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Article *in* Asia Pacific Journal of Clinical Nutrition · January 2019

DOI: 10.6133/apjcn.201912_28(4).0020

Original Article

Nutritional potential of underutilized food crops to improve diet quality of young children in food insecure prone areas of Madura Island, Indonesia

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Background and Objectives: Attention is currently given to the nutrition potential of underutilized food crops; however, only few studies have focused on this potential for young children. We investigate the nutrient composition of selected underutilized food crops in Bangkalan District, Madura Island, Indonesia, to determine its potential in meeting the nutritional needs of young children during the complementary feeding period. **Methods and Study Design:** We obtained data on the availability of underutilized food crops from a cross-sectional study conducted in 2014 in Bangkalan District, Indonesia, and nutrient composition primarily from the Indonesian Food Composition Database. We considered underutilized food crops to hold nutritional potential if they contributed at least 15% per 100 g edible portion recommended nutrient intake for children aged 6–11 months and 12–23 months or 5% recommended nutrient intake per 100 kcal for iron, zinc, calcium, niacin and folate. **Results:** We identified nutritionally potential underutilized food crops from several food groups, including *Sorghum bicolor*, *Canna edulis*, *Colocasia esculenta* (the starchy roots and leaves), *Plectranthus rotundifolius*, *Amorphophallus paeoniifolius*, *Moringa oleifera* (the leaves and pods), *Limonia acidissima*, and *Benincasa hispida*—all of which can be utilized for formulating the complementary feeding diet of young children. **Conclusions:** In a food insecure area where malnutrition is prevalent, underutilized food crops have potential to improve the nutrient intake of young children in their complementary feeding period. These should be promoted through the creation of acceptable recipes and formulation of complementary feeding recommendations, which include these underutilized nutrient-dense crops.

Key Words: underutilized food crops, diet quality, children, food insecurity, complementary feeding

INTRODUCTION

Goal 2 of the United Nations's Sustainable Development Goals (SDGs)—"End hunger, achieve food security and improve nutrition and promote sustainable agriculture"—set the target of ending hunger and all forms of malnutrition by 2030. Food security, however, remains a challenging issue. The number of chronically undernourished people increased globally from 777 million in 2015 to 815 million in 2017. An estimated 155 million children suffer from stunted growth, and 52 million children are wasted.[1]

Indonesia is also facing challenges in achieving a state of food security. In 2018, the national prevalence of stunting among children aged under five years—one of the food insecurity indicators—was 30.8%.[2] At district level, the prevalence of stunting in Bangkalan District, East Java Province, was over 40%, a proportion categorized by the WHO-UNICEF Technical Expert Advisory Group on Nutrition Monitoring as "very high."[3]

Stunting often starts during the pregnancy stage, when the child is still in utero, and continues for at least the first two years after birth.[4] Stunting therefore needs to be prevented at the earliest possible stage of life. In areas that are prone to food insecurity, poor dietary quality due to low access to healthy and nutritious foods leads to nutritional problems. Improving the diet quality of young children, particularly during the complementary feeding period, is therefore an important strategy for reducing the prevalence of stunting. Stunting is reportedly related to long term deficiency of nutrition and food insecurity,[5,6] which can be influenced by many factors, including food availability, food access, and stability. Poverty—known to be closely linked to food insecurity, and the major contributor to household food insecurity—may prevent households from getting access to adequate nutritious foods.

Underutilized food crops may have an important role in the context of food insecurity as a coping strategy during

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Manuscript received 30 April 2019. Initial review completed 16 July 2019. Revision accepted 26 August 2019.
doi: 10.6133/apjcn.201912_28(4).0020

food shortage, mainly among rural poor households. Underutilized species, as defined by Jaenicke and Höschle-Zeledon, are species with under-exploited potential for contributing to food security, health (nutritional/medicinal), income generation, and environmental services.[7] Padulosi and Hoeschle-Zeledon confined the use of the term "underutilized" to wild and cultivated plants whose potential has not been fully realized.[8] The potential of underutilized food crops for food and nutrition security currently received increased attention, yet only a few studies have focused on their potential dietary contribution for vulnerable groups, such as young children. Here we aim to describe the nutrient composition of selected underutilized food crops, in order to determine their potential in meeting the nutritional needs of young children during the complementary feeding period in the food insecure prone area of Madura Island, Indonesia.

METHODS

Study design and participants

Data were collected from a cross-sectional study conducted in Bangkalan District, Madura, East Java, between January and June 2014. Bangkalan District is located in East Java Province—categorized as one of the areas of concern for chronic food insecurity in Indonesia. In East Java, Madura Island had the highest number of food insecure districts. Bangkalan District is one among three districts in East Java Province with the highest percentage of poverty. More than 20% of the population currently live below the poverty line.[9]

Bangkalan District comprises 18 sub-districts. This study was conducted in two sub-districts selected based on three factors: 1) topography—that is, the potential of forests and plantation areas, possibly reflecting the potential for underutilized food crop availability; 2) number of poor households, possibly reflecting the low accessibility of food; and 3) number of food insecure villages.

The study subjects were households with children aged less than five years. We choose households with children under five years – which children under two years is part of this group – because for the households with children age >2–5 years old, they already have experience on feeding children during their younger age, so we assume that they are knowledgeable to answer our research questions. We randomly selected 100 households from two sub-districts—namely Modung sub-district, located at a lower altitude, close to the coastal area (5 m above sea level), and Geger sub-district, located at a higher altitude, 100 meters above sea level—the highest altitude area in Bangkalan District. We chose these two areas with different altitudes to represent different characteristics of areas in Bangkalan District. In consultation with key informants from the District Food Security Agency and District Agriculture Office, who consider the food security status of the villages, we selected one village per sub-district.

Data collection and analysis

Household interviews were conducted by six trained graduates from the bachelor degree program of public health, majoring in nutrition. Each household was visited by one interviewer, who interviewed the housewife—considered the most knowledgeable person in relation to food availability, consumption, and the household food situation—with the intention of collecting information on socioeconomic characteristics of the households, the household food security status, the community's current knowledge concerning the availability of underutilized food crops, and current practices related to their consumption. Household food security was assessed by using the US Household Food Security Survey Module,[10] which was translated into Bahasa Indonesia. In addition, to collect information on underutilized food crops in the study area, four focus group discussions (two groups of women and two groups of men, six to seven persons per group) and field observations were conducted.

The Indonesian food composition database was our primary source of data on nutrient composition.[11] For nutrients unavailable in the Indonesian Food Composition Database (FCD), such as vitamin B-6 and folate, we borrowed values from the US and Indian food composition databases. In addition, values for certain nutrients in some underutilized food crops were not available in the Indonesian FCD, and these values were also borrowed from these two food composition databases.[12,13] The foods presented in this article were selected and considered as having nutritional potential based on the criteria used in the codex standard of nutrient labelling for nutrient content claims for protein, vitamin and mineral source foods—that is, either the food meets one of the following criteria: 1) contains at least 10% (for protein) or 15% (for vitamins/minerals) of the nutrient reference value per 100 g; or 2) contain at least 5% of the nutrient reference value per 100 kcal. Foods containing twice the amount stipulated in those conditions are considered "high" in those nutrients.[14] For the purpose of this analysis, we used the Recommended Nutrient Intake (RNI) of young children aged 6–11 months and 12–23 months as the nutrient reference value.[15,16] The analysis focused on six micronutrients—namely, zinc, iron, calcium, niacin, folate (a common problem nutrient for young children in developing countries),[17-24] and vitamin A (a micronutrient essential for child growth and development). In addition, we also measured the vitamin C content of the foods.

Since the Indonesian FCD has no data on amino acid composition and phytate content in foods, we derived data on the amino acid content primarily from the FAO's Amino Acid Content of Foods and Biological Data on Proteins and from USDA's online Food Composition Database.[12,25] We converted all values (in the FAO database, from mg/100 g food, and in the USDA database, from g/100 g food) to mg/g protein in fresh weight edible portions, following the FAO/INFOODS Guidelines for Converting Units, Denominators and Expression, Version 1.0.[26] In addition, for foods for which the amino acid composition data was not available in the FAO's publication, we derived the data from other published sources.[27-29] We obtained the phytate content from FAO/INFOODS/IZinCG Global Food Composition Database for Phytate Version 1.0.[30] We present all nutrients and phytate content per 100 g edible portion. We calculated the phytate:mineral (iron and zinc) molar ratio based on the following formula:[31]

Phytate : mineral = [phytate (mg) / MW] : [mineral (mg) / AtW]

MW = molar weight of phytate (660)
AtW = atomic weight (iron=55.845; zinc=65.38)

Ethical approval

We obtained permission to conduct this study from the local government of Bangkalan District, East Java Province. We informed the randomly selected respondents of the purpose of the study, their involvement in data collection, and the confidentiality of their information. We obtained informed consent for the respondents to be included in the study, and ethical approval from the research ethical committee of the Faculty of Public Health, Universitas Airlangga, Indonesia.

RESULTS

Characteristics of the study population

Most of the respondents had low educational background, only 28.0% took basic formal education for at least 9 years. As much as 47.0% were graduated from elementary school, and 13.0% never enrolled in formal education. Similarly, the household heads also had low educational background (48.5% graduated from elementary school). They worked in informal sector, such as farmer (29.9%), labourer (14.4%), self-employed (13.4%) and migrant workers (12.4%), with average household income of IDR 375,000 (approximately 26.8 USD) per capita per month. As much as 54.0% households experienced food insecurity, which consisted of 41.0% food insecure without hunger, and 13.0% food insecure with hunger.

Availability and nutrient potential of underutilized food crops

Twenty five underutilized food crops were identified, which consisted of 1 grain (*Sorghum bicolor*), 9 starchy roots and tubers (*Canna edulis*, *Colocasia esculenta* starchy roots and the leaves, *Plectranthus rotundifolius*, *Amorphophallus paeoniifolius*, *Dioscorea hispida*, *Xanthosoma sagitifolium*, *Dioscorea esculenta L*, *Maranta arundinacea*, *Dioscorea alata*), 1 legume (*Leucaena leucocephala*), 5 vegetables (*Moringa oleifera* -the leaves and the pods-, *Sesbania grandiflora* flower, *Artocarpus camansi*, *Artocarpus altilis*, and semeloh leaves – locally available leafy vegetables which we cannot identify the scientific name), 9 fruits (*Passiflora foetida*, *Morinda citrifolia*, *Sonneratia caseolaris*, *Muntingia calabura L*, *Sandoricum koetjape*, *Syzigium cumini*, *Spondias dulcis*, *Syxigium polyanthum*, *Inocarpus fagifer*).

In our study focusing on the nutritional potential of underutilized foods for young children aged between 6–11 months and 12–23 months, we selected nine underutilized food crops from four food groups, basing our selection on the safety (e.g. *Dioscorea hispida* was not included because it contains substance which may cause poisoning if the pre-cooking treatment is not proper) and percentage contribution of those foods toward the RNI of zinc, iron, calcium, niacin, vitamin A, and folate (Figure 1). We selected sorghum (*Sorghum bicolor*) from the grains group; edible canna (*Canna edulis*), taro (*Colocasia esculenta*), Madagascar potato (*Plectranthus rotundifolius*) and elephant foot yam (*Amorphophallus paeoniifolius*) from the starchy roots and tubers group; moringa or drumstick (*Moringa oleifera*) from the vegetable group; and wood apple (*Limonia acidissima*), wax gourd (*Benincasa hispida*), and mango (*Mangifera indica*) from the fruits group. We present the nutrient composition and the contribution to the recommended RNI for children of the underutilized food crops in Table 1 and Table 2.

Among the selected underutilized food crops, the highest protein content was found in *S. bicolor* (10.4 g/100 g edible portion), followed by *M. oleifera* leaves (5.1 g /100 g) and *L. acidissima* (3.5 g/100 g). However, the highest protein density was to be found in *M. oleifera* leaves (5.5 g/kcal), *C. esculenta* leaves (5.1 g/kcal), and *M. oleifera* pods (3.9 g/kcal). All of the selected underutilized food crops contributed to more than 5% (varying from 5.8% to 57.7% per 100 kcal) of young children's RNI, indicating that all of the food crops are viable sources of protein. However, if the contribution was calculated on a per 100 g basis, four underutilized food crops—namely, *C. edulis*, *P. rotundifolius*, *M. indica*, and *B. hispisa*—contributed less than 10% to the RNI. In terms of protein quality, some underutilized food crops contained appreciable quantities of amino acids. In all amino acids, compared with the scoring pattern of animo acid requirements for young children, *P. rotundifolius* and *C. esculent*a easily exceeded these requirements. *Sorghum bicolor*, *M. oleifera* leaves and *M. indica* also showed potential, as in these crops almost all amino acid contents in these crops proved higher than the requirement (Table 3).

While the best sources of calcium, iron, and zinc are generally from animal foods, plant source foods—including underutilized food crops available in this study area—may also provide significant amounts of these minerals. *Moringa oleifera* leaves had the highest iron content (6.0 mg/100 g edible portion), followed by *S. bicolor* (5.4 mg/100 g edible portion), and *C. esculenta* leaves (2.4 mg/100 g edible portion). Per 100 kcal, these food crops contributed 70.1%–112.4%, 17.7%–28.3%, and 43.7%–70.1% to young children's RNI, respectively. The other underutilized food crops, apart from *P. rotundifolius*, contributed over 5% to the RNI per 100 kcal, and were therefore also considered as sources of iron. *Sorghum bicolor* was rich not only in iron but also in zinc, providing 1.6 mg/100 g edible portion or 40.7% zinc RNI for young children. With the exception of *P. rotindifolius* and *M. indica*, almost all of the selected underutilized food crops, when evaluated per 100 kcal, were viable sources of zinc, contributing over 5% of the zinc RNI for young children. When the percentage contribution was evaluated per 100 g, however, only *S. bicolor*, *C. esculenta* and *M. oleifera* leaves emerged as sources of zinc. Plant source foods are generally not a good source of calcium; however, four underutilized food crops showed potential as contributors to young children's calcium RNI—namely, *C. esculenta*, *L. acidissima*, *M. oleifera*, and *A. paeoniifolius*. In *C. esculenta* leaves and *L. acidissima*, the calcium content is high, contributing over 30% of RNI per 100 kcal.

Despite the potential of their mineral content, underutilized food crops also have limitations in their mineral bioavailability, particularly in the presence of phytates—known as one of the anti-nutrients. Most underutilized food crops have a high phytate content, the three highest of these occurring in *S. bicolor* (427.0 mg), *M. oleifera* leaves (128.0 mg), and *L. acidissima* (101.0 mg). The

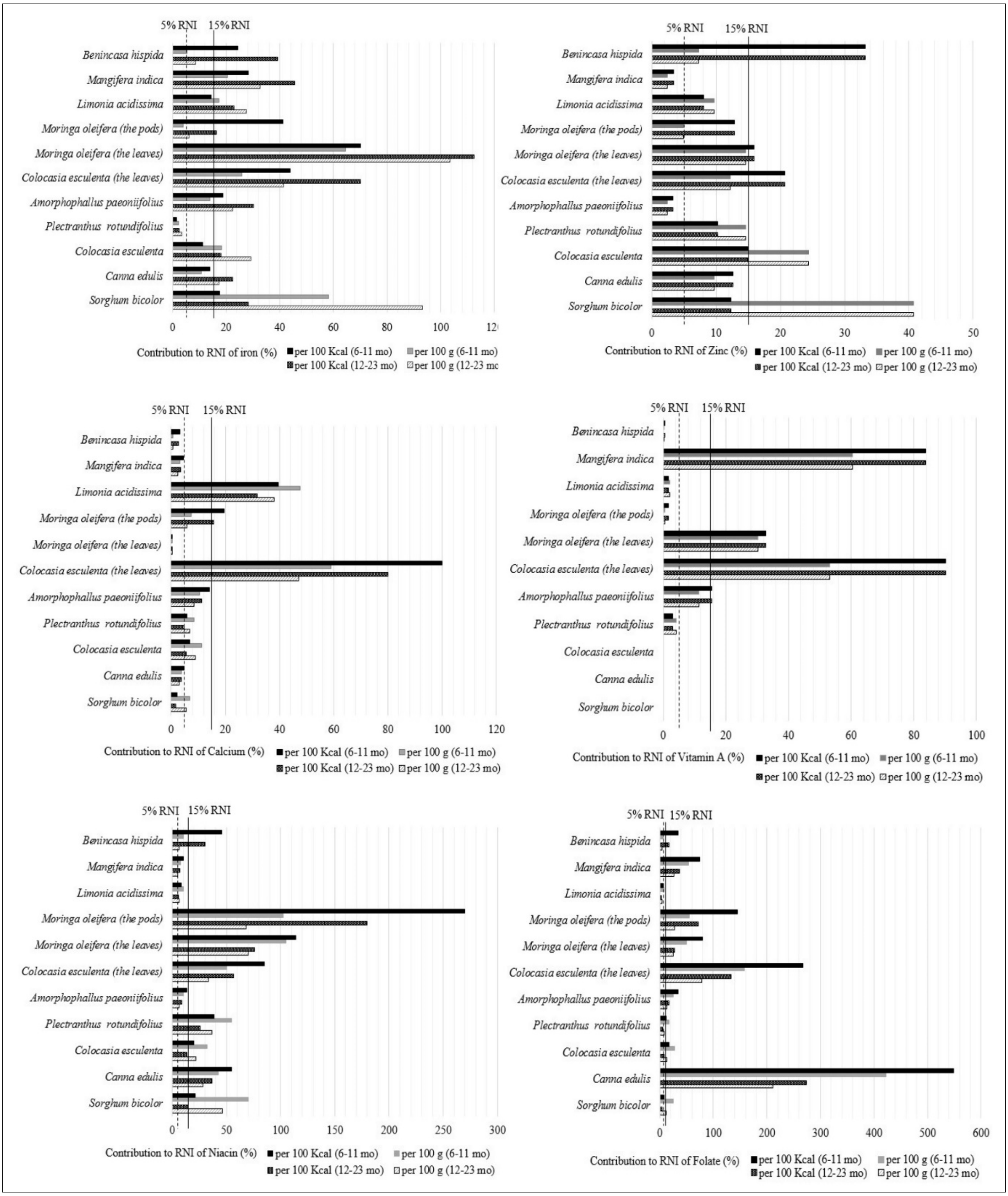

Figure 1. Percentage contribution of underutilized food crops toward the Recommended Nutrient Intake (RNI) of zinc, iron, calcium, niacin, vitamin A, and folate.

phytate:iron molar ratio ranged from 0.68 to 20.15, whereas the phytate:zinc molar ratio ranged from 1.34 to 42.47. *M. oleifera* pods, *S. bicolor* and *L. acidissima* had the highest phytate:iron molar ratio and phytate:zinc molar ratio. The ratios of phytate to those two minerals were the lowest in *C. esculenta* (both the starchy roots and the leaves) (Table 4). Fortunately, most of the underutilized food crops, apart from *S. bicolor*, were also sources of vitamin C, which is known as a mineral absorption enhancer. *Plectranthus rotundifolius*, *M. oleifera* pods, *C. esculenta* leaves, *M. oleifera* leaves, *M. indica*, and *C. edulis* all have a high vitamin C content, contributing more than 30% of the RNI per 100 g and more than 10% of the RNI per 100 kcal. As expected, vitamin A is high in orange colored fruit, such as *M. indica*, and in green leafy vegetables, such as *C. esculenta* leaves and *M. oleifera* leaves. *C. edulis*, *C. esculenta* leaves, *M. oleifera* pods and leaves, and *M. indica* all have high folate content, while niacin is available in all underutilized food crops, the three with the highest content being *M. oleifera* leaves, *M. oleifera* pods, and *S. bicolor*.

Table 1. Nutrient composition of selected underutilized food crops in food insecure prone area of Bangkalan District, Madura, Indonesia

Food group	Underutilized food crops		Nutrient composition (per 100 g raw edible portion)															
	Local name, common name	Scientific name	E (kcal)	P (g)	Water (g)	Fat (g)	CH (g)	Ca (mg)	Fe (mg)	Zn (mg)	Vit C (mg)	Thiamin (mg)	Riboflavin (mg)	Niacin (mg)	Vit B-6 (mg)	Vit B-12 (µg)	Folate (µg)	Vit A (µg)
Grains	*Bulir*, Sorghum	*Sorghum bicolor*	329.0	10.4	11.0	3.1	73.0	28.0	5.4	1.6†	0.0	0.1	0.14	2.8	0.44†	0.14	20†	0
Starchy roots	*Ganyong*, Edible canna	*Canna edulis*	77.0	0.6	79.9	0.2	18.4	15.0	1.0	0.4	9.0	0.1	0.06†	1.7†	0.27†	0	338†	0
Starchy roots	*Talas*, Taro	*Colocasia esculenta*	163.0	2.3	60.0	0.5	36.4	45.0	1.7	1.0	4.0	0.02	0.1	1.3	0.28†	0.1	22†	0
Starchy roots	*Larbek*, Madagascar potato	*Plectranthus rotundifolius*	142.0	0.9	64.0	0.4	33.7	34.0	0.2	0.6	38.0	0.02	0.1	2.2	0.12†	0.1	13.9†	224‡
Starchy roots	*Sobeg*, Elephant foot yams	*Amorphophallus paeoniifolius*	74.0	1.4	80.1	0.1	17.2	42.0	1.3	0.1	2.0	0.04	0	0.4	0.22†	0	20.5†	599‡
Vegetables (DGLV)	*Talas* leaves, Taro leaves	*Colocasia esculenta (leaves)*	59.0	3.0	81.1	0.4	13.5	236.0	2.4	0.5	24.0	0.07	0.6	2.0	0.15†	0	126†	5,740
Vegetables (DGLV)	*Mronggi*, Moringa leaves	*Moringa oleifera (leaves)*	92.0	5.1	75.5	1.6	14.3	1.1	6.0	0.6	22.0	0.3	0.1	4.2	1.2†	0	40†	3,266
Vegetables (Other)	*Klentang*, Moringa/ drumstick pods	*Moringa oleifera (pods)*	38.0	1.5	89.5	0.2	7.5	30.0	0.4†	0.2	25.0	0.1	0.1	4.1	0.12†	0.1	44†	31
Fruits	*Bistah, Kawista*, Wood apple	*Limonia acidissima*	120.0	3.5	71.8	2.5	20.8	190.0	1.6	0.4	3.0	0.07	0.07	0.4	0.17‡	0	6.5‡	99
Fruits	*Mangga gedong*, Mango	*Mangifera indica*	72.0	0.8	80.2	0.2	18.7	13.0	1.9	0.1	16.0	0.06	0.02	0.3	0.12†	0	43†	2,900
Fruits	*Kundur*, Wax gourd	*Benincasa hispida*	22.0	0.4	94.0	0.2	4.7	3.0	0.5	0.3	1.0	0.1	0.03	0.4	0.04†	0	6†	7.0

E: Energy; P: Protein; CH: Carbohydrate; Ca: Calcium; Fe: Iron; Zn: Zinc; Vit: Vitamin.
†USDA Food Composition Database 201812; ‡Indian Food Composition database 201713; DGLV: Dark Green Leafy Vegetables.

Table 2. Contribution of selected underutilized food crops to the Recommended Nutrient ntake (RNI) of young children, per 100 g and per 100 kcal, and protein density

Underutilized food crops			Contribution to RNI (%) per 100 grams								Contribution to RNI (%) per 100 kcal								Protein density (g/Kcal)
Local name, common name	Scientific name	Age (months)	Protein	Fe	Zn	Ca	Vit A†	Niacin	Folate	Vit C	Protein	Fe	Zn	Ca	Vit A†	Niacin	Folate	Vit C	
RNI/day‡		6–11	9.6	9.3	4.1	400	400	4	80	30									
		12–23	10.9	5.8	4.1	500	400	6	160	30									
Bulir, Sorghum	*Sorghum bicolor*	6–11	108.3	58.1	40.73	7.0	0	70.0	25.0	0	32.9	17.7	12.4	2.1	0	21.3	7.6	0	3.2
		12–23	95.4	93.1	40.73	5.6	0	46.7	12.5	0	29.0	28.3	12.4	1.7	0	14.2	3.8	0	
Ganyong, Edible canna	*Canna edulis*	6–11	6.3	10.8	9.8	3.8	0	42.3	422.5	30.0	8.1	14.0	12.7	4.9	0	54.9	548.7	39.0	0.8
		12–23	5.5	17.2	9.8	3.0	0	28.2	211.3	30.0	7.2	22.4	12.7	3.9	0	36.6	274.4	39.0	
Talas, Taro	*Colocasia esculenta*	6–11	24.0	18.3	24.4	11.3	0	32.5	27.5	15.0	14.7	11.2	15.0	6.9	0	19.9	16.9	9.2	1.4
		12–23	21.1	29.3	24.4	9.0	0	21.7	13.8	15.0	13.0	18.0	15.0	5.5	0	13.3	8.4	9.2	
Larbek, Madagascar potato	*Plectranthus rotundifolius*	6–11	9.4	2.2	14.6	8.5	4.3	55.0	17.3	126.7	6.6	1.5	10.3	6.0	3.0	38.7	12.2	89.2	0.6
		12–23	8.3	3.5	14.6	6.8	4.3	36.7	8.7	126.7	5.8	2.4	10.3	4.8	3.0	25.8	6.1	89.2	
Sobeg, Elephant foot yams	*Amorphophallus paeoniifolius*	6–11	14.6	14.0	2.4	10.5	11.4	10.0	25.7	6.7	19.7	18.9	3.3	14.2	15.5	13.5	34.7	9.0	1.9
		12–23	12.8	22.4	2.44	8.4	11.43	6.7	12.8	6.7	17.4	30.3	3.3	1.4	15.5	9.0	17.4	9.0	
Talas leaves, Taro leaves	*Colocasia esculenta* (leaves)	6–11	31.3	25.8	12.2	590	53.2	50.0	157.5	80.0	53.0	43.7	20.7	100.0	90.1	84.8	266.9	135.6	5.1
		12–23	27.5	41.4	12.2	47.2	53.2	33.3	78.8	80.0	46.65	70.1	20.7	80.0	90.1	56.5	133.5	135.6	
Mronggi, Moringa/ drumstick leaves	*Moringa oleifera* (leaves)	6–11	53.1	64.5	14.6	0.3	30.2	105.0	50.0	73.3	57.7	70.1	15.9	0.3	32.9	114.1	79.7	79.7	5.5
		12–23	46.8	103.5	14.6	0.2	30.2	70.0	25.0	73.3	50.9	112.4	15.9	0.24	32.9	76.1	27.2	79.7	
Klentang, Moringa/ drumstick pods	*Moringa oleifera* (pods)	6–11	15.6	3.9	4.9	7.5	0.7	102.5	55.0	83.3	41.1	41.1	12.8	19.7	1.7	269.7	144.7	219.3	3.9
		12–23	13.8	6.2	4.9	6.0	0.7	68.3	27.5	83.3	36.2	16.3	12.8	15.8	1.7	179.8	72.4	219.3	
Bistah, Wood apple	*Limonia acidissima*	6–11	36.5	17.2	9.8	47.5	2.1	6.7	4.1	10.0	30.4	14.3	11.7	39.6	1.7	8.3	6.8	8.3	2.9
		12–23	32.1	27.6	9.8	38.0	2.1	6.7	4.1	10.0	26.7	23.0	8.1	31.7	1.7	5.6	3.4	8.3	
Mangga gedong, Mango	*Mangifera indica*	6–11	8.3	20.4	2.4	3.3	60.4	7.5	53.8	53.3	11.6	28.4	3.4	4.5	83.9	10.4	74.7	74.1	1.1
		12–23	7.3	32.8	2.4	2.6	60.4	5.0	26.9	53.3	10.2	45.5	3.4	3.6	83.9	6.9	37.3	74.1	
Kundur, Wax gourd	*Benincasa hispida*	6–11	4.2	5.4	7.3	0.8	0.2	10.0	7.5	3.3	18.9	24.4	33.3	3.4	0.7	45.5	34.1	15.2	1.8
		12–23	3.7	8.7	7.3	0.6	0.2	6.7	3.8	3.3	16.7	39.2	33.3	2.7	0.7	30.3	17.1	15.2	

Fe: Iron; Zn: Zinc; Ca: Calcium; Vit: Vitamin.

†Adjusted for conversion factors of β-carotene in food sources to vitamin A: grains=3.6:1; starchy roots=13.1:1; DGLV=27:1; other vegetables=12:1; fruits=12:154.

‡RNI for protein based on Joint FAO/WHO/UNU Expert Consultation on Protein and Amino Acid Requirements in Human Nutrition, from WHO (2007);

RNI for vitamins and minerals based on Joint FAO/WHO Expert Consultation on Human Vitamin and Mineral Requirements, taken from WHO and FAO (2004)

Table 3. Amino acids requirements of young children and composition of selected underutilized food crops

	His	Ile	Leu	Lys	SAA	AAA	Thr	Trp	Val	Reference
Amino acid requirements (mg/kg/day)										
Age (years):										
0.5	22	36.0	73.0	64.0	31.0	59.0	34.0	9.5	49.0	FAO
1–2	15	27.0	54.0	45.0	22.0	40.0	23.0	6.4	36.0	
Scoring pattern (mg/g protein requirement)										
Age (years):										
0.5	20	32.0	66.0	57.0	28.0	52.0	31.0	8.5	43.0	FAO
1–2	18	31.0	63.0	52.0	26.0	46.0	27.0	7.4	42.0	
Amino acids composition (mg/g protein)										
Sorghum bicolor	20.9	38.2	129.6	19.6	28.2	73.8	29.4	11.8	48.8	FAO
Canna edulis	16.0	37.0	61.0	39.0	32.0	71.0	49.0	n.a.	45.0	Other publication†27
Colocasia esculenta	13.9	27.8	57.8	30.4	31.3	68.7	32.2	11.3	48.3	FAO
Plectranthus rotundifolius	32.2	66.7	84.4	83.3	43.3	134.4	83.3	14.4	90.0	FAO
Amorphophallus paeoniifolius	39.3	50.1	59.1	44.0	10.4	62.1	44.9	6.2	50.1	FAO
Colocasia esculenta (the leaves)	38.0	86.7	130.7	82.0	47.7	124.3	55. 7	16.0	85.3	USDA
Moringa oleifera (the leaves)	35.5	75.5	134.9	93.3	61.2	94.7	72.2	0.0	96.3	FAO
Moringa oleifera (the pods)	7.0	21.7	39.2	17.5	n.a.	18.9	23.1	n.a	30.1	Other publication‡28
Limonia acidissima	17.8	123.0	7.6	0.0	n.a.	n.a.	0.0	49.5	20.2	Other publication‡29
Mangifera indica	23.8	36.3	62.5	82.5	10.0	53.8	38.8	16.3	52.5	USDA
Benincasa hispida	n.a.	n.a.	n.a.	22.5	n.a.	n.a.	n.a.	5.0	n.a.	USDA

His: Histidine; Ile: Isoleucine; Leu: Leucine; Lys: Lysin; SAA: Sulphur Amino Acids; AAA: Aromatic Amino Acid; Thr: Threonine; Trp: Tryptophan; Val: Valine; n.a.: data not available.
†Adapted value and unit from g/16g N in dry weight to mg/g protein in fresh weight edible portion.
‡Adapted value and unit from mg/g and mg/100g food in dry weight to mg/g protein in fresh weight edible portion.

Table 4. Zinc, Iron, Phytate content, phytate:iron molar ratio and phytate:zinc molar ratio of selected underutilized food crops

Underutilized food crops	Iron (mg)	Zinc (mg)	Phytate (mg)†	Phy:Fe	Phy:Zn
Sorghum bicolor	5.40	1.67	427	6.69	25.33
Canna edulis	1.00	0.40	n.a.	n.a.	n.a.
Colocasia esculenta	1.70	1.00	13.57	0.68	1.34
Plectranthus rotundifolius	0.20	0.60	n.a.	n.a.	n.a.
Amorphophallus paeoniifolius	1.30	0.10	16.23	1.06	16.08
Colocasia esculenta (the leaves)	2.40	0.50	10.00	0.35	1.98
Moringa oleifera (the leaves)	6.00	0.60	128.00	1.81	21.13
Moringa oleifera (the fruit)	0.36	0.20	85.74	20.15	42.47
Limonia acidissima	1.60	0.40	101.00	5.34	25.01
Mangifera indica	1.90	0.10	25.00	1.11	24.77
Benincasa hispida	0.50	0.30	14.60	2.47	4.82

n.a: data not available.
†Phytate content is taken from FAO/INFOODS/IZiNCG Global Food Composition Database for Phytate Version 1.0.

DISCUSSION

Our study analyzed underutilized food crops found in a food-insecure area where undernutrition amongst children aged less than two years was prevalent. We found these underutilized food crops to be nutrient-dense for at least three of the typical problem nutrients among young children in developing countries. Our findings indicated an opportunity to improve the nutritional status of vulnerable groups through optimal use of nutrient-dense underutilized food crops.[32]

As access to affordable animal source foods for rural low socioeconomic households is generally low, higher accessibility to other food groups will allow low-income households to allocate the resources they have to dairy products or animal source foods. In rural and resource poor settings, the availability and utilization of potential underutilized food crops (in term of cost and nutrition) may indirectly improve the overall diet quality of household members, including children, through better allocation of their limited resources to access nutrient-dense foods.

Studies among low and middle income countries have showed the RNI requirements of nutrients iron, zinc, and calcium to be typically difficult to fulfil in young children's usual diets.[17-24] Additionally, in Indonesia, Myanmar, and Cambodia, niacin and folate were also potential problem nutrients.[20-24] On the other hand, many underutilized food crops from several food groups are available and are good sources of these nutrients. In this study area, almost all underutilized food crops (with the exception of

S. bicolor) contributed >5% RNI per 100 kcal in at least 4 out of 6 typical problem nutrients. *Moringa oleifera* even contributed >5% RNI per 100 kcal in all 6 problem nutrients, indicating the potential of those food crops to improve the complementary feeding diet of young children. However, protein is still low in some of these foods, such as in *C. edulis*, *P. rotundifolius*, *M. indica*, and *B. hispida*, which contribute less than 10% of the protein RNI per 100 grams for young children.

The other foods can be an alternative source of protein and meet the average desired protein density for complementary foods (1 g/100 kcal for children aged 6–11 months and 0.9 g/100 kcal for children aged 12–23 months[33]), the three crops with the highest protein density being *M. oleifera* leaves (5.54 g/100 kcal), *C. esculenta* leaves (5.08 g/100 kcal), and *M. oleifera* pods (3.95 g/100 kcal). However, beside generally containing lower proportions of protein per portion compared to animal based foods, plant based foods also have lower protein quality, as seen from the amino acid composition, digestibility, and other food properties—such as chemical integrity and the presence of interfering substances.[34] Even though some underutilized food crops in this study area have a good amino acid composition, the digestibility of most plant source protein is generally around 70%–80%. In comparison, eggs and milk have 97% and 95% protein digestibility.[15] With regard to protein quality, animal based foods such as meat, milk, fish, and egg products are often referred to as standards. To achieve the desirable amino acid composition and to improve protein digestibility, a diet needs to include a variety of food items. In the study area, the available protein source from underutilized food crops could be combined with conventional, locally available legumes, such as cowpeas, broad-beans, long beans, fermented soybean products (tempeh or tofu), and so on, and with affordable animal protein source foods such as eggs, fresh water fish (for instance, catfish), or sea foods (for instance, anchovy, knife clams, and so on).

More importantly, as studies in developing countries showed that among breastfed children, protein did not present as a limiting nutrient, breastfeeding should be promoted to ensure that it continues during the complementary feeding period. Among non-breastfed children, a diet without animal source foods was still able to provide adequate protein, but its quality may have been marginal.[35] An analysis of datasets from six low income countries showed that the dietary protein intake requirement of children aged 6–35 months was generally met, except when the complementary food intake was low,[36] suggesting that a sufficient quantity and quality of food intake among young children should be promoted during their complementary feeding period.

Another challenge of the plant-based diet is the phytate concentration and its effect on the bioavailability of iron, zinc and calcium. Phytate—which refers to phytic acid (myo-inositol hexaphosphate) and is found primarily in pulses, cereals and oleaginous seeds—is known as an inhibitor of iron, zinc and calcium absorption.[30,37] As these nutrients, particularly iron and zinc, are usually the most problematic nutrients during the complementary feeding period of children in developing countries, their bioavailability is a major concern. The inhibitory effect of phytate on zinc and iron absorption is apparently dose dependent, and the molar ratio of phytate:minerals has been used to estimate the proportion of the affected minerals absorbed.[30,31] Hence, to increase the likelihood of iron and zinc absorption, the molar ratio of phytate:iron and phytate:zinc has to be considered when formulating complementary foods. The molar ratio of phytate:iron, according to Hurrel and Egli, should be less than 1 or preferably less than 0.4 in plain cereal- or legume-based meals without any iron enhancers, or less than 6 in composite meals with vegetables containing ascorbic acid and meat as enhancers.[38] For zinc, Hotz and Brown reported the tentatively desirable phytate:zinc molar ratio of less than 18.[31] The underutilized food crops presented in this study had a molar ratio of phytate:iron ranging from 0.35 to 20.15, and a molar ratio of phytate:zinc ranging from 1.34 to 25.33, indicating that most of these foods have low bioavailability. Only *C. esculenta* (the roots and leaves) met the desirable molar ratio of phytate:iron and phytate:zinc of 0.68 and 1.34, respectively, for the starchy root, and 0.35 and 1.98, respectively, for the leaves. *Benincasa hispida* met the desirable molar ratio of phytate:zinc of 4.82; however the molar ratio of phytate:iron was higher than 1. We did not calculate the molar ratio of phytate:calcium, because the critical phytate:calcium molar ratio is currently under dispute, although some researchers suggest less than 0.17 as the desirable phytate:calcium molar ratio. Furthermore, unlike zinc and iron status, calcium deficiency status during infancy and childhood appears more likely to be due to low intake rather than low absorption affected by phytate.[39]

Several strategies for improving the bioavailability of iron and zinc in a plant-based diet include 1) phytate degradation and 2) dietary modification—for instance, iron or zinc enhancers such as vitamin C (ascorbic acid) and animal protein in a meal or diet, or 3) increasing the iron or zinc content in food through fortification. At the household level, the first two mentioned strategies are applicable. Traditional food processing and preparation practices at the household level to reduce the phytate content in foods include germination and malting for cereals such as maize, millet and sorghum, and for legumes and oilseeds; the traditional process of milling or household pounding, to remove the bran from cereals such as sorghum, rice, maize; microbial fermentation, such as that employed in producing the Asian fermented soybean product, tempeh; and soaking and discarding the soaking water, as when processing cereals and legume flours.[40-42] The best strategy for increasing mineral bioavailability would be an integrated approach combining these traditional food processing and preparation practices with the addition of (even a small amount of) animal source foods.[42] The utilization of underutilized food crops may influence access to animal source food. Since underutilized foods are commonly available and can be obtained at a low cost, or no cost. Household spending can be more beneficially allocated to access animal source foods, which usually have a higher cost.

Individually, the underutilized food crops presented in this study have nutritional potential. However, since a diet is composed of a combination of foods, there is an urgent need to determine which combinations or patterns are able to fill the critical nutrient gap in young children. While generic dietary guidelines may not be applicable for an entire population, a specific dietary recommendation may be developed based on problem nutrients found in the target group and precise calculation of the prevailing nutrients gaps and their fulfilment using locally available, affordable and culturally acceptable food sources. This may be done using a mathematical approach to diet modelling—namely, linear programming.[43] Optifood, the Cost of Diet tool, and Nutrisurvey are examples of tools used in diet modelling using a linear modelling approach.[44-48]

The WHO suggested that strategies to improve the feeding of young children should maximize locally produced foods. Additional products can be promoted only if they can fill a critical gap in the required nutrients in an acceptable, feasible, affordable, sustainable, and safe way, as a complement to continued breastfeeding and the local diet—not as a replacement.[49] In certain situations, filling the nutrient gap for all problem nutrients using local or underutilized food ingredients may not be feasible; nevertheless, diet modelling tools such as linear programming are able to provide evidence for planning further strategy or programmed actions. In this situation, a combination of local or underutilized ingredients with fortification or supplementation might prove cost-effective. A study in rural Mozambique showed the minimum cost of formulating nutritious porridge for children aged between 1 year and 2 years, using local ingredients only, to be infeasible. An optimal porridge composition formulated using local ingredients together with calcium and zinc supplements had a lower cost than that using only local ingredients.[50] Diet modelling studies using linear programming in rural Kenya, Indonesia and Myanmar showed that, using only local foods, the dietary adequacy of iron, zinc and calcium (in addition to niacin in Indonesia and Myanmar, and folate, thiamine and vitamin B6 in Myanmar) were difficult to ensure. Fortified foods and animal source foods needed to be included to fill the nutrient gap.[21,22,24,51]

While many studies have been conducted on complementary feeding diet optimization using local foods, similar studies using underutilized food crops remain limited. The main issue at stake in using underutilized food crops—which may be wild or cultivated plants—is their potential to meet nutrient needs at a minimum cost. A diet modelling study in Kenya using the Cost of Diet linear programming tool found that the addition of wild foods to the modelled diet enabled the fulfilment of the recommended iron intake for young children aged 12 months to 23 months, at a lower cost.[52] A similar study in Ghana showed that by limiting the cost of nutritionally optimized diet to a certain level, the researchers were able to meet the criteria of nutritional adequacy when wild foods were included in the food basket of rural low income households.[53] These two studies indicate that underutilized food crops, which may be wild food crops, may potentially improve quality of the complementary feeding diet for young children. There is an urgent need for further studies on diet optimization and the formulation of complementary feeding recommendations including nutrient-dense underutilized food crops, to be conducted, introduced and tested on the target population through an intervention study.

Conclusion

For at least three typical problem nutrients among young children in developing countries, all underutilized food crops presented in this analysis are nutrient-dense, indicating that in food insecure areas where malnutrition is prevalent, there is the opportunity to improve the nutritional status of vulnerable groups through optimal use of nutrient-dense underutilized food crops. This potential should be promoted through the creation of acceptable recipes and the formulation of complementary feeding recommendations which include these underutilized nutrient-dense crops. Since the use of underutilized food crops may reduce the cost of the complementary feeding diet, the implication of improving intakes of animal source foods, which are important for key problem nutrients iron and zinc, should also be explored.

ACKNOWLEDGEMENTS

The authors thank the local government of Bangkalan District, East Java Province, respondents and all informants of this study for their cooperation and participation.

AUTHOR DISCLOSURES

The Authors report no conflict of interest. This work was supported by Directorate of Research and Community Engagement Universitas Indonesia under grant number 5282/UN2.R3.1/HKP 05.00/2018 and Neys van Hoogstraten Foundation under grant number IN242.

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