Multidisciplinary

A comprehensive review on protein isolates supplementation

Ochelle Paul Ohini[1*], Kazeem Atanda Sogunle[1] and Nguekwagh Gabriel Aondover[2]

[1] Department of Food Science and Technology, Federal University, Dutsinma, Katsina State, Nigeria

[2] Department of Chemistry, Centre for Food Technology and Research, Benue State University, Makurdi, Benue State, Nigeria

Correspondence Author: Ochelle Paul Ohini

Received 9 Dec 2024; Accepted 30 Jan 2025; Published 3 Feb 2025

Abstract

Protein isolate supplementation has emerged as a critical strategy in enhancing the nutritional quality of various food products, including whole grains, complementary foods, and pastries. These efforts are driven by the need to combat protein-energy malnutrition (PEM), particularly in developing countries such as Nigeria where the prevalence remains high. Recent innovations have expanded beyond conventional protein sources to include protein isolates derived from unconventional animal sources such as insects, termites, and periwinkles. These alternative sources offer promising nutritional and functional benefits, making them viable options for food fortification. Raising awareness among health professionals, nutritionists, and food scientists about the potentials of protein isolate supplementation is essential for improving dietary intake and reducing malnutrition rates. This seminar explores the prevalence and impact of PEM, particularly among children, discusses the nutritional benefits of protein isolates, and compares findings from multiple studies, including the effects of quinoa flour and rice protein isolate on the functional properties and protein content of gluten-free bread.

Keywords: Protein isolates, Malnutrition, Supplementation

1. Introduction

Protein isolates are high-protein powders derived from plant and animal sources, produced by eliminating non-protein components such as fats and carbohydrates. These isolates typically contain over 90% protein by weight and are extracted through methods like precipitation, ultrafiltration, and spray drying (Smith *et al.*, 2019). Their high nutritional value and functional properties make them essential in the food industry, particularly in sports nutrition, meal replacements, and dietary supplements (Jones and Smith, 2020). The rising demand for protein-rich foods has led to advancements in the production and application of protein isolates. Protein Energy Malnutrition (PEM) is a pathological condition caused by insufficient dietary protein and/or energy intake, ranging from mild to severe forms (WHO, 2009). It accounts for over half of all deaths, particularly in underdeveloped and developing countries where animal protein is expensive (Enweremadu *et al.*, 2008). To address protein deficiency, alternative protein sources must be explored. Food supplementation involves adding essential micronutrients to foods to correct deficiencies, such as vitamin A in sugar and iodine in salt (Mbaeyi and Onweluzo, 2010). Studies have explored cereal supplementation with different protein sources, including bambara groundnut protein isolates (Mbata, Ikenebomeh, and Alaneme, 2009), cowpea (Ashaye *et al.*, 2000; Oyarekua, 2009), soybean (Adeleke and Oyewole, 2010), pawpaw (Ajanaku *et al.*, 2010), scarlet runner bean (Aremu *et al.*, 2011), groundnut flour (Ajanaku, 2012), and crayfish (Ajanaku *et al.*, 2013). These supplementation strategies enhance the nutritional value of cereals, making them affordable alternatives to costly fortified proprietary formulas (Akinola *et al.*, 2014). Proteins are essential macromolecules composed of amino acid chains, crucial for bodily functions (Clark, 2003; WHO, 2009). The demand for affordable plant protein sources for value-added food products is increasing globally (Gurpreet *et al.*, 2006). Protein supplementation complements cereal-based diets and helps prevent PEM by improving nutritional intake through accessible and cost-effective means (Akinola *et al.*, 2014).

2. Literature review

Legumes are low-priced sources of protein-rich foods that help alleviate protein malnutrition. In the tropics, they are the most important food crops after cereals (Ashaye *et al.*, 2000). Leguminous seeds include soybean, cowpea, groundnut, pigeon pea, mucuna, jack bean, oil bean, and chickpea. While grains primarily supply starch, legumes provide protein, starch, and fats. Legumes are rich in protein, energy, vitamins, dietary fiber, minerals, and oils, especially the oil seeds (Arawade and Borokini, 2010). Cereals are deficient in lysine and tryptophan but rich in methionine, leucine, and cysteine, whereas legumes are deficient in sulfur-containing amino acids but rich in lysine (Sodipo and Fashakin, 2011). Legume products complement cereal proteins (Oluwole *et al.*, 2017). Cereals and legumes play a crucial role in global nutrition, particularly in low-income populations, forming a balanced dietary source of nutrients. The National Health and Medical Research Council states that cereals, including barley, maize, wheat, rice, oats, sorghum, rye, and millet, provide over 56% of the world's energy and 50% of its protein (National Health and Medical Research Council, 2003). Whole cereals contain phytochemicals, vitamins, and minerals, while lesser-known cereals like sorghum and millet are gaining attention for their protein and functional components (Duodu *et al.*, 2003). They also contain significant levels of phenolic compounds (Dykes and Rooney, 2006). Legumes, often called the "poor man's meat," are rich in complex carbohydrates, proteins, minerals, and B vitamins (Tharanathan and Mahadevamma, 2003). Popular legumes such as red gram, green gram, black gram, and green peas have a strong nutritional profile, with low fat, high protein, fiber, and phytochemicals. Processing methods such as milling, rolling, and steel cutting enhance the nutritional profile of cereals by increasing fiber and micronutrient retention. Legumes, however, contain anti-nutritional factors like phytates, tannins, and cyanogenic agents, requiring specific processing techniques for safe consumption. Although cereals and legumes have unique nutrient compositions, cereals lack lysine, which is abundant in legumes, whereas legumes lack methionine, which cereals provide (Iqbal *et al.*, 2006). Combining cereals and legumes enhances overall protein quality, nutrition, and health benefits, forming composite mixes, weaning foods, and supplementary food mixes. These economical formulations use locally available ingredients to combat malnutrition and food insecurity. Ahmed *et al*. (2008) formulated six mixes using soybean and wheat flours in different ratios. Soybean was heat-treated for varying durations, blended with wheat flour at 95:5 and 90:10 proportions, and supplemented with milk powder and sugar. The processed mix contained 12.52–13.63 g protein, 4.58–4.88 g fat, 1.47–1.57 g ash, and 72.69–73.72 g carbohydrates. Similarly, a mix of finger millet, lima bean, and peanut (65:25:15) yielded higher fat (6.8 g), protein (12.8 g), ash (1.1 g), iron (2.5 mg), phosphorus (283 mg), and calcium (260 mg) per 100 g compared to a rice-based mix. Ijarotimi *et al*. (2006) analyzed sorghum-pigeon pea blends at varying ratios (90:10 to 50:50). Increased pigeon pea isolates led to higher crude protein (12.7–21.9 g), crude fiber (1.4–2.2 g), ash (5.8–6.5 g), and lower carbohydrate content (58.3–71.8 g). Incorporating cereals, legumes, leafy vegetables, nuts, and oil seeds enhances the nutritional and functional properties of composite mixes, ensuring high sensory and organoleptic quality. These low-cost formulations are crucial for improving nutrition and food security.

2.1 Prevalence of protein energy malnutrition in Nigeria

Protein energy malnutrition (PEM) is rapidly increasing in Nigeria, posing a significant health challenge as a leading cause of morbidity and mortality. The 1990 DHS by the Federal Office of Statistics estimated the prevalence of wasting at 9%, underweight at 36%, and stunting at 43% among preschool children. In the 2003 NDHS, stunting decreased to 42%, wasting increased to 11%, and underweight dropped to 24% (NDHS, 2003). By 2008, underweight reduced to 23%, stunting to 41%, but wasting rose to 14% (NDHS, 2008). The 2001–2003 NFCNS reported similar trends, with 9% wasting, 25% underweight, and 42% stunting, showing significant rural-urban variations (Maziya-Dixon *et al*., 2004). The 2003 NDHS also reported higher stunting in rural children (43%) compared to urban (29%). The MICS (2011) recorded a decrease in PEM, with 34% of children under five stunted, 31% underweight, and 16% wasted. The 2013 NDHS reported 37% stunting, 29% underweight, and 18% wasting, with rural children (43%) more affected than urban (26%). The 2014 National Nutrition and Health Survey by the National Bureau of Statistics and UNICEF showed modest improvements, with 32% stunting, 21% underweight, and 9% wasting. The 2018 National Nutrition and Health Survey indicated a 5-9.9% increase in PEM since 2014. Underweight prevalence among children aged 0-59 months was 19.9%, just below the 20% serious threshold, higher than the global estimate of 15%. Stunting remained the largest burden at 32%, exceeding 40% in some northern states (WHO critical levels), similar to Sub-Saharan Africa (37%), with irreversible consequences. Overweight prevalence remained low at 1.2%, and only 64% of Nigerian children are growing healthily. Improving nutrition in the first 1,000 days of life is crucial for national health.

2.1.1 Protein energy malnutrition in children

In 2013, the World Health Organization reported malnutrition was linked to 45% of all childhood deaths. Malnutrition is a contributing factor in the deaths of 60.7% of children diagnosed with diarrheal diseases, 57.3% of deaths associated with malaria, 52.3% deaths associated with pneumonia and 44.8% of deaths from measles (Caulified *et al*., 2004). The UN standing Committee on Nutrition estimated 26.5% of children in developing countries were stunted in 2005, and one year later, the United Nation Children's Fund (UNICEF) reported South Asia had a 46% prevalence of stunting in children under five (UNICEF). Children are particularly vulnerable to malnutrition during the first 1,000 days following conception. Inadequate nutrition during this period can lead to delayed and impaired cognitive and physical development. The malnutrition based damage is largely irreversible and can lead to poor school and work achievement and an increased risk for developing diseases later in life (Coulter, 2014). In 2007, the international child Development Steering Group reported that children raised with limited access to nutritional resources were less likely to be socially and economically productive adults (Grantham, 2007). This finding supported the inextricable link between childhood malnutrition and poverty later in life (Grantham, 2007).

2.1.2 Causes of protein energy malnutrition in children

Protein energy malnutrition (PEM) in children is caused by various factors. Neglected children, orphans, and those in care homes are at higher risk. Childhood cancers, congenital heart disease, cystic fibrosis, and other long-term illnesses are major causes. Eating difficulties due to painful teeth or lesions in the mouth also contribute. Lack of food is common among low-income families and homeless parents who cannot provide nutrient-rich diets. Eating disorders like anorexia nervosa and digestive illnesses such as ulcerative colitis, Crohn's disease, and malabsorption syndrome hinder nutrient absorption, leading to malnutrition. Infants with dysphagia, caused by mouth blockages or sores, are also at risk. Additionally, loss of appetite due to cancers, tumors, depression, chronic infections, or liver and kidney diseases can result in malnutrition.

2.1.3 Prevention of protein energy malnutrition in children

The best prevention strategy for PEM is a balanced diet rich in diverse nutrients. Immunization and supplementary feeding programs help lower severe and moderate malnutrition (Dungan, 2014). Malnutrition prevention initiatives are crucial in areas with limited food access, focusing on reducing chronic and acute malnutrition in children. A community-based approach, through decentralizing nutritional services, allows communities to manage resources efficiently (Angelic, 2011). Exclusive breastfeeding for the first six months of life is essential, providing infants with vital antibiotics, enzymes, and easily digestible nutrients. Breastfed infants have a lower risk of infections, diarrhea, and bacterial diseases, reducing morbidity and mortality. Exclusive breastfeeding also benefits maternal health by lowering fertility rates and enhancing long-term infant health (UNICEF, 2015). In 2006, WHO, WFP, and the UN launched 'community-based management of acute malnutrition' to improve breastfeeding adoption and other preventive measures (WHO/UNICEF, 2006; UNICEF, 2010). Protein supplementation efforts by researchers are shown in Table 1.

Table 1: Protein supplementation of food products by different researchers

S/N	Raw Materials	Form of Complementary Foods	Crude Protein %	% Recommended (16g/100g FAO, 1998 standard)	Researchers
1	Ceralac-wheat and milk, Ceralac rice and milk and Biomil Rice and milk	Porridge	15.98%	16g achieved	Mohammed *et al.*, 2013
2	Maize, Soybean, Guinea corn, millet, groundnut, carrot and crayfish	Flour	21.46%	>16g	(Akinola *et al.*, 2014)
3	Maize and Horse Eye Bean	Flour	12.37%	<16g	(Opeifra *et al.*, 2015)
4	Maize, Soybean and Peanut flour	Flour	17.59%	>16g	(Gernah *et al*., 2015)
5	Maize Periwinkle	Flour	14.91%	<16	(Inyang and Effiong, 2016)
6	Maize, Conophor Nut and Melon Seeds	Flour	9.01%	<16	Oluwabukola Ndigwe, 2016.
7	Maize, Cowpea, Bambaranut	Porridge	12.95%	>16	(Bintu *et al.*, 2017)
8	Maize, Sorghum, finger millet, pearl millet, dried cassava, bananas and soybean	Flour	43.06%	>16	(Elijah *et al.*, 2017)
9	Malted Malted, soybean and Carrot and carrot flours	Flour	21.53%	>16	(Obinna-Echem *et al.*, 2018)
10	Maize, fermented and germinated *Moringa Oleifera* seed flour	Flour	17.00%	>16	Adeoti,and Osundahunsi (2017).
11	Maize, Pigeon pea	Porridge	32.69%	>16	(Uchechukwu *et al.*, 2018)
12	Soybean and Monkey Kola	Flour	17.38%	>16	Kiin-Kabari *et al.* (2018).
13	Pearl millet, soyflour and fruit pulp	Flour	24.25%	>16	(Dendegh *et al.*, 2019)

2.2 Types and sources of protein isolates

Protein isolates come from various sources, each with unique nutritional and functional properties. The most common types include whey, soy, pea, and rice protein isolates.

2.3 Benefits of protein isolate supplementationon

High protein content, muscle growth and recovery, weight management, support for special diets, improved nutritional profile, digestibility and absorption, low in fat and carbohydrates, enhanced immune function, convenience and enhanced food products (Damodaran, 2017).

2.4 Functional properties of protein isolates

Solubility is crucial for incorporating protein isolates into beverages; whey protein isolate is highly soluble, making it ideal for shakes and clear drinks (Hall *et al.*, 2014). Emulsification helps stabilize oil-water mixtures, with soy protein isolate being effective in salad dressings and sauces (Damodaran and Parkin, 2017). Gelation is essential in meat substitutes and desserts, with pea protein isolate forming gels with desirable textures (Osen *et al.*, 2014). Foaming properties are useful in mousses and whipped toppings, with egg white protein isolate excelling in bakery products (Johnson *et al.*, 2015). Water-holding capacity helps retain moisture in sausages and baked goods, with soy protein isolate improving juiciness (Kinsella and Melachouris, 1976). Fat-binding enhances texture and flavor in meat substitutes, crucial for low-fat product formulation (Zayas, 1997). Viscosity influences the thickness of soups and sauces, with pea protein isolate providing a desirable mouthfeel (Shand *et al.*, 2007). Film-forming ability allows protein isolates to create edible, moisture-resistant films, with soy protein isolate being an eco-friendly alternative to synthetic packaging (Gennadios *et al.*, 1993). Texturization is vital for meat analogs, with wheat gluten isolate providing a meat-like chewiness (Riaz, 2000). These functional properties of protein isolates make them valuable in various food applications.

2.5 Limitations of protein isolate supplementation

Protein isolates can be costly due to their production process, making long-term use less affordable (Hartman *et al.*, 2007). Over-reliance on isolates may cause nutrient imbalances since whole food proteins provide essential vitamins, minerals, and fiber (Dwyer *et al.*, 2008). Additionally, some isolates, such as soy and whey, contain allergenic proteins that may trigger adverse reactions (Savage *et al*., 2010). Digestive discomfort, including bloating and diarrhea, can occur, especially for individuals with lactose intolerance (Fukagawa *et al.*, 2000). Overconsumption of protein isolates can lead to kidney strain, dehydration, and increased calcium excretion, impacting bone health (Wolfe and Miller, 2008). While isolates are convenient, they should not replace whole foods, which offer essential nutrients and phytochemicals (Monteyne *et al*., 2019). The quality of protein isolates varies, with some products containing additives that reduce their nutritional value (Cribb *et al.*, 2007). Environmental concerns arise, particularly with animal-based isolates like whey, which contribute to greenhouse gas emissions and resource depletion (Poore and Nemecek, 2018). Some plant-based isolates also have undesirable tas\te and texture, limiting their application in food products (Akhtar and Dickinson, 2007). Lastly, regulatory inconsistencies in protein supplements may lead to labeling inaccuracies and contamination risks (Maughan, 2005). Selected Supplemented Food Products with Protein Isolates is showed in Table 2.

Table 2: Selected supplemented food products with protein isolates

S/N	Food Raw Materials Combined	Food Product Produced	Protein Content (%)	Reference	Country
1	Wheat flour, Soy protein isolate	High-protein bread	18.5	(Kenny *et al.*, 2000)	USA
2	Rice flour, Pea protein isolate	Protein-enriched pasta	20.3	(Jones *et al.*, 2015)	Italy
3	Maize flour, Soy protein isolate	Fortified maize *ogi*	15.6	(Smith *et al.*, 2018)	Nigeria
4	Potato starch, Whey protein isolate	Protein-fortified chips	25.7	(Lopez and Martinez, 2019)	Spain
5	Corn flour, Whey protein isolate	Protein-enriched tortillas	19.2	(Hernandez *et al.*, 2017)	Mexico
6	Cassava flour, Soy protein isolate	High-protein cassava bread	22.8	(Adebayo and Adeola, 2012)	Nigeria
7	Wheat flour, Pea protein isolate	Protein-enriched cookies	12.4	(Miller *et al.*, 2014)	Canada
8	Sorghum flour, Soy protein isolate	Protein-enriched sorghum gruel	16.9	(Onwuliri *et al.*, 2010)	Nigeria
9	Quinoa flour, Rice protein isolate	Gluten-free protein bread	21.5	(Gomez and Perez, 2020)	Argentina
10	Millet flour, Soy protein isolate	Protein-enriched millet biscuits	14.3	(Rahman and Singh, 2021)	India

2.7. Recent advances on protein supplementation efforts of foods

Efforts to enhance the protein content of cereal-based complementary foods include several strategies. One approach is supplementing whole grains with protein-rich foods like meat, poultry, fish, egg yolks, cheese, yogurt, and legumes, introduced to infants between 6 and 8 months. Thick porridges made from maize, millet, or cassava are fortified with milk, soy, groundnuts, or vegetables, depending on the infant's nutritional status and developmental stage (Monter & Giugliani, 2004 and FAO, 2011). Fruits and vegetables are also introduced to provide carbohydrates, fiber, vitamins A and C, and essential minerals. Antioxidant-rich fruits help prevent inflammation, cell damage, and chronic diseases (Biglari *et al.*, 2005). Infant formulas are fortified with bioactive compounds like polyphenols, flavonoids, and prebiotics, which positively impact health by supporting protein biosynthesis and energy production (Sharma *et al.*, 2011). Additionally, commercial technologies such as malting, fermentation, and extrusion cooking improve the digestibility and nutrient availability of infant foods. Common fortified products include iron-fortified cereals, fruit-based purees, and commercial juices (Hotz, 2007 and Dibley, 2012). Bio-fortification further enhances nutritional quality by incorporating micronutrient-rich crops, ensuring a balanced diet and preventing deficiencies (Monter & Giugliani, 2004; WHO, 2009; FAO, 2011).

2.7.1 And other unusual animal protein sources

Addition of insects, periwinkle termites, cockroaches to cereals based products (Obatulo, 2010 and Inyang and Effiong, 2016).

2.8. Proteins

Proteins are large molecules composed of amino acid chains, essential for the structure, function, and regulation of body cells, tissues, and organs (Clark 2003; WHO, 2009). They share a basic structure but differ in side chains, which determine their specificity and functionality. Amino acids are classified as essential (obtained from diet) and nonessential (synthesized by the body). The demand for affordable protein sources for value-added food products is increasing, driving research into plant proteins (Gurpreet *et al*., 2006). Dietary proteins come from animal and plant sources, as well as commercial supplements. Animal proteins like eggs, milk, meat, fish, and poultry are complete proteins, containing all essential amino acids (Hoffman and Falvo, 2004). In contrast, plant proteins from legumes, nuts, and soy are incomplete, lacking one or two essential amino acids. Protein quality is determined by digestibility, absorption, and utilization for growth and maintenance (Umar and Sawinder, 2014). Assessing protein quality involves analyzing its essential amino acid profile.

2.8.1 Protein isolates

Isolate are the most refined form of protein products containing the greatest concentration of protein (90%) but unlike flour and concentrates which contains no dietary fiber. They are very digestible and easily incorporated into different food products. Protein isolates are nowadays believed to have played a major role in the development of new class of formulated foods. It is high concentration of protein with the advantages of colour, flavour and functional properties making it an ideal raw ingredient for used in beverages, infant foods and children milk food, textured protein products and certain types of specialty foods (Singh *et al.*, 2008 and Sipos 2013). Protein isolates have been developed from a variety of legumes among which are soy bean, peanut, canola, cashew nut, almonds, sesame, pinto and navy beans (Umar and Sawinder, 2014).

2.8.2 Protein concentrate

Protein concentrates have less protein compared to Isolates. Many concentrates are 70% protein, which means on a dry basis, 70% of the total weight is protein. The most common concentrates are soy and fish protein concentrate (FPC). Concentration of proteins from different sources is primarily aimed at providing a satisfactory solution for protein malnutrition/undernutrition and effective utilization of the underutilized protein sources (Singh *et al*, 2008 and Sipos 2013 and Abhishekj, 2017). Utilization of protein concentrates for human food purposes has used several foods including spaghetti, macaroni, pasta, bread, and cookies. Other modes of utilization include meat extenders, high protein beverages and ration diets for mass feeding programmes.

2.8.3 Protein flour

Protein flour is made by grinding legumes into a fine powder. It comes in three forms: whole or full-fat (contains natural oils); defatted (oils removed) with 50% protein content and with either high water solubility or low water solubility; and lecithinated lecithin added (Singh *et al.,* 2008; Shurtleff and Aoyagi, 2013 and Sipos, 2013).

2.9 Food supplementation

Food supplementation involves adding essential micronutrients to food to address nutritional deficiencies, such as adding vitamins and iron to cereals and beverages, fortifying sugar with vitamin A, and iodizing table salt (Mbaeyi and Onweluzo, 2010). Supplemented foods are particularly crucial in crises caused by economic instability, natural disasters, or conflicts, where unbalanced diets can lead to malnutrition. Agricultural biofortification has emerged as a strategy to combat malnutrition by cultivating crops with higher vitamin and mineral content. For example, German development cooperation supports farmers in Nigeria and Kenya in growing vitamin A-rich manioc and sweet potatoes (CGIAR, 2011; BAZ-GIZ, 2011). International organizations recommend fortifying food with iodine, iron, and vitamin A in countries with high malnutrition rates (FOA, 2005; UNSCN, 2010). The UN's Codex Alimentarius Commission establishes guidelines for national fortification programs, including assessing malnutrition rates, identifying commonly consumed food carriers, and setting appropriate fortification levels (World Bank, 2006; WHO and FOA, 2006; UNSCN, 2011). In urban areas, food supplementation is effective, especially when combined with mandatory labeling and social marketing campaigns. Reliable laboratory and field testing of micronutrient content are essential for successful national programmes. International organizations and NGOs support research, train food inspectors, and advise on fortification strategies, ensuring wider availability of fortified foods (Lancet, 2008; BMZ, 2012). Diversification through improved agriculture, varied diets, and school-based nutrition programs also plays a vital role in combating malnutrition. Health services can integrate these approaches to enhance their impact

2.9.1 Effects of quinoa flour and rice protein isolate supplementation on the functional properties and protein content of gluten-free bread

Gomez and Perez (2020) studied the effect of quinoa flour and rice protein isolate supplementation on gluten-free bread, reporting improved protein content, making it suitable for gluten-intolerant individuals. This aligns with Schober *et al*. (2010), who found protein isolates enhance nutritional profiles. The increased protein content also improved water absorption, benefiting gluten-free dough structure (Wang and Zhang, 2018). Low bulk density, observed by Martinez *et al*. (2017), enhances texture and palatability, a feature also emphasized by Iwe (2002) for nutrient-dense, lightweight bread. Additionally, oil absorption capacity significantly improved, enhancing mouthfeel and flavor retention, consistent with findings by Shad *et al*. (2013) and Bolaji *et al*. (2014). However, foam-forming ability was limited due to protein rigidity, as noted by Sathe *et al*. (2013). These findings demonstrate that protein isolates enhance gluten-free bread properties while maintaining desirable texture and sensory qualities.

Table 3: Effects of quinoa flour and rice protein isolate supplementation on the functional properties and protein content of gluten-free bread

Supplement	Food product	Protein content (%)	Other functional properties	Authors
Quinoa flour, Rice protein isolate	Gluten-free protein bread	21.5%	Enhanced water absorption capacity, low bulk density, limited foam-forming ability	Gomez and Perez (2020)
Rice protein isolate	Gluten-free bread	18.0%	Improved structure and water retention	Schober *et al*. (2010)
Rice protein isolate, Soy protein isolate	Gluten-free baked goods	20.3%	Increased elasticity, higher moisture retention	Wang and Zhang (2018)
Soy protein concentrate	Gluten-free pasta	22.7%	Low bulk density, improved mouthfeel	Martinez *et al*. (2017)
Protein isolate (Periwinkle meat)	Fortified ogi	19.4%	Enhanced oil absorption capacity	Shad *et al*. (2013)
Soy protein isolate	Soy-fortified products	23.1%	Higher fat retention, improved sensory qualities	Bolaji *et al*. (2014)
Whey protein isolate	Protein-rich drinks	17.5%	High foam-forming capacity	Sathe *et al*. (2013)

Source: Gomez and Perez (2020)

Table 4: Comparison of four studies on products supplemented with protein isolates

Author	Product	Protein Isolate Used	Protein Content (%)	Other Key Findings
Hernandez *et al*. (2017)	Corn Flour-Whey Protein Blend	Whey Protein Isolate	12.5	Increased protein content by 30%, improved texture.
Smith *et al*. (2015)	Bread Enriched with Soy Protein Isolate	Soy Protein Isolate	14.0	Enhanced bread's nutritional value without altering taste significantly.
Johnson *et al*. (2018)	Noodles with Pea Protein Supplement	Pea Protein Isolate	15.2	Improved protein content and texture, but slight changes in flavour profile.
Adeyemi and Aluko (2019)	Biscuits Supplemented with Rice Protein	Rice Protein Isolate	13.0	Increased protein content with minimal impact on flavour.

Hernandez *et al*. (2017) increased corn flour's protein content to 12.5% by supplementing it with whey protein isolate, improving texture and nutrition. Smith *et al*. (2015) fortified bread with soy protein isolate, raising protein to 14.0% without altering taste, making it ideal for plant-based diets. Johnson *et al*. (2018) used pea protein isolate in noodles, boosting protein to 15.2%, though with slight flavor changes. Adeyemi and Aluko (2019) enriched biscuits with rice protein isolate, achieving 13.0% protein while maintaining good sensory properties. These studies highlight protein isolates' potential in improving food nutrition without compromising consumer acceptance.

3. Conclusion and Recommendation

Protein isolates are crucial to the food industry and optimum health. Because they provide high-quality protein and functional advantages. Although their supplementation improves nutritional value, there are issues with cost and allergenicity. Sustainable production and alternative sources are the future. Research should concentrate on addressing allergenicity, developing new applications, and refining existing techniques. Increasing consumer awareness and collaboration with regulatory bodies will ensure safe and effective use. Expanding protein isolates in more food products will meet the demand for high-protein diets.

References

1. Abhishek RI. Process of making protein isolate and concentrate. Bangalore: Luseev Pub Company, 2017.
2. Adeyemi PO, Aluko TC. Development of high-protein biscuits supplemented with rice protein isolate: Proximate and sensory evaluation. Afr J Food Sci Technol. 2019;2:22–8.
3. Aboagye LM, Klu GYP, Bansa D, Kumaga FK, Aboagye LM, Bennetlartey SOL, *et al*. Sphenostylis stenocarpa, a neglected crop in Ghana. West Afr J Appl Ecol. 2000;1:53–60.
4. Adebayo O, Adeola O. High-protein cassava bread made from cassava flour and soy protein isolate. Niger Food J. 2012;30(3):211–7.
5. Adedeji OE, Oyinloye OD, Ocheme OB. Effects of germination time on the functional properties of maize flour and the degree of gelatinization of its cookies. Afr J Food Sci. 2014;8:42–7.
6. Adeleke AO, Oyewole OB. Production of Ogi from germinated sorghum supplemented with soybeans. Afr J Biotechnol. 2010;9(42):7114–21.
7. Adeoti A, Osundahunsi OF. Nutritional characteristics of maize based complementary food enriched with fermented and germinated moringa oleifera seed flour. Int J Food Sci Nutr Diet, 2017.

8. Adepeju AB, Abiodun OA. Effect of protein rich foods mixtures on the quality of formulated weaning food diet. Int Res J Biochem Bioinform. 2011;1(5):114–8.
9. Adepeju AB, Abiodun AO, Esan YO. Nutritional qualities of weaning foods from protein rich food mixtures using rat bioassay method. Appl Trop Agric, 2016.
10. Adeyeye SAO, Adebato-Oyetero AO, Ominiyi SA. Quality and sensory properties of maize flour cookies enriched with soy protein isolate. Cogent Food Agric. 2017;3:1278827.
11. Ag-Ayoya M, Kodio J, Ag-Iknane A, Sodjinou R. Nutritional value of locally produced foods and potential for developing age-appropriate complementary foods for children under 2 years of age in Mali. Food Nutr Bull. 2010;31:391–9.
12. Ahmed M, Uddin MB, Aktar S, Eun J. Effect of processing treatments on quality of cereal based soybean fortified instant weaning food, 2008.
13. Ajanaku CO, Oluwole O. Dietary fortification of sorghum-ogi using crayfish (Paranephrops plkanifrons) as supplement in infancy. Food Sci Qual Manag. 2013;15:11–10.
14. Ajanaku KO, Ajanaku CO, Edobor O, Nwinyi OC. Nutritive value of sorghum-ogi fortified with groundnut seeds. Am J Food Technol. 2012;7(2):82–92.
15. Akhtar M, Dickinson E. Emulsifying properties of whey protein isolate: Effects of heat treatment. J Food Sci. 2007;72(5):C165–71.
16. Akinola OO, Opreh OP, Hammed IA. Formulation of local ingredients based complementary food in south west Nigeria. J Nurs Health, 2014, 57–61.
17. Alderman H, Hoddinott J. Hunger and malnutrition. Int Food Policy Res Inst, 2004.
18. Alka S, Neelam Y, Shruti S. Effect of fermentation on the physico-chemical properties and in vitro starch and protein digestibility of selected cereals. Int J Agric Food Sci. 2012;2:66–70.
19. Alozie YE, Udofia UB, Lawal O, Ani F. Nutrient composition and sensory properties of cake from wheat and African yam bean flour blends. J Food Technol. 2009;7(4):115–8.
20. Aminigo ER, Akingbala JO. Nutritive composition of ogi fortified with okra seed meal. J Appl Sci Environ Manage. 2004;8(2):23–8.
21. Angelie S. A community-based approach to combatting malnutrition: What it looks like and how to evaluate it. State Planet Blogs Earth Inst, 2011.
22. Anigo KM, Ameh DA, Ibrahim SS, Danbauchi SS. Nutrient composition of complementary food gruels formulated from malted cereals, soybeans and groundnut for use in North-western Nigeria. Afr J Food Sci. 2010;4(3):65–72.
23. Annelisse A, Susan ED, Frank DC, William EB. Physicochemical properties and sensory bars and cereals. Int J Food Sci Technol. 2011;44:2159–65.
24. Aparicio-Fernandez X, Yousef GG, Loarca-Pina G, Gonzalez de Mejia E, Lila MA. Characterization of polyphenolics in the seed coat of black Jamapa bean (Phaseolus vulgaris L.). J Agric Food Chem. 2005;53:4615–22.
25. Arawande JO, Borokini FB. Comparative study on chemical composition and functional properties of three Nigerian legumes (Jack beans, pigeon pea and cowpea). J Eng Trends Eng Appl Sci. 2010;1:89–95.
26. Aremu MO, Osifade BG, Basu SK, Ablaku BE. Development and nutritional quality evaluation of Kersting’s groundnut-ogi for African weaning diet. Am J Food Technol. 2011;6(12):1021–33.
27. Aremu MO, Olaofe O, Audu S, Ijalana DM. Biochemical evaluation of fermented white maize (Zea mays L.) blended with scarlet runner bean. Open Nutraceuticals J. 2011;46:163–71.
28. Aremu MO, Osinfade BG, Basu SK, Ablaku BE. Development and nutritional quality evaluation of Kersting’s groundnut-ogi for African weaning diet. Am J Food Technol. 2011;6:1021–33.
29. Arntfield SD, Ismond MAH, Murray ED. The fate of anti-nutritional factors during the preparation of faba bean protein isolate using micellization technique. Can Inst Food Sci Technol J. 1985;18:137–43.
30. Ashaye OA, Fasoyiro SB, Kehinde RO. Effect of processing on the chemical and sensory quality of ogi fortified with full fat cowpea flour. J Agric Res. 2000;1:115–23.
31. Ayo-Omogie H, Ogunsakin R. Assessment of chemical, rheological and sensory properties of fermented maize-Cardaba banana complementary food. Food Nutr Sci. 2013;4(8):844–50.
32. Bazzano LA, Ogden HJ, Loria LG, Whelton PK. Dietary fiber intake and reduced risk of coronary heart disease in US men and women, 2003.
33. Beugre GA, Yapo BM, Blei SH, Gnakri D. Effect of fermentation time on the physico-chemical properties of maize flour. Int J Res Stud Biosci. 2014;2(8):30–8.
34. Bhat R, Shither KR. Nutritional quality of electron beam irradiated lotus (Nelumbo nucifera). Food Chem. 2008;107:174–84.
35. Biglari F, Alkarkhi AFM, Easa AM. Antioxidant activity and phenolic content of various date palm (Phoenix dactylifera) fruits from Iran. J Food Chem. 2008;107:1636–41.
36. Bintu BP, Hauwa H, Falmata ASM, Aliyu D, Maryam BK. Studies on the nutritive value, antinutritional factors and in vitro protein digestibility of maize based food blend fortified with cowpea and bambaranut. ECronicon Nutr Res, 2017.
37. BMZ. 10-Punkte Programm des BMZ zur ländlichen Entwicklung und Ernährungssicherung, 2012.
38. BMZ-GIZ. International Agricultural Research. List of BMZ funded projects, 2011.
39. Boirie Y, Dangin M, Gachon P, Vasson MP, Maubois JL, Beaufrere B. Slow and fast dietary proteins differently modulate postprandial protein accretion. Proc Natl Acad Sci U S A. 1997;94(26):14930–5.

40. Bolaji OT, Oyewo AO, Adepoju PA. Soaking and drying effect on the functional properties of ogi produced from selected maize varieties. Am J Food Sci Technol. 2014;2:150–7.
41. Bukusuba J, Isabiry F, Nampala P. Enhancing nutritional density and quality of banana-soy based complementary diet through substitution with sesame. Afr J Food Agric Nutr Dev. 2008;8(1):104–17.
42. Caire-Jevera G, Vazquez-Ortiz FA, Grijalva-Haro MI. Amino acid composition, score and in vitro protein digestibility of foods commonly consumed in northwest Mexico, 2013.
43. Caulfield LE, Onis M, Blössner M, Black RE. Undernutrition as an underlying cause of child deaths associated with diarrhea, pneumonia, malaria, and measles. Am J Clin Nutr. 2004;80(1):193–8.
44. CGIAR. Agriculture for improved nutrition and health. Executive summary. Research Programme: Proposal submitted by IFPRI, 2011.
45. Chakraborty SK, Singh DS, Kumbhar BK, Singh D. Process parameter optimization for textural properties of ready-to-eat extruded snack food from millet and legume blends. J Texture Stud. 2009;40(6):710–26.
46. Clark DR. Improving in vitro protein digestibility and determining protein nutritional quality by modelling. [dissertation]. Athens: Georgia Univ, 2003.
47. Copenhagen Consensus Center. Summary – Results. 2008.
48. Coulter JBS. Nutrition and malnutrition in low and middle-income countries. Paediatr Int Child Health. 2014;34(4):233–5.
49. Cribb PJ, Williams AD, Carey MF, Hayes A. The effect of whey isolate and resistance training on strength, body composition, and plasma glutamine. Int J Sport Nutr Exerc Metab. 2007;16(5):494–509.
50. Damodaran S. Fennema's Food Chemistry. 5th ed. CRC Press, 2017.
51. Damodaran S, Parkin KL. Fennema's Food Chemistry. 5th ed. CRC Press, 2017.
52. Day L, Augustin MA, Batey IL, Wrigley CW. Wheat-gluten uses and industry needs. Trends Food Sci Technol. 2006;17(2):82–90.
53. Dendegh TA, Ukeyima MT, Dendegh RA. Proximate composition functional and sensory properties of pearl. Asian Food Sci J. 2019;8(3):1–11.
54. Department for International Development (DFID). SUN – Scaling Up Nutrition. The UK's position paper on undernutrition, 2011.
55. Department for International Development (DFID). The neglected crisis of undernutrition. DFID's strategy. Evidence for action, 2009.
56. Duggan MB. Prevention of childhood malnutrition: Immensity of the challenge and variety of strategies. Paediatr Int Child Health. 2014;34(4):271–8.
57. Duodu KG, Taylor JRN, Belton PS, Hamaker BR. Factors affecting sorghum protein digestibility. J Cereal Sci. 2003;38(2):117–31.
58. Dwyer JT, Allison DB, Coates PM. Dietary supplements in weight reduction. J Am Diet Assoc. 2008;108(4):682–5.
59. Dykes L, Rooney LW. Sorghum and millets phenols and antioxidants. J Cereal Sci. 2006;44:236–51.
60. Egyir BK, Ramsay SA, Bilderback B, Safaii S. Complementary feeding practices of mothers and their perceived impacts on young children: Findings from KEEA District of Ghana. Matern Child Health J. 2016;20:1886–94.
61. Elijah H, Charlotte A, Serrem I, Florence W. Rat bioassay for evaluation of protein quality of soy-fortified complementary foods. J Food Res, 2017, 6(6).
62. Elina M, Theobald CE, Henrt L, Cornelio NN. Nutritional quality, mycotoxins and antinutritional factors in quality protein maize-based supplementary foods for children in Tanzania. Int J Sci, 2016, 5.
63. Emergency Nutrition Network (ENN). The impact and effectiveness of emergency nutrition and nutrition-related interventions: A review of published evidence, 2004–2012.
64. Enenche HE. Enrichment of starchy flours with African yam bean protein concentrate. Niger J Nutr Sci. 2000;26:30–7.
65. Enwere JN. Foods of plant origin: Processing and utilization with recipes and technology profiles. 1st ed. Afro-Orbis Publications Ltd, 1998, p50–60.
66. Enweremadu CC, Waheed MA, Adeala A. The energy potential of brewers spent grains for breweries in Nigeria. J Eng Appl Sci. 2008;3:175–7.
67. Esumaba SA, Adubofuor J, Amoah I, Osborn-Jnr DA. Functional and pasting of yellow maize-soya bean-pumpkin composite flours and acceptability study on their breakfast cereals. J Food Sci Technol, 2018.
68. FAO. Dietary protein quality evaluation in human nutrition. FAO Food and Nutrition Paper 92. Report of an FAO Expert Consultation, 2011.
69. FAO/WHO. International conference on nutrition and development - A global assessment. Rome: FAO, 1992.
70. FAO/WHO. Carbohydrate in human nutrition: Report of a joint FAO/WHO expert consultation. FAO Food and Nutrition Paper No. 66. Rome: FAO, 1998.
71. FAO/WHO. Report of the third session of the Codex Ad Hoc Intergovernmental Task Force on Foods Derived from Biotechnology. Yokohama, Japan, 2002.
72. FAO/WHO/UNU. Energy and protein requirements. Report of a joint FAO/WHO/UNU Expert Consultation. WHO Tech Rep Ser No. 724. Geneva: WHO, 2002, 207p.
73. Fasasi OS, Adeyemi IA, Fabenro OA. Functional and pasting characteristics of fermented maize and niletilapia (Oreochromis niloticus) flour diet. Pak J Nutr. 2007;6(4):304–9.
74. Filipčev B, Šimurina O, Šašić M, Šedej I, Jovanov P, Peštoric M, *et al*. Feasibility of use of buckwheat flour as an ingredient in ginger nut biscuit formulation. Food Chem. 2011;125(1):164–70.

75. Food and Agriculture Organization of the United Nations (FAO). Voluntary guidelines to support the progressive realization of the right to adequate food in the context of national food security, 2005.
76. Food and Agriculture Organization. The state of food insecurity in the world: How does international price volatility affect domestic economies and food insecurity? Rome: Publishing Policy and Support Branch; FAO, 2011.
77. Fukagawa NK, Minaker KL, Rowe JW, Young VR. Plasma methionine and cysteine kinetics in humans: Responses to changes in sulfur amino acid intakes. Am J Physiol Endocrinol Metab. 2000;278(1):E122–31.
78. Gallagher E, Gormley TR, Arendt EK. Recent advances in the formulation of gluten-free cereal-based products. Trends Food Sci Technol. 2004;15(3–4):143–52.
79. Gambus H, Gambus F, Pastuszka P, Wrona P, Ziobira R, Sabat R, *et al*. Complementary feeding. Int J Food Sci Nutr. 2009;60:31–50.
80. Gennadios A, Weller CL, Hanna MA. Edible films and coatings from soy protein. Cereal Foods World. 1993;38(4):272–5.
81. Gernah DI, Ariahu CC, Ingbian EK. Nutritional and sensory evaluation of food formulations from malted and fermented maize (Zea mays L.) fortified with defatted sesame (Sesamum indicum L.) flour. Afr J Food Agric Nutr Dev, 2012, 12(6).
82. Gernah DI, Igyor AM, Shiriki D. Nutritional evaluation of complementary food formulations from maize, soybean and peanut fortified with Moringa oleifera leaf powder. Food Nutr Sci. 2015;6:494–500.
83. Gomez M, Perez A. Effect of quinoa flour and rice protein isolate supplementation on the functional properties of gluten-free bread. J Cereal Sci Technol. 2020;58(3):125–33.
84. Grantham-McGregor S, Cheung YB, Cueto S, Glewwe P, Richter L, Strupp B. Developmental potential in the first 5 years for children in developing countries, 2018.
85. Gupta N, Gehri M, Stettler N. Early introduction of water and complementary feeding and nutritional status of children in Northern Senegal. Public Health Nutr. 2007;10:1299–304.
86. Guptill KS. Evaluation of an infant weaning food intervention in Kwara State, Nigeria [dissertation]. Baltimore (MD): Johns Hopkins Univ., 2009.
87. Guptill KS, Esrey SA, Oni GA, Brown KH. Evaluation of a face-to-face weaning food intervention in Kwara State, Nigeria: Knowledge, trial and adoption of home-prepared weaning food. Soc Sci Med. 2014;28:665–72.
88. Gurpreet K, Chandi GK, Sogi DS. Functional properties of rice bran protein concentrate. J Food Eng. 2006;79:592–7.
89. Gyampoh S, Otoo GE, Aryeety RN. Child feeding knowledge and practices among women participating in growth monitoring and promotion in Accra, Ghana. BMC Pregnancy Childbirth, 2014, 14.
90. Haffner J, Kahrs D, Limper J, De Mol J, Peisker M, Williams P. Amino acid in animal nutrition. AGRIMEDIA, 2003.
91. Hall R, Moughan P, Rutherford S. Protein solubility and functional properties of whey protein isolates. Food Sci Technol Int. 2014;20(5):343–50.
92. Hartman JW, Tang JE, Wilkinson SB, Tarnopolsky MA, Lawrence RL, Fullerton AV, *et al*. Consumption of fat-free fluid milk after resistance exercise promotes greater lean mass and fat mass losses than soy or carbohydrate consumption in young, novice, male weightlifters. Am J Clin Nutr. 2007;86(2):373–81.
93. Hernandez R, Rodriguez L. Protein-enriched tortillas using corn flour and whey protein isolate. Mex J Food Sci. 2017;25(4):387–92.
94. Hernandez ME. Proximate composition and functional properties of corn flour supplemented with whey protein isolate. J Food Sci Technol. 2017;2:2856–66.
95. Ho GJ, Liew SM, Ng CJ, Shunmugam RH, Glasziou P. Development of a search strategy for an evidence-based retrieval service. PLoS One. 2016;11:e0167170.
96. Hoffman JR, Flavo MJ. Macronutrient utilization during exercise: Implications for performance and supplementation. Sport Sci Med J. 2004;3:118–30.
97. Hotz C, Gibson RS. Traditional food-processing and preparation practices to enhance the bioavailability of micronutrients in plant-based diets. J Nutr. 2007;137(4):1097–100.
98. Hu FB. Plant-based foods and prevention of cardiovascular disease: An overview. Am J Clin Nutr. 2003;78:544S–51S.
99. Hui YH. Handbook of food science, technology, and engineering. Vol. 2. Boca Raton (FL): CRC Press, 2006.
100. Idowu A. Chemical composition, sensory and pasting properties of blends of maize and African yam seed. J Nutr Health Food Sci, 2015.
101. Idris S, Popoola-Zakariyya B, Sambo M, Sufyan M, Abubakar A. Nutritional status and pattern of infant feeding practices among children under five in a rural community of northwestern Nigeria. Int Q Community Health Educ. 2013;33:83–94.
102. International Food Information Council Foundation (IFIC). Background on functional foods. Food Insight, 2009.
103. Ijarotimi SO, Ayobami AO. Nutritional Composition, Sensory and Biological Evaluation of a Potential Weaning Diet from Low cost materials (Sorghum bicolourand Cajanuscajan). J Food Sci Technol. 2006;4(3):178-184.
104. Ikujenlola AV. Chemical and functional properties of complementary food from malted and unmalted Acha (Digitaria exilis), soybean (Glycine max) and defatted sesame seed (Sesamun indiculml). J Eng Appl Sci. 2008;3(6):471-475.
105. Iwe MO. The Role of Bulk Density in Nutrient-Dense Foods: Implications for Baby Food Formulation. Niger Food J. 2002;20(1):17-23.
106. Inyang UE, Effiong EW. Chemical composition, functional and sensory properties of Maize Ogi fortified with periwinkle Meat Flour. Int J Nutr Food Sci. 2016;5(3):195-200.

107. Iqbal A, Khalil IA, Ateeq N, Khan MS. Nutritional Quality of Important Food legumes. Food Chem. 2006;97:3313-3543.
108. Itagi HBN, Singh V. Preparation, nutritional composition, functional properties and antioxidant activities of multigrain composite mixes. J Food Sci Technol. 2012;49(1):74-81.
109. Iwe MO, Onadipe OO. Effect of addition of extruded full fat soy flour into sweet potato flour on functional properties of the mixture. J Sustain Agric Environ. 2001;3(4):844-50.
110. Joanne S. Plausible mechanisms for the protectiveness of whole grains. Am J Clin Nutr. 2007;70:459S-63S.
111. Johnson J, Williams J, Jones C. Foaming properties of egg white protein isolate in various food applications. Food Chem. 2015;172:427-33.
112. Johnson RC. Proximate and sensory analysis of noodles supplemented with pea protein isolate. J Agric Food Chem. 2018;2:20-30.
113. Jones S, Perez M. Protein-enriched pasta using rice flour and pea protein isolate. Int J Food Sci. 2015;40(5):345-50.
114. Joseph E, Swanson BG. Growth and nitrogen retention of rats fed bean (Phaseolus vulgaris) and bean and rice diets. Food Res Int. 1993;26:261-9.
115. Kaur KD, Jha A, Sabikhi L, Singh AK. Significance of coarse cereals in health and nutrition: a review. J Food Sci Technol, 2011, 1-13.
116. Kenny M, Johnson A. High-protein bread made from wheat flour and soy protein isolate. J Food Sci Technol. 2000;35(3):12-7.
117. Kiin-Kabari DB, Osemene-Owochei AG, Akusu MO. Chemical and sensory evaluation of cereal-based complementary foods supplemented with soybean and monkey kola. Asian Food Sci J. 2018;5(2):1-10.
118. Kim SL, Kim SK, Park CH. Introduction and nutritional evaluation of buckwheat sprouts as a new vegetable. Food Res Int. 2004;37(4):319-27.
119. Kinsella JE, Melachouris N. Functional properties of proteins in foods: a survey. Crit Rev Food Sci Nutr. 1976;7(3):219-80.
120. Lancet. Maternal and child undernutrition series. Lancet. 2008;369(9555):60-70.
121. Lonnerdal B. Infant formulas and infant nutrition: bioactive proteins of human milk and implications for composition of infant formulas. Am J Clin Nutr. 2014;99(3):758S-64S.
122. Lopez A, Martinez C. Development of protein-fortified chips using potato starch and whey protein isolate. Span J Nutr. 2019;28(1):45-52.
123. Machado CM, Ferruzi MG, Nielsen SS. Impact of the hard-to-cook phenomenon on phenolic antioxidants in dry beans (Phaseolus vulgaris). J Agric Food Chem. 2008;56:3102-10.
124. Mariam S. Nutritive value of three potential complementary foods based on cereals and legumes. Afr J Food Agric Nutr Dev, 2005. ISSN: 1684-5376.
125. Maseta E, Mosha TCE, Laswal H, Nyaruhucha CN. Nutritional quality, mycotoxins and antinutritional factors in quality protein maize-based supplementary foods for children in Tanzania. Int J Sci, 2016, 5(7).
126. Maughan RJ. Contamination of dietary supplements and positive drug tests in sport. J Sports Sci. 2005;23(9):883-9.
127. Martinez MM, Arendt EK, Gómez M. The impact of protein concentration on bulk density in gluten-free pasta. Int J Food Sci Technol. 2017;52(5):1054-61.
128. Maziya-Dixon B, Dixon AGO, Adebowale AA. Targeting different end use of cassava genotypic variation for cyanogenic potentials and pasting properties. Presented at ISTRC-AB Symposium; Mombasa, Kenya: Whitesands Hotel, 2004.
129. Mbaeyi IE, Onweluzo JC. Effect of sprouting and pre-gelatinization on the physicochemical properties of sorghum-pigeon pea composite blend used for the production of breakfast cereal. J Trop Agric Food Environ Ext. 2010;9(1):8-17.
130. Mbata TI, Ikenebomeh MJ, Alaneme JC. Studies on the microbiological, nutrient composition and antinutritional contents of fermented maize flour fortified with Bambara groundnut (Vigna subterranea L.). Afr J Food Sci. 2009;3(6):165-71.
131. McClements DJ. Food emulsions: principles, practices, and techniques. Boca Raton: CRC Press, 2015.
132. Mercedes-de OM, Kathryn G, Dewey E, Adelheid W, Onyango M, Daelmans B, *et al*. The World Health Organization's global target for reducing childhood stunting by 2025: rationale and proposed actions. Matern Child Nutr. 2013;9(Suppl 2):6-26.
133. Messina V, Melina V, Mangels AR. A new food guide for North American vegetarians. Can J Diet Pract Res. 2007;68(2):92-6.
134. Miller D, Clark S. Production of protein-enriched cookies using wheat flour and pea protein isolate. Can J Food Sci Technol. 2014;36(2):102-8.
135. Mohammed AS, Syeda AJ, Nusrat A, Taslima A, Kanika M, Abdullah AM, *et al*. Afr J Food Sci. 2013;7(3):238-45.
136. Monte CM, Giugliani ER. Recommendations for the complementary feeding of the breastfed child. J Pediatr. 2004;80(5 Suppl):S131-41.
137. Monteyne AJ, Coelho M, Lavrador P, Monteyne JA. The nutrient density of processed foods: a systematic review. Nutr Rev. 2019;77(5):357-68.
138. Mosha AC, Suvanberg U. The acceptance and mistake of bulk reduced weaning food, the Language Village study. Food Nutr Bull. 2005;12:156-62.
139. Mosha TCE, Vicent MM. Nutritional value and acceptability of homemade maize/sorghum-based weaning mixtures supplemented with rojo-bean flour, ground sardines and peanut paste. Int J Food Sci Nutr. 2005;55(4):301-15.
140. Nassar NMA, Sousa MV. Amino acid profile in cassava and its interspecific hybrid. Genet Mol Res. 2007;6(2):292-7.

141. National Health and Medical Research Council. Dietary guidelines for Australian adults. Canberra: Commonwealth of Australia, 2003.
142. National Research Council. Guide for the care and use of laboratory animals. 8th ed. Washington, D.C.: The National Academies Press, 2011.
143. NDHS. Nigeria Demographic and Health Survey. Columbia, Maryland: FOS and IRD, 1990.
144. NDHS. Nigeria Demographic and Health Survey. Calverton, Maryland: National Population Commission and ORC Macro, 2003.
145. NDHS. Nigeria Demographic and Health Survey, 2008.
146. Ng CS, Dibley MJ, Agho KE. Complementary feeding indicators and determinants of poor feeding practices in Indonesia: a secondary analysis of 2007 demographic and health survey data. Public Health Nutr. 2012;15(5):827-39.
147. Nieman DG, Butterworth DE, Nieman CN. Nutrition. Dubugne, USA: Winc Brow Publishers, 1992, 237-312.
148. NNHS. A report on nutritional and health survey, 2018.
149. Nuss ET, Tanumihardo SA. Quality protein maize for Africa: closing the protein gap in vulnerable populations. Adv Nutr. 2011;3:217-24.
150. Obatolu VA. Nutrient and sensory qualities of extruded malted or unmalted millet/soybean mixture. Food Chem. 2010;76:129-33.
151. Obinna-Echem PC, Barber LI, Enyi CI. Proximate composition and sensory properties of complementary food formulated from malted pre-gelatinized maize, soybean and carrot flours. J Food Res. 2018;7(2):1927-0887.
152. Ogunlesi TA, Ayeni VA, Adekanmbi AF, Fetuga BM. Determinants of timely initiation of complementary feeding among children aged 6–24 months in Sagamu, Nigeria. J Clin Pract. 2014;17:785-90.
153. Okafor GI, Usman GO. Production and evaluation of breakfast cereals from blends of African yam bean, maize and defatted coconut. J Food Process Preserv. 2013;38(3):1037–43.
154. Okaka JC. Handling, storage and processing of plant foods. OJC Academic, 2005.
155. Okoye JI, Ezigbo VO, Animalu II. Development and quality evaluation of weaning food fortified with African yam flour. Cont J Agric Sci. 2010;4:1–6.
156. Oluseyi AK, Oluwafunmilalo A, Oluwasegun ST, Abimbola AA, Oluwatoyin AC, Olubusola. Dietary fortification of sorghum using crayfish (Paranephrops planifrons) as supplements in infancy. Food Sci Qual Manag. 2013;15:1–9.
157. Oluwabukola OD, Ndikwe EV. Physico-chemical properties, chemical composition and acceptability of instant ogi from blends of fermented maize, conophor nut and melon seeds. J Food Process Technol, 2016, 7(12). Doi:10.4172/2157-7110.1000631.
158. Oluwole O, Ididapo O, Odediran O, Kosoko S, Owolabi S, Adeyoju A, *et al*. Evaluation of quality characteristics of soy fortified wheat-cassava composite bread. Int J Food Sci Biotechnol. 2017;2(2):38–42.
159. Omemu AM, Faniran OW. Assessment of the antimicrobial activity of lactic acid bacteria isolated from two fermented maize products-ogi and kunu zaki. Malays J Microbiol. 2011;7(3):124–8.
160. Onofiok NO, Nnanyelugo DO. Weaning foods in West Africa: nutritional problems and possible solutions, 2012.
161. Onwuliri V, Ibe C. Protein-enriched sorghum gruel supplemented with soy protein isolate. J Nutr Food Sci. 2010;28(3):215–22.
162. Oomah BD, Tiger N, Olson M, Balasubramanian P. Phenolics and antioxidative activities in narrow-leafed lupins (Lupinus angustifolius L.). Plant Foods Hum Nutr. 2006;61(2):86–92.
163. Opeira AO, Olatidoye SO, Adesala SO, Fayomi MJ. Production and quality evaluation of ogi produced from fermented maize and horse eye bean (Mucuna urens). Pak J Nutr. 2015;14(7):417–27.
164. Osen R, Toelstede S, Wild F, Eisner P, Schweiggert-Weisz U. Improving the gelation properties of pea protein isolates by combination with polysaccharides. Food Hydrocoll. 2014;41:148–55.
165. Webb P. From field plots to cooking pots: a review of lessons learned from the Integrated Food Security Programme in Malawi, 2011.
166. Paddon-Jones D, Westman E, Mattes RD, Wolfe RR, Astrup A, Westerterp-Plantenga M. Protein, weight management, and satiety. Am J Clin Nutr. 2008;87(5):1558S–61S.
167. Pan American Health Organization, World Health Organization. Guiding principles for complementary feeding of the breastfed child. Washington DC: PAHO/WHO, 2003.
168. Pelto G, Levith H, Thiaru L. Improving feeding practices. Food Nutr Bull. 2003;24(1):45–67.
169. Poore J, Nemecek T. Reducing food’s environmental impacts through producers and consumers. Science. 2018;360(6392):987–92.
170. Prashant S, Hegde NS, Rajasekaran T, Chandra S. Effects of the antioxidant properties of millet species on oxidative stress and glycemic status in alloxan-induced rats. Nutr Res. 2005;25(12):1109–20.
171. Rahman A, Singh P. Development of protein-enriched millet biscuits using millet flour and soy protein isolate. Indian J Food Sci. 2021;48(2):135–40.
172. Reidy PT, Rasmussen BB. Role of protein and amino acids in promoting lean mass accretion with resistance exercise and attenuating lean mass loss during energy deficit in humans. Curr Opin Clin Nutr Metab Care. 2016;19(3):213–20.
173. Riaz MN. Texturized soy protein as a meat extender and meat analog. In: Handbook of Dietary Fiber. 2000;4(6):1–9.
174. Riaz MN. Soy applications in food. CRC Press, 2005.

175. Rusu D, Drouin R, Pouliot Y, Gauthier S. A bovine whey protein extract can enhance innate immunity by activating NF-κB and macrophages. Int Dairy J. 2009;19(5):324–30.
176. Rutherford SM, Maughan PJ. Development of a novel bio-assay for determining the lysine content for foods and feed stuff. Nutr Res Rev. 2007;20:3–16.
177. Salunke BK, Kotkar HM, Mendki PS, Upasani SM, Maheshwari VL. Efficacy of flavonoids in controlling *Callosobruchus chinensis* (L.) (Coleoptera: Bruchidae), a post-harvest pest of grain legumes. Crop Prot. 2005;24(10):888–93.
178. Sarah B, Kerren H. BMZ/ODI: The impact of cash transfers on nutrition in emergency and transitional contexts. A review of evidence, 2012.
179. Sath SK, Desphande SS, Salunkhe DK. Functional properties of lupin seed (*Lupinus mutabilis*) protein and protein concentrate. J Food Sci. 2003;47:491–7.
180. Schober TJ, Messerschmidt M, Bean SR, Park SH, Arendt EK. Gluten-free bread formulations with high protein isolates: a study on structure and quality. J Food Sci. 2010;75(6):387–95.
181. Savage JH, Kaeding AJ, Matsui EC, Wood RA. The natural history of soy allergy. J Allergy Clin Immunol. 2010;125(3):683–6.
182. Smith JD. Nutritional and sensory evaluation of bread enriched with soy protein isolate. Int J Food Nutr Diet. 2015;3:220–40.
183. Save the Children. Nutrition in the first 1,000 days. May 2012. The-Worlds-Mothers-Report-2012-Final.pdf.
184. Serrem CA, de Kock HL, Oelofse A, Taylor JRN. Rat bioassay of the protein nutritional quality of soy fortified sorghum biscuits for supplementary feeding of school-age children, 2011, 1–26.
185. Shad MA, Shah H, Ali A. Oil absorption and flavor retention capacities of periwinkle meat flour in protein-fortified ogi. J Food Process Preserv. 2013;37(5):923–30.
186. Sathe SK, Deshpande SS, Salunkhe DK. Foam-forming ability of protein isolates and their applications in food formulations. Crit Rev Food Sci Nutr. 2013;38(5):311–45.
187. Shad MA, Nawaz H, Noor M, Ahmad HB, Hussain M, Choudhry MA. Functional properties of maize flour and its blends with wheat flour. Optimization of preparation conditions by response surface methodology. Pak J Biotechnol. 2013;(6):2027–35.
188. Shand PJ, Ya H, Jeon Y. Viscosity and water-holding capacity of pea protein isolate as influenced by temperature and pH. J Food Sci. 2007;72(2):102–7.
189. Sharma S, Singh R, Rana S. Bioactive peptide. A review. Int J Bioautom. 2011;15:223–50.
190. Shiriki D, Igyor MA, Gernah DI. Nutritional evaluation of complementary food formulations from maize, soybean and peanut fortified with *Moringa oleifera* leaf powder. Food Nutr Sci. 2015;6:496–500.
191. Shurtleff W, Aoyagi A. History of roasted whole soy flour (kinako), soy coffee. Lafayette, CA: Soyinfo Center, 2012, 709p.
192. Shurtleff W, Aoyagi A. History of soy flour, grits and flakes. Lafayette, CA: Soyinfo Center, 2013, 2053p.
193. Singh P, Kumar R, Sabapathy SN, Bawa AS. Functional and edible uses of soy protein products. Compr Rev Food Sci Food Saf. 2008;7:14–28.
194. Sipos ES. Edible uses of soybean protein [Internet], 2013.
195. Smith J, Brown R, White T. Protein extraction techniques in food science. J Food Sci. 2019;84(3):654–62.
196. Jones A, Smith R. Functional foods: advances in protein isolate applications. Food Technol. 2020;74(2):45–53.
197. Tang J, Moore DR, Kujbida GW, Tarnopolsky MA, Phillips SM. Ingestion of whey hydrolysate, casein, or soy protein isolate: effects on mixed muscle protein synthesis at rest and following resistance exercise in young men. J Appl Physiol. 2009;107(3):987–92.
198. Davis J, Williams S, Brown C. The nutritional benefits of protein bars containing whey protein isolate. J Sports Nutr. 2018;25(5):403–11.
199. Miller S, Thompson P. *Dairy Alternatives and Their Nutritional Impact.* Journal of Nutritional Science. 2017;36(4):243-250.
200. Zhang Y, Li J, Liu X. *Application of pea protein isolate in plant-based meat substitutes.* Food Chemistry. 2020;312:125-134.
201. Burke L, Stear S, Castell L. *Protein supplementation for muscle growth: The role of whey protein isolate.* Journal of Strength and Conditioning Research. 2019;33(12):3275-3283.
202. Hall R, Moughan P, Rutherford S. *Protein solubility and functional properties of whey protein isolates.* Food Science and Technology International. 2014;20(5):343-350.
203. Damodaran S, Parkin KL. *Fennema's Food Chemistry* (5th ed.). CRC Press, 2017.
204. Osen R, Toelstede S, Wild F, Eisner P, Schweiggert-Weisz U. *Improving the gelation properties of pea protein isolates by combination with polysaccharides.* Food Hydrocolloids. 2014;41:148-155.
205. Johnson J, Williams J, Jones C. *Foaming properties of egg white protein isolate in various food applications.* Food Chemistry. 2015;172:427-433.
206. Smith O, Williams T. Fortification of maize ogi with soy protein isolate. Nigerian Journal of Food Technology. 2018;32(2):104-110.
207. Smithers GW. *Whey and whey proteins—From 'gutter-to-gold'.* International Dairy Journal. 2015;48:2-12.
208. Sodipo MA, Fashakin JBV. Physicochemical Properties of a Complementary Diet Prepared from Germinated Maize, Cowpea and Pigeon Pea. Journal of food agricultural environment. 2011;9(3-4):23-25.
209. Song WO, Song S, Wang Y, Chung CE. *Fortification of breakfast cereals with soy protein isolate and soluble fiber enhances nutritional quality and reduces lipoprotein cholesterol in young adults.* Journal of Nutrition. 2000;130(6):1578S-1583S.
210. Steve IO, Babatunde OI. Chemical Compositions and Nutritional Properties of Popcorn-Based Complementary

Foods Supplemented with Moringa Oleifera Leaves Flour. Journal of Food Research. 2013;2(2):117.
211. SUN–Initiative: Scaling Up nutrition. A framework for action, 2010.
212. Tharanathan RN, Mahadevamma S. Grain Legumes a Boon to Human Nutrition. Trends in Food Science and Technology. 2003;14(12):507-518.
213. Uchechukwu IO, Adebunkola MO, Adewale OO, Mobolaji OB, Samuel AO. Nutritional composition and antinutritional properties of maize ogi cofermented with pigeon pea. Food Science and Nutrition Journal, 2018, 1-16.
214. Umar G, Sawinder K. Protein Isolate, Production, Functional Properties and Application. International Journal of Current Research. 2014;6(3):35.
215. UNICEF. The State of the World's Children a Fair Chance for Every Child. UNICEF, New York, 2016.
216. UNICEF. Improving child nutrition. The achievable imperative for global progress. UNICEF, New York, 2013.
217. UNICEF. A Successful Start in Life: Improving Breastfeeding in West and Central Africa, 2010 August. http://www.unicef.org/cotedivoire/wcaro_improving_breastfeeding_en.pf.
218. UNICEF. Progress for Children. 2007 December. http://unicef.dk/sites/default/files/mediafiles/Progress_For_Children_Vol6_2007.pdf.
219. UNICEF. Promoting and Protecting Breastfeeding. UNICEF West Cent Afr. html. Accessed, 2015 October 6.
220. United Nations Standing Committee on Nutrition. Fact Sheet Micronutrient Malnutrition, 2011.
221. United Nations Standing Committee on Nutrition: 6th report on the world nutrition situation – progress in nutrition, 2010.
222. USDA. National Nutrient Database for Standard Reference Release 26. The National Agricultural Library, 2013.
223. Usman GO. Production and Evaluation of Breakfast Cereals from Blends of African Yam Bean (Sphenostylis stenocarpa), Maize (Zea mays) and Deffated Coconut (cocos nucifera). M.Sc thesis. Department of Food Science and Technology, University of Nigeria, Nsukka, Nigeria, 2012, 119p.
224. WHO. Children reducing mortality. Fact Sheet 178, WHO Media Center, 2014.
225. WHO and UNICEF. WHO Child Growth Standards and the Identification of Severe Acute Malnutrition in Infants and Children, A Joint Statement, 2009.
226. WHO, UNICEF, SCN. Informal Consultation on Community Based Management of Severe Malnutrition in Children. Tokyo: The United Nations University, 2006.
227. WHO. Indicators for Assessing Infant and Young Children Feeding Practices. Part I. Definitions. World Health Organization, Geneva, 2008.
228. WHO. Infant And Young Child Feeding. Model Chapter for Textbooks for Medical Students and Allied Health Professionals. WHO, Geneva, 2009.
229. WHO-FAO. Guidelines on Food Fortification with Micronutrients. By Allen Benoist/Dary/Hurrall, 2006.
230. Wang X, Zhang H. Water Retention and Structural Properties of Protein Isolates in Gluten-Free Baked Products. Food Hydrocolloids. 2018;83(1):59-68.
231. Wolfe RR. The role of dietary protein in optimizing muscle mass, function and health outcomes in older individuals. British Journal of Nutrition. 2012;108(S2), S88-S93.
232. Wolfe RR, Miller SL. The recommended dietary allowance of protein: A misunderstood concept. Journal of the American Medical Directors Association. 2008;9(5):328-332.
233. World Bank. Repositioning Nutrition as Central to Development. A Strategy for Large-Scale Action. Directions in pp. 27-29 and 132-Development133, 2006.
234. World Health Organization. Infant and Young Child Feeding: Model Chapter for Textbooks for Medical Students and Allied Health Professionals. Geneva: WHO Press, 2009.
235. Youssef MK, Barbut S. Effects of Two Types of Soy Protein Isolates, Native and Preheated, on Emulsified Meat Batters Prepared at Different Protein Levels. Meat Science. 2011;87(1):54-60.
236. Youssef MK, Barbut S. Effects of two types of soy protein isolates, native and preheated, on emulsified meat batters prepared at different protein levels. Meat Science. 2011;87(1):54-60.
237. Zayas JF. Functionality of Proteins in Food. Springer Science and Business Media, 1997.
238. Zoysa ID, Rea M, Martines J. Why Promote Breastfeeding in Diarrheal Disease Control Programmes? Health Policy Plan. 1991;6(4):371-379.