TRADITIONAL FOOD PROCESSING TECHNIQUES AND MICRONUTRIENTS BIOAVAILABILITY OF PLANT AND PLANT-BASED FOODS: A REVIEW

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Abstract
Majority of the world's population, especially those inhabited in the developing countries lack access to balanced diets because larger portion of the population live on staple plant-based foods which usually lack diversity and consequently resulted in micronutrient deficiencies. It has been established that micronutrient deficiencies arising from the consumption of plant and plant-based foods are mainly caused by failure of absorption rather than dietary deficiency. It is therefore necessary to explore the means through which substantial part of the available minerals would be made bioavailable. Fortunately, many simple, low cost household's traditional food processing techniques have the potentials to improve the bioavailability of many of these essential micronutrients including zinc, iron, vitamins B group and C majorly through reduction of the inherent anti-nutritional factors. This paper therefore discusses micronutrients absorption and bioavailability using iron and zinc as examples and the traditional food processing techniques that could enhance the bioavailability of some of these micronutrients in plant-based diets with the aim of ensuring nutrition security and eradicating hidden hunger among the indigenous people of Africa and other developing countries. This review also realised the need for more studies on the in-vitro and in vivo micronutrients bioavailability of plant and plant-based foods in order to effectively tackle micronutrient deficiency among the populace.
Keywords: Anti-nutritional factors, micronutrients, traditional food processing techniques, bioavailability, nutrition security

Received: 18.12.2018 Reviewed: 07.03.2019 Accepted: 08.03.2019

1. INTRODUCTION

Food supply nutrients which are absolutely vital for sustenance and maintenance of good health. Adequate supply of these nutrients is best achieved through consumption of a balanced food-based diet (Adda Bjarnadottir, 2017). However, the typical modern diet is deficient in several essential nutrients. Children, young women, the elderly and vegetarians seem to be the most vulnerable to these nutrients deficiencies (Adda Bjarnadottir, 2017). Micronutrient deficiencies also known as hidden hunger include both vitamins and minerals deficiencies. Nutrient deficiencies alter bodily functions and processes such as water balance, enzyme function, nerve signalling, digestion, and metabolism at the most basic cellular level. Tackling these deficiencies is important for optimal body growth, development, and function. The various micronutrient deficiency disorders including vitamin A deficiency (VAD), folic acid, vitamin B_{12}, iron and iodine deficiency disorders (IDD) remain important global public health challenges (Aworh, 2008). For instance, osteopenia and osteoporosis which are conditions characterised by brittle bones are attributed to calcium and vitamin D deficiencies while anaemia has also been known as a disorder of iron deficiency. VAD has damaging consequences on the eye (xerophthalmia and night blindness) and it is also a major contributory factor to the high rates of child and maternal morbidity and mortality (Aworh, 2008). Consumption of balanced food-based diets containing nutrients from both plant and animal origins could be regarded as the most effective approach to tackle nutrient deficiency.

In third world countries, insufficient amounts of food coupled with poor nutritional quality of the available food supply especially among plant-based diets containing only little amounts of micronutrient-dense animal-source foods are responsible for various forms of malnutrition (Brown, 1991; Golden, 1991). The major factor limiting the quality of plant foods such as cereals, legumes and spices is the low availability of nutrients owing to the presence of certain anti-nutritional factors such as oxalate and phytate which have strong binding affinity to important minerals such as calcium, iron and zinc (Apata and Ologhobo, 1997; Enneking and Wink, 2000; Akeem *et al.*, 2016). Considering the heavy reliance of low-income populations on plant diets, the detrimental effects of low mineral bioavailability on mineral status and consequently health are therefore worth given special considerations (Hotz and Gibson, 2007).

2. IRON ABSORPTION AND BIOAVAILABILITY

Iron deficiency leads to anaemia and it is well-known as the most common dietary deficiency in different parts of the world affecting mostly children and women of reproductive age (Gillespie, 1998; Ruel and Levin, 2000; McLean *et al.*, 2009). Iron deficiency is detrimental regardless of age. For example, iron deficiency could cause the impairment of cognitive development, immunity and physical growth in young children and affect their school performance at school age; fatigue and reduction in work capacity could be observed at adulthood while anaemia which is known to be responsible for a large proportion of maternal deaths may cause foetal growth retardation or low birth-weight among pregnant women (Gillespie, 1998). It has been established that more than half of all pregnant women in the world and minimum of one third of preschoolers suffer from anaemia, and more are iron deficient to some extent (UN ACC/SCN, 1997; McLean *et al.*, 2009). The existence of iron in food is in two forms; namely haem (found in flesh foods such as meat, fish, and poultry) and non-haem (found in dairy products and eggs, and in plant foods such as beans, cereals, nuts, fruits, and vegetables) (Ruel, 2001). They differ based on their bioavailability with haem iron having about 15-35% absorption and lower absorption range of 2-20% non-haem iron (Allen and Ahluwalia, 1997). The individual's iron status and requirements, the sources and content of iron in the meal, and the other meal constituents are some of the factors that could influence the amount of iron absorbed from a meal. While individual characteristics generally influence iron absorption, anti-nutritional factors such as tannins, selected dietary fibres and phytate pose a more serious threat to the bioavailability of non-haem iron (Hallberg, 1981; Lestienne *et al.*, 2005a). Phytic acid is considered the most potent inhibitor of non-haem iron and is present in large concentrations in cereals, legumes, and vegetables (Allen *et al.*, 1992; Gibson, 1994). The main source of iron for the majority of people in developing countries is non-haem iron and therefore any approach to reduce the phytic acid content of plant foods should be helpful in improving the absorption of non-haem iron and the iron status of at-risk populations (Ruel and Levin, 2000).

3. ZINC ABSORPTION AND BIOAVAILABILITY

Phytate is a common constituent of most cereal grains, some vegetables and fruits (Wang *et al.*, 1992). The anti-nutritional role of phytate in human nutrition is attributed to its mineral binding capacity, which inhibits the absorption and bioavailability of minerals such as zinc (Sandstrom, 1997). Myoinositol hexaphosphate (IP6) is the most abundant form of phytate existing in plants. However, food processing techniques and digestion could result in degradation of IP6 to less phosphorylated products like pentaphosphates, tetraphosphates, and triphosphates which have lower mineral-binding ability (Agte and Joshi, 1997). Other familiar zinc inhibitors include oxalate, fibre, ethylene diamine tetra-acetate (EDTA) and polyphenols such as tannins (Larsson *et al.*, 1996). In many low-income countries, diets are primarily composed of few animal-sourced foods which are both free of phytates and rich in zinc (Wallwork and Sandstead, 1990). Dietary combinations of foods that have high levels of phytates are consumed mostly by rural populations and may have complexities regarding bioavailability and utilization of zinc. This calls for serious consideration of the assessment of the indigenous food processing techniques that could enhance zinc bioavailability in order to prevent or alleviate its malnutrition.

4. CHARACTERISTICS OF TRADITIONAL FOOD PROCESSING TECHNIQUES

Traditional food processing techniques constitutes indigenous methods gathered through experience from time immemorial. This crucial indigenous knowledge has been passed from one generation to another and this is the rationale for which most of the traditional processing techniques have survived through ages (Aworh, 2008). Traditional foods and traditional food processing techniques have been integrated into the total way of life of people, most especially, those in the rural areas. Unfortunately, this vital body of indigenous knowledge is often lowly regarded (Aworh, 2008). The contributions of various simple, low-cost, traditional food processing techniques to food security and national development most especially in Africa cannot be overemphasized. Based on the fact that most of the traditional methods of food processing and preservation in West Africa are still based on experience gathered through trial and error experimentation, the methods are still crude and not standardized making them currently unsuitable for commercial scale production (Aworh, 2008). The processes are also laborious and time consuming for substantial profit to be made. In general, traditional technologies tend to be cheap, easy to produce, apply, maintain, and repair. Traditional food processing in Nigeria is characterized by rudimentary technologies, inconsistent quality and quantity, lack of innovativeness and product diversification, inadequate use of appropriate packaging, poor processing methods, poor market for processed foods, and access to appropriate technologies and processing information (Karim *et al*., 2014). Other characteristics of traditional food processing include poor handling and storage techniques. Several studies have shown that physical treatments, including dehulling, soaking, cooking, thermal treatments and protein fractionation, moreover, germination and fermentation, could reduce anti-nutritional compounds in plant foods (Frias *et al*., 1995; Kozlowska *et al*., 1996). Hence, the effective use of traditional processing methods for preparation of locally available and inexpensive food is very essential to ensure food and nutrition security especially among the rural populace of the developing nations. Roasting and malting of grains are village level traditional food processing techniques which are known to improve acceptability, flavour and texture of food, destroy anti-nutritional compounds and prolong the shelf-life of food (Manay and Sadaksharaswamy, 2000). Aworh (1993) has presented the objectives and main features of some of the West African indigenous traditional food processing techniques. It is therefore essential to review the traditional processing techniques that could enhance the bioavailability of micronutrients in plant-based foods.

4.1. Soaking

Soaking is mostly used as a prerequisite to many other food processing techniques such as germination, roasting, fermentation, drying and cooking. Soaking which involve steeping the food materials in water increases the amount of soluble minerals such as iron through passive diffusion or leaching of water soluble anti-nutritional factors including sodium, potassium, or magnesium phytate. For example, soaking of flour for 24 hours has been shown to increase the amount of soluble iron by tenfold (Ruel and Levin, 2000). The *in vitro* iron and zinc bioavailability of white sorghum varieties has been shown to increase from 8.02−13.16% to 14.62−20.75% and 7.35−9.73% to 9.07−10.72%, respectively after soaking treatment (Afify *et al*., 2011). Simple soaking could therefore lead to improvements in the iron, zinc and calcium absorption of cereal-based foods. Soaking may also promote the hydrolysis of some polyphenols and oxalates that inhibit iron and calcium absorption, respectively (Erdman and Pneros-Schneier, 1994). Agte and Joshi (1997) also attributed the decrease in IP6 and a corresponding increase in zinc solubility by about 40% after soaking of wheat batter for 12 hours at 10°C to probable increase in the activity of endogenous phytases. According to Hotz and Gibson (2007), the extent of hydrolysis of phytic acid depends on the species, pH conditions, temperature, conditions of soaking and soaking time. Phytate content of unrefined maize flour could be reduced by 50% with the use of simple and appropriate households soaking procedure (Hotz and Gibson, 2001). The leaching of water soluble micronutrients especially during long soaking period is however an impediment to the use of this processing technique (Taiwo, 1998; Lestienne *et al*., 2005b). This challenge could be overcome by combining soaking with other processing techniques or by carrying out the soaking process at optimized conditions.

4.2. Dehulling

Dehulling, also known as decortication, is another traditional processing technique of importance that is commonly applicable to legume seeds and it involves the removal of hull from the seeds. Dehulling is usually preceded by processing techniques such as roasting, milling or grinding, soaking and boiling depending on the hardness of the seed coat or hull and the objective of the dehulling process. In contrast, dehulling could also act as a prerequisite to other processing techniques such as drying, fermentation and extraction of macronutrients such as oil, starch and protein. Generally, traditional dehulling could be achieved in two ways; dry method in which the seeds are milled or ground (mechanically processed) and the hulls are blown off and wet method in which the hulls are manually separated from the cotyledons after boiling and/ or soaking and the separated hulls are decanted with water (Omafuvbe *et al*., 2007). Ghavidel and Prakash (2007) have shown the further enhancement potentials of dehulling on thiamine, *in vitro* iron and calcium bioavailability of germinated cowpea, chickpea, green gram and lentil with reductions in phytate and tannin concentrations, although a dehusker was used for the dehulling process. The study of Pal *et al*. (2016) depicted that dehulling resulted in reduction of tannin, phytate, oxalate, trypsin inhibitors, iron, zinc and calcium contents but in an increase in copper content of horsegram flours. The authors attributed the reduction in anti-nutrients and minerals to their concentration in the hulls of the legumes. The scarcity of information on the influence of dehulling on micronutrients bioavailability of plant foods calls for more studies on which evident conclusion could be drawn.

4.3. Germination/Malting

Germination is a natural process that involves placement of dormant but viable seeds in the dark at room temperature with frequent watering usually for about 72 hours to induce sprouting. Phytase activity increases and phytic acid is broken down during germination. Other anti-nutritional factors such as tannin and polyphenols are also adversely affected by germination. For example, Laminu *et al*. (2014) observed a significant reduction in phytic acid (65%) and tannin content (64%) with a significant increase in the levels of calcium, iron and zinc in germinated wheat. Similarly, a recent study has shown the anti-nutritional factors (phytate and tannin) in finger millet to be reduced by 50% after germination for 0-96 hours (Abioye *et al*., 2018). Afify *et al*. (2011) have also shown the potential of germination in enhancing iron and zinc bioavailability of white sorghum varieties. Similarly, decrease in phytate, tannin and oxalate contents after germination for 48 hours has been reported to enhance the calcium, iron and copper contents of horsegram flours (Pal *et al*., 2016). Germination of green gram, chickpea and finger millet for 24 and 48 hours was observed to decrease tannin but not the phytate contents and consequently improved the bioaccesibility of iron but not that of zinc (Hemalatha e*t al*., 2007). Another study has also observed significant increase in the thiamine, *in vitro* iron and calcium bioavailability of lentil, cowpea, chickpea and green gram with about 20% and 30% reductions in phytate and tannin respectively after 24 hours germination (Ghavidel and Prakash, 2007). Some vitamins such as riboflavin, vitamins B_6 and C of legume seeds could also be improved by germination (Fasoyiro *et al*., 2012). It has been postulated that the increase in activity of endogenous phytase activity in cereals, legumes, and oil seeds during germination or malting could be attributed to the de novo synthesis and/or activation of intrinsic phytase of the plant materials (Hotz and Gibson, 2007). Lower endogenous phytase activity has been reported for some tropical cereals such as maize and sorghum compared to buckwheat, wheat, barley, rye and triticale (Egli *et al*., 2002). Therefore, micronutrients malnutrition could be prevented in infants and children through preparation of porridge containing a mixture of germinated and ungerminated tropical cereal flours. The rate of phytate hydrolysis varies depending on the pH, stage of germination, variety, species, temperature, moisture content, presence of certain inhibitors and solubility of phytate (Sandberg *et al*., 1999; Egli *et al*., 2002). Germination reduces the phytate content of millet, rice and mung to a very large extent (Egli *et al*., 2002). Significant reductions of phytates and increase in riboflavin of black and white cultivars of beans, lentils, chicken-pea and peas after germination have been documented (Camacho *et al*., 1992). The reductions in these anti-nutritional factors are expected to promote iron and other relevant minerals absorption. Malting is a process that involves grinding and softening of grains by soaking them in water until spouting occurs and this process also increases the bioavailability of iron and zinc by reducing phytic acid level through activation of native phytases (Ruel and Levin, 2000). The ability of malting to improve vitamin C and facilitate the availability of phosphorus and tryptophan in foods has also been documented (Manay and Sadaksharaswamy, 2000).

4.4. Fermentation

Fermentation being one of the oldest and perhaps the most important traditional food processing and preservation techniques (Aworh, 2008) has contributed immensely in ensuring food and nutrition security among local and urban populace in various parts of the world. Food fermentation is defined as a process of biochemical modification of primary food products brought about by microorganisms and enzymes for the production of foods with distinct quality characteristics such as taste, aroma, shelf-life, texture and nutritional value which are quite different from the original agricultural raw material. It simply involves the metabolism of food sugars such as lactose and glucose mostly by action of lactic acid bacteria and yeast to produce lactic acid, alcohol and carbon-dioxide (Badmos *et al*., 2014). Fermentation is a common household technology in many parts of the world though regional differences occur in manufacturing practices, consumption habits, quality and level of acceptability of the fermented products. Traditional food fermentation; a biotechnological process produced by taking advantage of the natural microbiota associated with fresh food materials, is one of the most practical, economical and widely applied empirical methods to preserve and often enhance organoleptic and nutritional quality of fresh foods; and it has been unique to historical countries in different parts of the world. Fermentation enhances the nutritive value of food by increasing thiamine, nicotinic acid, riboflavin, minerals and protein content or quality as a result of microbial activity (Steinkraus, 1985; Odunfa, 1985; Soetan and Oyewole, 2009). Fermentation has been reported to reduce phytic acid and tannin content of pearl millet (*akamu*) by 72% and 71% respectively resulting in a significant increase in the levels of calcium, iron and zinc (Laminu *et al*., 2014). Lopez *et al*. (1983) also observed availability of minerals and release of phosphorus from phytate during fermentation of corn (*Zea mays*).

The principle of micronutrients availability through fermentation is based on hydrolysis of phytate to lower inositol phosphate usually less than 5 phosphate groups by the action of phytase enzymes (Lopez *et al*., 1983; Ragon *et al*., 2008). This is desirable due to the fact that lower myo-inositol phosphates (IP3 and IP4) have been reported to have no adverse effect on zinc and calcium absorption (Lonnerdal *et al*., 1989), although the findings of Sandberg *et al*. (1999) recommended the degradation of inositol phosphates to be less phosphorylated inositol phosphates than IP3 to improve iron absorption of cereals and legumes. Based on this processing technique, higher inositol phosphate of food commodities such as maize, soy beans, sorghum, cassava, cocoyam, cowpeas, and lima beans could be reduced by 90% or more. Naturally, the microbial phytases are often originated from the microflora on the surface of plant food materials. The phytate content of some cereals such as bulrush millet and red sorghum may not be reduced effectively due the inhibition of phytase activity by tannin (Sandberg, 1991). The low-molecular-weight organic acids such as citric, malic and lactic acids produced during fermentation have the capability to enhance iron and zinc absorption through the formation of soluble ligands while simultaneously generating a low pH that optimizes the activity of endogenous phytase from cereal or legume flour (Teucher *et al*., 2004). However, majority of the available knowledge on the potential of organic acids in enhancing iron and zinc absorption are based on in-vitro studies which needs to be verified by relevant in vivo experiments (Hotz and Gibson, 2007).

4.5. Mechanical processing

Pounding or milling is another technique that could be used to reduce the phytic acid content of cereals at household level provided the phytic acid is localized within a specific portion of the grain such as germ in corn or aleurone layer in wheat, triticale, sorghum, rice, or rye (O' Dell *et al*., 1972). Mbofung and Ndjouenkeu (1990) have shown that processing maize by traditional method (pounding in mortal and pestle for dehulling and milling into flour) made iron about 14 times more available than from flour processed directly by mechanical method. Milling has also been reported to favour the reactions between phytases and phytate content (Lestinne *et al*., 2005c) and this may facilitate the degradation of phytate into its less phosphorylated derivatives with lower minerals binding affinity. Accessibility and bioavailability of carotenoids could also be enhanced by mechanical processes through disruption of the subcellular membranes in which the carotenoids are bound (Hotz and Gibson, 2007). Though this technique could enhance the bioavailability of iron, zinc, and calcium, it may not be the best choice owing to the fact that significant amount of vitamins and minerals may be lost during the process. As a result of this limitation, superiority may be attached to other processing techniques such as fermentation and germination/malting which have been described earlier in this paper.

4.6. Thermal processing techniques

Thermal processing involves the use of heat treatment such as boiling, cooking and roasting to promote the bioavailability of some micronutrients including vitamins and minerals through destruction of heat labile anti-nutritional factors such as goitrogens, thiaminases, trypsin inhibitors etc. Some existing evidence have shown that boiling of tubers and blanching of green leaves incurred moderate losses (5–15%) of phytate (Yeum and Russell, 2002; Yadav and Sehgal, 2002). However, mild heat treatment is known to reduce the phytic acid of tubers but not cereals and legumes and this could be due to the strong and complex interraction of phytate with nutrients in cereals and legumes. Cooking in iron pots has been found to be effective in enhancing iron bioavailability of plant-based foods (Lestinne *et al*., 2005c). The disruption of food matrix caused by thermal processing could result to release of certain micronutrients such as thiamine, vitamin B_6, niacin, folate, and carotenoids, thereby enhancing their bioavailability (Rodrigues-Amaya, 1997;

Yeum and Russell, 2002). However, there is dearth of information on whether the micronutrients bioavailability enhancing effect of thermal processing compensate for the losses of heat-labile and water-soluble vitamins such as thiamine, riboflavin, vitamin C and folate (Hotz and Gibson, 2007). Shorter cooking time and steaming rather than boiling could minimize the oxidation of carotenoids and its loss in cooking water (Rodriguez-Amaya, 1997).

4.7. Combined and Food-based Strategies

Combined strategy is a short term integrated approach that aims at combining two or more traditional processing techniques to enhance the bioavailability of micronutrients in plant-based diets. For instance, dehulling and milling of millet grains before soaking promoted the leaching of phytate and phytases, degraded phytate and decreased phytate-iron and phytate-zinc molar ratios (Lestinne *et al*., 2005c). Combination of soaking and sprouting or germination has been shown to decrease phytate content, increase digestibility, enhance iron and zinc bioavailabilities in legumes and cereals (Gibson, 1994; Luo and Xie, 2014; Asogwa *et al*., 2017). Recently, fenugreek seeds were soaked in water for 24 hours followed by germination for 24─72 hours (Atlaw *et al*., 2018). Although the highest reduction in anti-nutrients was observed after 72 hours of germination, the highest amounts of minerals (iron, calcium and zinc) were recorded after 48 hours of germination. This suggests the requirement for further study to assess the relationship between this increment in minerals content, germination period and minerals bioavailability on which effective conclusion could be drawn. Also, the report of Erba *et al*. (2018) showed that while combine strategy (germination and cooking) generally decreased the phytate and increased the calcium content of chickpea and green pea, its effect on their other minerals (magnessium, iron, zinc and phosphorus) and accessibility of calcium and magnesium was conflicting. Similar observations have been reported for the bioaccessible selenium and selenium content of chickpea, green gram and finger millet subjected to soaking (16 hours) and germination (48 hours), although the germination was able to compensate in most cases for the loss of selenium that occurred during the soaking procedure (Khanam and Platel, 2016). The potential of combination of germination (24 hours) and dehulling in the better enhancement of thiamine, *in vitro* calcium and iron bioavailability of chickpea, lentil, cowpea and green gram, with about 50% and 48% reductions in phytate and tannin respectively, compared to germination alone has been documented (Ghavidel and Prakash, 2007). Combined strategy may also involve food fortification such as the addition of legume or fortificant to cereal-based foods as a plan to enhance the content and bioavailability of micronutrients of plant-based diets in poor communities (Gibson *et al*., 2003). The study of Podder *et al*. (2018) showed higher iron concentration, ferritin formation and relative *in vitro* iron bioavailability but lower phytate and phytate-iron molar ratio for iron (NaFeEDTA with iron concentration of 2800 μg/g) fortified lentil meals in comparison to the unfortified lentil meals. The authors also noted significant correlation between iron concentration and relative iron bioavailability as well as between relative iron bioavailability and phytate-iron molar ratio of iron fortified lentil meals. Cooking has been found to enhance the selenium bioaccessibility of fermented batters of *dosa* (non-oil pan fried rice and decorticated black gram mixture in 3:1), *idli* (steam cooked mixture of rice and decorticated black gram in 2:1) and *dhokla* (steam cooked mixture of chickpea, decorticated green gram, decorticated black gram and rice in 2:2:1:1) which are commonly consumed breakfast diets in India, though the increment did not compensate for the loss of selenium observed during soaking (10 hours) and fermentation (14 hours) that preceded the cooking procedures (Khanam and Patel, 2016). Also, Hemalatha *et al*. (2007) have shown the potential of fermentation (14 hours) in reducing phytate and tannin contents and consequently improved the bioaccessibility of zinc and iron of the batters of cereal-pulse combination used in the preparation of *idli* and *dosa* but not that of *dhokla*. Similarly, investigation on the influence of traditional fermentation and cooking of finger millet sour porridge consumed by the inhabitants of Ushe community in Zimbabwe was recently investigated (Gabaza *et al*., 2018). Four traditional finger millet varieties were used in the preparation of the porridge and about 41% and 35% reductions were reported for phenolic compounds and condensed tannins respectively while only one variety recorded a phytate reduction of 22-54%. The authors however did not observe any significant improvement in iron and zinc bioavailability of the porridges. It could therefore be asserted that the effectiveness of combine strategy in enhancing micronutrients of plant-based foods and their accessibilities depends on the specific micronutrient, the type, structure, combination and composition of plant materials, the processing methods and conditions employed. Hence, optimization of ingredients and processing conditions could be explored as a combined approach for enhancing micronutrients bioavailability of plant foods in the future. Food-based strategy is a long term micronutrients intervention and sustainable micronutrient deficiencies' solution approach that is mainly based on dietary modification (through food fortification, supplementation, diet diversification, diet planning and nutrition education) and evaluation of the targeted population. Unlike combined strategy which focused on mere fortification and supplementation programmes, food based strategy aimed at increasing the micronutrients composition of plant-based diets as well as enhancing their bioavailability for efficient absorption and utilization (Ruel, 2001). Many researchers have elaborated the use and efficiency of food-based strategy in tackling micronutrients deficiencies most especially in developing countries (Ruel, 2001; Oyarzun *et al*., 2001; Tontisirin *et al*., 2002). Food-based strategy has been found to be very effective in reducing anti-nutritional factors, enhancing micronutrients bioavailability of plant foods and consequently eradicating hidden hunger. However, Mamiro *et al*. (2004) studied and compared the effects of feeding unprocessed and processed complementary food on anaemia and iron status in a large community based randomized controlled trial involving 6 months old infants in Tanzanian. The traditionally processed foods had lower phytate-iron molar ratio than the unprocessed food but the unprocessed food had higher total iron content and this suggests no significant improvement in the iron absorption. A similar trend has been reported for zinc and this necessitates the evaluation of phytate-iron and phytate-zinc molar ratios that could result in significantly improved iron and zinc absorption and consequently, higher iron and zinc bioavailability of plant foods. In contrast, Erba *et al*. (2017) reported insignificant correlation between phytate-calcium molar ratio and calcium *in vitro* accessibility of whole-wheat products (bread, biscuits and pasta), semi-skimmed milk and parmesan. This implied that phytate-calcium molar ratio may be unreliable in predicting the availability of calcium in food-based diets. The exploration and effectiveness of food-based or combined strategies are based on the fact that no single strategy can eradicate hidden hunger globally. Apart from eradicating nutritional deficiencies, food-based strategy could also ensure food security in the targeted communities. However, the major limitations of food-based strategy compared to combine approach such as mere food fortification are the high initial expenditure and long time (5-10 years) required for its implementation and evaluation (Ruel, 2001).

5. CONCLUSION

This review has clearly shown that many traditional food processing techniques have the potential to address many of the concerns about the bioavailability of micronutrients mostly through reduction of the inherent anti-nutritional factors in plant-based diets thereby eradicating hidden hunger and ensuring nutrition security among the indigenous people of Africa and other developing countries.

Fortunately, many of the processing technologies involve simple, low-cost home-processing techniques, which in some cases are even part of the cultural background of the people. Food-based strategies serve as essential part of the long-term global strategy that could be adopted in alleviating micronutrient malnutrition though their real potential is yet to be fully explored. The feasibility, sustainability and impact of food-based strategies in community trials should therefore be promoted, implemented and evaluated. More studies on micronutrients bioavailability of plant food materials especially the indigenous foods are required for effective tackling of micronutrient deficiencies in different parts of the world since higher content of a particular micronutrient may not necessarily correspond to higher bioavailability of such nutrient. This review also realised the need for the use of *in vivo* studies in assessing the micronutrient bioavailability of plant and plant-based foods.

6. ACKNOWLEDGEMENT

We sincerely acknowledge the authors whose contributions were used in compiling this review paper for their wealth of knowledge.

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