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Review article

Processing techniques and nutrient retention in complementary foods for older infants and young children

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A B S T R A C T

Prevalent malnutrition in older infants and young children is a persistent problem in developing countries. Processing methods like soaking, germination, fermentation, roasting, and extrusion help to retain the nutrient composition, improve digestion, bioavailability, and increase sensory acceptability in complementary food. Complementary food prepared from a desired proportion of cereals, legumes, roots, tubers, fruits, and vegetables is effective in alleviating malnutrition and promoting adequate growth and development in older infants and young children. Narrative literature review approach was employed in the preparation of this review article. Complementary porridge, gruels, soup, and instant flour are the most common types of complementary foods in many countries. Crude protein, fat, fiber, carbohydrate, and energy contents of many complementary porridges, gruels, and instant flours formulated from combinations of cereals, legumes, fruits, vegetables, and tubers were in line with their recommended levels in the complementary food. Micronutrients such as iron and zinc were increased in complementary food due to substitution levels of some legumes, fruits, and tubers. In addition, vitamin C contents of all complementary foods assessed in this review did not meet the dietary reference intake for older infants. This might be attributed to the heat-labile properties of vitamin C during thermal processing. Furthermore, vitamin A contents of complementary foods produced from a combination of soybeans, cooking bananas, and Hungary rice met the dietary reference intake for older infants and young children. Optimum levels of table sugar, refined oil, salt, and some spices with suitable processing methods could be utilized to improve the sensory attributes of complementary food by considering the nature of the raw ingredients.

Keywords: Processing; Protein; Energy value; Sensory attributes; Complementary food.

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1. Introduction

Complementary food refers to food that is given to older infants and young children after the age of six months to provide them with the amount of nutrients they need in addition to breast milk (Bhandari and Chowdhury, 2016). Older infants refer to persons from the age of 6 months and not more than 12 months of age, while Young children refer to persons from the age of more than 12 months up to the age of three years (Codex Alimentarius Commission, 2013). In Sub-Saharan African countries, inadequate complementary food contributes to chronic malnutrition in older infants and young children (FAO, 2008). It has resulted in substantial increases in mortality rates, lowered cognitive development, and an overall disease burden, particularly among vulnerable population groups like reproductive women, children, and the elderly (Zewdie et al., 2021). Complementary food is effective in alleviating malnutrition, promoting adequate growth and development in older infants and young children (Martorell et al., 1994). According to the World Health Organization, WHO, (2003), complementary feeding should be started from 6 months onwards, appropriate in texture and adequate for rapid child growth.

Several studies have reported that the complementary food made

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from cereal given to infants by many mothers and other caretakers in developing countries are deficient in some macronutrients (protein and fat, leading to protein energy malnutrition), micronutrients (minerals and vitamins leading to specific micronutrient deficiencies) or both (Dewey and Brown, 2003; Dewey et al., 2008; Ijarotimi, 2008; Melese, 2013). Production of low cost, nutritious, culturally acceptable, technologically applicable complementary foods are feasible approaches to combat both macro and micronutrient deficiency.

Complementary foods can be produced solely from cereals, legumes, roots, tubers, fruits and vegetables and their combination in desired proportion with retaining sensory acceptability. Most complementary nourishments utilized in low-income families are bulky porridges prepared conventionally from locally accessible cereals (Motuma et al., 2016). According to Hardwick and Sidnell (2014), those complementary foods are frequently characterized by low calories, low mineral bioavailability, excessive bulk, poor protein quality, and low nutritional density. Complementary foods prepared from cereals or legumes are characterized by low nutrient availability due to their inhibiting effects of anti-nutrients like tannin, phytic acid, and oxalate (Lopez et al., 2002; Pynaert, 2006; Gibson et al., 2010). Processing techniques, such as fermentation, roasting, cooking, germination, autoclaving, drying, have been reported as an effective food processing methods for the reduction of these anti-nutrients in cereals (Sandberg, 2002; Singh et al., 2012; Nzewi and Egbuonu, 2011). These processing techniques could enhance nutrient contents, facilitate digestion, and increase food flavor and palatability. Soaking involves placing cereals and legumes in water for a specific ratio and duration, which aids in activating the grains, removing unwanted water-soluble compounds, and enhancing nutritional value. On the other hand, germination of grains causes an important modification in their biochemical and nutritional qualities that are beneficial for maintaining the individual's health. Research indicates that germination increases nutrient availability, digestibility, and vitamin and mineral concentration while significantly reducing anti-nutrients in complementary foods (do Nascimento et al., 2022).

Fermentation is another biochemical process that uses microorganisms to improve food quality and safety. It enhances shelf life, texture, taste, nutritional value, and digestibility while lowering anti-nutrients in cereals, legumes, fruits, and vegetables (Rezac et al., 2018). Incorporating fermented ingredients into complementary foods contributed to the increase of soluble proteins and free amino acids.

Roasting is a cooking method used for cereals and legumes that enhances their taste, smell, texture, and nutrition by applying high or moderate heat for a given time (Mridula et al., 2008). Roasted cereals and legumes are ground into flour to make various acceptable complementary food products. Further advanced processing methods like extrusion are important for production of complementary foods by utilizing mixing, forming, and cooking food in a short time using high heat and shear. This method results in changes to the food's structure and has led to the development of nutrient retained ready-to-eat complementary foods having superior physical and functional properties (Shah et al., 2019).

When formulating complementary foods for infants and older children, it's important to consider local ingredients and the specific nutritional needs based on the baby's age. Ensuring the inclusion of protein, energy-rich carbohydrates, sensory acceptability for babies and micronutrients for immune support is vital. This review is, therefore, aimed to assess processing methods and their nutrient retention potential in complementary food formulated from different ingredients during 2009 to 2023 relative to their recommended levels.

2. Methodology

This review paper was prepared by using a narrative literature review approach. The number of processing techniques and complementary foods, such as porridge, gruels, instant complementary food, and flour prepared from different ingredients, was assessed. Published works on complementary foods, reports from international organizations, and recognized websites from 2009 to 2023 were used in the preparation of this manuscript. Furthermore, the proximate composition (protein, crude fat, fiber, carbohydrate, and energy value), calcium, iron, zinc, vitamin A, and vitamin C of the selected complementary foods were presented in the table for the most preferred products in their sensory attributes.

3. Processing techniques in the production of complementary food

Complementary foods are prepared using various food processing techniques in numerous countries. The most widely used techniques include roasting, grinding, fermentation, drying, soaking, malting, and extrusion cooking. These techniques can increase nutrient contents, facilitate digestion, increase nutrient bioavailability, significantly lower anti-nutritional factors, reduce viscosity and dietary bulkiness, and enhance the complementary food's sensory acceptability.

3.1. Soaking

Soaking is the immersion of grain in water to a determined ratio at ambient temperature for a given time (El-Safy et al., 2013; Agume et al., 2017). Soaking transforms the inactive tissue into living tissue and leaches some unnecessary compounds from cereals, legumes, roots, tubers, and vegetables. The soaking of maize in the ratio of 1:2 (wt/v) for 24 hours at room temperature was reported to be utilized for enhancing the nutritional properties of complementary foods used by infants and young children (Mihafu et al., 2017). For preparation of legume flour and incorporating into complementary food formulation, legume seeds could be subjected to optimum soaking process. The cleaned legume seeds can be soaked for 12 hours at room temperature in a 1:3 (w/v) /1:4 (w/v ratio using tap water in a medium-sized plastic container, depending on legume type. Soaked beans, then dried using different drying methods/ roasted to medium heat for 15 to 20 min before ground to flour using a pulse grinding machine. Incorporating cowpea after being soaked for six hours in cassava-cowpea-orange-fleshed potato flour blend is reported as optimum in the retention of nutrients and health-promoting compounds during production of the complementary foods (Olaniran et al., 2020).

3.2. Germination

Germination of grains causes some important changes in the biochemical and nutritional characteristics that may be beneficial to human health and overall improvement of nutritional status. Germination improved the nutrient availability, digestibility, phenolic compounds, vitamins, carotenoids, texture, and organoleptic qualities of complementary food products while decreasing anti-nutritional factors, according to several studies

(Singh et al., 2015; Nkhata et al., 2018; Bourneow and Toontam, 2019; do Nascimento et al., 2022). The mung bean and cowpea's phosphorus, zinc, and antioxidant activity levels rose over the 48-hour germination period (Yasser et al., 2020). In vitro protein digestibility also increased after germination of maize, sorghum, barley, wheat (Ongol et al., 2013). Protein digestibility increased after germination is due to proteolysis and partial solubilization that comes with sprouting the seeds, as evidenced by increased water-soluble proteins and free amino acids in the germinated grains. Increased in vitro digestibility of protein and starch and calcium bioavailability were found in germinated green gram, cowpea, lentil, and chickpea flour (Ghavidel and Prakash, 2007). Incorporating germinated ingredients for complementary food production have been shown an increment of protein levels, bioavailability of minerals, and digestibility of starch and protein (Bazaz et al., 2016). According to Mihafu et al. (2017) enhanced iron, phenolic compound and reduced phytate contents was noted for 72 hour germinated maize used in complementary feeding. Germinated maize, millet and soybean mix for 48 hours at room temperature are desirable for complementary food production as it exhibits reduced water holding capacity and swelling power (Akinsola et al., 2018).

3.3. *Fermentation*

Fermentation is an ancient and useful process where microorganisms like bacteria, yeast, and mold modify the main food ingredients using their enzymes to produce lactic acid, alcohol, CO_2, and organic acids (Behera et al., 2019). This process leads to a general improvement in the shelf life, texture, taste, aroma, nutritional value, safety, protein and starch digestibility, bioavailability, and significantly lowers the content of anti-nutrients of the fermented products for cereals, legumes, fruits, and vegetables (Singh et al., 2012; Swain et al., 2014; Rezac et al., 2018; Jeyakumar and Lawrence, 2022). Fermentation also increases vitamin B content, particularly thiamine, and improves mineral availability (Mungula et al., 2003). According to Blandinob et al. (2003), the changes that occur during the fermentation process are mainly due to enzymatic activity exerted by the microorganisms and/or the indigenous enzymes in the grain itself. Its importance in modern-day life is underlined by the wide spectrum of fermented foods marketed for the benefit of preservation, safety and for their highly appreciated sensory attributes (Holzapfel, 2002).

Use of fermented ingredients in the production of complementary foods caused an increase in the amounts of soluble proteins and the free amino acids. The increase can be attributed to the microbial synthesis of proteins from metabolic intermediates during their growth cycles. It can enhance the synthesis of compounds that improve absorption by influencing the uptake of nutrients in the intestine (Leder, 2004).

Reduction of polyphenol, tannins, and phytic acid content was reported with an increase in fermentation time during production of complementary food (Wakil et al., 2012). The reduction is as a result of exogenous and endogenous enzymes, such as the phytase enzyme formed during fermentation. Fermentation also provides optimum pH conditions for enzymatic degradation of phytate, which is present in cereals in the form of complexes with polyvalent cations such as iron, zinc, calcium, magnesium, and proteins. Such a reduction in phytate may increase the amount of soluble iron, zinc, and calcium several fold (Nout and Ngoddy, 1997). During fermentation, the reduction of phytic acid content may partly be due to phytase activity, as it is known to be possessed by a wide range of microflora. The optimal temperature for phytase activity has been known to range between 35 °C and 45 °C (Sindhu et al., 2001). Tannin levels may be reduced as a result of lactic acid fermentation, leading to increased absorption of iron, except in some high-tannin cereals, where little or no improvement in iron availability has been observed (Nout and Ngoddy, 1997). The effect of fermentation on diminishing polyphenols may be due to the activity of polyphenol oxidase present in the food grain or microflora (Sindhu et al., 2001). Consuming fermented foods helps to reduce oxidative stress, reduce free radicals, balance gut microbes, control antioxidants, increase immune system activity and brain functionality, and neutralize free radicals (Bell et al., 2018). Fermentation time and fermentation conditions are the main factors that affect the final quality of fermented foods. Optimized fermentation conditions for production of complementary food should be stated. Fermented ingredients were incorporated into the production of complementary foods in many countries (Zhang et al., 2022). Fermented sorghum incorporated into pigeonpea flour for production of nutritious and acceptable complementary blend (Marete, 2015). Nutritionally and sensory acceptable complementary porridge was developed by incorporating 70% fermented sorghum flour to 25% walnut and 5% ginger flour (Adebay-Oyetoro et al., 2012).

3.4. *Roasting*

Roasting is a method of cooking cereals and legumes that uses higher temperature for a short time, or moderate heat for a longer time. It has been mainly practiced in the semi-arid tropics, India and Africa. Roasting involves exposing whole, husked, or dehusked grains to dry heat, often by placing them near a fire or on a hot griddle in contact with the fire. Optimum roasting process is useful to increase palatability, improves the flavor, aroma, texture, nutritive value, bioavailability, shelf life and reduce heat labile harmful compounds (Nzewi and Egbuonu, 2011; Castro-Alba et al., 2019; Tekgül Barut et al., 2023). However, excessive roasting more than 160 °C is known by formation of harmful compounds like acrylamide (Schlörmann et al., 2020). Leguminous seeds are commonly roasted with the husk and eaten as snacks. In many African countries roasting chickpeas, common beans, field peas, grass peas, and cowpeas helps to remove their husks. The dehusked legumes, ground into flour and mixed with cereal flour for formulation of different value-added complementary food products. The quality of complementary foods manufactured from maize, millet, and soybeans utilizing fermentation and roasting techniques is investigated by Adeoye et al. (2018). According to the report, complementary foods made using two different techniques (fermentation and roasting) were usually well acceptable.

3.5. *Extrusion process*

Extrusion is an advanced, quick, high-temperature, high-shear process that utilizes mixing, kneading, shaping and cooking unit operation for the production of extruded food products. It improves flavor, digestibility, nutritional, functional, safety, and shelf life of food (Dalbhagat et al., 2019; Egal and Oldewage, 2020). Extrusion techniques involved feeding of granular starchy food ingredients into the extruder barrel where usually, pushed by revolving spiral screws from a small hole. Immediately, when the product exits the die, usually around 120 °C, remaining water in the starchy melt swells into steam forming foam. Extrusion is the best method in the production of a variety of snacks, cereal based modified starch, complementary food, dietary fiber and breakfast cereal foods (Chaiyakul et al., 2008; Shelar and Gaikwad, 2019).

The high stress and temperatures present during the extrusion process can cause a variety of reactions and structural changes. The chemical and physical structure of extruded end products can be determined by protein denaturation, texturization, the maillard reaction, lipid modification, starch gelatinization, and the breakdown of pigments takes place during extrusion cooking (Yadav et al., 2022). There have been reports of a number of nutritionally improved and organoleptically acceptable ready-to-eat extruded complementary foods made using extrusion technology. The extruded complementary food with low viscosity, good in appearance, soft in texture and highly accepted in sensory attributes were developed from 15% malted ragi enriched with extrudates developed from sorghum, rice, greengram, roasted bengal gram and soybeans (Lakshimi et al., 2014). In addition, using blending and extrusion cooking of oats, soybean, linseed, and premix, a nutrient dense complementary food with acceptable sensory qualities were produced (Forsido et al., 2019). Complementary food with enhanced macro and micronutrients, safe levels of anti-nutrient and high in sensory qualities from orange-fleshed sweet potato complemented with amaranth seeds, and soybean flour has been developed using extrusion cooking (Nkesiga et al., 2022). Extruded complementary foods were also developed and evaluated by Kavitha and Parimalavalli (2014). Composite flour of wheat, maize, green grams, and groundnuts is used to make extruded weaning food. The result showed that extruded weaning food made from a combination of cereal and pulses might be made to offer the nutrients needed for weaning babies at a reasonable cost. To obtain the extruded products with the desired nutrients and sensory qualities, compositing of ingredients and optimization of barrel temperature, moisture content, screw speeds, particle size of the flour, and die types should be considered.

4. Complementary food formulation

The main focus for formulating and preparing complementary foods are: - identification of the local food sources, understanding the nutritional content, the age of the baby, health status, food preparation methods, amount of nutrients required and malnutrition problems. It is often necessary to include body-building foods called protein and carbohydrates, which are known as energy sources, in the infant formula for growing babies. In addition, it is encouraged to include immunity boosting foods rich in vitamins and minerals to the infant formula. The nutritional content of the complementary foods required for physical growth and mental development to the daily intake of a child is established by the World Health Organization as well as the World Food and Agriculture Organization, the World Food Program and others (WHO, 1998; 2015; 2021). In addition, when developing complementary food formulas, the sensory acceptability for the babies should be considered. Food formula program/software can be utilized to obtain the required ratio of ingredients for complementary food formulation. Formulation of complementary food that addressed vitamin A deficiency and meet the nutritional requirements of infants aged six months to three years, based on sweet potatoes, millet, and soybeans was developed (Laryea et al., 2018).

5. Macro-nutrient composition of complementary foods

Complementary food is considered to be safe and nutritious food supplemented for older infants and young children in addition to breastfeeding. Complementary feeding period is the time when malnutrition starts in many older infants and young children. The complementary feeding is moreover a basic opportunity to anticipate all kinds of childhood malnutrition, including stunting, wasting, micronutrient deficiencies, overweight, obesity, and diet-related non-communicable illnesses (White et al., 2017).

During this period, older infants and young children need nutritionally balanced complementary foods in addition to breast milk for their body growth and development (Yaseen et al., 2014). Thus, an adequate supply of protein is important for repairing damaged cells, maintaining integrity and promoting normal wellbeing, growth and development in humans. Protein requirements for children vary over their age. Recommended protein intake from complementary food in addition to breastfeeding is 6.2 g/day for 6-23 months (WHO,1998). Fat accounts about 50% of breast milk's energy and served as main energy source for infants during the first 6 months of life. According to WHO/FAO (2004) the fat content of complementary foods should range from 10% to 25%. Therefore, adequate nutrition and health care during the first new years to five years are fundamental to prevent malnutrition and child death (Melese, 2013). Provision of adequate dietary energy is vital during the period of rapid growth in infancy and early childhood (WHO, 2002). An adequate protein intake with a balanced amino acid pattern is important for the growth and development of the infant and young child (WHO, 2003). During complementary feeding specially, until 3 years of age, a child's diet should not be deficient, because this may lead to inadequate protein and energy intake (protein energy malnutrition), too high in fat and micronutrient deficiency. It is considered wise to consume fat that accounts for between 30 and 40 percent of total energy. Consumption of added sugars should be limited to about 10% of total energy, because a high intake might be compromised with micronutrient utilization (Nordic Nutrition Recommendations, 2012; WHO, 2015). The energy needed from complementary foods depends on the energy obtained from breast milk and the energy requirements of the individual older infants and young children. It can be calculated by subtracting the energy consumed as breast milk from the recommended energy intake. Values used for the recommended energy intake are those proposed by Butte (1996).

Carbohydrates supply a critical extent of vitality in the human diet. Ultimately, all carbohydrates in food are converted to monosaccharides and absorbed as primary glucose. Glucose is an essential fuel for all body tissues and particularly the brain, which is unable to metabolize fat for energy. High-fiber foods have a lower energy density, satisfy hunger, "flatten" the postprandial glycaemic response and slow the rates of food ingestion, gastric emptying, and digestion. However, there are very few useful studies of these effects in children. Dietary fiber is essential for proper bowel movement, prevent constipation, and digestion, though it does not contribute nutrients to the body. According to the Codex Alimentarius commission, (1991), the dietary fiber content of complementary foods for older infants should not exceed 5 g per 100 g because it may affect the efficiency of various nutrient absorption. In older children, no adverse effects have been reported from the consumption of fiber-containing foods, and there is no information available from developing countries where higher fiber intakes frequently co-exist with low energy intake.

Whole grain products, legumes, milk, egg, fish, fruits, vegetables, root and tubers can serve as sources for protein, fat, carbohydrates, fibers, and micronutrients (Table 1). The development and use of nutritious products from diverse food

Table 1. Macro nutrient composition of some complementary foods.

Types of complementary food	Mixes	Protein (%)	Crude fiber (%)	Crude fat (%)	Carbohydrate (%)	Energy (kcal/100g)	References
Recommended level		>15	<5	10-25	≥ 65 g/100g	400-425	WHO/FAO, 2003; WHO/FAO,2004; CODEX CAC/GL (1991)
Complementary blend	50% Fermented sorghum and 50% pigeon pea flour	14.9±3.82	2.7±1.25	3.7±1.32	70.3±4.26	*	Marete, 2015
Weaning Gruels	100% Sorghum flour	12.56±0.09	1.55±0.02	3.05±0.03	72.93	369.41	Alemu, 2009
Complementary food	60%Maize, 30%soybean, 10% peanut + 10% *Moringa*	17.08 ± 0.01	3.68± 0.01	21.60 ± 0.03	48.24 ± 0.01	455.68 ± 0.0	Shiriki et al., 2015
Complementary porridge	Raw QPM 36g+raw chickpea 36g+red teff 10g+OFSP 18g	12.70+0.74	4.19+0.17	4.94+0.00	73.32+0.74	386.75+0.02	Berhanu, 2013
Porridge	30% plantain and 70% cowpea flour	22.7	1.73	2.20	60.2	351	Olapade et al., 2015
Porridge	30% chickpea+70% amaranth	16.39±0.07	7.51±0.02	7.1 ±0.08	68.8±0.04	*	Zebdewos et al., 2015
porridge	60% cooking banana and 40% soyabean	22.56	2.46	7.51	51.62	367.70	Agomoh-Adeoye and Ezenwa , 2015)
Complementary diet	60% Maize, 20%Soybean and 20% Banana	9.98 ± 0.0	2.77 ± 0.0	6.62 ± 0.02	73.32 ± 0.07	*	Ezeokeke and On uoha, 2016
Complementary porridge	50% taro, 30% maize and 20% soyabean	22.23±0.6	3.57±0.67	6.32±0.78	56.5±0.46	372±0.43	Melese Temesgen,2018
Complementary gruel	46.4% malted sorghum, 27.1% blanched soybean and 16.6% boiled karkade seeds flour with 10.0% premix	23.89	4.54	10.87	57.63	423.91	Keyata et al., 2021
Complementary food	70% maize, 15% plantain and 15% soybean	12.95±0.07	0.22±0.01	5.25±0.01	79.54±0.06	*	Aduke , 2017
Complementary diet	53.9 %Maize, 31%pea, 15.1% anchote	14.92	2.75	8.74	66.22	404.62	Gemede, 2020
Complementary porridge	80% fermented maize, 10% soyabean and 10% carrot flour	17.99±2.82	0.28±0.00	6.09±0.20	63.14±4.29	379.33±00	Barber et al., 2017
Complementary gruels	55% oat,23% soybean,7% lin seed and 15% premixes	20.60	3.80	9.30	59.80	405.00	Forsido et al., 2019
Complementary gruels	60% malted maize, 20% roasted soybeans and 20% roasted groundnut	7.20 ± 0.41	0.87 ± 0.01	1.05 ± 0.17	89.21 ± 0.58	*	Anigo et al., 2010
Complementary gruels	55% fermented sorghum, 30% soybeans and 15% plantain	11.17 ± 0.01	2.27 ± 0.02	5.14 ± 0.01	30.10 ± 0.01	211.34	Onoja et al., 2014
Complementary flour	60% maize, 30% haricot bean flour and 10% cooking banana flour	14.54	3.41	6.23	70.21	395.28	Feyera et al., 2020
Complementary porridge	71.77% malted sorghum, 18.23% soybeans and 10% *Moringa oleifera* seed	16.58 ±0.02	1.68±0.01	7.42 ±0.01	62.51 ±0.01	381.52	Bello et al., 2020
Instant complementary food	50% sorghum and 50% pigeon pea	14.91±3.82	2.71±0.72	3.74±0.76	70.35±2.2	*	Kinyua et al., 2016
Weaning food	44% germinated wheat flour, 36% germinated mung bean, 10% full fat milk powder and 10% sucrose	23.975 ± 0.986	1.654 ± 0.089	1.30 ± 0.114	65.082± 1.47	377.16 ± 0.869	Imtiaz et al., 2011
Complementary flour	60% Misola: 20%Pennisetum glaucum, 10%Soja hispida: 10% Arachis hypogae	16.8±0.05	*	13.39±0.07	63.95±0.04	443.51±0.01	Faso, 2011
Complementary gruels	70% Fermented sorghum and 30% soybean	16.73±0.21	4.41±0.63	9.78±0.79	67.80	426.02	Tufa et al., 2016
Complementary food	100 fonio/hungary rice:100 soyabean	30.5 ± 0.03	5.18 ± 0.02	8.4 ± 0.08	49.36 ± 0.02	*	Okoronkwo et al., 2023
Complementary porridge	40% amaranth,20% soybeans, 15% pumpkin and 25% orange fleshed sweet potato	3.20 ± 0.01	0.20 ± 0.01	12.80 ± 0.01	74.40 ± 0.40	425.00 ± 1.89	Marcel et al., 2022
Complementary porridge	65% Sorghum, 25% walnut and 5% ginger	8.20±0.00	0.29±0.01	1.81±0.00	81.92±0.00	376.78	Adebayo-Oyetoro et al., 2012

*= not presented

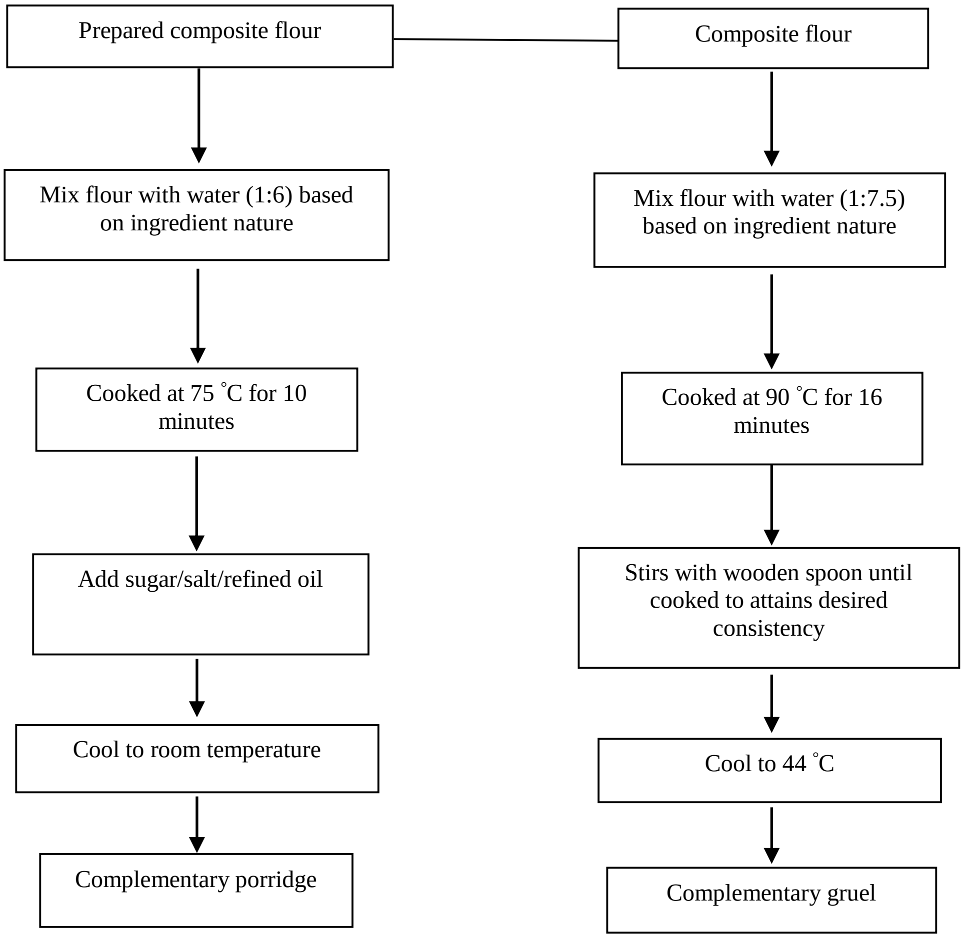

Fig. 1. Flow diagram for complementary foods preparation (The source of the contents of the left column is Aduke (2017), and the source of the right one is Keyeta et al. (2021)).

sources, as well as modified processing methods have been advocated to alleviate problems of short food supply and malnutrition (Fig. 1). Some of the strategies employed in improving the quality of complementary foods include the use of complementary flours from cereals, legumes and fruits and household preparation methods such as fermentation and germination (Gibson et al., 2006).

6. Micro-nutrient composition of complementary

Whole cereal products, legumes, milk, egg, fish, fruits, vegetables, root and tubers can serve as sources of vitamin A, vitamin C, calcium, iron and zinc. Fruits and vegetables are introduced particularly over time to provide infants with vitamins A and C, and minerals (FAO, 2011). Concentration of iron and zinc in breast milk during breastfeeding is slightly varied depending on the dietary pattern of mothers, environment and lactating stage (Bjorklund et al., 2012). Micronutrients, like vitamin A, vitamin C, calcium, iron, and zinc, have occupied a prominent place in child health and nutrition in low and lower-middle-income countries (Table 2).

Calcium is an essential micronutrient for bone and teeth formation and development in infants and children. Iron is essential for formation of blood cells, crucial for mental health, and reducing the prevalence of iron deficiency anemia in infants and children (Shubham et al., 2020). In other words, zinc is an important cofactor for more than 70 enzymes and plays a central role in cell division, protein synthesis and growth. Zinc deficiency will result in growth failure, impair cognitive development, enlarged liver and spleen, and impaired skeletal development.

Vitamin A regulates healthy eyesight, immune system functions, essential for cell differentiation and modulation of apoptosis (Wolf, 2008; WHO, 2021). Children with vitamin A deficiency face an increased risk of blindness and death from infections such as measles and diarrhea. Vitamin A is obtained from animal food products like liver, dairy products, egg and fish as retinol and from plant sources converted from carotenoids, particularly beta carotene from orange, green vegetables, carrot, sweet potatoes, papaya and banana. According to Garrow et al., (1999), vitamin A recommendations range between 350-400 RE (international units) per day for older infants and young children aged from six months to 3 years.

Vitamin C (Ascorbic acid) is vital to deactivate or scavenge free radicals (highly reactive molecules) and activate oxygen, protect against cellular damage, and heal wounds. The main sources of vitamin C are plant-based food products, including citrus fruits, tomato, pepper, cabbage, banana, plantain, etc. Vitamin C

Table 2. Dietary reference intake of micro nutrients in some complementary foods.

Types of complementary food	Mixes	Calcium (mg/100g)	Iron (mg/100g)	Zinc (mg/100g)	Vitamin C (mg/100g)	Vitamin A (μg/100g)	References
From 6 months to 3 years		260–700	0.27 to 11	3 to 8.40	15–50	300–500	USDA, 2012; WFP, 2018
Complementary blend	50% Fermented sorghum and 50% pigeon pea	29.81±11.62	6.95±2.92	1.59±0.30	*	*	Marete , 2015
Weaning gruels	100% Fermented sorghum flour	15.557±0.01	7.59±0.01	1.96±0.02	*		Alemu,2009
Porridge	30% chickpea and 70% amaranth	245 ±0.2	15.16±0.03	2.59±0.01	*	*	Zebdewos et al., 2015
porridge	60% cooking banana and 40% soybean	87.05	21.45	*	11.83	561.80	Agomoh-Adeoye and Ezenwa , 2015)
Complementary diet	60% Maize, 20%Soybean and 20% Banana	198.00 ±0.00	3.82 ± 0.02	4.21 ± 0.01	49.88 ± 0.04	*	Ezeokeke ans Onuoha, 2016
Complementary porridge	50% taro,30% maize and 20% soybean	29.43±0.65	3.9±0.21	11.17±0.54	*	*	Melese Temesgen, 2018
Complementary gruel	46.4% malted sorghum, 27.1% blanched soybean and 16.6% boiled karkade seeds flour with 10.0% premix	259.48	6.8	3.68	*	*	Keyata et al., 2021
Complementary food	70% maize, 15% plantain and 15% soybean	*	*	3.54±0.04	*	1.18±0.01	Aduke, 2017
Complementary diet	53.9 %Maize, 31% pea, 15.1% anchote	225.45	11.48	2.73	*	*	Gemede , 2020
Complementary porridge	80% fermented maize, 10%soybean and 10% carrot flour	42.50±21.21	18.617±2.87	0.554±0.00	*	*	Barber et al., 2017
Complementary gruels	55% oat,23% soybean,7% lin seed and 15% premixes	124.40	7.80	3.00	*	*	Forsido et al., 2019
Complementary gruels	60% malted maize, 20% roasted soybeans and 20% roasted ground nut	39.82	19.91	10.79	*	*	Anigo et al., 2010
Complementary gruels	55% fermented sorghum, 30% soybeans and 15% plantain	7.63 ± 0.03	0.77 ± 0.00	0.76 ± 0.00	*	*	Onoja et al., 2014
Complementary flour	60%maize, 30% haricot bean flour and 10% cooking banana flour	47.83	4.22	5.24	4.95	*	Feyera et al., 2020
Complementary porridge	71.77% malted sorghum, 18.23% soybean and 10% *Moringa oleifera* seed	19.02 ±0.01	4.59 ±0.03	3.20 ±0.02	*	1.65±0.01	Bello et al., 2020
Instant complementary food	50% sorghum and 50% pigeonpea	29.81±6.7	6.95±1.68	1.59±0.17	*	*	Kinyua et al., 2016
Complementary flour	60% Misola: 20%Pennisetum glaucum, 10%Soja hispida:10% Arachis hypogae	100.00	100.00	6.00	*	*	Faso, 2011
Complementary gruels	70% Fermented sorghum and 30% soybean	186.93±2.47	4.27±0.04	2.60±0.06	*	*	Tufa et al., 2016
Complementary food	100 fonio/hungary rice:100 soyabean	104.21 ± 0.04	7.25± 0.02	3.48± 0.02	18.32 a ± 0.02	1134 ± 0.60	Okoronkwo et al., 2023
Complementary porridge	40% amaranth , 20% soybeans, 15% pumpkin and 25% orange fleshed sweet potato	49.60 ± 3.08	13.40 ± 6.37	7.10 ± 0.32	7.50 ± 0.01	224.50 ± 0.66	Marcel et al., 2022

*= not presented

recommendation is 20 RE (international units) per day for older infants and young children aged from six months to 3 years (Garrow et al., 1999).

7. Sensory attributes of complementary food

Sensory attributes are sensory evaluation tools used to evoke, measure, analyze and interpret the responses towards food products as perceived through the senses of sight, hearing, touch, smell, and taste. According to Kemp et al. (2009), the sensory organs, such as the eyes, tongue, nose, and ears, interact with food components in order to perceive the sensory qualities of food products. These sensory attributes of a food product include appearance, color, flavor, aroma, texture, taste, and overall acceptability. The selection of sensory attributes might be varied depending on the type of food products. The following list of sensory attributes is the most commonly used to evaluate the acceptability of complementary food.

Appearance: It is the first characteristic perceived by the human senses and plays an important role in food choice and acceptance. This is how food appears to the eye, taking into account factors including size, shape, gloss, dullness, and transparency.

Color: It reflects the suitable raw material used for the preparation and also provides information about the formulation and quality of the product (Mepba et al., 2007). The color of the complementary food has been affected by the type of ingredients used. Color is less important for older infants and young children, as the mother or child care provider has a major role in determining the color preference and acceptability of complementary food.

Flavor: It is a sensory phenomenon which is used to denote the sensations of odor, taste and mouthfeel.

Aroma: It is the first cousin of taste. The sensory tissues in the nasal cavity detect these volatile chemicals through their odor receptors. Aromatic compounds are released during the mastication process.

Texture: According to Pareyt and Delcour (2008), texture is basic to assessing whether or not cereal-based foods are accepted by consumers. Texture of food products is perceived by a combination of senses i.e., touch, mouth feel, sight, and hearing. It includes: consistency, thickness, fragility, chewiness, softness, and crispness. Thin and slightly thick complementary foods are preferred for older infants and young children.

Taste: Taste is the primary factor that determines the acceptability of any product, which has the highest impact as far as market success of the product is concerned. It involves the taste receptors in the superficial taste buds located on the tongue and other regions of the mouth or gullet, sensing ingredients after they have been dissolved in saliva, oil, or water. The sensory properties of complementary food, like taste, can be improved with the addition of sugar and salt. Incorporation of optimum level of granulated table sugar and refined vegetable oil would be recommended to enhance taste attributes and palatability of cooked complementary food.

8. Challenges and scaling up

The commonly consumed complementary food consists of only cereals that do not contain adequate nutrients needed for proper body functioning and growth of older infants and young children, in many developing countries. These need to be solved by complementing cereals with other nutrient-rich legumes, fruits and vegetables, that could that will enhance the nutrient composition, sensory profiles and nutritive values. The limited knowledge of diet diversification, inadequate consumption of a balanced diet, and low awareness of nutrition education are the major contributors to the persistence of chronic malnutrition in older infants and young children.

Promoting economically feasible and nutrient-dense complementary foods prepared from locally available ingredients is an effective approach in alleviating malnutrition. Complementary food prepared from a desired proportion of cereals, legumes, roots, tubers, fruits, and vegetables is critical for ensuring optimal growth, development, and overall health. The cost-effective processing techniques, along with nutrient retention, improved bioavailability and digestibility, are encouraged to scale up and promoted. As infants transition from exclusive breastfeeding to complementary foods, it is essential to introduce a variety of nutrient-dense options that support their growth and development.

Simultaneously, lactating women require an adequate amount of nutrients to maintain their health and secrete sufficient amounts of breast milk. Demonstrating complementary food preparation and consumption patterns empowers caregivers with the knowledge and skills needed to provide balanced diets. Creating awareness for the community, government and nongovernmental organizations on the importance of complementary food for growth and development of older infants and young children in low-income countries. Encourage government intervention on sustainability of raw ingredients, affordability in optimum prices, and increase the accessibility of complementary foods in vulnerable areas.

Provide training on the principles of infant feeding, highlight the significance of diverse food choices, and promote healthy diets for reproductive mothers, caregivers, older infants, and young children. Promoting and scaling up of novel processing techniques for production of nutritious complementary food products in rural, urban, and peri-urban communities using social media, TV, leaflets, and radio broadcasting.

9. Conclusion

Processing methods like soaking, germination, fermentation, roasting, and extrusion help to retain the nutrient composition, improve digestion, bioavailability, and increase sensory acceptability in complementary food. When formulating complementary foods for babies and children, it is crucial to availability of local ingredients and their nutritional needs based on age and health. Complementary food produced from a mixture of different flours of cereals, legumes, fruits, vegetables, root and tubers can meet macro and micro nutrient requirements for older infants and young children.

The highest protein content was obtained in complementary food produced from equal proportions of fonio / Hungary rice and soybean flour. Complementary food consisting of maize, soybean, peanut and Moringa composite flour showed the highest in crude fat and energy value. Iron, zinc and vitamin C contents in a complementary diet composed of maize, soybean and banana flour attained the recommended dietary reference intake for older infants and young children. Vitamin A and calcium concentrations obtained in this review could not meet the reference dietary intake for older infants and young children.

To enhance vitamin A and calcium concentrations of complementary food, calcium and vitamin A-rich food products like milk could be used as complementary substitutes. Sensory attributes of complementary food produced from different proportions of composite flours were in the acceptable range. The combination of cereals, legumes, roots and tubers is recommended in the production of nutritious, low-cost and acceptable complementary foods for older infants and young children.

Conflict of interest

The author declares that there is no conflict of interest.

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