg^{-1} dry flour). Most of the complementary foods are poor in animal protein and fat, with very low micronutrient contents, especially vitamin A and iron.[13] Moreover, commercial weaning foods are not often affordable for most of the urban populations and are not distributed in rural areas because of their high price. On the other hand, many studies have been and are conducted to assess, among others, ethnobotanical knowledge, geographical distribution, seasonal availability, nutrient content and nutritional value of resources traditionally used by local communities in Benin. Those studies reported numerous local edible resources as important sources of vitamins, minerals, fibers, carbohydrates and protein.[13,15–18] Thus the basic information required for developing a framework for actions that are needed to protect, promote and support appropriate feeding practices in early childhood is increasingly available.[11,19] However, a scheme of the overall potential of the documented food resources to tackle infant and child malnutrition is still lacking. The aim of the present review is to provide an overview of local food resources that can potentially be used for complementary food formulations, with a focus on their distribution, nutritional values and availability across agro-ecological zones of Benin.

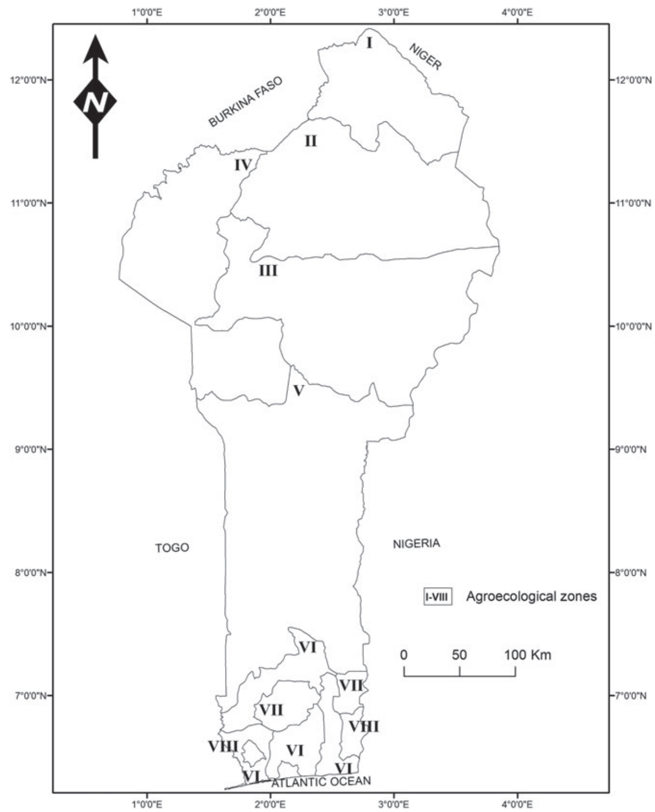

Figure 1. Agro-ecological zones of Benin. I, Extreme Northern; II, North cotton zone; III, South Borgou crop zone; IV, West Atacora zone; V, Central Benin cotton zone; VI, Clayey earth zone; VII, Depression zone; VIII, Fishering zone. Source: UNDP, MEPN-Benin: United Nations Climate Change Map; Benin Climate Change Adaptation National Action Program (PANA-BENIN), January 2008, Cotonou, Benin.

METHODOLOGY

Strategy for searching information

A web search was conducted for peer-reviewed papers on the websites of relevant institutions (UAC (University of Abomey-Calavi), IITA (International Institute of Tropical Agriculture), IRD (Institut de Recherche pour le Développement) libraries) and through online databases such as AGORA, Web of Science, Scopus, Science Direct and Google Scholar. A total of 1046 studies were explored within the period from May to October 2015.

Data collection

The review focused on plant and animal food resources available in Benin with potential for use as complementary food nationwide. Information gathered included distribution per morphological type, seasonal availability, consumption forms across agro-ecological zones (Fig. 1) and food component value. Targeted food components included macronutrients, minerals, amino and fatty acids, vitamins and antinutritional factors. The food components were reported in international standard units (g or kcal kg^{-1} dry weight). The validity of the component values could not be checked as this went beyond the scope of this study.

Data quality

The built database was sifted and potential complementary food ingredients were selected based on their nutrient and antinutritional factor contents. Food ingredients that are already widely studied and mostly known as conventional were not or hardly considered. The recommended macronutrient component of infant flour[14] and reference nutrient intake values of amino acids, vitamins and minerals[14] were used as benchmarks for comparing and discussing the ten most suitable food resources, providers of energy and nutrients as potential ingredients for complementary food formulations.

RESULTS

Diversity and distribution of potential ingredients in complementary foods

A total of 347 food resources were compiled in a database according to agro-ecological zones (see supporting information document). Papers have reported on herbs, trees, bushes, creepers, and cryptogams; and on mammals, fish/aquatics, mollusks and insects as potential ingredients in complementary foods in Benin. Figure 2 shows the diversity and morphological characteristics of these food resources in each agro-ecological zone. The diversity of food resources in the country decreases from the south (245 in zone VIII, the country's fishery zone) to the extreme north (34 in Zone I). Similar distributions were observed in zones II (the Northern cotton zone), III (the food-producing zone of Southern Borgou), in zones IV (Western Atacora zone) and V (the Southern cotton zone). Animal food resources, mammals and mollusks were only available in agro-ecological zone VI (Tray zone), and edible insects only in zone IV (Western Atacora zone); aquatic food resources were reported from depressions (agro-ecological zones VI and VII) and fishery zones (agro-ecological zone VIII).

Plant resources were either cultivated (on farmland or home gardens) or harvested from forests, savannahs, shallow areas, riversides, roadsides or mountains. Fruits and fruit pulp were the most consumed plant parts (43%), followed by leaves (31%), seeds/kernels (9%), flowers (4%), whole plants (3%), roots (3%) and tubers (3%) (Fig. 3). As for plants, animal resources were also from domesticated species or hunted/collected in the wild from forests,

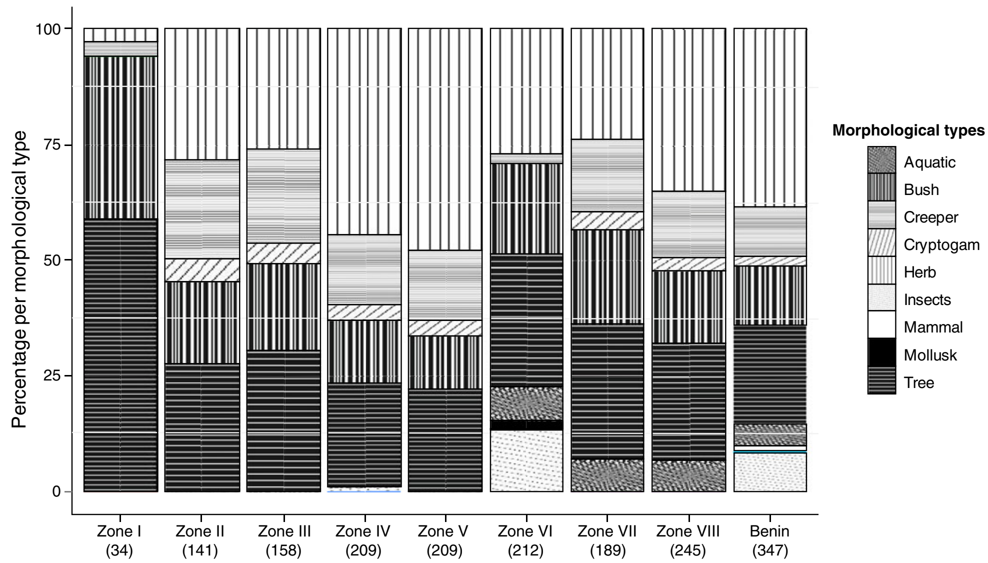

Figure 2. Distribution of local food resources selected as potential ingredients in complementary foods among morphological types per agro-ecological zone in Benin. The graph presents the proportion of food resources morphological types (aquatic, bush, creeper, cryptogam, herb, insects, mammal, mollusk and tree) for each agro-ecological zone (ZAE I, ZAE II, ZAE III, ZAE IV, ZAE V, ZAE VI, ZAE VII and ZAE VIII). Source: Microsoft Excel 2010.

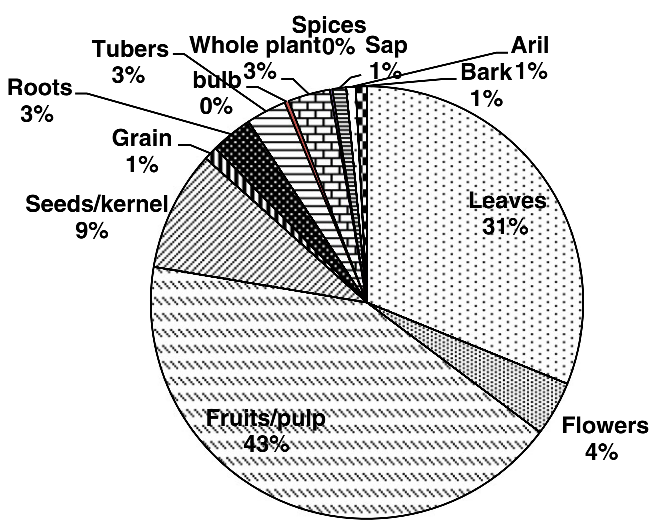

Figure 3. Distribution of selected edible resources according to consumed organs in Benin. Proportions of local resources organs consumed (seeds/kernel, grain, tubers, roots, pulp, flowers, leaves, fruits, bulbs, spice, sap, aril, bark and whole plant) in Benin. Source: Microsoft Excel 2010.

fields, fallows or the sea. Unlike plants, animal food resources were not seasonal except for insects and mollusks, which were only available in the rainy season. Mammals and mollusks were used for their muscles, whereas the whole body of aquatic species and insects was consumed (see supporting information document).

Availability of food resources and traditional uses

Fruit and fruit pulp

Fruits were generally available year-round, although some species (e.g. *Lannea barteri*, *Syzygium guineense*) were available only during 1–4 months.[20] In the eight agro-ecological zones fruits were consumed raw, boiled, roasted and as juice, either as snacks (e.g. *Dialium guineense*), energy food (e.g. *Artocarpus altilis*) or in beverage preparations (e.g. *Tamarindus indica* and *Adansonia digitata*).

Leaves

Leaves were abundantly available during the rainy season and scarce in the dry season.[12,20,21] Despite the diversity of leaves, their use (fresh or dried) was limited to the preparation of sauces[11,22] and dry leaf powder.[23,24] In northern Benin, where vegetable drying is a common practice, leaves of species such as *Adansonia digitata*, *Ceratotheca sesamoides*, *Sesamum radiatum*, *Vernonia* sp., *Amaranthus* sp., *Celosia laxa*, *Celosia trigyna*, *Chromolaena odorata*, *Cleome viscosa*, *Emilia coccinea*, *Emilia praetermissa*, *Emilia sonchifolia*, *Heliotropium indicum*, *Gynandropsis gynandia*, *Gomphrena globosa*, *Macrosphyra longistyla*, etc. were dried, pounded and sieved for use when the fresh material is scarce.[16,17] Thus these leaves are commonly available in all seasons, fresh or dried.

Other plant food resources

Apart from fruits and leaves, other plant food resources were available throughout the year (e.g. *Vitellaria paradoxa* and *Parkia biglobosa*). However, accessibility of tubers and roots was predominant in the rainy season and in the dry season for *Adansonia digitata* and *Ceiba pentandra* roots and seeds.[12,20] Consumption forms varied much between resources. For instance, fermented *Parkia biglobosa* seeds were used as condiment for stew and soup consumed by children over 12 months old.[25,26]

Animal food resources

Aquatic food resources such as fish (e.g. *Scomberomorus tritor*, *Pseudotholithus* sp.) were fermented, smoked, fried or cooked fresh in sauces.[27,28] Homemade foods based on mollusks (e.g. *Achatina* spp., *Archachatina marginata*) included flour enriched with snail, sauce and skewer-snail.[29,30] Mammals (e.g. *Potamochoerus porcus*, *Thryonomys swinderianus*, *Cricetomys gambianus*) and edible insects including grasshopper (*Ruspolia differens*) and termites (*Macrotermes bellicosus*) were important protein sources in sauces.[30,31] Apart from insects and fish that were roasted or dried, all other animals, including mammals, were either cooked with water and sometimes further fried or smoked, so that they could be used in sauces and stews.

Nutritional value of potential ingredients for infant food formulations

The nutritional value of the documented food resources are presented in Tables 1–6, in terms of energy content, macronutrients, fatty and amino acids, minerals, vitamins and antinutrients. The recommended macronutrient intake and reference nutrient intake values of amino acids, vitamins and minerals[14] were taken into account to allow comparison and to determine which food resources were the best potential sources of nutrients for infant food formulations. Table 7 lists the nutritious food resources according to agro-ecological zones of Benin.

Energy

The energy value of *Elaeis guineensis*,[12,32] pulp of *Blighia sapida*,[32–35] nut of *Arachis hypogaea*,[36] *Anacardium occidentale*,[12,32] *Sesame* spp.[12,32] and *Vitellaria paradoxa*[12,37,38] ranged from 5000 to 6200 kcal kg^{-1} dry weight (DW). *Adansonia digitata* kernels and seeds,[15,33,39,40] *Parkia biglobosa*[26,40,41] and *Glycine max*[32,42] provided less energy, namely 4000–4700 kcal kg^{-1} DW. These ingredients are suitable as an additional energy source to cereals and tubers used in the formulation of infant foods.

Carbohydrates

Apart from cereals and tubers, which are not considered in this review, leaves and fruit pulp were the best indigenous sources of carbohydrates. Indeed, certain local foods can provide more than 750 g carbohydrates kg^{-1} DW. The highest reported values (g kg^{-1} DW were 784–810 for *Dialium guineense* leaves,[43] 466–877 for *Adansonia digitata* pulp[24,40] and 769 for *Afraegle paniculata* fruits.[40] However, most of the documented food resources contain lower amounts of carbohydrates (g kg^{-1} DW: *Balanites aegyptiaca* fruit (733),[40] *Adansonia digitata* leaves (92–690),[24,32] *Borassus aethiopum* (641),[40,44] *Pleurotus tuber-regium* (edible mushrooms) (340–562),[45,46] *Adansonia digitata* seeds (52–568),[15,33,40] *Balanites aegyptiaca* leaves (407)[47] and *Parkia biglobosa* leaves (329–330).[26,40,41] All these carbohydrate values were lower than the recommended daily proportion of energy from carbohydrates, which is 45–65% of energy for infants 1–3 years old.[48] Indeed, in an infant food, most carbohydrates typically come from a cereal and/or tuber source.

Sources of plant proteins

Numerous plant food resources contain considerable amounts of protein (g kg^{-1} DW) in the range of 150–320: *G. max* (320),[42] *Parkia biglobosa* (301–323),[37,40,41] *Balanites aegyptiaca* leaves (288),[47] *Amaranthus hybridus* leaves (235–270),[47,49] *Adansonia digitata* kernels (140–327),[24,40] *Ceratotheca sesamoides* leaves (250),[36] *Blighia sapida* pulp (24–227),[34,35,50] *Arachis hypogaea* (217–229)[32] and *Moringa oleifera* (67–271).[18,40]

Sources of animal proteins

Meat, fish and insects are known to provide proteins of good quality. Important representatives of this group were: snails (830–881 g kg^{-1} DW), *Ruspolia differens* (43.6–75.3 g kg^{-1} DW),[51,52] termites (32.0–54.9 g kg^{-1} DW), and *Engraulis japonicus* and *Engraulis encrasicolus* (fish) (53.1–72.5 g kg^{-1} DW).[52,53]

Sources of crude fats

Food resources that can provide significant amounts of fat (g kg^{-1} DW) for food formulations were *Irvingia gabonensis* kernels (655–683),[54,55] *Blighia sapida* (201–567),[32–35] *Elaeis guineensis* nuts (553),[12,32] *Vitellaria paradoxa* nuts (490–492),[37,38] *Sesame* spp. (489),[12,32] *Arachis hypogaea* (461–475),[36] *Adansonia digitata* kernels (189–347),[15] *Anacardium occidentale* nuts (444)[12,32] and *C. nucifera* (369).[32] Besides, edible insects such as *Ruspolia differens* and *Macrotermes bellicosus* contain from 18 up to 50 g kg^{-1} DW fat.[52,56]

Sources of fiber

Leaves, fruits and seeds of some food resources contain from 270 up to 500 g kg^{-1} DW fiber. The sources with the highest amounts of fiber (g kg^{-1} DW) in Benin were: *Adansonia digitata* seeds (169–497),[15,33,40] *Blighia sapida* pulp (32–414),[32–35] *Parkia biglobosa* seeds (41–161),[26,32,40,41] *A. senegalensis*, *Ximenia americana*, *Ziziphus mauritiana*, *Vigna subterranea* (291–370),[36] *Ceratotheca sesamoides* leaves (511)[36] and *Balanites aegyptiaca* (155).[47] After combination of all ingredients, the fiber content of infant food should be less than 50 g kg^{-1} DW.[14]

Total ash

The sources with the highest amounts of total ash (g kg^{-1} DW) were: *Adansonia digitata* leaves (28–159) and kernels (50–79),[24,32] *Moringa oleifera* leaves (24–151),[18,40,48] *Ceratotheca sesamoides* (136),[36] *Balanites aegyptiaca* leaves and fruits (127 and 74, respectively),[40] *Ceiba pentandra* leaves (75–104),[57,58] *Blighia sapida* pulp (13–86),[32–35] *Hibiscus sabdariffa* (65–68)[59] and *Parkia biglobosa* seeds (41–54).[26,32,40] The best animal sources of ash were fish (170–270 g kg^{-1} DW) and *Macrotermes bellicosus* (54–70 g kg^{-1} DW).[52]

Note that the total ash content is an indication of the amount of micronutrients.

Micronutrients

Major minerals.

Calcium. Lockett *et al.*[40] qualified food products containing per more than 17.5 g kg^{-1} DW calcium as good sources of calcium and those with less than 15.8 g kg^{-1} DW as poor sources. Thus good sources of calcium with highest amounts (g kg^{-1} DW) were *Citrus limon* (84.5),[60] *Moringa oleifera* leaves (4.4–34.7),[18,40] *Adansonia digitata* leaves (3.1–26.4),[15,40,61] *Parkia biglobosa* pulp (1.2–24.0),[41] *Grewia mollis* fruit (34.7)[40] and *Amaranthus viridis* leaves (15.9–16.4).[61] Poor calcium sources were essentially animal food resources, containing 0.4–2.1 g kg^{-1} DW.[29,62,63]

Magnesium. With respect to magnesium, Lockett *et al.*[40] considered species with at least 5.0 g kg^{-1} DW as rich in magnesium and those with less than 1.0 g kg^{-1} DW as poor in magnesium. The richest sources of magnesium reported were leaves of *Amaranthus viridis* (11.5–12.6 g kg^{-1} DW),[61] *Citrus limon* (14.3 g kg^{-1} DW),[60] *Moringa oleifera* (0.3–8.3 g kg^{-1} DW),[18,40] *Hibiscus sabdariffa* (7900 g kg^{-1} DW),[61] leaves and seeds of *Adansonia digitata* (0.9–5.5 g kg^{-1} DW)[15,40] and *Parkia biglobosa* pulp (0.9–4.6 g kg^{-1} DW).[40,41]

Potassium. The highest amounts of potassium (g kg^{-1} DW) (i.e. 10 and more) were recorded for *Citrus limon* peel (86),[60] pulp of *Vitellaria paradoxa* (17),[64,65] pulp (7–33), leaves (1–1.1) and seeds

Table 1. Energy and macronutrient contents of the ten best resources for complementary infant food formulas in Benin

Ingredient	Energy (kcal kg^{-1})	Ref.
Palm nut (*Elaeis guineensis*)	6090	12,32
Pulp of ackee (false cashew) (*Blighia sapida*)	5466–6143	32–35
Peanut (*Arachis hypogaea*)	5830–5840	36
Cashew (*Anacardium occidentale*)	5850	12,32
Sesame (*Sesame* spp.)	5770	12,32
Nut of shea butter tree (*Vitellaria paradoxa*)	5615	12,37,38
Kernel of baobab (*Adansonia digitata*)	4701	24,39
Seed of baobab (*Adansonia digitata*)	3804–4629	15,33,40
Seed of African locust bean (*Parkia biglobosa*)	4354	26,40,41
Soya bean (*Glycine max*)	4100	32,42
Ingredient	Carbohydrate (g kg^{-1} DW)	Ref.
Leaves of black tamarind (*Dialium guineense* Wild.)	784–810	43
Pulp of baobab (*Adansonia digitata*)	466–877	24,40
Fruit of *Afraegle paniculata*	76.9	40
Fruit of *Balanites aegyptiaca*	733	40
Leaves of baobab (*Adansonia digitata*)	92–690	24,32
Pulp of *Borassus aethiopum*	641	40,44
Edible mushrooms (*Pleurotus tuber-regium)*	340–562	45,46
Seed of baobab (*Adansonia digitata*)	52–568	15,33,40
Leaves of soap berry tree (*Balanites aegyptiaca* (L) Del.)	407	47
Leaves of African locust bean (*Parkia biglobosa*)	329–330	26,40,41
Ingredient	Protein (g kg^{-1} DW)	Ref.
Soybean (*Glycine max*)	320	42
Seed of African locust bean (*Parkia biglobosa*)	301–323	37,40,41
Leaves of soap berry tree (*Balanites aegyptiaca* (L) Del.)	288	47
Leaves of *Amaranthus hybridus*	235–270	47,49
Kernel of baobab (*Adansonia digitata*)	140–327	24,40
Pulp of ackee (false cashew) (*Blighia sapida*)	240–227	34,35,50
Peanut (*Arachis hypogaea*)	217–229	32
Leaves of horseradish tree (*Moringa oleifera* Lam.)	67–271	18,40,48
Leaves of false sesame (*Ceratotheca sesamoides*)	250	36
Snail (*Limicolaria* sp.); (*Achatina fulica*);	830–881	51,52
Termites (*Macrotermes bellicosus*)	319–548	52,53
Fish	531–725	52
Grasshopper	436–753	51
Ingredient	Lipid (g kg^{-1} DW)	Ref.
African bush mango (*Irvingia gabonensis*)	655–683	54,55
Pulp of ackee (false cashew) (*Blighia sapida*)	201–567	32–35
Palm nut (*Elaeis guineensis*)	553	12,32
Nut of shea butter tree (*Vitellaria paradoxa*)	490–492	37,38
Sesame (*Sesame* spp.)	489	12,32
Peanut (*Arachis hypogaea*)	461–475	36
Grasshopper	459–465	52,56
Cashew (*Anacardium occidentale*)	444	12,32
Coconut, mature (*Cocos nucifera*)	369	32
Kernel of baobab (*Adansonia digitata*)	189–347	15
Ingredient	Fiber (g kg^{-1} DW)	Ref.
Leaves of false sesame (*Ceratotheca sesamoides*)	511	36
Seed of Bambara groundnuts (*Vigna subterranea*)	291–370	36
Seed of baobab (*Adansonia digitata*)	169–497	15,33,40
Pulp of baobab (*Adansonia digitata*)	60–451	15,40
Pulp of ackee (*Blighia sapida*)	321–414	32–35
Leaves of baobab (*Adansonia digitata*)	72–275	24,32

Table 1. Continued

Ingredient	Fiber (g kg^{-1} DW)	Ref.
Leaves of soap berry tree (*Balanites aegyptiaca* (L.) Del.)	267	47
Kernel of Baobab (*Adansonia digitata*)	212	15
Leaves of horseradish tree (*Moringa oleifera* Lam.)	9–168	18,40,48
Ingredient	Ash (g kg^{-1} DW)	Ref.
Leaves of baobab (*Adansonia digitata*)	28–159	24,32
Leaves of horseradish tree (*Moringa oleifera* Lam.)	24–151	18,40,48
Leaves of false sesame (*Ceratotheca sesamoides*)	136	36
Leaves of soap berry tree (*Balanites aegyptiaca* (L) Del.)	124	40
Kapok tree, silk-cotton tree (*Ceiba pentandra*)	75–104	57,58
Pulp of ackee (false cashew) (*Blighia sapida*)	13–86	32–35
Kernel of baobab (*Adansonia digitata*)	50–79	15
Fruit of soap berry tree (*Balanites aegyptiaca* (L) Del.)	742	40
Calyces of roselle bissap (*Hibiscus sabdariffa* L.)	65–68	59
Seed of African locust bean (*Parkia biglobosa*)	41–54	26,40,41
Fish	170–270	52
Termites (*Macrotermes bellicosus*)	54–70	52

(4–14) of *Adansonia digitata*,[24,40,61] *Anacardium occidentale* (22)[66] and *Parkia biglobosa* pulp (17).[32,40,41]

Sodium. The richest sources of sodium (g kg^{-1} DW) were *Citrus limon* peel (7.56),[60] followed by *Ruspolia differens* meat (2.29–2.31),[51,52,56] leaves of *Amaranthus viridis* (0.87)[61] and pulp of *Blighia sapida* (0.29–0.84).[33–35]

Phosphorus. High amounts of phosphorus in g kg^{-1} DW (≥2.5) were available in *Citrus limon* peel (66.6),[60] leaves (1.2–8.8) and seeds (0.056–7.4) of *Adansonia digitata*,[15,40] *Parkia biglobosa* seeds (2.9),[41] *Ximenia americana*,[40] *Borassus aethiopum* fruits (0.9–5.7),[40,44] *Moringa oleifera* leaves (0.2–3.1),[18,40] leaves of *Hibiscus sabdariffa* (6.6), leaves of *Amaranthus viridis* (5.8)[61] and certain animal species such as snails (*Limicolaria* sp., *Achatina fulica*, *Achatina achatina*, *Archachatina marginata*) (2.7–2.7).[29,62,63]

Iron. Iron bioavailability varied according to the iron source. Heme iron from animals was more bioavailable than non-heme iron coming from plants.[67] The best sources of heme iron (g kg^{-1} DW) were *Ruspolia differens* (2.59–2.61)[51,52,56] and *Macrotermes bellicosus* (0.51–0.54).[68] However, snails (*Limicolaria* sp., *Achatina fulica*, *Achatina achatina* and *Archachatina marginata*) (0.09–0.10)[29,63] and fish (0.07–0.08)[52] also showed significant amounts of heme iron (g kg^{-1} DW) relative to the standard (0.058) for medium (10%) dietary iron bioavailability. Regarding non-heme iron (g kg^{-1} DW), the best sources were seeds of *Parkia biglobosa* (0.05–5.07),[32,40,41] *Adansonia digitata* pulp (0.01–2.99) and leaves (0.01–2.54),[24,40] *Citrus limon* peel (1.48),[60] leaves of *Ceratotheca sesamoides* (1.24), *Hibiscus sabdariffa* leaves (1.19)[61] and *Moringa oleifera* leaves (0.07–0.11).[18,40]

Manganese. High amounts of manganese (g kg^{-1} DW) (i.e. ≥0.11) were recorded in *Moringa oleifera* leaves (0.06–0.11),[18,40] pulp (0.05–3.53) and beans (0.07–3.45) from *Parkia biglobosa*,[32,40,41] *Hibiscus sabdariffa* leaves (0.11), *Afraegle paniculata* fruits (0.05),[40] and for certain species of animal-based resources such as termites (0.22–0.26) and fish (0.248–0.36).[41]

Zinc. The highest zinc content (g kg^{-1} DW (≥0.03) was available in *Citrus limon* peel (0.14),[60] *Adansonia digitata* leaves (0.007–0.22) and seeds (0.03–0.07),[15,40] *Parkia biglobosa*,[41] jujube fruit,[37,52] *Vitellaria paradoxa* fresh fruit,[64,65] *Hibiscus sabdariffa* leaves (0.07) and *Amaranthus viridis* leaves (0.06),[61] and dried snail flesh (0.38–0.40),[62] fish (0.20–0.28),[52] *Macrotermes bellicosus* (0.19–0.21)[68] and *Ruspolia differens* (0.12).[51,52,56]

Vitamins. Vitamin C was more often detected in the documented food resources than vitamins A, B and D (Table 3). Vitamin C was highly abundant in baobab pulp (2.09–3.6 g kg^{-1} DW),[15,40] dried *Moringa oleifera* leaves (1.2 g kg^{-1} DW),[18,40] and *Parkia biglobosa* pulp (0.00005–2.42 g kg^{-1} DW).[41,69] Provitamin A was available in *Parkia biglobosa* beans (0.35 g kg^{-1} DW),[41,69] *Moringa oleifera* leaves (0.068 g kg^{-1} DW),[18,40] and queen *Macrotermes bellicosus* (0.076–0.077 g kg^{-1} DW).[68] The highest amounts of vitamin B1 (g kg^{-1} DW were recorded in *Amaranthus hybridus* leaves (0.275),[49] *Tamarindus indica* leaves (0.001–0.002), *Vitellaria paradoxa* pulp (0.005),[32] and pulp (0.001–0.11) and seed (0.002–0.007) of *Parkia biglobosa*.[32,41] Riboflavin was recorded in *Boerhavia diffusa* leaves (0.18–0.26)[70] and *Amaranthus hybridus* leaves (0.042).[49]

Niacin was available in *Boerhavia diffusa* leaves (0.89–1.05 g kg^{-1} DW)[70] and *Adansonia digitata* pulp (0.018–0.0027 g kg^{-1} DW).[24] Good sources of vitamin D were pulp (0.0–3.9 g kg^{-1} DW) and beans (0.0–0.7 g kg^{-1} DW) from *Parkia biglobosa*.[32,41]

Amino acids

Amino acids recommended by FAO[71] for infants and children were present in many food resources, including leaves, pulp, seed, and meat (Table 4). With regard to tryptophan, plant species do not contain a sufficient quantity (content was lower than the required FAO standard). Only fish, namely *Trachurus trachurus*, *Clupea* spp. and *Engraulis* spp.,[72] met tryptophan requirements (10 g kg^{-1} DW). Isoleucine, leucine and lysine contents of several food resources were higher than or similar to FAO[71] recommendations (32, 66 and 57 g kg^{-1} DW, respectively). Indeed (g kg^{-1} DW), *Blighia sapida* seeds (37.0, 65.8 and 51.1, respectively),[50] *Amaranthus hybridus* leaves (33.9, 67.0 and 30.3, respectively),[49]

Table 2. Minerals

Resource	Ca(g kg^{-1} DW)	Ref.
Peel of lemon (*Citrus limon* (L.) Burm.f.)	84.53	60
Leaves of ben oil tree, horseradish tree (*Moringa oleifera* Lam.)	4.4–34.68	40,61,96
Fruit of *Grewia mollis*	34.74	40
Leaves of *Amaranthus viridis* L.	15.9–16.4	61
Leaves of Soap berry tree (*Balanites aegyptiaca* (L) Del.)	15.8	40
Leaves of baobab (*Adansonia digitata*)	3.07–26.4	15,40,61
Pulp of African locust bean (*Parkia biglobosa*)	1.18–23.98	41
Soap berry tree (*Balanites aegyptiaca* (L) Del.)	15.8	40
Seed of African locust bean (*Parkia biglobosa*)	5.74–14.703	32,40,41
Fruit of *Afraegle paniculatum* (Shum. et Thonn.) Engl.	9.14	40
Resource	Fe (g kg^{-1} DW)	Ref.
Seed of African locust bean (*Parkia biglobosa*)	0.054–5.067	32,40,41
Pulp of African locust bean (*Parkia biglobosa*)	0.011–2.985	32,40,41
Leaves of baobab (*Adansonia digitata*)	0.012–2.540	24,40
Leaves of *Cerathotheca sesamoides* Endl.	1.240	61
Peel of lemon (*Citrus limon* (L.) Burm.f.)	1.477	60
Leaves of *Hibiscus sabdariffa* L.	1.191	61
Leaves of soap berry tree (*Balanites aegyptiaca* (L) Del.)	0.579	40
Leaves of ben oil tree, horseradish tree (*Moringa oleifera* Lam.)	0.07–1.05	18,40
Seed of *Vitellaria paradoxa*	0.519–0.521	64,65
Leaves of *Amaranthus viridis* L.	0.477	61
Grasshopper (*Ruspolia differens*)	2.59–2.61	51,52,56
Termites (*Macrotermes bellicosus*)	0.508–0.54	68
Snail (*Limicolaria* sp); (*Achatina fulica*); (*Achatina achatina*); (*Archachatina marginata*)	0.095–0.101	29,63
Fish	0.07–0.08	52
Resource	Zn (g kg^{-1} DW)	Ref.
Peel of lemon (*Citrus limon* (L.) Burm.f.)	0.139	60
Hibiscus sabdariffa L.	0.073	61
Leaves of baobab (*Adansonia digitata*)	0.007–0.224	15,40,61
Leaves of *Amaranthus viridis* L.	0.063	61
seed of baobab (*Adansonia digitata*)	0.026–0.073	15,40,61
Leaves of *Cerathotheca sesamoides* Endl.	0.028	61
Fruit of soap berry tree (*Balanites aegyptiaca* (L) Del.)	0.029	40
Fruit of *Ficus sycomorus*	0.0284	40
Leaves of ben oil tree, horseradish tree (*Moringa oleifera* Lam.)	0.0204–0.0227	40,61,96
Leaves of soap berry tree (*Balanites aegyptiaca* (L) Del.)	0.0227	40
Snail (*Limicolaria* sp.); (*Achatina fulica*; *Achatina achatina*; *Archachatina marginata*)	0.376–0.404	29,63
Fish	0.202–0.280	52
Termites (*Macrotermes bellicosus*)	0.191–0.207	68
Grasshopper (*Ruspolia differens*)	0.124	51,52,56
Resource	Na (g kg^{-1} DW)	Ref.
Peel of Lemon (*Citrus limon* (L.) Burm.f.)	7.555	60
Grasshopper (*Ruspolia differens*)	2.290–2.310	51,52,56
Leaves of *Amaranthus viridis* L.	0.874	61
Aril of ackee (false cashew) *Blighia sapida*	0.292–0.842	33–35
Leaves of black tamarind (*Dialium guineense* Willd)	0.751–0.769	43
Termites (*Macrotermes bellicosus*)	0.612–0.652	68
Snail (*Limicolaria* sp); (*Achatina fulica*; *Achatina achatina*; *Archachatina marginata*)	0.508–0.651	29,63
Leaves of ben oil tree, horseradish tree (*Moringa oleifera* Lam.)	0.484	40,61,96
Apple of cashew (*Anacardium occidentale* L.)	0.348	66
Resource	K (g kg^{-1} DW)	Ref.
Peel of lemon (*Citrus limon* (L.) Burm.f.)	86	60
Pulp of baobab (*Adansonia digitata*)	7.26–32.72	15,40,61
Apple of cashew (*Anacardium occidentale* L.)	21.9	66

Table 2. Minerals

Resource	K (g kg^{-1} DW)	Ref.
Pulp of *Vitellaria paradoxa*	16.86	64,65
Pulp of African locust bean (*Parkia biglobosa*)	16.7	32,40,41
Seed of baobab (*Adansonia digitata*)	4.28–13.87	15,40,61
Leaves of baobab (*Adansonia digitata*)	1.4–10.8	15,40,61
Leaves of Ben oil tree, horseradish tree (*Moringa oleifera* Lam.)	9.12	40,61,96
Leaves of *Cerathotheca sesamoides* Endl.	6.26	61
Resource	Mg (g kg^{-1} DW)	Ref.
Leaves of *Amaranthus viridis* L.	11.5–12.6	61
Peel of Lemon (*Citrus limon* (L.) Burm.f.)	14.3	60
Leaves of ben oil tree, horseradish tree (*Moringa oleifera* Lam.)	0.24–8.31	40,61,96
Hibiscus sabdariffa L.	7.865	61
Fruit of *Grewia mollis*	7.430	40
Leaves of Baobab (*Adansonia digitata*)	0.936–5.49	15,40,61
Pulp of African locust bean (*Parkia biglobosa*)	0.88–4.59	32,40,41
Leaves of Soap berry tree (*Balanites aegyptiaca* (L) Del.)	2.96	40
Aril of ackee (false cashew) *Blighia sapida*	0.211–2.4	33–35
Fruit of *Ficus sycomorus*	2.12	40
Resource	P (g kg^{-1} DW)	Ref.
Peel of lemon (*Citrus limon* (L.) Burm.f.)	66.563	60
Leaves of baobab (*Adansonia digitata*)	1.15–8.75	15,40,61
Seed of baobab (*Adansonia digitata*)	0.056–7.38	15,40,61
Hibiscus sabdariffa L.	6.64	61
Leaves of *Amaranthus viridis* L.	5.79	61
Pulp of *Borassus aethiopum*	0.92–5.67	40,44
Leaves of ben oil tree, horseradish tree (*Moringa oleifera* Lam.)	0.20–3.12	40,61,96
Tallow nut (*Ximenia americana*)	2.95	40
Seed of African locust bean (*Parkia biglobosa*)	2.93	40,41
Snail (*Limicolaria* sp.); (*Achatina fulica*; *Achatina achatina*; *Archachatina marginata*)	2.653–2.731	29,63
Resource	Mn (g kg^{-1} DW)	Ref.
Pulp of African locust bean (*Parkia biglobosa*)	0.054–3.53	32,40,41
Seed of African locust bean (*Parkia biglobosa*)	0.068–3.415	32,40,41
Leaves of *Cerathotheca sesamoides* Endl.	0.38	61
Fish	0.248–0.36	52
Termites (*Macrotermes bellicosus*)	0.0219–0.0259	68
Leaves of ben oil tree, horseradish tree (*Moringa oleifera* Lam.)	0.058–0.113	40,61,96
Hibiscus sabdariffa L.	0.114	61
Fruit of *Afraegle paniculatum*	0.049	40
Leaves of soap berry tree (*Balanites aegyptiaca* (L) Del.)	0.047	40
Leaves of *Amaranthus viridis* L.	0.038	61

Syntermes soldiers (29.5–34.2, 49.9–53.4 and 18.2–65.1, respectively)[73] and fish (60, 84 and 88, respectively)[72] were the most interesting food resources with regard to these amino acids.

Threonine, valine and histidine are required to ensure adequate growth in infants and young children. FAO[71] recommended that infant food products should contain more than 31, 43 and 20 g kg^{-1} DW, respectively, of threonine, valine and histidine. Thus the most important food resources with high amounts of amino acids (g kg^{-1} DW) were fish (46, 60 and 20, respectively),[72] *Syntermes* soldiers (28.1–29.1, 37.4–44.7 and 19.3–22.4, respectively),[73] *Blighia sapida* pulp (35.0, 43.3 and 16.1, respectively) and seeds (23.5, 40.4 and 23.0, respectively),[50] *Parkia biglobosa* pulp (31.5, 16.4 and 23.9, respectively) and seeds (0.3–28.1, 3.8–40.5 and 26.5, respectively).[74]

Fatty acids

Few authors have investigated the fatty acid content of food resources (Table 5). Sena *et al.*[61] and Belluco *et al.*[75] reported that linoleic acid (18:2 n-6) and α linolenic acid (18:3 n-3) are two essential fatty acids for human health. The richest sources of linoleic acid within the documented food resources were baobab kernels (0.23–0.39 g kg^{-1} DW) and seeds (0.12–0.36 g kg^{-1} DW)[24,39] and *Rhamdia quelen* (silver catfish) (1.92 g kg^{-1} DW),[76] whereas α linolenic acid content was mostly important (0.11–0.15 g kg^{-1} DW) in leaves of *Moringa oleifera*, *Hibiscus sabdariffa* and *Amaranthus viridis*,[61] and *Rhamdia quelen*.[76]

Antinutritional factors

Antinutritional factors can reduce the digestibility and bioavailability of other useful nutrients. The main antinutritional factors

Table 3. Vitamins

Resources	Vitamin D (g kg^{-1} DW)	Ref.
Pulp of African locust bean (*Parkia biglobosa*)	0–0.0039	32,41
Seed of African locust bean (*Parkia biglobosa*)	00.0007	32,41
NERs	Carotene/vit. A (g kg^{-1} DW)	Ref.
Seed of African locust bean (*Parkia biglobosa*)	0–0.3487	41,69
Leaves of horseradish tree (*Moringa oleifera* Lam.)	0.068	18,40
Leaves of kapok tree, silk-cotton tree (*Ceiba pentandra*)	0.0073	57,58
Queen termites (*Macrotermes bellicosus)*	0.0764–0.077	68
Soldier termites (*Macrotermes bellicosus*)	0.022–0.026	68
NERs	Vitamin C (g kg^{-1} DW)	Ref.
Pulp of baobab (*Adansonia digitata*)	2.09–3.6	24,40
Leaves of horseradish tree (*Moringa oleifera* Lam.)	1.2	18,40
Boerhavia diffusa L	0.039–0.051	70
Pulp of ackee (false cashew) (*Blighia sapida*)	0.026	32
Pulp of African locust bean (*Parkia biglobosa*)	0.00005–0.00242	41,69
Kapok tree, silk-cotton tree (*Ceiba pentandra*)	0.049	57,58
Termites (*Macrotermes bellicosus*)	0.009–0.011	68
NERs	Vit. B1, thiamine (g kg^{-1} DW)	Ref.
Leaves of *Amaranthus hybridus*	0.028	49
Pulp of African locust bean (*Parkia biglobosa*)	0.001–0.011	41,69
Seed of African locust bean (*Parkia biglobosa*)	0.002–0.007	41,69
Fruit of *Vitellaria paradoxa*	0.0052	37
Leaves of *Tamarindus indica*	0.001–0.002	32
NERs	Vit. B2, riboflavin (g kg^{-1} DW)	Ref.
Boerhavia diffusa L.	0.178–0.263	70
Leaves of *Amaranthus hybridus*	0.0424	49
Grasshopper (*Ruspolia differens*)	0.008–0.02	51,56
Pulp of ackee (false cashew) (*Blighia sapida*)	0.0014	32
Leaves of *Tamarindus indica*	0.001–0.0011	32
NERs	Vit. B3, niacin (g kg^{-1} DW)	Ref.
Boerhavia diffusa L	0.889–1.05	70
Seed of African locust bean (*Parkia biglobosa*)	0.03–0.75	41,69
Leaves of *Tamarindus indica*	0.028–0.041	32
Grasshopper (*Ruspolia differens*)	0.016–0.032	51,56
Pulp of baobab (*Adansonia digitata*)	0.018–0.027	24

common in food resources encompass trypsin and chymotrypsin inhibitors, cyanogenic glucosides, anthocyanins, steroids, alkaloids, hemagglutinins and total phenolic components such as tannins/catechin and phytates, and flavonoids.[77,78] Table 6 shows that oxalate content can pass 0.005 g kg^{-1} DW in the seed cover of *Parkia biglobosa*, *Blighia sapida* pulp and *Adansonia digitata* leaves; and phytates can reach 1.185 g kg^{-1} DW in *Pleurotus tuber-regium*.

Nutritious species according to agro-ecological zones

Many nutritious species described in the present review are located in various agro-ecological zones of Benin (Table 7). Some resources are present in all agro-ecological zones (*Adansonia digitata*, *Borassus aethiopum*, *Glycine max*, *Moringa oleifera*, *Parkia biglobosa*, *Tamarindus indica*, *Tilapia*, *Vitellaria paradoxa*) or in seven out of eight agro-ecological zones *Arachis hypogaea* and *Sesamum* spp.). These species are providers of most nutrients because, according to their nutrient content, they can significantly contribute to energy, proteins, minerals and vitamins. As such it is possible to find a good combination of ingredients for complementary foods for all agro-ecological zones considering the distribution of the resources according to important nutrients.

DISCUSSION AND CONCLUSIONS

Implications of the unbalanced distribution of food resources across agro-ecological zones on complementary food formulation for children

This review demonstrates a high diversity of potential ingredients for complementary food formulations in Benin. Regarding the documented plant food resources, their distribution among morphological types is comparable to that of all (1334) edible plant species previously documented in Benin, including herbs (36.5% against 45.1% within potential plant ingredients for infant food formulation), trees (27.1% against 24.9%), bushes (18.8% against 15.2%), creepers (13.9% against 12.5%) and cryptograms (3.7% against 2.4%).[11,17] The morphological type gives an indication of

Table 4. Amino acid (g kg^{-1} protein)

Type of product	Resource parts	Trp	Ile	Leu	Lys	Met	Cys	SAA	Phe	Tyr	AAA	Thr	Val	His	Ala	Arg	Asp	Glu	Gly	Pro	Ser	PrA	Ref.
Baobab (*Adansonia digitata*)	Leaves	1.0–3.4	4.7–7.5	7.2–9.8	4.7–6.7	0.9–2.6	1.5–3.9	–	4.8–6.7	3.4–5.1		3.4–4.8	5.2–7.0	1.7–2.6	58–75	6.4–11.1	8.1–12.9	7.4–14.6	4.8–6.7	49–68	3.6–5.6	–	15,39,61
	Pulp of baobab	0.7–6.4	2.2–5.1	4.1–7.6	1.7–6.0	0.2–4.9	1.1–1.7	–	2.1–4.4	0.9 –20.6		2.4–2.8	1.6–6.0	0.4–3.4	2.2–8.2	2.3–8.4	3.0–11.0	3.9–14.6	1.2–11.4	2.4–8.7	1.2–4.4	2.2–5.1	15,39
	Seed	1.4–3.7	3.6–9.6	7.0–17.8	5.0–10.1	1.0–3.4	1.5–5.2	–	4.0–12.3	1.5–7.4		3.8–7.9	5.9–13.5	2.2–5.4	5.4–11.5	1.1–25.5	10.3–23.4	23.7–59.2	5.3–12.5	4.9–13.3	5.8–12.9	6.9	
Ackee (false cashew) (*Blighia sapida*)	Pulp (fruit)		25	56.5	40.3	12.5	8.6		36.0	25.4		35.0	43.3	16.1	30.4	72.5	86.5	114	35.6	16.3	17.1		50
	Seed		37	65.8	51.1	12.5	25.1		41.1	30.2		2.35	40.4	23.0	38.4	44.0	91.8	127	30.3	27.5	31.4		50
African locust bean (*Parkia biglobosa*)	Pulp		21.1	40.7	26.4	8.2	13.1	3.13	30.5	18.0	48.5	31.5	16.4	23.9	21.4	43.3	41.3	75.1	24.5	20.3	29.6		74
	Seed		2.3–24.0	8.4–73.5	4.2–65.6	16.2	12.3	2.85	48.8	2.4–32.8	81.6	0.3–28.1	3.8–40.5	26.5	3.5–36.6	68	68.7	24.5–141.2	0.4–47.1	0.8–26.3	48.4	–	69,74
Moringa oleifera	Leaves	6.1	11.9	20.5	13.0	3.3	3.3		13.9	9.9		10.0	14.8	5.1	14.1	18.9	20.5	28.4	10.8	14.3	9.7		61
Edible mushrooms (*Pleurotus tuber-regium*)	Cap, stalk, tuber		20.2–21.1	28.4–41.5	23.8–27.4	4.8–5.7	4.3–5.3		20.4–21.9	4.2–5.7		29.2–32.0	31.9–37.5	12.3–14.7	23.1–28.8	30.5–31.4	43.5–45.6	54.2–65.7	7.4–9.5	5.7–6.6	11.6–14.5		45
Amaranthus hybridus	Leaves	–	33.9	67.0	30.3	17.6	4.6	2.22	40.0	30.5	70.5	26.2	35.0	21.5	33.5	39.4	54.0	157.9	38.1	34.3	30.4		49
Hibiscus sabdariffa L.	Leaves	5.9	10	17.4	12.2	2.9	3.4		13.1	8.5		9.5	13.3	6.4	11.8	17.5	31.8	26.6	11.7	13.8	11.9		61
Amaranthus viridis L.	Leaves	3.8	13	21.4	13.3	35	46		14.1	9.9		11.0	15.6	4.8	15.0	19.7	23.4	31.1	12.3	12.4	11.1		61
Ceratotheca sesamoides Endl.	Leaves	2.3	5.1	8.2	4.9	1.4	1.9		5.3	3.8		3.9	5.8	2.0	5.8	7.3	17.3	12.3	4.3	4.9	3.9		61
Termites seri (*Syntermes* soldiers)	Heads	7.1	29.5–34.2	49.9–53.4	18.2–65.1	7.9–10.1	4.0–5.2		19.3–22.4	28.0–41.4		28.1–29.1	37.4–44.7	19.3–22.4	50.6–72.6	34.8–44.3	53.4	74.3–86.3	25.8–28.8	36.6–49.6	38.5–50.8		73
	Thorax and abdomen	5.8	21.7–46.6	33.9–83.2	18.2–65.1	4.1–5.4	2.7–3.7		11.7–48.1	25.3–27.3		20.0–47.6	32.7–48.9	13.5–28.5	53.6–54.6	23.9–62.7	38.1–53.6	50.8–125.5	25.0–50.3	37.8	35.6–40.7		73
Fish	Fresh	10	60	84	88	40	40		39			46	60	20									72
FAO/WHO standard, child (6 months to 3 years)		**8.5**	**32**	**66**	**57**	**15**		**27**		**39**	**52**	**31**	**43**	**20**									97

His, histidine; Ile, isoleucine; Leu, leucine; Lys, lysine; SAA, sulfur amino acids; AAA, total aromatic amino acids; Thr, threonine; Trp, tryptophan; Val, valine; Met, methionine; Phe, phenylalanine; Tyr, tyrosine; Cys, cystine; Ala, alanine; Arg, arginine; asp, aspartic acid; Glu, glutamic acid; Gly, glycine; Pro, proline; Ser, serine; PrA, prolamine.

Table 5. Fatty acids (g kg^{-1} DW)

Type of product	Resource part	Total saturated	Total monoun-saturated	Total poly-unsaturated	C:8 (Caprylic)	C:12 (Lauric)	C14:0 (Myristic)	C16:0 (Palmitic)	C16:1 (Palmitoleic)	C16:2 Hexadecadienic	C18:0 (Stearic)	C18:1 Oleic	C18:2 (Linoleic)	C18:3 (Linolenic)	C20:0 (Arachidic)	C20:1 (Gadoleic)	C22:0 Behenic	C24:0 Lignoceric	Malvalic	Sterculic	Ref.
Baobab (*Adansonia digitata*)	Leaves				0.8	0.09	0.37	0.2–3.2	0.01–0.2		0.04–0.35	0.06–0.39	0.1–1	0.08–4.1	0.15						24,61
	Pulp				–		0.2–0.2	0.2–27.0	–		3.3	25	0.0–27.0	0.2–0.9	0.07	0.04					24,61
	Seed				–	0–0.3	0.3–1.5	2.22–46	0.2–1.7	0.70	0.21–3.98	4.6–59	12.0–35.8	0–30.7	0.5–1.0	0–3.6	0.36–0.9	0.31–0.7	3.1–2.6	1.0–1.9	24,39
	Kernel				–	3.98	1.46	2.22–4.43	1.7		3.98	26.1–58.7	23.3–39.4	8.2	2.26	3.6–4.01	3.46	10.7			24
African locust bean (*Parkia biglobosa*)	Seeds	39.2–89.8	0.0–15.5	8.9–44.7				8.8–11.2							10.5–11.7	0.0–14.8	8.9–44.7	0.0–0.6			98
Moringa oleifera	Leaves					0.09	0.4	5.90	0.6		0.57	0.65	2.0	13.3	0.12						61
Hibiscus sabdariffa L.	Leaves				0.053	0.074	0.4	5.0	0.5		0.94	1.1	3.30	12.0	0.23						61
Amaranthus viridis L.	Leaves					0.06	0.1	6.0	0.9		0.66	0.84	2.8	11.1	0.06						61
Ceratotheca sesamoides Endl.	Leaves						0.06	1.50	0.11		0.24	0.20	0.64	2.90	0.09						61
Grasshopper (*Ruspolia differens*)	Brown	59.6–60.6	25.7–26.9	33.4–34.2	0.1–0.3		0.3–1.1	31.9–32.3	1.3–1.5		23.7–26.1	29.3–29.7	3.7–4.7								56
	Green	37.9–38.7	25.3–27.9	34.2–34.6	0.3–0.5		0.3–1.5	30.8–32.2	0.8–3		23.1–26.1	30.9–31.5	3–3.4								56
Termites (*Syntermes soldiers*)	Thorax and abdomen	22.9	42.5	100.00		0.1	1.1	7.2	1.0		37.4	24.5	0.2	0.8							73
	Heads	18.7	46.3	100.00		0.0	0.4	5.7	0.8		43.5	25.2	0.2	0.7							73
Silver catfish (*Rhamdia quelen*)	Fillet						13.4	246.0			83.8	298.0	192.0	14.1		9.5	12.4	06.6			76

Table 6. Antinutritional factors

Resources	Oxalates(g kg^{-1} DW)	Ref.	NERs	Phytates (g kg^{-1} DW)	Ref.
Testa (seed cover) of African locust bean (*Parkia biglobosa*)	0.039–0.059	25,26	Edible mushrooms (*Pleurotus tuber-regium*)	3.38–11.85	45
Pulp of ackee (false cashew) *Blighia sapida*	0.054	35	Breadfruit (*Artocarpu saltilis*)	2.8–5.3	77
Leaves of baobab (*Adansonia digitata*)	0.044–0.053	24	Seed of baobab (*Adansonia digitata*)	0.73	24
Pulp of African locust bean (*Parkia biglobosa*)	0.024–0.04	25,26			
Pulp of baobab (*Adansonia digitata*)	0.00004	24			

the frequency of reproduction of the plant and hence availability of the food ingredient.

The distribution of the referenced food species across Benin's agro-ecological zones is highly unbalanced, which is likely to result from climatic and agro-ecological differences between zones. The issue here should not be the access, but rather appropriate processing to transform the products to a more stable form. This will ensure accessibility by all, irrespective of the zone one is living in. In case no correspondence is found in a zone, further studies on indigenous food plants should address their ecology and domestication issues for such an area. Studies provide the nutritional value of tree products but do not report on their accessibility. Researchers from different fields (crop production, food technology, biotechnology, nutrition, ecology, forestry, sociology and logistics) have to work together to find appropriate solutions to the pronounced unbalanced diversity of food resources in Benin.

As such, instead of proposing a general formulation of complementary foods for infants and children, formulas have to be specific to agro-ecological zones or groups of agro-ecological zones when they have food resources in common. Further research should therefore take into account this unbalanced situation and target the enhancement of potentiality of the study area in food resources. Such an application can set the tone for similar studies in other countries that have comparable agro-ecological zones as Benin, such as Togo or Nigeria.

Nutritional value of local food resources *versus* international requirements

This review revealed a high diversity in the nutritional value of food resources. Any proper complementary food should be rich in calories and good-quality protein, vitamins and minerals.[79] According to the recommended nutrient densities, a complementary food should provide 58% of its calories from carbohydrates.[80] Most featured documented carbohydrate providers were *Dialium guineense*, *Adansonia digitata* pulp and *Afraegle paniculata* fruit. Fortunately, sources of carbohydrates were available across all agro-ecological zones and could be used in addition to common carbohydrate providers (i.e. cereals, tubers and roots).

Apart from energy, one of the most important elements in the diet of infants and young children is the amount of protein, which should be 60–150 g kg^{-1} infant flour,[14] with a daily intake of 160 g kg^{-1} DW.[48] Best documented plant protein providers were *Glycine max*, *Parkia biglobosa*, *Balanites aegyptiaca* leaves, *Amaranthus hybridus* leaves, *Adansonia digitata* kernels, *Ceratotheca sesamoides* leaves and *Arachis hypogaea*, which all contain more than 200–320 g kg^{-1} DW protein. For instance, without considering the conversion factor or the effect of processing, such as cooking, the consumption of 20 g baobab dry leaf material would cover 10–16% of the protein recommended daily intake (RDI) for children (4–8 years).[81] Animal protein sources have at least twice the RDI (320–880 g kg^{-1} DW). Animal proteins have better digestibility than plant proteins but are more expensive.[82]

Among the major minerals, calcium is essential for bone structure and function,[83] with a daily requirement of 5 g kg^{-1} DW.[14] For food complementation, preference should be given to *Citrus limon* peel, *Moringa oleifera*, *Amaranthus viridis* and *Adansonia digitata* leaves, and ** *Grewia mollis* fruits, which all contain more than 3 g kg^{-1} DW Ca.

Iron is an essential mineral for humans and its recommended intake for infants is 0.116 g kg^{-1} DW Fe given for 5% of dietary iron bioavailability.[14] Haem iron, which comes only from animal foods, is known to have a higher and more uniform absorption (estimated at 15–35%) than non-haem iron, which comes essentially from plant foods.[84] Best haem iron providers were grasshoppers, termites, snails and fish; best non-heme iron providers were seeds of *Parkia biglobosa*, and *Adansonia digitata* pulp and leaves. Non-heme iron providers were more widely available and often cheaper than haem iron sources. Iron absorption enhancers like acidulants (vitamin C) can improve bioavailability of non-heme iron and should then be consumed together with the plant sources of iron.[85] However, this enhancing effect of ascorbic acid on iron absorption is unfortunately reduced by thermal processing and storage degradation.[86] Fortunately, adding muscle tissue (meat, fish or poultry) to vegetarian meals has been shown to considerably enhance iron absorption with less sensitivity to heat and oxygen.[86] Hence including even a small quantity of animal protein in infant foods may highly improve bioavailability of non-haem iron, which is the most common iron source available in Benin. This is important for sensitization among populations and as such should be considered by policy makers in nutrition plans at national level.

Zinc is a particularly important element for human metabolism, immune system and neurobehavioral development.[87] When the dietary bioavailability is medium, the required proportion of zinc is 0.041 g kg^{-1} DW.[14] Snails, fish and termites were the best-documented indigenous zinc sources. Incorporating these sources into infant foods can highly reduce immunodeficiency and infectious disease morbidity.[88]

Magnesium is important for any biochemical process in an organism, and it is necessary for muscles, nervous system, activity of hormones, manufacture of energy and maintenance of health.[89] The most remarkable sources were *Amaranthus viridis*, *Citrus limon* peel, *Moringa oleifera* leaves, *Hibiscus sabdariffa* leaves, and leaves and seeds of *Adansonia digitata*, which all contain on average

Table 7. Location of nutritious species in agro-ecological zones of Benin

Species	Resources	Nutrients provided	Agro-ecological zones
Adansonia digitata	Kernel	Energy, lipid, fiber, ash, fatty acids	I, II, III, IV, V, VI, VII, VIII
	Seeds	Energy, carbohydrates, fiber, phosphorus, amino acids, fatty acids, phytates	
	Pulp	Carbohydrates, fiber, vitamin C B3, amino acids, fatty acids, oxalates	
	Leaves	Carbohydrates, fiber, ash, phosphorus, amino acids, fatty acids, oxalates	
Afraegle paniculata	Fruit	Carbohydrates, manganese	III, V, II, IV, VI
Amaranthus hybridus	Leaves	Protein, phosphorus, manganese, vitamin B1 B2, amino acids	IV, V
Amaranthus viridis	Leaves	Amino acids, fatty acids	IV, V
Anarcadium occidentalis	Cashew	Energy, lipid	III, IV, V, VI, VII, VIII
Arachis hypogea	Peanut	Energy, protein, lipid	II, III, IV, V, VI, VII, VIII
Balanites aegyptiaca	Fruit	Carbohydrates, ash	I, II, III, IV
	Leaves	Carbohydrates, protein, fiber, ash, manganese	
Blighia sapida	Ackee pulp	Energy, protein, lipid, fiber, ash, vitamin C B2, amino acids, oxalates	V, VI, VII, VIII
	Seeds	Amino acids	
Boerhavia diffusa		Vitamin C B2 B3	II, III, IV, V, VII, VIII
Borassus aethiopum	Pulp	Carbohydrates, phosphorus	I, II, III, IV, V, VI, VII, VIII
Ceiba pentandra	Kapok tree	Ash	V, VI, VII, VIII
	Leaves	Vitamins A C	
Ceratotheca sesamoides	Leaves	Protein, lipid, ash, manganese, amino acids, fatty acids	II, III, IV, V, VII, VIII
Citrus limon	Peel	Phosphorus	VI, VII, VIII
Cocos nucifera	Coconut	Lipid	
Dialium guineense	Leaves	Carbohydrates	II, III, IV, V, VI, VII, VIII
Elaeis guineensis	Palm nut	Energy, lipid	V, VI, VII, VIII
Glycine max	Soya bean	Energy, protein	I, II, III, IV, V, VI, VII, VIII
Hibiscus sabdariffa	Calyces	Ash, phosphorus, manganese	IV, V, VI, VIII
	Leaves	Amino acids, fatty acids	
Irvingia gabonensis	Fruit	Lipid	V
Limicolaria sp.	Snail	Protein, phosphorus	VI
Macrotermes bellicosus	Termites	Protein, ash, manganese, vitamin C	IV
	Queen	Vitamin A	
	Soldiers	Vitamin A	
Moringa oleifera	Leaves	Protein, fiber, ash, manganese, phosphorus, vitamins A C, amino acids, fatty acids	I, II, III, IV, V, VI, VII, VIII
Parkia biglobosa	Seeds	Energy, protein, ash, manganese, phosphorus, vitamins D A B1 B3, amino acids, fatty acids	I, II, III, IV, V, VI, VII, VIII
	Leaves	Carbohydrates	
	Pulp	Manganese, vitamins D, C B1, amino acids, oxalates	
	Testa (seed cover)	Oxalates	
Pleurotus tuber-regium	Mushroom	Carbohydrates, amino acids, phytates	III, V, VII, VIII
Rhamdia quelen	Fillet	Fatty acids	III, VII, VIII
Ruspolia differens	Grasshopper	Protein, lipid, vitamins B2 B3, fatty acids	IV
Sesamum spp.	Sesame	Energy, protein, lipid	II, III, IV, V, VII, VIII
Syntermes soldiers	Heads	Amino acids, fatty acids	II, IV
	Thorax		
	Abdomen		
Tamarindus indica	Leaves	Vitamins B1 B2 B3	I, II, III, IV, V, VI, VII, VIII
Tilapia	Fish	Protein, ash, manganese, amino acids	I, II, III, IV, V, VI, VII, VIII
Vigna subterranea	Seeds	Fiber	IV, V
Vitellaria paradoxa	Shea nut	Energy, lipid	I, II, III, IV, V, VI, VII, VIII
	Fruit	Vitamin B1	
Ximenia americana	Tallow nut	Phosphorus	II, III, V, VI, VII, VIII

more than 4.2 g kg^{-1} DW, against a recommended daily intake of 0.6 g kg^{-1} DW. High quantities of other major minerals, including potassium, phosphorus and manganese, as well as high quantities of essential amino acids, were also reported for numerous food resources. Pulp of baobab contained up to 32.72 g kg^{-1} and pulp of *Vitellaria paradoxa* up to 16.86 g kg^{-1} DW potassium, while leaves of *Amaranthus viridis* contained up to 12.6 g kg^{-1} DW magnesium. Digestive factors unique to the individual can also influence the amount of magnesium absorbed in the gastrointestinal tract. These include the ability to break down magnesium-containing foods in the stomach, and the ability to absorb magnesium in the small intestine. Aging, disease, stress and illness can also reduce magnesium absorption. The type of molecule also matters. Potassium – magnesium citrate provided an equivalent potassium bioavailability as potassium citrate and potassium chloride, and a comparable magnesium bioavailability to magnesium citrate.[90]

As to vitamins, vitamin C abounds (2.09 – 3.60 g kg^{-1} DW) in *Adansonia digitata* pulp, and a high quantity (more than 1.2 g kg^{-1} DW) was also found in *Moringa oleifera* leaves as compared to the recommended intake of 0.3 g kg^{-1} DW. As underlined above, this vitamin is an interesting iron absorption enhancer that can significantly improve bioavailability of non-heme iron. Without considering conversion factors, 13.9 g of baobab pulp would be enough to cover the vitamin C RDI of an infant.[81] Other featured vitamin sources were *Amaranthus hybridus* leaves (for vitamin B1), *Boerhavia diffusa* leaves (for riboflavin and niacin) and *Parkia biglobosa* (for vitamin D). The required proportion of vitamin D for an infant is 0.00005 g kg^{-1} DW.[14]

Antinutritional factors were also present in food resources, but just a few studies documented such compounds. Oxalates that were mostly found in seed shells of *Parkia biglobosa*, *Blighia sapida* pulp and *Adansonia digitata* leaves and phytates that were mostly found in *Pleurotus tuber-regium*, were the most documented ones. It is worth noting that studies reported that the antinutritional factors investigated in certain food resources can be reduced by food-processing techniques like soaking (cold/hot water, alkaline solutions), mechanical removal, acid treatment, germination, fermentation, enzymatic treatment and cooking),[24,77,91] which could be included in the processing of complementary foods.

Variability in the reported data

The present review shows large variability in reported values, especially for mineral and vitamin contents. These variations may have several causes. For instance, some studies investigated the chemical composition of 42 populations of the shea butter or karité tree (*Vitellaria paradoxa*) in 11 countries and showed very high variability in all measured parameters, both within and between populations.[92] Variability may come from the quality, habitat, maturity, treatment before analysis, analytical methods used, storage conditions and processing method of the sample plant or animal assessed.[93,94] Variability may also originate from a probable genetic variation, the soil structure and chemical composition.[93] In Benin, for instance, genetic variability has been identified for baobab populations[95] but the relation to the composition of the food products from these baobab populations is not yet known.

The present review suggests that more attention should be paid to all stages involved in performing analyses to allow making reliable statements about the nutritional value of food ingredients.

potential of indigenous food resources to provide functional foods

Most research reviewed in the framework of the present study investigated nutritional values of different plant and animal species and parts. Research may also target the improvement of the nutritional potentialities of these resources. Indigenous food resources are more quantitatively presented in the different agro-ecological zones, and there is a need to develop nutritious foods and herbal functional food from indigenous species and ingredients, which will complement staple foods for an equilibrated diet. Indigenous species and their parts are very good sources of natural antioxidants, including polyphenolic compounds, vitamins E and C, and carotenoids. They are also rich in lysine and total protein. These food ingredients could be used to increase consumer wellbeing. From a nutritional view some combinations with cereals are very desirable. These foods with high protein and high amounts of micronutrients are needed by children and teenagers. In these stages of age, the quantity and nutritional quality of proteins are significant in increasing physical and cognitive functions in the human body.

Research should help to address the crucial problems of diversity and the seasonal availability of indigenous food resources. Research should valorize nutritious indigenous species as ingredients in the formulation of complementary foods for infants and children.

Potential resources for infant food formulations

The present review study showed the potential nutrients that different species may offer to formulating infant food at local levels. Table 7 summarizes the species parts that can potentially complement usual food resources (cereals, tubers, roots, legumes) to reach the nutritional needs of infants and children in agro-ecological zones of Benin. For instance, kernels of baobab, cashew nuts, peanuts, shea nuts and sesame seeds may be used to complement the energy content of a complementary food. In addition, mineral content can be complemented by most fruits (pulp of baobab, African locust beans, *Balanites aegyptiaca*, *Blighia sapida*, etc.), leaves (*Moringa oleifera*, baobab, *Ceiba pentadra*, *Parkia biglobosa*) and foods from animal origin such as insects, fish and mollusks. Concerning protein, foods from animal origin are the best sources, while soya bean and moringa leaves are valuable plant-based sources. For each agro-ecological zone, there are species that provide many nutrients, whereas others provide little nutrient. Among the most advantageous sources are *Adansonia digitata*, *Parkia biglobosa*, *Moringa oleifera*, *Bligjia sapida* and *Amaranthus hybridus*. Table 7 provides a variety of resources to formulate an equilibrated complementary food for infants and children.

FINAL REMARKS

This literature review attests that complementary foods with good protein quality and energy density can be prepared by processing locally available raw materials already used in human feeding practices. From knowing the diversity of food ingredients that stand as alternatives for common nutrient providers along with their nutritional value and distribution across the country, adequate combinations can be achieved for tackling infant malnutrition in all agro-ecological zones of Benin. For their effective use in complementary feeding, foods must fit cultural consumption patterns while meeting, at the same time, the quality standards. Hence, apart from still lacking information on certain nutrient contents of numerous food resources, cultural habits and beliefs about edible food resources also merit further research. In fact, knowledge on the latter will contribute highly to the development of readily accepted food formulae. Based on such cultural information and taking the distribution of food resources into account, complementary food formulae can be developed per agro-ecological zone. For instance, food resources like meat and edible insects are available and consumed by Wama communities in some northern agro-ecological zones of Benin. Thus the introduction of edible insects in infant diets is an opportunity to address the scarcity issue of animal protein sources in Benin. Several formulas should be developed per agro-ecological zone, taking the seasonal availability of food resources into account. Further research recommendations include safety and toxicological studies, as well as the screening of various combinations of different locally available resources as complementary foods.

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SUPPORTING INFORMATION

Supporting information may be found in the online version of this article.

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