Review

Folates in various African foods: Contents, food processing and matrix effects

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Abstract: Poor folate status is implicated in a wide variety of health disorders including megaloblastic anaemia, neural tube defects, and cardiovascular diseases. Human diet remains the main provider par excellence. Despite several public-health options to overcome this micronutrient deficiency, dietary folate intakes of women of childbearing age and children are still below recommendations in many African countries. Therefore, this review aims at presenting the current knowledge on folate contents in various African foods, and on folate losses during food processing. Seventy one food sources were evaluated in this study. These various food sources included thirty six vegetables, six cereals, height cereal products, six processed leafy vegetables, six pulses, three fruits, three legumes and three roots. All of them were originated from six African countries including Burkina Faso, Côte d'Ivoire, Egypt, Ethiopia, Nigeria, and South Africa. Folate content ranged between 11 and 73.4 μg/100 g in cereals, 1.8 and 39 μg/100 g in cereal-based processed foods, 8.48 and 48.6 μg/100 g in cooked leafy vegetables, 11.6 and 633 μg/100 g in vegetables, 10 and 22 μg/100 g in pulses, 52 and 148 μg/100 g in legumes, 8 and 106 μg/100 g in fruits. The structure of the food matrix has been shown to influence folate digestibility in foods. High bioaccessible folate, assessed by in vitro digestion, was observed among food products with dense porosity structures while low bioaccessible folate was recorded among food products with open porous structures such as porridges and some gelatinized doughs. Numerous food processing steps have also been shown to influence negatively folate contents in foods.

Keywords: Folate, processing, food matrix, food composition, Africa

Introduction

Poor folate status has been implicated in a wide variety of health disorders commonly encountered in many African countries. These public health disorders include mostly megaloblastic anaemia, neural tube defects (NTDs) and cardiovascular diseases [1, 2, 3]. In sub-Saharan Africa where low folate status has a high prevalence, megaloblastic anaemia is common in pregnant, non-pregnant women, and pre-school children [4, 5]. From 1993 to 2005, the prevalence of anaemia in this population group varied from 47.5 to 67.6% [6]. In recent studies, incidence rates of NTDs are 1.99; 2.5 and 7 for 1000 births in Yaoundé-Cameroon, South Africa and the middle belt Nigeria respectively [7, 8, 9].

The World Health Organization (WHO) and the Food and Agricultural Organization (FAO) of the United Nations (UN) have established a Population Reference Intake of 400 μg/d with an increase to 500 μg/d or 600 μg/d during lactation or pregnancy [10]. Various public health interventions including fortification and supplementation with synthetic folic acid have been undertaken, but none have succeeded to overcome micronutrient deficiencies including folate in Africa [11]. Although it is clear that some of them are providing substantial positive effects in many African countries, there appears to be no end in sight because of limitations in their implementation. For example, the percentage of women taking folic acid daily during gestation was recently reported to be 63% at its maximum in many African countries [11]. In most West African countries like Benin, Ghana, Senegal or Burkina Faso, mandatory fortification of staple foods concerns only a limited number of food vehicles including salt, wheat flour and oil [12]. Furthermore, these food vehicles are not consumed by whole population in Africa. For example, the consumption of wheat flour is very low compared to other unfortified staple cereal flours like rice, millet, sorghum, or maize [11]. Besides, fortification of cereals is often limited to industrially milled grains, which in many regions covers only a part of the total consumption of cereals.

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There are many folate-rich foods across the continent. However, many people are not aware of the nutritional value of such foods and may look down on them. Besides, folate contents in African foods, currently available in different food composition tables, are recorded from a limited amount of foodstuffs. The shortage of comprehensive nutritional data on the common African foods could also be an obstacle to assess current folate daily intakes by the population as it is done elsewhere [13].

Given the above, there is a need to establish the current knowledge on folate contents in foods commonly consumed in Africa, and on their fates during food processing in order to optimize folate supplies from foods. Therefore, in this review, we will summarize the current data on folate contents in various African foods including cereals and cereal products, pulses, fruits and vegetables, and effects of food matrices and processing on the folate contents.

Data collection on folate contents in various African foods

Figure 1 provides information on the origins of the different food sources of folates, which include four regions of Africa: West Africa (Burkina Faso, Côte d'Ivoire, and Nigeria), Eastern Africa (Ethiopia), North Africa (Egypt) and Southern Africa (South Africa).

Data were retrieved from Web of Science and Google Scholar by using the following key words: African food plant composition, or food plant folates, or proximate composition of leafy vegetables, cereals, fruits, processed foods, or functional nutrients in African foods, or influence of food processing, cereals and folates, vegetables and folates, fruits and folates, or the concentration of vitamin B9 or folates in foods, or nutritional importance or nutritional benefits of folates, or folic acid or vitamin B9. The search was limited to articles including original, reviews, meta-analyses, and systematic reviews articles published over the past 15 years (since 2005). This review specifically does not provide food composition data according the FAO INFOODS directory. Therefore, national and regional Food Composition Tables for use in Africa and African countries including West African Food Composition Table, Food Composition Table for Central and Eastern Uganda, Food Composition Table for Use in The Gambia, Food Composition Tables for Mozambique, Tanzania Food Composition Tables, Lesotho Food Composition Table and 'Nutritive value of foods of Zimbabwe' accessible online (http://www.fao.org/infoods/infoods/tables-et-bases-de-donnees/afrique/fr/) were not examined.

A total of seventy one food items were recorded: six were cereals, thirty six were leafy vegetables, fourteen were processed foods, six were pulses, six were legumes, roots/tubers, and three were fruits. Seven of processed foods were cereal-based foods widely consumed in west Africa as staple foods (akassa, ben-kida, ben-saalga, doncounou, fura, kaffa and massa), while six of them were leafy vegetables *Adansonia digitata* (baobab), *Amaranthus cruentus, A. hybridus, A. thunbergii* (pig weed), *Corchorus olitorius* (jew's mallow), *Crassocephalum crepidioides* (benth), *Launaea taraxacifolia* (African lettuce) and *Solanum macrocarpon, S. nigrum, S. retroflexum* (black nightshade).

Folate contents in leafy vegetables

Folate contents in various leafy vegetables are presented in Table 1, which regroups contents determined by different methods: High Performance Liquid Chromatography (HPLC) and Microbiological Assay (MA), differentiated by the symbols used. Folate contents were given in µg/100 g fresh weight (FW). Foods are grouped according to their folate contents into rich (>100 µg/100 g), good (50–100 µg/100 g), and moderate (15–50 µg/100 g) sources [14].

Folate contents of leafy vegetables varied from 21 µg/100 g FW (*Solanum macrocarpon* from Nigeria) to 633 µg/100 g FW (jew's mellow from Egypt). Overall, leafy vegetables are reasonably rich sources of folates. However, there are considerable differences in folate contents between various leafy vegetables. Among thirty-six leafy vegetables under reviewed, sixteen leafy vegetables could be considered as good sources with folate contents being above 100 µg/100 g FW. The order of good sources of folates is as follow: Jew's mellow (*Corchorus olitorius*) from Egypt (633 µg/100 g)>Bitter leaves (*Vernonia* sp.) from South Africa (457 µg/100 g)>Black nightshade (*Solanum nigrum*) from Côte d'Ivoire (404 µg/100 g)>Black jack (*Bidens pilosa*) from South Africa (351 µg/100 g)>Spider plant (*Cleome gynandra*) from South Africa (121–346 µg/100 g) >*Spinacia oleracea* from Egypt and South Africa (129–194 µg/100 g)>Cowpea (*Vigna unguiculata*) from South Africa (105–154 µg/100 g)>African baobab (*Adansonia digitata*) from Nigeria (149.6 µg/100 g)>Amaranth (*Amaranthus hybridus*) from South Africa (122–130 µg/100 g) (Table 1).

Even though the origin of each recorded leafy vegetable has been indicated in this review, these vegetables are also frequently produced and consumed in other African area such as West Africa and the savanna zone of Africa, including the Sudan for baobab (*Adansonia digitata*) leaves and *Solanum macrocarpon* [15, 16], West Africa for bitter leaves and *Corchorus olitorius* [17], Kenya, Uganda and other Eastern African countries for cowpea leaves (*Vigna unguiculata*). These leafy vegetables are used as part of the main dishes or as condiments in African diets [17].

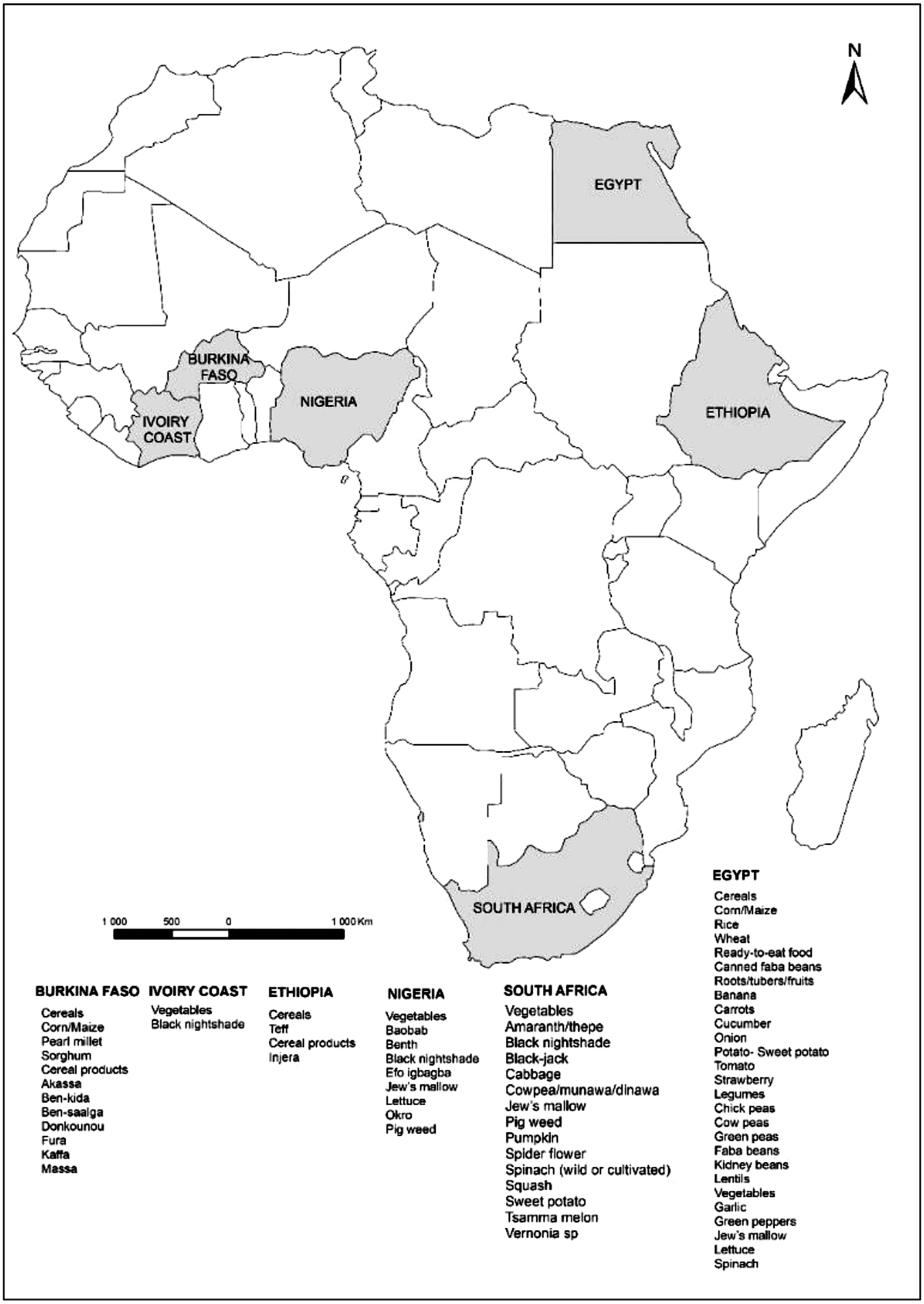

Figure 1. Origin of food sources of folates in Africa.

Based on folate requirements of different age groups, expressed as recommended nutrient intakes (RNIs) by the Food and Agriculture Organization of the United Nations/ World Health Organization (2004) [10], consumption of 100 g per day of jew's mellow from Egypt (633 µg/100 g FW) would provide 158% RNI for adults and 253% RNI for children aged 7–9 years old while 200 g per day of African baobab would provide more than 100% RNI for children aged 7–9 years old and more 70% % RNI for adults. Therefore, these leafy vegetables may be recommended to the population at risk of folate deficiency, e.g., young children and pregnant women.

Folate contents in cereals

Folate contents in cereals are presented in Table 2. Maize, pearl millet, rice, sorghum, teff and wheat are among the cereals widely consumed in Africa. The folate content in cereals ranged between 11 (rice) and 73 µg/100 g FW (pearl millet). For the pearl millet originating from the same area, folate contents were variable, ranges being from 24 to 26 µg/100 g FW according to Saubade et al. (2018) [19] and from 54 to 73 µg/100 g FW according to Bationo et al. (2020) [18]. According to these authors, different factors such as agro-climatic conditions, cultivar, growing area and postharvest handling may explain these variations. Apart from pearl millet and teff which exhibited a moderate content of folate, all cereals are low sources of folates.

Folate contents in processed foods

Fifteen processed foods and their folate contents are presented in Table 3. Folate contents in processed foods ranged between 8 (canned faba beans) and 48.6 µg/100 g edible portion for boiled leaves of African lettuce (*Launaea taraxacifolia*). When considering cereal-based foods, folate contents are higher in injera with 39 µg/100 g FW whereas ben-kida and ben-saalga, pearl-millet based porridges, were the poorest. However, all of processed foods are low sources of folates.

Traditional African diets are rich in variety but less investigated for their folate contents. Even if quite short, the present list of processed foods provides a basis for understanding their potential to contribute to folate intakes in Africa. These foods are not high in folates but could be the cheapest sources of this vitamin owing to their frequency of consumption.

Folate contents in legumes, pulses, roots/tubers and fruits

Data on folate contents in the legumes, roots and tubers in this study were recorded from North Africa [20]. Six legumes, roots and tubers in their fresh form (carrots (*Daucus carota*), potato (*Solanum tuberosum*), sweet potato (*Ipomea batatas*), cucumber (*Cucumis sativus*), tomato (*Lycopersicon esculentum*), onion (*Allium cepa*)), contained between 10 and 22 µg/100 g of folates, sweet potato having the highest and potato having the lowest folate content [20]. Carrots had 21 µg/ 100 g whereas the folate content of tomato (11 µg/100 g) was almost 50% folate content in carrots. Cucumber and onion had 14 and 12 µg/100 g, respectively. Roots and tubers recorded in this study were low sources of folates.

Six pulses in their dried form (chick peas (*Cicer arietinum*), cowpeas (*Vigna unguiculata*), green peas (*Pisum sativum*), kidney beans (*Phaseolus vulgaris*), faba beans (*Vicia faba*), lentils (*Lens culinaris*)) contained between 52 and 148 µg/100 g folates, chick peas having the highest and green peas having the lowest folate content. Faba and kidney beans had 96 µg/ 100 g, Cowpeas and lentils had 103 µg/100 g and 75 µg/100 g, respectively [20]. Chick peas and cowpeas were good sources of folates whereas others were moderate sources.

Three fruits in their fresh form (okra fruit (*Abelmoschus esculentus*), strawberry (*Fragaria ananassa*), banana (*Musa paradisiacal*)) contained between 8 and 106 µg/100 g folates [20, 21], *A. esculentus* fruit having the highest and banana having the lowest folate content. Strawberry had 80 µg/100 g folates. *A. esculentus* fruit is considered good source of folates whereas others were poor sources of folates.

A large number of studies have shown that many African regions are greatly blessed with lots of pulses, roots, tubers, legumes and fruits including domesticated and wild fruits [20–22]. The importance of these crops in African regions is evident through their annual global production. For example, African regions produced 38% of the global production of roots and tubers estimated at 237 million tonnes but almost no data exist on their folate contents [23].

Effects of food processing and matrices on folates

Only a few studies, like those on Ethiopian injera [24], on West African cereal-based fermented porridges such as ben-saalga and ben-kida and other cereal-based fermented food types (gelatinized doughs, dumplings, and fritters) [18, 19, 25, 26] and Tanzanian fermented togwa [27], were based on the effect of processing on folate contents in foods. Apart from one study by Bationo et al. (2020) on food matrix effects on folates, almost no data exist [18].

Table 1. Folate contents in leafy vegetables

Scientific name of vegetables (English name, Local/Common name)	Study area	Sampling source	Folate content (µg/100 g fresh weight)	Method of folate analysis	Categorization of vegetables (µg/100 g per serving) 15–50 µg: Low source 50–100 µg: Moderate source >100 µg: Good source	References
Abelmoschus manihot L. Medikus (Okro, Ilasa), fresh leaves	Nigeria	Field sampling	47	HPLC	Low source	[21]
Adansonia digitata (Baobab, Luru/Kuka), dry leaves	Nigeria	Market sampling	150	HPLC	Good source	[21]
Allium schoenoprasum (Garlic), dry leaves	Egypt	Market sampling	73	HPLC	Moderate source	[20]
Amaranthus hybridus L. subsp. cruentus (L.) Thell. (Amaranth/Thepe), fresh leaves	South Africa	Field sampling	72	MA	Moderate source	[32]
Amaranthus cruentus L. (Pig weed), fresh leaves	South Africa	Field sampling	75	MA	Moderate source	[33]
Amaranthus hybridus L. (Pig weed, Efo tete/green), fresh leaves	Nigeria	Field sampling	62	HPLC	Moderate source	[21]
Amaranthus hybridus L. subsp. hybridus var hybridus (Amaranth/Thepe), fresh leaves	South Africa	Field sampling	122	MA	Good source	[32]
Amaranthus thunbergii Moq. (Amaranth/Thepe), fresh leaves	South Africa	Field sampling	130	MA	Goode source	[32]
Bidens pilosa (Black-jack), dry leaves	South Africa	NA	351	NA	Good source	[34]
Brassica sp. (non-heading Chinese cabbage), dry leaves	South Africa	NA	16	NA	Low source	[34]
Brassica rapa L. subsp. chinensis (non-heading Chinese cabbage), fresh leaves	South Africa	Field sampling	92	M	Moderate source	[33]
Capsicum annuum (Green peppers), dry leaves	Egypt	Market sampling	22	HPLC	Low source	[20]
Chenopodium album, dry leaves	South Africa	NA	30	NA:	Low source	[34]
Citrullus lanatus (Tsamma melon), fresh leaves	South Africa	Field sampling	68	MA	Moderate source	[33]
Cleome gynandra L. (Spider flower), fresh leaves	South Africa	Field sampling	121	MA	Good source	[33]
Cleome gynandra L. (Spider flower/Lerotho), dry leaves	South Africa	Household sampling	217	MA	Good source	[32]
Cleome sp (Spider flower), dry leaves	South Africa	NA	346	NA	Good source	[34]
Corchorus olitorius (Jute mallow, Ewedu), dry leaves	Nigeria	Market sampling	183	HPLC	Good source	[21]
Corchorus olitorius L. (Jew's mallow), fresh leaves	South Africa	Field sampling	45	MA	Low source	[33]
Corchorus olitorius (Jew's mellow, molkhya), dry leaves	Egypt	Market sampling	633	HPLC	Good source	[20]
Crassocephalum crepidioides (Benth.) S. Moore, fresh leaves	Nigeria	Field sampling	71	HPLC	Moderate source	[21]
Cucurbita maxima Duchesne (Pumpkin), fresh leaves	South Africa	Field sampling	47	MA	Low source	[33]
Cucurbita pepo (Squash), dry leaves	South Africa	NA	36	NA	Low source	[34]
Ipomoea batatas (Sweet potato), dry leaves	South Africa	NA	80	NA	Moderate source	[34]

Table 1. Folate contents in leafy vegetables (Continued)

Scientific name of vegetables (English name, Local/Common name)	Study area	Sampling source	Folate content (μg/100 g fresh weight)	Method of folate analysis	Categorization of vegetables (μg/100 g per serving) 15–50 μg: Low source 50–100 μg: Moderate source >100 μg: Good source	References
Lactuca sativa (Lettuce), dry leaves	Egypt	Market sampling	80	HPLC	Moderate source	[20]
Launaea taraxacifolia Amin, ex C. Jeffrey, (African lettuce/Wild lettuce, Yanrin.), fresh leaves	Nigeria	Field sampling	91	HPLC	Moderate source	[21]
Solanum macrocarpon (Efo igbagba), fresh leaves	Nigeria	Field sampling	21	HPLC	Good source	[21]
Solanum nigrum (Black nightshade), dry leaves	Côte d'Ivoire	NA	404	NA	Good source	[34]
Solanum nigrum L. Var virginicum (Black nightshade), dry leaves	Nigeria	Market sampling	12	NA	Very low source	[35]
Solanum retroflexum Dun. (Black nightshade), fresh leaves	South Africa	Field sampling	56	MA	Moderate source	[33]
Spinacea oleracea (Spinach), dry leaves	South Africa	NA	194	NA	Good source	[34]
Spinacia oleracea (Spinach), dry leaves	Egypt	Market sampling	129	HPLC	Good source	[20]
Vernonia sp, dry leaves	South Africa	NA	457	NA	Good source	[34]
Vigna unguiculata (Cowpea), dry leaves	South Africa	NA	141	NA	Good source	[34]
Vigna unguiculata (L.) Walp. Subsp. Unguiculata (Cowpea/Munawa/Dinawa), fresh leaves	South Africa	Field sampling	154	MA	Good source	[32]
Vigna unguiculata L. Walp. (Cowpea), fresh leaves	South Africa	Field sampling	105	MA	Good source	[33]

MA: Microbiological assay; HPLC: High performance liquid chromatography; NA: Not Available. Recommended nutrient intakes (RNI) of folic acid are 80–300 μg/day for children aged 0–9 years old; 400 μg/day for 10–65+ years old; 500 μg/day and 600 μg/day during lactation or pregnancy respectively [10].

Table 2. Folate contents in cereals

Food item	Study area	Folate content (µg/100 g fresh weight)	Method of folate analysis	Categorization of cereals (µg/100 g per serving) 15–50 µg: Low source 50–100 µg: Moderate source >100 µg: Good source	References
Eragrostis tef (Tef flour)	Ethiopia	59	MA	Moderate source	[36]
Oryza sativa (Rice flour)	Egypt	11	HPLC	Low source	[20]
Pearl millet (Millet flour)	Burkina Faso	24–26	MA	Low source	[19]
	Burkina Faso	54–73	MA	Good source	[18]
Sorghum flour	Burkina Faso	16	MA	Low source	[18]
Triticum aestivum (Wheat flour)	Egypt	23–25	HPLC	Low source	[20]
Zea mays (Corn flour)	Burkina Faso	14–21	MA	Low source	[18]
	Egypt	25	HPLC	Low source	[20]

MA: Microbiological assay; HPLC: High performance liquid chromatography; NA: Not Available. Recommended nutrient intakes (RNI) of folic acid are 80–300 µg/day for children aged 0–9 years old; 400 µg/day for 10–65+ years old; 500 µg/day and 600 µg/day during lactation or pregnancy respectively [10].

Studies on the effect of processing on folate contents in foods have reported a clear relationship between food processing steps and folate contents in the consumed products [18, 19, 25, 26]. Effects of processing steps on folate in foods are summarized in Table 4. Folate contents in several cereals of major importance in Africa such as sorghum, maize and millet were affected by a large number of processing steps including washing, soaking, grinding, kneading, sieving, fermentation and cooking [18, 19, 24, 25]. Folate contents may drastically decrease from the raw material to the consumed products. For steps that lead to the removal of the grain outer layers and germ such as decortication, extensive washing prior to cooking or grinding, the addition of high volume of water in the processed products such as sieving steps, folate contents in the final products may be below 50% [19]. Decortication of cereals such as millet and sorghum is wide-spread practice in sub-Saharan Africa to remove the bran from the starchy endosperm [28]. Sun drying may also reduce drastically folate contents in the final products and its effects may be more pronounced under long sun drying due to the folate degradation by UV [29]. Several cooking methods are commonly used in Africa. These cooking methods vary from thorough boiling, which may include the replacement of the first cooking water with fresh water to steaming involving the use of very small quantities of water and short cooking times. Hydrothermal cooking may result in significant losses due to folate leaching from the food matrix into the cooking water [18]. In rural areas, women may discard and/or replace the cooking water several times to get rid of the bitter taste which may affect the water soluble nutrients including folates [30, 31]. In high-temperature short-time cooking, a significant impact on the folate contents has been reported with a maximum folate losses of 52.8% [24]. However, Bationo et al. (2020) and Saubade et al. (2018) showed that short-time cooking could have no effect on folate [18, 19, 26].

Fermentation is an ancestral food technology widely used in Africa for food processing. However, there is no clear relationship between this food technology and the folate contents in foods. For example, soaking is usually associated to alcoholic fermentation and settling to lactic acid fermentation. During pearl millet soaking, Saubade et al. (2018), in controlled laboratory conditions, reported folate production (+26% to +31%), whereas Bationo et al. (2020), under natural conditions in the yard of the traditional production units (TPUs), reported folate losses (–19% to –49%). During the settling step, findings of these authors were also opposite. Indeed, the settling performed by Saubade et al. (2018) [19] in the laboratory conditions did not influence the folate content in the fermented food. However, this step performed under natural conditions in the yard of the TPUs has been correlated to an increase of folate contents, varying from 60 to 148% according to Tamene et al. (2019) and from +9 to +27% according to Bationo et al. (2020) [18, 24].

Table 3. Folate contents in processed foods

Food item	Description	Study area	Folate content (µg/100 g fresh weight)	Method of folate analysis	Categorization of cereals (µg/100 g per serving) 15–50 µg: Low source 50–100 µg: Moderate source >100 µg: Good source	References
Cereal-based foods						
Akassa	Thick fermented and cooked gelatinized dough made from corn	Burkina Faso	1.8–3.1	MA	Low source	[18]
Bn-saalga	Fermented porridge made from pearl millet, very often used as complementary food for infants and young children	Burkina Faso	1.9–2.9	MA	Low source	[29]
Ben-kida	A granular porridge which is a variant of ben-saalga, frequently eaten by the population for breakfast	Burkina Faso	2.5	MA	Low source	[18]
Donkounou	Thick fermented and cooked gelatinized dough made from whole grain of maize	Burkina Faso	3.6–4.8	MA	Low source	[18]
Fura	Semi-solid dumpling meal made from pearl millet	Burkina Faso	16.2–31.3	MA	Low to good source	[18]
Injera (Tef injera)	Injera is thin, prepared from teff flour, water and starter (a fluid collected from previously fermented mix) after successive fermentations, traditional common staple food consumed in all the parts of the Ethiopia and Eretria, some parts of the Somalia	Ethiopia	39	MA	Low source	[24]
Kaffa	Thick fermented and cooked gelatinized dough made from sorghum	Burkina Faso	5.2	MA	Low source	[18]
Massa	Small and thick pancakes made from pearl millet batter and fried in oil	Burkina Faso	7.2–12.6	MA	Low source	[18]
Pulses						
Faba beans, canned	Ready-to-eat canned faba beans	Egypt	8	MA	Moderate source	[20]

Table 3. Folate contents in processed foods (Continued)

Food item	Description	Study area	Folate content (µg/100 g fresh weight)	Method of folate analysis	Categorization of cereals (µg/100 g per serving) 15–50 µg: Low source 50–100 µg: Moderate source >100 µg: Good source	References
Processed leafy vegetables						
Adansonia digitata (Baobab leaves Luru/Kuka), boiled leaves	Boiled leaves are used as vegetable in sauces, soups, and many other dishes	Nigeria	17.4	HPLC	Low source	[21]
Amaranthus hybridus L. (Pig weed, Efo tete/green), boiled leaves	Boiled leaves are used as vegetable in sauces; soups, and many other dishes	Nigeria	32.2	HPLC	Low source	[21]
Corchorus olitorius (Jew's mallow, Ewedu) boiled leaves	Boiled leaves are used as vegetable in sauces; soups, and many other dishes	Nigeria	47.3	HPLC	Low source	[21]
Crassocephalum crepidioides (*Benth*) S. Moore, boiled leaves	Boiled leaves are used as vegetable in sauces; soups, and many other dishes	Nigeria	17.2	HPLC	Low source	[21]
Launaea taraxacifolia (Willd.) Amin, ex C. Jeffrey, (African lettuce/wild lettuce, Yanrin.) boiled leaves	Boiled leaves are used as ingredient in salads	Nigeria	48.6	HPLC	Low source	[21]
Solanum macrocarpon (black nightshade, (Efo igbagba), boiled leaves	Boiled leaves are used as vegetable in sauces; soups, and many other dishes	Nigeria	8.5	HPLC	Very low source	[21]

MA: Microbiological assay; HPLC: High performance liquid chromatography; NA: Not Available. Recommended nutrient intakes (RNI) of folic acid are 80–300 µg/day for children aged 0–9 years old; 400 µg/day for 10–65+ years old; 500 µg/day and 600 µg/day during lactation or pregnancy respectively [10].

Table 4. Food processing steps and their effects on folates

Processes	Actions (Conditions)	Effect(s) on folate content	Statistically significant	Prevention/Protection of folate losses	References
Sorting/Winnowing	– Removes all impurities (raw, pebble, foreign material)	– No effect on the folate content if done under conditions limiting folate exposure to factors that can induce its degradation, such as open containers, light, heat) – Decrease folate content if done under conditions that can induce its degradation, such as light, open containers, oxygen)	NC	– Use of closed containers may limit the exposure to oxygen and light – Limit the exposure of folate to factors that can induce its degradation, such as oxygen, light and heat	[18, 19]
Decortication/ Debranning	– Removes bran and germ	– Folate losses, this micronutrient being mainly located in the outer layers and germ of cereal grains – Decrease folate content (50% of folate losses during this step in average was reported)	NC	– Some cereal fractions like bran and germs are rich sources of folate – Use of wholegrain cereals such as wheat, maize, millet or sorghum protects folate in cereals – Use of wholemeal flour provides high proportion of folate in the human diet	[18]
Soaking	– Leaching of folate in soaking water – Grains germination	– Leaching of folate in soaking water can cause folate losses up to 17–26% – Grains germination can increase folate up to 26%–79%	Yes	– During the soaking step, promote the germination, by alternating soaking and incubation under high relative humidity conditions)	[18, 19]
Washing/Draining	– Leaching of folate in washing water	– Leaching of folate in washing water can cause folate losses (amount of folate losses in washing water not available)	NC	– Short-time of washing and draining can limit folate losses in washing water	[18, 19]
Drying	– Exposure of folate to factors that can induce their degradation, such as oxygen, light, high temperatures	– Oxidative degradation of folate occurs resulting in folate losses in dried products – High temperatures can cause folate degradation or inter-conversion of several folate forms	NC	– Avoid sun drying – Limit the exposure of folate to factors that can induce their degradation, such as oxygen, light, and high temperatures	[18, 19]
Milling (Wet or dried)	– Removes bran and germ – Adds a high volume of water in the grains – Oxidation due to milling conditions (oxygen, light)	– Oxidative degradation of folate occurs resulting in folate losses in milled products – The added of high volume of water "diluted" folate initially present in the food products	NC	– Perform milling in the closed containers – Limit the exposure – Of food product during milling to factors that can induce folate degradation, such as oxygen, light and high temperatures	[18, 19]
Sieving (Filtration with water addition)	– The removal of the grains outer layers that contain a non-negligible amount of folate – Dilution effect on folate due to the addition of a high volume of water in the flours or other food products	– The removal of the grains outer layers combined to the addition of a high volume of water in the sieved batter can cause folate losses up to 20–37%	Yes	– Use of cereal wholemeal flours for the preparation rather than filter flours using high volume of water	[18, 19]
Setting/ Decantation/ Fermentation	– Leave the sieved batter to rest at ambient temperature lead to decantation and fermentation	– Fermentation can increase folate up to 9–148% – Fermentation can cause folate losses up to 20–40%	Yes No	– Optimize conditions such as temperature and incubation time to promote folate production during the settling/fermentation – Use of backslopping could be a natural way to select good folate producing microorganisms	[18, 19, 24]
Heat treatment/ Cooking – Hydrothermal cooking – Steaming – Frying	– Cooking of food under high temperatures on folate – Oxidation effect on folate during cooking – is also the major cause of folate losses during steam-flaking, spray-drying and extrusion cooking of cereals	– Heat treatment can cause folate losses up to 24%– 88%, due to folate degradation or the inter-conversion of several folate forms – Heat treatment can cause folate losses by oxidation of folate if done under conditions which expose folate to oxidation factors such as open containers, oxygen and light – Short-time cooking (5 minutes at 80 °C) results in no or modest losses of folate	Yes No	– Use of closed containers during cooking may limit the exposure to light and oxygen – Use of natural antioxidant compounds such as baobab fruit pulp, rich in vitamin C could help – Protecting folate against oxidizing degradation – Prefer short-time cooking or steaming	[18, 19, 22, 24]

NC: Not Calculated.

The study on folate bioaccessibility by Bationo et al. (2020) has reported a food matrix effect on the consumed products [18]. For example, gelatinized doughs had very different digestibility and bioaccessible folate compared to porridges with open porous structures, dumplings and fritters with dense and low porosity structures [18].

Various ways to limit or protect folate contents during food processing exist (Table 4). Among these ways, promote a sufficient time, up to 24 h during soaking could lead to a germination with folate synthesis. The use of wholegrain of cereals in the preparation of African dishes or the consumption of wholegrain products might be preferred to decorticated grains as grain outer layers are high in folate. For cooking methods, steaming appears to be more interesting to protect folate during the cooking. Overall, the reduction of the cooking time whatever the cooking method is recommended to prevent folate degradation. The use of food fractions rich in folate could be also an option for increasing folate contents in processed foods [11].

Folate is a complex group of molecules in native food plants. This review specifically did not investigate current knowledge on folate distribution in African foods even if information on folate profiles in these foods could be relevant to mitigate folate losses, particularly in the processing of cereals and vegetables. Folate degradation kinetics and mechanisms in recorded foods have not been take into account in this review. Besides, data on food matrix effects on folates did not allow more detailed information on the presence of inhibitors of folate digestive enzymes in humans. Nevertheless, our findings are relevant in current state of knowledge on folate in Africa.

Conclusion

To our knowledge, no exhaustive data exist on the folate contents in African foods although the deficiency of this vitamin has been detected in many African countries. In this review, the current knowledge on folate contents in various African foods and on their losses during food processing is presented. Even if most of recorded foods are not high in folates, they have the potential to contribute to the alleviation of the deficiency of this vitamin in Africa owing to their high frequency of consumption. Therefore, information provided in this paper could be useful for this purpose.

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Conflict of interest

The authors declare that there are no conflicts of interest.

Authors contribution

Fabrice Bationo and Boubacar Savadogo conceived and designed the paper; Fabrice Bationo and Mahamadé Goubgou wrote the paper; Boubacar Savadogo revised the manuscript for important intellectual content; Fabrice Bationo, Boubacar Savadogo and Mahamadé Goubgou read and approved the final version of the manuscript.

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