

## Chapter

# Food Applications of *Telfairia occidentalis* as a Functional Ingredient and Nanoencapsulation as a Promising Approach toward Enhancing Food Fortification

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## Abstract

The cucurbitaceous vegetable *Telfairia occidentalis* Hook. f. “Fluted pumpkin” is grown in West Africa, especially in Nigeria for its nutritious leaves and seeds. It has various industrial applications, such as food and medicine. *T. occidentalis* contains essential nutrients that could play a significant role in human nutrition. Based on its chemical composition and nutritional properties, it can be used to overcome malnutrition. *T. occidentalis* leaves and seeds are rich in phenolic compounds, minerals, vitamins, proteins, essential amino acids, and other essential phytochemicals which can play a regulatory and functional role. The leaves and seeds of this plant have also been used in different food applications. This chapter highlights the reported knowledge relevant to the use of *T. occidentalis* as a food fortificant and therapeutic agent based on its prominent biological activities and the presence of phytochemicals. However, conventional food fortification methods do not completely meet the functional requirements for bioactive compounds. They also have unsatisfactory flavor profiles, as well as poor stability and bioavailability. These disadvantages can be mitigated by encapsulating the bioactive components in nanoparticle-based delivery systems. Nanofood fortification has a wide range of advantages in the protection of phytochemicals through the use of an encapsulation technique, and some micronutrients that are rapidly degraded or not properly absorbed by the body can also be aided by food fortification on the nanoscale. Nanosuspensions, nanoemulsions, nanoliposomes, and cyclodextrin carriers are some of the various nanotechnology techniques that can be used for food fortification, which have been discussed in this chapter.

**Keywords:** fluted pumpkin, minerals, vitamins, *Telfairia occidentalis*, food fortification, nanoencapsulation, nanoliposomes, nanoemulsions, nanosuspensions

## 1. Introduction

Plants have existed on Earth since ancient times, as depicted in holy books about the creation of the universe. Plants are regarded as immediate companions of humans and are used to meet basic human needs, such as clothing, food, shelter, and medicine. As a result, plants will always be economically, industrially, environmentally friendly, historically, and spiritually important to humanity's survival and advancement. The presence of natural phytochemical compounds in plants is critical for human and animal health [1]. These phytochemical compounds are primarily synthesized in plants *via* primary and secondary metabolic pathways. These are flavonoids, alkaloids, steroids, and glycosides that have a variety of biological activities [2]. Food demand has increased in developing countries in recent decades in order to combat hunger and malnutrition. The Food and Agriculture Organization (FAO) also encourages 70–80% of the world's population to consume medicinal plants in order to reduce the economic cost (25%) of synthesized drugs [3, 4].

*Telfairia occidentalis* Hook F. (fluted pumpkin) belongs to the *Cucurbitaceae* family. It is a West African native that is primarily grown in Sierra Leone, Ghana, and Nigeria [5]. It is thought to have originated in Nigeria's southeastern region and been spread by the *Igbos*, who have been cultivating this crop since antiquity. Initially, *T. occidentalis* was wild throughout its current range; nevertheless, wild plants may have been harvested to local extinction and are now substituted with cultivated types [6, 7]. *T. occidentalis* is a nutritious vegetable widely cultivated for its palatable and nutritious leaves and seeds and contains essential nutrients that can play a major role in human nutrition [8, 9]. *T. occidentalis* find numerous applications in different industries, such as food and medicine [10–12]. The leaves of *T. occidentalis* are good sources of phenolic compounds, essential amino acids, vitamins, minerals, proteins, antioxidants, and other essential nutrients, which [13] can play a regulatory and functional role. The leaves and seeds of this plant have also been used in different food applications, such as bread, cookies, *chin-chin*, cassava pasta, smoothies, complementary food, and soups condiment (*Ogiri ugu*) [2]. The chemical and nutritional profile of *T. occidentalis* suggests its use to overcome malnutrition.

However, traditional fortification programs have primarily focused on disease eradication through the use of higher concentrations of active ingredients for deficiency disease eradication; however, the focus has shifted recently to lowering dietary intakes and achieving higher bioavailability of nutrients. As a result, there is a critical need for an appropriate delivery vehicle for active ingredients, as their fortification poses numerous issues, such as physical or chemical instability, low bioavailability, incompatibility with food matrix, and unpleasant taste. Nanoformulations are mostly synthesized using bottom-up or top-down processes. The challenge is frequently addressed by nanoformulations, which encapsulate the fortificant in an appropriate loading vehicle for fortification of the desired food matrix. The use of a nanoformulation-based delivery system with an appropriate design may overcome the limitations associated with food matrix fortification. Effective nanoformulation design and fabrication for active ingredient delivery in the food system provides advantages such as protection against biochemical and microbial degradation, retention of sensory attributes such as texture, flavor, mouthfeel, and overall acceptance; improved bioavailability and storage stability of fortified product.

Nevertheless, concerns about consumer health and safety are an ongoing challenge in dealing with the development of nanotechnology in food systems, and thus

mandatory testing of nanofoods is required before they are released to the market. This chapter highlights the reported knowledge relevant to the use of *T. occidentalis* in food fortification and as a therapeutic agent based on its prominent biological activities and the presence of phytochemicals. There are no elaborate reports on the significance of nanofood fortification in enhancing conventional methods of food fortification. This study aims to bridge the gap so that the need for planned and well-structured experimental designs to deliver possible future applications could be highlighted. To our knowledge, this is the first article that unites two essential aspects, food application of *T. occidentalis* and nanoencapsulation as an approach for enhancing food fortification.

## 2. Popular and common/vernacular names

*T. occidentalis* is commonly known in the following languages and countries: Fluted pumpkin, oyster nut, oil nut, fluted gourd and Telfairia nut (English); Oroko, pondo-koko and Gonugbe (Sierra Leone); Costillada (Spanish); “*iroko*” or “*apiroko*” (Yoruba-Nigeria), “*ubong*” (Efik-Nigeria), “*ugwu*” (Igbo-Nigeria), “*umeke*” (Edo-Nigeria), and “*umee*” (Urhobo-Nigeria); Krobonko (Ghana) [5, 14].

## 3. Description of the plant

*T. occidentalis* is a dioecious, perennial, tropical vine grown for its leaves and edible seeds [15]. It is a creeping herbaceous vegetable having lobed leaves and twisted tendrils which extends over the soil [16]. Fluted pumpkins can be grown on flat lands or on mounds. It is commonly grown beside fences or adjacent to a tree in domestic gardens, thus allowing the fruit to be suspended from a branch [17]. It can also be grown on a variety of trellis, including bamboo [5]. **Figure 1** shows a photograph of the plant (**Table 1**).



**Figure 1.**  
Photo of *Telfairia occidentalis* [18].

#### 4. Botanical classification of *Telfairia occidentalis*

|               |                                                                                                                             |
|---------------|-----------------------------------------------------------------------------------------------------------------------------|
| Kingdom       | Plantae–plantes, Planta, Vegetal, plants                                                                                    |
| Subkingdom    | Viridaeplantae–green plants                                                                                                 |
| Infrakingdom  | Streptophyta–land plants                                                                                                    |
| Division      | Tracheophyta–vascular plants, tracheophytes                                                                                 |
| Subdivision   | Spermatophytina–spermatophytes, seed plants, phanérogames                                                                   |
| Infradivision | Angiospermae–flowering plants, angiosperms, plantas com flor, angiosperma, plantes à fleurs, angiospermes, plantes à fruits |
| Class         | Magnoliopsida                                                                                                               |
| Superorder    | Rosanae                                                                                                                     |
| Order         | Cucurbitales                                                                                                                |
| Family        | Cucurbitaceae–gourds, squashes, citrouilles, gourdes                                                                        |
| Genus         | <i>Telfairia</i> Hook.                                                                                                      |
| Species       | <i>Telfairia occidentalis</i> Hook. f.–oysternut.                                                                           |

Adopted from Eseyin et al. [19] and Imosemi [18].

**Table 1.**

*Telfairia occidentalis* is classified as follows by the integrated taxonomic information system.

#### 5. Nutritional value of *T. occidentalis*

##### 5.1 Leaves

*T. occidentalis* is a storehouse of important nutrients. The leaves of *T. occidentalis* [20] have a wide range of medicinal, industrial, and nutritional properties [19, 21]. The leaves, according to Akanbi et al. [22], are high in fat (18%), minerals, and vitamins (20%). *T. occidentalis* leaves have a greater protein content (56%) than most other green leafy vegetables [23]. The leaves are also a rich source of P, Ca, Zn, Fe, K, Cu, and Mn [2, 19, 24, 25] which are essential in human and animal nutrition [8]. *T. occidentalis* had a total amino acid content of 455.3 mg/g, with a total essential amino acid content of 256.1 mg/g, or 56.3%, indicating that the plant proteins are high in essential amino acids. The essential amino acid contents are compared favorably with those of important legumes [26]. The essential amino acid profile of *T. occidentalis* had also been shown to be very rich and include alanine, aspartate, glycine, glutamine, histidine, lysine, methionine tryptophan, cysteine, leucine, arginine, serine, threonine, phenylalanine, valine, tyrosine, and isoleucine [7, 27, 28]. According to Iweala and Obidoa's [29] study, long-term feeding of *T. occidentalis*-supplemented diet caused a significant increase in the weight of animals, which may be due to its rich nutrient content. Vitamins E and C are present in aqueous extracts of the leaf at 5.07 mg/100 mL and 40 mg/100 mL, respectively [19]. Palmitoleic acid (16.62%) and elaidic acid (0.85%) are the predominant omega-9 fatty acid present in the leaf [30]. *T. occidentalis* leaves are rich in beta-carotene and contained a significantly high amount of vitamin C, total flavonoids and phenolics than *Psidium guajava* stem bark. *T. occidentalis* is rich in minerals that are blood boosters such as iron, folic acid, copper, zinc, potassium, cobalt, sodium, and

calcium; vitamins such as nicotinamide, thiamine, vitamins A, C, and K, and other core amino acids: glycine, aspartate, leucine, isoleucine, alanine, arginine, serine, methionine, tryptophan, phenylalanine, valine, tyrosine, cysteine, threonine, and histidine [28, 31, 32]. Phytochemicals such as alkaloids, tannins, terpenoids, glycosides, saponins, anthraquinones, reducing sugar, flavonoids, and phenolic compounds, are present in *T. occidentalis* leaves [2, 19].

## 5.2 Seeds

*T. occidentalis* seeds can be ground and added to soups, or they can be roasted, cooked, and eaten. The dried seeds contain 32.50% fat, 11.43% carbohydrates, 34.56% protein, 15.71% fibers, and 4.40% total ash [33]. Glucose, fructose, sucrose, and sixteen amino acids are also present, with glutamic acid (16.4 g/100 g) being the highest and lysine (2.6 g/100 g) being the lowest. In addition, phospholipid, glycolipid, and neutral lipid contents of 58, 26, and 15%, respectively, are contained in the seeds [34, 35]. The antioxidant activity of the seed has also been reported by Eseyin et al. [35] and Osukoya et al. [36]. The seed also contained significant amounts of vitamins A and C, which can be used to supplement other dietary sources. Unsaturated fatty acids make up 61% of fluted pumpkin seed oil [24]. The high content of unsaturated fatty acids in the seed confers a high nutritive value on these seeds. The younger seeds are nutritionally preferable as food because they contain fewer anti-nutrients and have a sweeter taste than the mature seeds [5]. *T. occidentalis* oil has high iodine values compared to palm oil, indicating that the oil has a high content of unsaturated fatty acids relative to palm oil. This suggests that it could be used as a cooking oil or in the production of margarine [37].

## 5.3 Anti-nutritive factors

Anti-nutritional factors are the biologically active secondary metabolites produced by plants as side products for their own defense and reduce the absorption of macronutrients (proteins) and micronutrients (vitamins and minerals) [38]. In *T. occidentalis*, phytic acid (22.11 mg/100 g) is present [2], which does not have any negative effect on the body if taken up to 10–60 mg/g but its prolonged intake can cause decreased bioavailability of some essential minerals in case of monogastric animals as phytate binds these nutrients in the digestive tract and causes their deficiency. It mainly decreases the levels of overall calcium, iron, and zinc balance [39]. The content of oxalate in *T. occidentalis* is (0.35 mg/100 g) [2] which have no any negative effect on the body as the established permissible levels of oxalate in the human body are 250 mg/100 g of food samples [40]. Soluble oxalates chelate calcium and magnesium that is released in the digestive system, making these micronutrients unavailable for absorption and utilization. Calcium is a mineral that the body requires for strong bone formation and maintenance. It is also involved in some hormonal and enzymatic functions, and in nerve impulse coordination. Soluble oxalates are excreted through the kidneys if absorbed, where they can also cause stone formation (calcium oxalate crystals). Oxalates that are insoluble have no metabolic function in the body and are excreted in feces [41]. Tannin content (4.98 mg/100 g) present in *T. occidentalis* has no bad effects on the health as it is acceptable up to 560 mg [42, 43]. However, its higher concentration of tannin in the diet minimize Fe absorption [44]. This component binds to Fe in the lumen, lowering Fe bioavailability, especially non-heme iron found in plant foods like leafy green

vegetables [45]. They are harmful at high levels and interfere with protein digestion and absorption, as well as vitamin and mineral utilization [46, 47].

#### 5.4 Processing of *T. occidentalis*

Different processing methods used also influence the contents of nutrients and anti-nutrients in *T. occidentalis*. Most plants lose their nutritive properties when processed. On comparing the nutritive content of boiled, roasted, and fermented *T. occidentalis* seed flour, it was found that all the nutrients, including protein, vitamins C, B3, and E,  $\beta$ -carotene, iron, and zinc, were significantly higher in the fermented samples [48]. The effects of roasting periods on the nutritional, anti-nutritional, and mineral compositions of *T. occidentalis* seeds were evaluated [49]. Interestingly, as a result of roasting *T. occidentalis* seeds for 60 minutes, there is a significant increase in all nutrients and mineral contents and decrease in the anti-nutrients [49]. In another study, Fluted pumpkin seeds were processed into raw, boiled, fermented, germinated, and roasted seeds, dried at 50°C, milled and sieved [50]. It was found that germination and fermentation enhance the protein quality of the fluted pumpkin seed flour. This can be a result of the biochemical activities during germination and microbial activity during fermentation, it also reduces deleterious elements and improve zinc bioavailability [50]. A study reported the anti-nutrient composition, including oxalate, phytic acid, cyanide, and tannin of *T. occidentalis* leaf, determined at three temperature regimes (normal (37°C), 60°C and boiling point (100°C) [51]. It was observed that the boiled sample at 100°C processing condition was most impactful for anti-nutrient reduction. In another research, Fagbemi et al. [52], reported that processing significantly reduced anti-nutritional factors of fluted pumpkin seed. Traditional processing methods using aqueous systems with boiling and cooking have been shown to reduce anti-nutrient levels in foods, particularly vegetables. Cooking effectively is thus recommended to reduce the concentrations of anti-nutrients in foods to levels that are permissible [53–55], while allowing consumers to benefit from the other phytochemicals that *T. occidentalis* contain. The cell wall of the vegetables is ruptured during cooking and blanching, thereby releasing anti-nutritional factors into the blanching medium [51, 56–59].

#### 5.5 *T. occidentalis* as food fortificant

Fortification is used interchangeably with the enrichment of staple food to add specific micronutrients to enhance the nutritional value of prepared foods. The fortificants must be easily obtainable, need to be well absorbed, must not interfere with the sensory attributes of fortified food, and must be cost-effective. It can be done in different forms such as mass, market-driven, and targeted fortification. Fortified food consumption must be adequate and sufficient for the targeted population. Whatever the goal of fortification, fortificants must be compatible with food characteristics and impart nutritional value to fortified foods while retaining their appearance and other organoleptic properties [60]. Consumers are most interested in a product's appearance, which is regarded as an important influencing factor in their decision to purchase it. Fortification of *T. occidentalis* can be significant to tackle nutrient deficiencies and malnutrition. The researchers indicate its applications in different kinds of foods as *chin-chin* [61], cassava pasta, [62], smoothies, [63], soups condiment (*Ogiri ugu*) [64, 65]. The foods are described here in detail.

## 5.6 Smoothies

*T. occidentalis* leaves powder has been incorporated at the rate of 1.5, 3.0, and 4.5% to the different ratios of smoothies [63]. The addition of the leaves significantly improves proteins, carbohydrates, and minerals, especially calcium and potassium in the smoothies. But while *T. occidentalis* leaves were able to significantly improve the crude protein content, the percentage inclusion should not be more than 1.5 [63].

## 5.7 Chin-chin

*Chin-chin* is a traditional Nigerian snack prepared by combining wheat flour, butter, milk and eggs into a stiff paste and then deep frying until golden brown [66]. *Chin-chin* can sometimes be baked instead of fried [67]. The long shelf life of *chin-chin* allows for large-scale production and distribution. Furthermore, good eating quality makes *chin-chin* appealing for fortification and other nutritional improvements. *Chin-chin* is a high-energy food, rich in carbohydrates and fat [68] but low in other nutrients such as protein, minerals, and vitamins [69]. Efforts have been made to improve the nutritional content of *chin-chin* by supplementing it with leafy greens. Different percentages *Telfairia occidentalis* leaves and Indian Spinach vegetable powder were incorporated into wheat flour to develop *chin-chin* and assess its proximate, mineral, and sensory acceptability [61]. The enriched *chin-chin* had an increase in protein, fiber, fat, potassium, magnesium, calcium, iron, and zinc concentrations, and was found to be acceptable by the consumers.

## 5.8 Bread

Wheat bread is widely accepted and consumed worldwide. Bread is a baked product made traditionally from wheat flour. It's high in carbohydrate but low in protein, vitamins, and minerals [68]. Attempts have been made to improve the nutritional content of bread by supplementing with flours like wheat and undefatted rice bran [68], wheat, maize, and orange-fleshed sweet potato [70], and moringa seed powder [71], vegetables leaf powder [72]. In addition, efforts have been made to promote the use of composite flours in which flour from locally grown high-protein legumes/oilseeds replace a portion of wheat flour for the production of high-protein composite breads [73], of which *Telfairia occidentalis* seed is one of them. The full-fat seeds of *Telfairia occidentalis* have about 27% protein and 54% fat while defatted seeds have about 71% crude protein and are valuable as a high-protein oilseed for human food in Nigeria [74]. Besides being boiled and eaten as a vegetable, the seeds of *Telfairia occidentalis* are sometimes processed into flour or fermented and used as a protein supplement, functional agent, or flavoring ingredient in a variety of local foods [75–77]. Because of its high-water absorption capacity, *Telfairia occidentalis* seed flour has been reported to have good potential for use in bakery products [78, 79]. An evaluation of the seed flour's functionality in bread making revealed that up to 10% of wheat flour could be replaced with fluted pumpkin seed flour to produce acceptable bread [80]. Several studies have shown that the nutritional quality of bread improved when wheat flour was supplemented with legume/oilseed flours [81–83]. According to Giami et al., [84] when wheat flour was replaced with 10% defatted fluted pumpkin seed flour, there was an increase of 80.8% in crude protein, 43.9% in calcium, 71.9% in potassium, and 63.0% in phosphorus contents of composite breads. Diets formulated with 5 or 10%

fluted pumpkin-substituted bread had significantly higher values for weight gain, protein efficiency ratio, and apparent and true digestibilities than diets formulated with 100% wheat flour bread, indicating an improvement of the nutritional quality of fluted pumpkin-substituted composite bread.

## **6. Cookies**

The development of value-added products from fluted pumpkin seed had been suggested as a way to increase the possibility of expanding the seed's utilization in the tropics [78, 79]. One potential food application for fluted pumpkin seed flour (FPF) is its use in composite flours for the production of bakery products, such as bread and cookies. Efforts have been made to promote the use of composite flours in which flour from locally grown high-protein oilseeds and legumes replace a portion of wheat flour for production of high-protein composite bakery products [73]. Replacing wheat flour (WHF) with defatted fluted pumpkin seed flour (FPF) at levels of 0–25% was studied for its effect on the chemical, physical, sensory, and nutritional properties of cookies [85]. The study showed that wheat flour supplemented with defatted FPF at the 5–15% levels produced acceptable cookies with spread ratio, hardness, color, and flavor similar to the control (100% WHF) cookies. When WHF was replaced with 15% FPF, there was an increase of 84.6% in crude protein, 62.9% in calcium, 131.0% in potassium, and 61.6% in phosphorus contents of composite cookies. Also, diets based on composite cookies containing 15% pumpkin flour were nutritionally comparable with a diet based on casein, indicating that the underutilized high protein fluted pumpkin seeds available in tropical countries could be processed into value-added products and used to combat malnutrition [85].

## **7. Complementary food**

Traditional weaning foods made from plant staples frequently fail to meet the nutritional needs of infants due to their stiff consistency and high volume, resulting in a low-cost filling meal that frequently lacks adequate nutrients [86]. They are therefore known to poorly support growth and development. Poor combination and formulation have partly contributed to the poor performance of traditional complementary foods. A number of researches [87, 88] in Nigeria have shown that a combination of cereals and legumes or tubers with vegetables and animal-sourced food rather than single diets, better-supported growth and development. A study to formulate complementary food from a blend of fluted pumpkin seeds and quality protein maize (QPM) has been done by Adedokun et al. [89]. The investigation revealed that combinations of fluted pumpkin seed flour and QPM increased the protein quality and chemical composition of the formulated diet.

## **8. Cassava pasta**

Lawal et al. [62] evaluated the techno-functional and sensorial properties of cassava pasta, as influenced by incorporating fluted pumpkin leaf powder and the cultivar variation effect. Cassava pasta fortified with leaf powder at 5 and 10% incorporation levels reduced particle sizes, whereas yellow cassava flour had a

larger particle size distribution than white cultivar. Pasta color was significantly influenced, as lightness values decreased as leaf powder concentration increased. Fluted pumpkin inclusion reduced the gelation capacity of the flour blends while increasing their water solubility, swelling power, and oil absorption capacities of the products. Interestingly, the addition of fluted pumpkin leaf powder reduced cooking time and gruel solid loss while increasing weight gain in the formulated pasta. With the addition of leaf powder, the hardness and pasting viscosities of the gel and pasta decreased by 12%, improving the textural properties of the cassava pasta. Pasting temperatures in the fluted pumpkin-fortified pasta were also lower than in the gluten-laden wheat pasta. Furthermore, yellow cassava products had significantly higher pasting viscosities than white cassava products, and cultivar variation affected the thermal properties of the food products significantly. Consumers' overall acceptance and likelihood of purchasing the novel pasta were modest (**Figure 2**).

Considering the views of several such fortifications, it is suggested that such addition can be done to other snacks as well. Addition of *T. occidentalis* to the snacks can add nutritive value to the snacks. However, further studies on *T. occidentalis* fortified snacks is required before bringing the commercialized product to the market.



1. Yellow cassava pasta



2. White cassava pasta



3. Yellow cassava-fluted pumpkin (5%) pasta



4. White cassava-fluted pumpkin (5%) pasta



5. Yellow cassava-fluted pumpkin (10%) pasta



6. White cassava-fluted pumpkin (10%) pasta

**Figure 2.**

Cassava pasta made with 0, 5, and 10 g 100 g<sup>-1</sup> fluted pumpkin (*Telfairia occidentalis*) leaf powder [62].

## 8.1 Other food applications of *T. occidentalis*

### 8.1.1 Ogiri

The fluted pumpkin seeds are used for the production of *ogiri*. It is a fermented product used as condiments to flavor and soups. The pumpkin seed is high in protein, therefore, the *ogiri* is a nutritious product and beneficial for people who have a deficiency of protein. The process of *ogiri* preparation is still traditional and also the packaging of the *ogiri* is in the leaves so it makes *Ogiri* more traditional [65]. *Ogiri* is an alkaline fermented food condiment made from fluted pumpkin seeds (*Telfairia occidentalis*). It is used for the preparation of soups by an ethnic group, Igbo in Southeastern Nigeria. *Ogiri* (**Figure 3**) is prepared by manually dehulling fluted pumpkin seeds and wrapping them in blanched plantain or banana leaves before boiling them for 6–8 hours. The seeds are then fermented for four to six days near

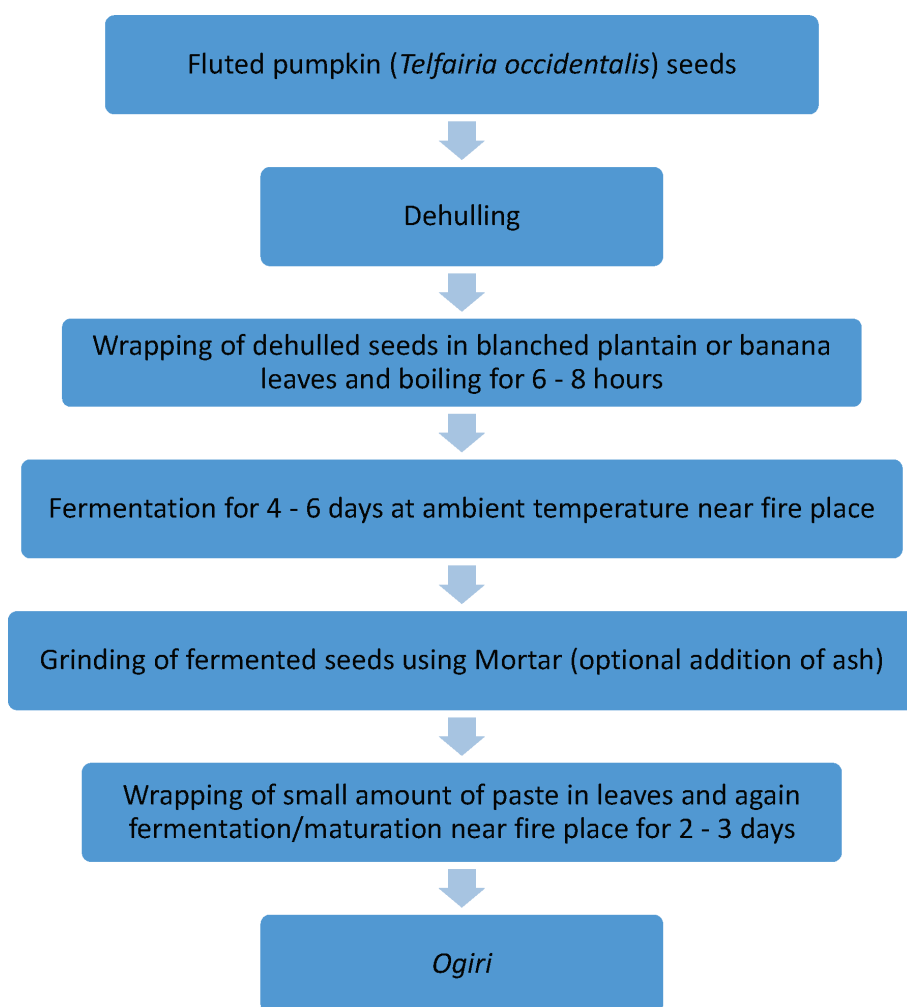


**Figure 3.** Fermented *T. occidentalis* seed (*Ogiri*) condiment wrapped with local leaves [64].

a fireplace. After fermentation, cotyledons are sticky with a characteristic aroma. It is then ground into a fine paste with a mortar and pestle, and small portions of the paste are then wrapped in banana leaves and kept near the fireplace for further fermentation or maturation for two to three days. The pH of the product at the end of fermentation is found to be around 7.9 [90]. *B. subtilis*, *B. pumilis*, and *B. licheniformes* are the microorganisms responsible for fermentation (**Figure 3**).

## 8.2 Nanotechnology approaches for enhancing food fortification

In recent years, large groups of the population have become increasingly deficient in micronutrients such as vitamins and minerals. Hence, essential micronutrients are incorporated into common foods by food fortification. Bioactive compounds are those that have an effect on the body and include carotenoids, essential oils, antioxidants, and molecules that are widely incorporated into food to increase its nutritional and health properties. These nutrients are normally present in plant-based foods in small amounts but have a wide range of health benefits to the human body. Conventional methods of food fortification do not completely satisfy the functional requirements for bioactive compounds. They also have drawbacks of unsatisfactory flavor profiles, and poor stability and bioavailability. These drawbacks can be overcome with the utilization of nanodelivery systems. The various nanotechnology techniques that can be used for food fortification include nanosuspensions, nanoemulsions, nanoliposomes, and cyclodextrin carriers. Nanofood fortification has a wide range of advantages in the protection of phytochemicals by using an encapsulation technique and some of the micronutrients which are degraded rapidly or not properly absorbed by the body can also be aided using food fortification in the nanoscale [91].

## 8.3 Nanoencapsulation

The term nanoencapsulation refers to the use of nanometer-scale encapsulation with films, layers, and coverings. The encapsulation layer is clearly nanometer in size, forming a protective layer on the food or flavor molecules/ingredients [92]. Nanoencapsulation technologies have the potential to meet food industry challenges regarding the effective delivery of health functional ingredients and the controlled release of flavor compounds. Nanoencapsulation packs substances in miniature by using techniques such as nanocomposite, nanoemulsification, and nanostructuration and provides a final product. The functional ingredient is transported to the desired site of action *via* nanoencapsulation. They safeguard the functional ingredient against chemical or biological degradation during processing, storage, and use. They must be able to regulate the release of the functional ingredient. Finally, the delivery system must be compatible with the final product's physical-chemical and qualitative properties. Nanocarrier systems are typically carbohydrate, protein, or lipid-based [93].

Nanoencapsulation is accomplished through the use of nano capsules. They have several advantages, including ease of handling, improved stability, oxidation resistance, retention of volatile ingredients, taste making, moisture-triggered controlled release, pH-triggered controlled release, consecutive delivery of multiple active ingredients, flavor character change, long-lasting organoleptic perception, and enhanced bioavailability and efficacy. They are defined as nano vesicular systems with a typical core-shell structure in which the drug is confined to a reservoir or cavity surrounded by a polymer membrane or coating. The active substance can be present in the cavity as a liquid, solid, or molecular dispersion. Nano capsules

are involved in the delivery of the desired component and entrapment of the odor and unwanted components in the food and thereby resulting in the preservation of the food [93]. In the biological system, nano capsules transport food supplements through the gastrointestinal tract, increasing the substance's bioavailability. The primary advantage of encapsulation is that it protects the hidden component, allowing it to be delivered precisely to the target even in adverse conditions. Nano capsules can be prepared in six different ways: (i) nano precipitation, (ii) emulsion diffusion, (iii) double emulsification, (iv) polymer coating, and (v) layer-by-layer.

#### **8.4 Nanoemulsions**

Nanoemulsions are dispersions of two immiscible phases (dispersed and continuous) with nanoscale particle diameters ( $< 200$  nm). Nanoemulsions are thermodynamically unstable but kinetically stable emulsions that differ in particle diameter from conventional emulsions [94]. Depending on whether the dispersed phase is oil or water, nanoemulsions can be either oil-in-water (o/w) or water-in-oil (w/o). By encapsulating lipophilic vitamins or omega-3 in the oil core, oil-in-water nanoemulsions have great potential for protecting, stabilizing, and delivering lipophilic bioactive compounds. Significant research has been conducted to develop nanoemulsion-based delivery systems for these compounds [95].

The formation of emulsions requires a water phase, an oil phase, an emulsifier, and either mechanical or physiochemical energy [96, 97]. An oil-in-water nanoemulsion has a three-component core-shell structure: a lipophilic core containing a lipophilic bioactive compound, a hydrophilic shell (aqueous phase), and an amphiphilic interface containing the emulsifier/surfactant [96]. Emulsifiers are surface-active molecules that adsorb on the oil-water interface of newly formed droplets and reduce interfacial tension, resulting in smaller droplet size emulsions. Depending on the processing conditions and emulsion composition, different types of food grade surfactants and emulsifiers can be used to form nanoemulsions [98, 99]. Because of the presence of hydrophilic groups and hydrophobic moieties in their structure, higher molecular weight biopolymers such as amphiphilic proteins (e.g., casein, lactoferrin, b-lactoglobulin, protein isolates, whey proteins) and polysaccharides (gum arabic and modified starch) can act as good emulsifiers [98, 100, 101]. Small molecule surfactants (e.g., tween 20, 40, 80, and Span 80), phospholipids (e.g., soy lecithin), quillaja saponins, sucrose esters are amphiphilic molecules that consist of a hydrophilic head and lipophilic tail groups [96, 99]. Nevertheless, among various types of emulsifiers, natural emulsifiers have great potential for use in food applications since there is an increasing demand for "clean-label" products in the global food market [101].

In general, nanoemulsions are produced either by high-energy methods (microfluidics, high-pressure homogenizers, or ultrasound equipment) or low-energy methods (spontaneous emulsification and phase inversion temperature) [102].

#### **8.5 Nanoliposomes**

Nanoliposomes are vectors that are used in both the pharmaceutical and food industries. These lipid nanostructures are incorporated into food products during the manufacturing process, primarily to improve texture, flavors, and food preservation. Nanoliposomes are an intriguing type of carrier for bioactive molecules due to their

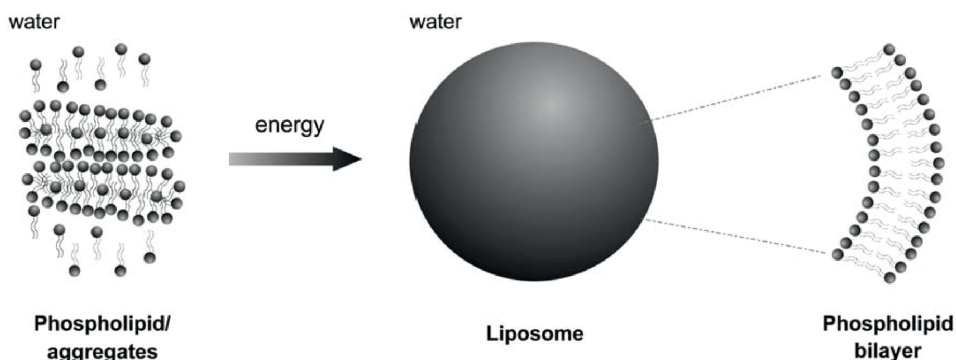


**Figure 4.**  
A simplified mechanism for the formation of liposomes and nanoliposomes [104].

natural lipid composition and ability to encapsulate both hydrophobic and hydrophilic compounds. Encapsulation of molecules known for their beneficial effects on specific organs or tissues in these lipid-based vectors can be envisioned in nutraceutical applications to create functional foods designed for disease prevention. To achieve this goal, however, certain parameters must be controlled during the preparation and storage of nanoliposomes to ensure optimal digestibility and bioavailability. Indeed, challenges remain in ensuring the stability of nanoliposomes during storage as well as after ingestion. There are numerous preparation methods available, but the oxidative nature of lipids and their phase transition temperature all have an impact on the [103] stability of nanoliposomes (**Figure 4**) [105].

## 9. *T. occidentalis* as nutraceutical

The term nutraceuticals is derived from the words “nutrition” and “pharmaceuticals,” and it refers to food-derived products that have health benefits. These have recently been investigated as suitable alternatives for the control and prevention of a wide range of diseases because they are considered safe and have potential nutritional value. Fruit and vegetables are good sources of functional foods because they contain a lot of phytochemicals, which have a lot of health benefits [19, 36, 106–117]. *T. occidentalis* and its various parts have been shown to have therapeutic and exploratory effects against a variety of diseases such as diabetes, cancer, malaria, and anemia [118, 119]. The presence of phytochemicals makes it a good medicinal agent.

### 9.1 Role of *T. occidentalis* in malnutrition

Malnutrition is a condition caused by eating a diet in which nutrients are either not enough or too much low which can cause health problems. It could be deficient in calories, carbohydrates, proteins, vitamins, or minerals and ultimately resulting in nutritional problems. Malnutrition casts long dimness, 800 million people are affected in which 20% of all people in the developing world [120]. It is noted from nutritional analysis that *T. occidentalis* leaves contain a wealth of essential, disease-preventing nutrients. Experimental finding has confirmed that *T. occidentalis* effectively maintain electrolyte balance, modulates pancytopenia and oxidative hepatorenal damage in

rats suggesting its protective potential against anemia and organ failure [121, 122]. In another study, the efficacy of ethanol leaf extract of *T. occidentalis* in phenyl hydrazine model of anemia in rats was investigated by Oladele et al., [113]. They found treatment with ethanol leaf extract of *T. occidentalis* modulates all the anomalies such as pancytopenia, anemia, and other related disorders which are characterized by altered hematological, biochemical, and molecular indices, compromised cellular and structural integrity, as well as physiological functions, suggesting its ameliorating effects against phenyl hydrazine-induced anemia and hematotoxicity, and may be useful in the treatment of chemically induced anemia or other related diseases. Fasuyi and Nonyerem [31] documented that the inclusion levels of about 15% *T. occidentalis* leaf meal in broiler starter diets was found to be the most nutritionally suitable protein supplement in their diets.

## 10. Conclusion and future prospects

The leaves and seeds of *T. occidentalis* are rich sources of phenolic compounds, essential amino acids, vitamins, proteins, and  $\beta$ -carotenes, which can play a regulatory and functional role. *T. occidentalis* leaves are considered as more nutritive than the other parts of this plant. *T. occidentalis* leaf powder is used as dietary supplement and also protects humans against iron deficiency, malnutrition, diabetes, cancer, and oxidative stress. Furthermore, fortification with its leaf powder improves the nutritional, technological, and functional properties of baked products.

As the demand for snacks in the market is huge, hence future prospects should focus more on the fortification of *T. occidentalis* into snacks to eradicate malnutrition, which has a twin advantage. The phytochemical contents of *T. occidentalis*-fortified products also need to be determined in future research. Traditional food fortification methods do not completely meet the functional requirements for bioactive compounds. They also have unsatisfactory flavor profiles, as well as poor stability and bioavailability. Yet another focal area of research is the effective design and fabrication of nanoparticle-based delivery systems for fortification of desired food matrix, which provides benefits such as protection against biochemical and microbial degradation, retention of sensory attributes such as texture, flavor, mouthfeel, and overall acceptance; improved bioavailability and storage stability of the fortified product. The plant as a native to Nigeria can become a great source of income for the nation if this potential for highly nutritional food is exploited by the industries and researchers by undertaking further research to corroborate earlier studies. This could be a “lead” to the discovery of novel nano-fortified food products. It will also improve the proper utilization of this popular and vital plant’s numerous benefits.

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