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TIGERNUT: A NUTRIENT-RICH UNDERUTILIZED CROP WITH MANY POTENTIALS

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ABSTRACT

There is a need to explore the nutritional and medicinal potentials of underutilized crops such as tigernut. Most conventional foods that are rich and balanced are scarce and expensive, and cannot be afforded by consumers in developing countries. Promoting tigernut consumption will play an imperative role in the health, nutrition, and economy of many developing countries. This review was intended to provide an overview on the nutritional and nutraceutical properties of various tigernut products. Also to provide information on the effects of various processing operations on the nutritional and functional properties of various tigernut products. Tigernut is rich in essential nutrients, numerous bioactive compounds with proven health benefits were found in all tigernut cultivars. Genetic variations, environmental and growing conditions make the yellow, brown, and black cultivars of tigernut to have different physicochemical, phytochemicals and functional properties. Tigernut and its products are recommended in the production of bakery goods and complementary foods. Tigernut extracts are potential candidates for the production of nutraceutical diets and drugs. Compounds with anti-inflammatory, antioxidant, anticancer, antidiabetic, antihypertensive, anti-obesity, antimicrobial and antiseptic properties were found in tigernut. The oil can be used in cooking and frying, the oil is rich in polyunsaturated fatty acids, phytosterols, and tocopherols. The fatty acids composition of the oil is affected by the extraction methods. In addition to industrial applications, wastes and by-products from tigernut processing can also be used as food and feed ingredients.

Keywords: Functional food, nutraceutical, tigernut flour tigernut milk, tigernut oil

INTRODUCTION

Tigernut (*Cyperus esculentus*) is a rhizome spherical crop that can be eaten raw, dry or processed (Bazine and Arslanoğlu, 2020). It is actually not a nut and it calls with other names such as nutgrass, Chupa, nutsedge, earth almond, etc. (Samuel, 2016). It is native to most tropical and temperate regions of the world (Rubert *et al*., 2017; Bazine and Arslanoğlu, 2020). It is majorly produced in Africa, Madagascar, Middle-East, Southern Europe and Indian subcontinent, the leading producing nations are Nigeria, Niger, Togo, Benin, United States, Iran, Iraq and Morocco. The plant can re-sprout severally, the leaves are very tough and fibrous, single plant can produce up to 2420 seeds, the tuber size ranges from 0.3 to 1.9 cm ("*Cyperus esculentus*", 2021). It grows in large quantities in many West-African countries and Spain (Rosell, 2020). Thermal stress can cause changes to the tuber membrane properties, this accounts for thermal adaptation of tigernut and makes it possible for the tuber to thrive under various environmental conditions (Rubert *et al*., 2018).

There are three cultivars of tigernut; yellow, brown and black cultivars (Figure 1). The cultivars possessed different physicochemical properties (Ayo *et al*., 2016; Nina *et al*., 2019; Ayaşan *et al*., 2020) and functional properties (Nina *et al*., 2019; Ismaila *et al*., 2020). The major factors that account for the chemical variation in tigernut are genetic makeup, production location (Ihenetu *et al*., 2021), environment and growing conditions (Duman, 2019).

Source: (Bado *et al*., 2015; Suleiman *et al*., 2018; Warra *et al*., 2017)
Figure 1: Tigernut yellow (A), brown (B) and black (C) cultivars

The tuber can be oval, ovoid or oblong (Asare *et al*., 2020). Moisture content is a key determinant factor on the rheological, functional (Gasparre and Rosell, 2019) and thermos-physical properties of tigernut. (Usman *et al*., 2019) The geometry, porosity, density and mechanical strength of the tuber are affected by freshness and moisture content (Emurigho *et al*., 2020). Physical properties of tigernut such as thickness, geometric mean diameter, length, width, bulk density, tuber density and surface area are also affected by its moisture content (İnce *et al*., 2017). Thermal conductivity, diffusivity, specific heat, bulk density and surface area increase with an increase in moisture content, while tuber porosity decrease with an increase in moisture content (Usman *et al*., 2019). The black variety possessed higher loose and bulk densities, swelling capacity and water absorption capacity (Ayo *et al*., 2016)

Raw tigernut produced sweet-nutty flavor while chewing (Maduka and Ire, 2018). The sweet taste resulted from the activities of various endogenous enzymes that act internally on the starch (Owuama and Owuama, 2020). Minimal processing such as soaking and mild roasting are employed to facilitate edibility (Umaru *et al*., 2018). It is preserved by drying and the tuber is available year-round in many places (Maduka and Ire, 2018). Brown tigernut is smaller in size, hence, dry faster and possesses low moisture content (Evbuomwan and Alabi, 2020).

Tigernut is an underutilized tuber rich in many essential nutrients including proteins, carbohydrates, vitamins, minerals (Mohdaly, 2019), phytochemicals, oil and fiber, (Ihenetu *et al*., 2021). The tuber was reported to have numerous nutritional and health benefits (Bazine and Arslanoğlu, 2020). The lipid and dietary fiber of tigernut resemble that of nut and starch content resembles that of tuber (Roselló-Soto *et al*., 2019). Tigernut oil is rich in phytosterols, tocopherols and essential unsaturated fatty acids (Roselló-Soto *et al*., 2018; Duman, 2019; Mohdaly, 2019). Muhammad *et al*. (2019) reported that total color value, total flavonoid, pH, and Ferric Reducing Antioxidant power (FRAP) of tigernut tuber are affected by blanching and plasma-activated water treatment.

Consumers continue to understand the potentials of tigernut in solving nutritional and health problems, awareness through social media and among allies remains relevant in promoting tigernut consumption (Akerele *et al*., 2020). In developed countries, plant-based foods are receiving more attention due to vegan consideration and allergenicity associated with food like milk, while in developing countries cheaper sources of nutrients are required from within to meet the nutritional requirements (Roselló-Soto *et al*., 2019), cut import and improve the socioeconomic status of the populace (Ahemen *et al*., 2018). Tigernut can be used in the production of baked products and other confectioneries (Sethi *et al*., 2016; Bolarinwa *et al*., 2021). Sabah *et al*. (2019) endorsed the utilization of tigernut milk as imitation milk.

Nutrition and Health Benefits of Tigernut

The tuber is grown for its nutritional and health benefits (Achoribo and Ong, 2017; Asare *et al*., 2020). It contains significant amounts of fiber, unsaturated fat and moderate amounts of protein (Rosell, 2020). The tuber contains 45.73 % carbohydrate, 30.01 % oil, 5.08 % protein, 2.23 % ash and 14.80 % crude fiber (Sabah *et al*., 2019). Ismaila *et al*. (2020) reported 7.90 and 10.25 % protein contents in yellow and black cultivar respectively. Tigernut contains 77.49 - 80.01 % essential fatty acids and 31.32 - 34.03 mg/100 g essential amino acids (Ijarotimi *et al*., 2018). The tuber is rich in disaccharide; D-saccharose, which yielded D-glucose, D-galactose, D-xylose and D-arabinose upon hydrolysis (Marchyshyn *et al*., 2021). Total sugar content between 10.09 - 12.64 % was reported in the yellow variety (Obinna-echem *et al*., 2019). The tuber can contains up to 13.49 % fructans (Marchyshyn *et al*., 2021). The brown variety is richer in fat and energy (Ayo *et al*., 2016) while the black variety is richer in minerals (Nina *et al*., 2019), protein, carbohydrates (Ayo *et al*., 2016) and fiber (Evbuomwan and Alabi, 2020). It is also rich in P and Ca (Roselló-Soto *et al*., 2019). Ismaila *et al*. (2020) reported Ca, Na, P, K, Fe, Zn and Cu in both yellow and black cultivars.

The tuber contains active ingredients such as sterols, alkaloids, tannins, saponins, resins and vitamins E and C (Marchyshyn *et al*., 2021). The phytochemicals in tigernut are exceptional and can be used in the production of drugs and therapeutic diets (Ihenetu *et al*., 2021). Tigernut contains 62 % flavonoids compounds, 23 % phenolic acids and their derivatives and 15 % phenylethanoid glycosides (Mayer, 2019). The black variety contains more tannin, phytate, oxalate and saponin and the brown variety contains more flavonoids, polyphenols and alkaloids (Ayo *et al*., 2016). Processing generally reduces the phytochemicals content of tigernut (Uchechi, *et al*., 2020a). The concentration of saponin, tannin, phytate, oxalate, hydrogen cyanide and hemagglutinin reduces after fermentation (Ji and Gi, 2018). Tannin, oxalate and saponin can be reduced by soaking and roasting (Umaru *et al*., 2018).

The presence of numerous phytochemicals with antioxidant potentials account for the health benefits of tigernut (Roselló-Soto *et al*., 2019; Willis *et al*., 2019). Tigernut drinks can be used as functional food based on their chemical composition (Oluwadunsin *et al*., 2021). Olagunju and Oyewumi (2019) recommended the use of a beverage containing tigernut in the prevention of cardiovascular diseases. Gugsa and Yaya (2018) reported several compounds with antioxidant, anti-inflammatory, anticancer, antimicrobial and antiseptic properties in smoke from burned tigernut. Consumption of tigernut improves antioxidant mechanisms and can also lower the risk of obesity and diabetes due to its α-amylase and lipase inhibition capacity (Willis *et al*., 2019). The phytochemicals in tigernut milk were reported to prevent drug-induced liver damage in rats by either inducing glutathione synthesis or by functioning as antioxidants (Onuoha *et al*., 2017). The quercetin and beta-sitosterol present in tigernut are known for their anti-cancer properties (Achoribo and Ong, 2019). The antioxidant activities of 24.5 - 54.9 % and 10.8 - 12.1% were reported for DPPH radical scavenging and iron chelation respectively (Ijarotimi *et al*., 2018). Higher DPPH radical scavenging was reported in germinated tuber (Adebayo and Arinola, 2017). Tigernut aqueous extracts showed an anti-proliferative effect on cancer cells 48 h post-treatment (Achoribo and Ong, 2019). Consumption of tigernut and its products prevent colon cancer, thrombosis, heart attack (Sethi *et al*., 2016) and can cure diarrhea and inflammation (Bazine and Arslanoğlu, 2020). Arogundade *et al*. (2018) associated an increase in memory function in rats fed with tigernut extract with antioxidant neurotherapeutic properties of tigernut. More researches are needed to fully understand the anti-cancer mechanisms of tigernut (Achoribo and Ong, 2017).

Tigernut was reported to have anti-diabetic properties. The higher carbohydrate and fiber contents are essential to metabolic processes (Bolarinwa *et al*., 2021). Ihenetu *et al*. (2021) recommended the use of tigernut in the food of hypertensive and edema patients due to the high potassium to low sodium ratio in both yellow and brown species. Tigernut is rich in many endogenous hydrolytic enzymes including proteolytic and lipolytic enzymes (Owuama and Owuama, 2020). Tigernut contains significant amounts of α-, β- and γ-amylases, hydrolysis was observed in soluble starch treated with tigernut extracts (Owuama and Owuama, 2020). A glycaemic index between 83.3% and 95.9% was reported in tigernut (Ijarotimi *et al*., 2018). Rubert *et al*. (2018) reported variations in the metabolomics products of tigernut collected from different locations with higher phospholipids content found in African species. Tigernut milk and other plant milk are potential alternatives, with many essential nutrients, to the individuals with lactose metabolism complications (Olagunju and Oyewumi, 2019). Fortifying cereals with tigernut flour reduces the risk of diabetics, digestion disorders and lactose intolerance in patients (Adebayo-Oyetoro *et al*., 2017). Ijarotimi *et al*. (2019) recommended the use of the tigernut-soy cake blend in the management of diabetes and coeliac diseases.

Tigernut milk is cheaper than animal milk, can be used as a milk alternative by lower-class individuals particularly in areas where the crop can grow (Roselló-Soto *et al*., 2019) or in developing countries where conventional milk is either expensive or the supply is inadequate (Ogo *et al*., 2019; Olagunju and Oyewumi, 2019). In developed countries, tigernut is used as a milk alternative and in the production of gluten-free diets (Roselló-Soto *et al*., 2019).

Tigernut oil is low in sterol and rich in polyunsaturated fatty acids (Aremu *et al.*, 2016). The black cultivar contains 77.71 % oleic, 16.17 % palmitic and 11.87 % linoleic while the brown cultivar contains 68.89 % oleic, palmitic 13.33 % and 4.46 % stearic (Nina *et al*. 2020b). The oil also contains important polyphenols including gallic, ferulic, *p*-coumaric, protocatechuic, syringic, sinapic, vanillic acids and quercetin (Özcan *et al.,* 2021).

Tigernut Products

Over the years, tigernut was consumed raw, little attention was given to its processing and content extraction (Maduka and Ire, 2018). The three most important products obtained from tigernut processing which can further be processed into wide varieties of foods are tigernut milk, tigernut oil and tigernut flour (Maduka and Ire, 2018).

Tigernut milk

Tigernut milk (*Kunun-aya*) is a traditional non-alcoholic beverage commonly consumed in West-African countries, it is an aqueous extract of tigernut, coconut, date and spices blend (Ibrahim *et al*., 2016a; Kayode *et al*., 2017). The milk is also used as an ingredient in the production of *Kunu*, a well-known traditional beverage in West Africa (Ezekiel *et al*., 2019). Its low acid vegetable milk rich in protein and starch (Elbrhami, 2016), also contains less energy when compared with dairy milk (Amponsah *et al*., 2017). Tigernut milk is a good substitute for vegetarians and persons with lactose intolerance (Amponsah *et al*., 2017). Beverages with acceptable sensory properties were developed by combining tigernut with other crops, these include tigernut and coconut (Echem and Torporo, 2018), tigernut and pineapple (Elizabeth and Tijesuni, 2020), tigernut and sweet potato (Idris *et al*., 2019), tigernut and cocoa (Oluwadunsin *et al*., 2021) and tigernut and baobab (Badejo *et al*., 2020).

A probiotic beverage produced from tigernut possessed sensory qualities similar to that of dairy probiotic beverage (Amponsah *et al*., 2017). The findings of Wongnaa *et al*. (2019) showed that yogurt consumers in Kumasi, Ghana are positive about the nutritional and sensory qualities of tigernut yogurt and are willing to pay more for it. Optimum conditions for the production of tigernut yogurt are incubation for 3.12 h at 35 °C and a starter culture concentration of 2.74 % (Odejobi *et al*., 2018).

In addition, tigernut milk was reported to improve the nutritional and sensory qualities of many foods. An increase in fat, calcium and potassium was reported in soy cheese containing 5 % tigernut (Balogun *et al*., 2019). Substitution of 40 % cow milk with tigernut milk improved the carbohydrate, protein, fat and mineral contents of *Burkina* – a Ghanaian fermented milk beverage (Nyarko-Mensah, 2018). Bosede and Oluwatobi (2019) also reported an increase in fat and carbohydrate contents in soy milk with an increase in tigernut milk. Kaushik (2017) recommended the utilization of 40 % tigernut milk in the production of ice cream. Ani *et al*. (2019) recommended the use of tigernut in the production of soft candy. Balogun *et al*. (2019) reported that the addition of 5 % tigernut reduces phytate and trypsin contents of soy cheese

Thermal processing reduces protein, vitamin C and phenolic contents of tigernut milk (Zhu *et al*., 2019). Thermal treatment also affects color of tigernut milk (Zhu *et al*., 2019). Obinna-echem *et al*. (2019) reported a decrease in crude fiber, protein and energy in pasteurized tigernut milk. In contrast, Obinna-echem *et al*. (2019) reported that pasteurization improves nutritional values by increasing carbohydrate ash, moisture, Fe, Cu and Mg. Bosede and Oluwatobi (2019) also reported an increase in the proximate value of tigernut-soy milk blends after pasteurization. Sprouting and roasting increase the lipid content and calorific value of tigernut milk (Ntukidem, 2019). Rubert *et al*. (2017) reported the effects of ultra-high temperature (UHT) treatment on the metabolites composition of tigernut milk, UHT significantly affects the micronutrients of the milk, they reported the presence of Citric Acid Esters of Mono- and Diglycerides (CITREM) in the UHT samples. Elbrhami (2016) also reported that subjecting tigernut milk to high hydrostatic pressure (HHP) treatment reduces protein, vitamin C and antioxidant contents of the milk. UV-C and HHP treatments have no effects on the antioxidant and protein content of tigernut milk (Zhu *et al*., 2019). UV treatment does not affect the tigernut shelf life stored under refrigeration (Elbrhami, 2016). Reduction in total soluble solid and calorific value was observed in tigernut milk treated with 5 % ginger and 3 % garlic (Maduka, 2017).

The tuber is rich in resistant starch (Yeboah, 2002) that can easily be gelatinized during pasteurization and other thermal processing, a phenomenon that increases milk viscosity and limits milk yield (Djomdi *et al*., 2020). Pre-gelatinization of the starch improves its viscosity, solubility and paste clarity (Olatidoye *et al*., 2019). Starch hydrolysis before extraction reduces gelatinization during thermal processing (Djomdi *et al*., 2020). The starch content can also be reduced to simple sugars after extraction by treating the milk with α-amylase and glucoamylase at 50 °C for 4 hours (Aude, 2015). Addition of okra pectin improves the viscosity of tigernut milk (Abe-Inge *et al*., 2020). Oil extraction methods affect starch crystallinity, branch-chain length and starch functional properties such as paste clarity, solubility, texture, swelling power and freeze-thaw characteristics (Liu *et al*., 2019)

An increase in protein, fat, carbohydrate and other mineral composition was observed in fermented symbiotic beverage developed by Yeboah (2002) using tigernut and millet. An increase in nutritional contents, glycaemic index and antioxidant activities were also reported by Ijarotimi *et al*. (2018) during fermentation. Uchechi *et al*. (2020b) reported improvement in the glycaemic index of biscuits by replacing 20 % of wheat flour with fermented tigernut flour. Uchechi *et al*. (2020a) also reported an increase in protein, amino acid and minerals during fermentation.

Effects of processing on sensory properties of tigernut milk

Processing improves the sensory properties of tigernut (Willis *et al*., 2019). Treatment with spices affects the acceptability of tigernut milk (Kayode *et al*., 2017). Higher sensory scores were reported in tigernut milk preserved with ginger extract (Ajayi and Bankole, 2020). Sensory properties were also reported to be improved during fermentation (Wakil and Ola, 2018). Sprouting and starch hydrolysis using exogenous amylases increase milk extraction rate and sweetness (Djomdi *et al*., 2020). Microwave treatment at 900 W for 2 minute improves milk acceptability by increasing sweetness and development of attractive flavor compounds (Abbey, 2018). Ultra-high pressure homogenization at 300 MPa improves the whiteness and luminosity of tigernut milk (Codina-Torrella *et al*., 2018). Roasting the tuber before milk extraction significantly improves the sensory attributes of the milk (Ntukidem, 2019). Enzymic hydrolysis of starch affects consumers' preferences and leads to the browning of milk (Aude, 2015).

Microorganisms in tigernut milk

Like other raw materials, contamination of tigernut can have detrimental effects on the quality and safety of the end products, contamination can occur during harvesting, storage, processing, packaging or retailing (Maduka and Ire, 2019). Storage of tigernut milk is associated with many challenges probably caused by microbial activities and fermentation (Akakpo *et al*., 2019). Maduka (2017) reported ethanol production during prolonged storage of tigernut milk, an indication of alcoholic fermentation.

Commercial samples of locally processed tigernut milk are unfit for human consumption due to poor hygiene that leads to microbial contamination (Samuel *et al*., 2020). A significant increase in the total plate and fungal counts was reported by (Kayode *et al*., 2017) during refrigeration storage of tigernut milk. Processing under contaminated conditions (Victor-Aduloju *et al*., 2020) and poor personal hygiene (Ire *et al.*, 2020; Pondei and Adenike, 2021) account for contamination of the locally processed commercial tigernut milk. Using simple grinding and extraction machines similar to that developed by Raji *et al.* (2019) will minimize contamination resulted from poor personal hygiene and inadequate processing equipment.

Bacterial isolates reported in locally prepared commercial tigernut milk are *Escherichia coli*, *Staphylococcus aureus, Salmonella* sp., *Klebsiella* sp, *Proteus* sp. (Opeyemi and Obuneme, 2020), *Pseudomonas* sp., *Bacillus* sp., *Micrococcus* sp., *Enterobacter* sp., *Corynebacterium* sp. (Ire *et al*., 2020), *Shigella* (Badau *et al.*, 2018), *Acinetobacter* sp, *Enterobacter* sp, *Neisseria* sp, *Vibrio* sp and *Aeromonas* sp (Ibrahim *et al*., 2016a). Fungal reported include *Saccharomyces cerevisiae*, *Rhizopus oryzae* (Ibrahim *et al*., 2016a) *Candida albicans*, (Badau *et al.*, 2018), *Aspergillus* sp., *Fusarium* sp., *Penicillium* sp. (Ire *et al*., 2020). *Shigella* sp. *Salmonella* sp. *E. coli*. *Streptococcus* sp., *Staphylococcus* sp. and *Vibrio* sp. were isolated from tigernut milk processing utensils (Pondei and Adenike, 2021). Bolarinwa *et al*. (2021) reported *Aspergillus niger, A. fumigatus, A. flavus* and *Penicillin citrinum* as the predominate fungi species in tigernut flour during storage.

Pasteurization of tigernut milk significantly lowers microbial counts (Orhevba *et al*., 2019). Ajayi and Bankole (2020) reported that addition of ginger and turmeric improved the microbial quality of tigernut milk during storage. The shelf life of tigernut milk is significantly increased when preserved by hurdle technology and stored under refrigeration (Akakpo *et al*., 2019). Addition of spices such as cinnamon, cloves, coriander, ginger, rosemary and black pepper and low-temperature storage at 4°C extends the shelf life of tigernut milk by 5 days (Kayode *et al*., 2017). Akoma *et al*. (2016) reported that pasteurization and the addition of 0.02 % sodium azide extended the shelf life of tigernut milk stored at 28 °C to 12 days without affecting the sensory attributes. Novel techniques such as high-pressure processing, high-pressure homogenization, pulsed electric fields, and ultrasound can affect the processing and preservation of tigernut milk when used as hurdle (Munekata *et al.*, 2020). Muhammad *et al.* (2019) reported that 15 min plasma-activated water treatment and blanching at 60 °C for 5 min reduced the population of *Klebsiella pneumonia* and initial bacterial population by 3.7 and 4.36 log CFU/g respectively. UV treatment and sterilization are effective in destroying spoilage bacteria during the storage of tigernut milk (Ibrahim *et al*., 2016a). A 5-log reduction was reported by Elbrhami (2016) in tigernut milk subjected to combine treatment of heating, high hydrostatic pressure and UV. Retorting in metallic containers can preserve the microbiological quality of the milk for 8 weeks (Abbey, 2018). Subjecting tigernut milk to ultra-high pressure homogenization treatment at 300 MPa extent its microbial shelf life by 57 days (Codina-Torrella *et al*., 2018).

Tigernut flour

Dry milling of tigernut produces flour rich in fiber and many essential nutrients. Adebayo and Arinola (2017) recommended the use of tigernut in baking and the production of complementary foods. Several nutritional and health benefits were reported in using tigernut flour. Bamigbola *et al*. (2016) reported 7 % increase in fiber content and 18 % increase in anti-oxidant properties in a wheat-tigernut composite containing 10 % tigernut. Ayo *et al.* (2018) reported 94 % increase in the fiber, 29 % increase in fat and 5 % increase in energy contents in *Acha* flour fortified with 10 % tigernut. A 500 % increase in fiber and160 % increase in minerals contents were observed in wheat flour fortified with 30 % tigernut (Adebayo-Oyetoro *et al*., 2017). Addition of 10 % tigernut increases the magnesium, calcium, zinc and iron contents of bread by 76 %, 200 %, 107 % and 10 % respectively (Shima *et al*., 2019). Adegunwa *et al*. (2017) reported progressive increase in protein, fat, ash and fiber in plantain flour substituted with 30-70 % tigernut flour progressively. A healthier and well-accepted beef bugger with improved mono- and polyunsaturated fatty acids content was produced by replacing beef fat with tigernut oil (Barros *et al*., 2020). Addition of 11.5 % tigernut flour to plantain flour raised its antioxidant properties from 0.6 to 11.29 mg AAE/g and produced blood glucose reducing potential similar to acarbose (anti-diabetic drug) (Oluwajuyitan and Ijarotimi, 2019).

Adegunwa *et al*. (2017) recommended plantain-tigernut composite flour for the production of gluten-free products. Gluten-free flour rich in essential amino and fatty acids and low anti-nutritional factors was developed by (Ijarotimi *et al*., 2019) using tigernut and soy cake. Gluten-free noodles were developed for celiac disorder persons by stabilizing rice-tigernut (90:10) composite with 0.5 % xanthan gum (Rosell, 2020), also by stabilizing 100 % tigernut with 0.5 % xanthan gum (Gasparre and Rosell, 2019). Obinna-Echem *et al.* (2020) also recommended the use of tigernut cowpea blend for the production of gluten-free baked products based on its functional properties.

Ebabhamiegbebho *et al*. (2021) developed complementary food with acceptable levels of tannin, phytate and oxalate and appreciable amounts of calcium, magnesium, potassium, phosphorus, vitamins A, B_1 and B_2 using tigernut, pearl millet and African yam bean. Fermented complementary food produced using maize and tigernut meets the protein content requirement recommended by Protein Advisory Group (Wakil and Ola, 2018). The nutrient contents of complementary food developed by Onuoha and Akagu (2019) using tiger nut, defatted watermelon seed and malted hungry rice meet recommended daily intake for infants between 0-3 years. Edith *et al*. (2018) recommended the inclusion of tigernut-chicken feet flour in the production of sauces, crust pastries and weaning foods.

The addition of tigernut reduces carbohydrate content and increases fiber, fat, ash and protein in bread (Shima *et al*., 2019). The addition of 20 % tigernut flour in the production of biscuits provides a good quality product with improved mineral and fiber contents, and excellent acceptability (Bello, 2021). Substituting wheat flour with 30 % tigernut flour improves protein, mineral and fiber contents, water and oil absorption capacities, antioxidants properties and amylose and amylopectin contents of the flour (Bamigbola *et al*., 2016). A moderate degree of preference was observed in biscuits produced using maize-tigernut composite at the ratio of 60:40 (Obinna-echem and Robinson, 2019). Adelekan *et al*. (2019) produced chin-chin with attractive sensory properties and good protein, fat, ash, dietary fiber, mineral and vitamin contents using plantain and tigernut composite. Nutrients and energy-rich pancake with acceptable sensory properties was produced from tigernut-cowpea flour blends (Obinna-Echem *et al*., 2021). Cookies with acceptable sensory properties were developed by Awolu *et al*. (2017) using composite flour produced using tigernut, soybean, rice and millet. (Adejuyitan *et al*., 2018) developed a *Pupuru* analog, a Nigerian traditional fermented food, with acceptable sensory qualities, using breadfruit supplemented with 10 % tigernut. (Bristone *et al*., 2018) recommended the consumption of Nigerian indigenous foods (*Upursah*) made from tigernut, soybean, sorghum and sweet potato.

Ahemen *et al*. (2018) reported that the addition of tigernut flour affects the functional properties of wheat flour and the physical properties of the bread. Addition of tigernut flour reduces the swelling and foaming capacities of wheat flour (Bamigbola *et al*., 2016). Decrease in oven spring, specific volume and loaf weight was observed in bread at 10 % tigernut substitution (Oke *et al*., 2019). Hardness intensification due to crumb drying and crust wetting was reported by Oke *et al*. (2019) during storage of bread containing 10 % tigernut flour.

Effect of processing on nutritional, functional and sensory properties of tigernut flour

Ji and Gi (2018) also recommended the use of fermented tigernut flour as a low-cost supplement for baking. Tigernut flour possessed similar functional properties to wheat flour and can be used as a wheat flour substitute (up to 60 %) in the production of puff puff (Bolarinwa *et al*., 2021). The addition of 30 % tigernut flour to wheat flour does not affect its pasting characteristics (Bamigbola *et al*., 2016). Flour from brown cultivar was characterized with better water absorption and swelling ability, while that from black cultivar shows good oil absorption and foaming capacities (Nina *et al*., 2019). The addition of tigernut increases oil absorption capacity, bulk density, swelling index, swelling power, and foaming capacity of *Acha*-tigernut composite produced for biscuit making (Ayo *et al*., 2018). Addition of tigernut fiber beyond 10 % significantly lower oil and water diffusivity of wheat flour (Verdú *et al*., 2017). Komolafe *et al*. (2020) reported that sprouting improves the flow ability of the tigernut flour. Tuber germination reduces the water absorption capacity of tigernut flour (Adebayo and Arinola, 2017).

Extrusion cooking improves phosphorus, magnesium, calcium, potassium and iron and reduces saponin, tannin, oxalate, phytate, alkaloids and total phenolic contents of a cassava-tigernut blend (Adebowale *et al*., 2017). Drying at elevated temperatures reduces the proximate value of the tuber (Omale *et al*., 2020). Ogo *et al.* (2019) reported that drying lower amino acids and carbohydrates content of the tuber. Germination increases protein, mineral (Ji and Gi, 2018) fat and crude fiber (Adebayo and Arinola, 2017) contents of tigernut. Fermentation increases the vitamin and mineral contents of cereal-tigernut blends (Wakil and Ola, 2018).

Oke *et al*. (2019) reported that 8 % substitution of tigernut flour does not affect the acceptability of bread. Substituting wheat with tigernut beyond 20 % affects the sensory qualities of biscuits (Bello, 2021). Similarly, Oke *et al*. (2019) reported that 10 % of substitution leads to rejection in bread. Adebayo-Oyetoro *et al*. (2017) recommended 20 % substitution in the production of chin-chin snacks.

Tigernut oil

Tigernut oil is among the recently discovered edible oils with limited data on its characteristics and functionalities (Ezeh *et al*., 2016b). Nina *et al*. (2020a) recommended the use of oil in cooking and frying. The oil content and the fatty acids composition vary among tigernut cultivars (Nina *et al*. 2020b). The oil is golden in color and the physical and chemical properties are very similar to that of conventional edible oils (El-Naggar, 2016). Oil content between 23 % and 32.8 % was reported in the literature. Ezeh *et al*. (2016b) reported 23 %, Aljuhaimi *et al*. (2018a) reported 25.5 % and El-Naggar (2016) reported 32.8 %. Ismaila *et al*. (2020) reported 26.1 % in the yellow cultivar and 28.4 % in the black cultivar. The variation may be due to production location, genetic makeup, environment and growing conditions as reported by Ihenetu *et al.* (2021) and Duman (2019). About 71.5 - 78 % of the oil fatty acid is unsaturated (El-Naggar, 2016; Ezeh *et al*., 2016a). The major fatty acids in tigernut are oleic, linoleic, palmitic (Aljuhaimi *et al*., 2018a) and stearic acids (Nina *et al*., 2020b). El-Naggar (2016) reported 65.8 % oleic, 15.4 % palmitic, 6.1 % arachidic and 5.5 % linoleic. Tigernut oil is stable and the free fatty acid and peroxide values meet virgin olive oil standards set by the International Olive Oil Council (Ezeh *et al*., 2016b). The stability of the oil is due to its low peroxide values, polyphenol (e.g. quercetin and vanillic acids) and tocopherol contents (Ezeh *et al*., 2016a). The total tocopherol content of the oil is 97.4 mg/100g, with delta, gamma and alpha tocopherols account for 50, 31.3 and 16.1 mg/100g respectively (El-Naggar, 2016). Pre-treatment with enzymes increase tocopherols and phenolic acids of tigernut oil, while pre-treatment using high-pressure processing improve tocopherols and total polyphenolic contents of the oils (Ezeh *et al.*, 2016a).

The oil can be extracted by conventional oil extraction methods and non-conventional such as supercritical fluid extraction, the later increases the yield and safety of the oil (Roselló-Soto *et al*., 2018). Mechanical expression with subcritical n-butane extraction and Mechanical expression with supercritical CO_2 increase oil yield by more than 240 % (Guo *et al*., 2021). Enzymatic treatment can raise oil recovery by 90 % (Ezeh *et al.*, 2016a). Microwave-ultrasonic assisted aqueous enzymatic extraction improves oil yield by 85.23 % (Hu *et al*., 2020). Extraction methods also affect bioactive compound contents of tigernut oil. Microwave-assisted extraction can increase total phenolic, α-tocopherol and βcarotene contents of the oil by 58 %, 24 % and 48 % respectively (Hu *et al*., 2018). The fatty acids profile of the oil is also affected by the extraction method. Aljuhaimi *et al*. (2018b) studied the effects of tuber roasting and solvent type on the fatty acid profile of tigernut oil, higher values were reported in oil extracted from the roasted tuber with n-hexane. Tigernut oil extraction can be facilitated by enzymic pre-treatment before extraction (Ezeh *et al.*, 2016b).

Tigernut by-products

Recent findings proved the potential of tigernut processing by-products in the production of oxidative stable and fiber-rich foods (Roselló-Soto *et al*., 2018; Mohdaly, 2019). Mycomeat with improved antioxidant and antimicrobial properties was produced from tigernut aggregate waste (Bamigboye *et al*., 2020). Acid hydrolysis of tigernut fiber after milk extraction using H_2SO_4 and H_3PO_4 at 85 °C and 90 °C respectively, converted 50 % of the fiber carbohydrate to reducing sugars (glucose and xylose) (Razola-Díaz *et al*., 2020). Tigernut and its processing wastes can be used as inexpensive raw material for ethanol production, tigernut fermentation using *Saccharomyces cerevisiae* yielded considerable amounts of ethanol at 50 °C (Ibrahim *et al*., 2016b). The inclusion of 5 % tigernut waste has no effects on the growth performance and carcass quality in broiler chicken (Olumide *et al*., 2020). Addition of 12 % tigernut meal into pig diet as maize substitute increases feed conversion rate, resulted in better growth performance and carcass values and significantly reduced backfat and abdominal fats (Ukpabi *et al*., 2019). Santos *et al*. (2018) demonstrate the production of biosurfactant from *Yarrowia lipolytica* IMUFRJ 50682 using tiger nut fiber and corn steep liquor as carbon and nitrogen sources. Ayaşan *et al*. (2021) recommended the use of tigernut as a cheap energy source for ruminants based on its fat and carbohydrate values. Fiber waste from tigernut processing can be used in the development of eco-friendly materials with low thermal conductivity to be used as low-cost insulating materials (Okorie *et al*., 2020). More researches are need to explore additional ways for utilizing tigernut processing byproducts, particularly the defatted residue after oil extraction which at present is mainly used for animal feeds production (Cui *et al*., 2021).

RECOMMENDATIONS

i. More researches are needed in the application of natural preservatives such as spices. Preservation using spices was reported to extend the shelf life under refrigeration storage but can alter sensory attributes and negatively affect acceptability.
ii. Promoting tigernut milk and oil consumption can improve the economy of developing countries depending on imports.
iii. Tigernut milk is highly perishable and can spoil within hours. There is a need to develop ambient stable tigernut milk, this will promote its consumption particularly in developing countries battling with essential nutrients deficiencies.
iv. Incorporation of tigernut into bake products will increase its utilization, cut wheat importation and save foreign exchange in countries with abundant tigernut.
v. The issue of lactose intolerance that affecting many in most developing countries can be curtailed by promoting tigernut milk consumption.
vi. Wastes obtained from tigernut processing can be used in feed formulation as recommended by some researchers
vii. Since tigernut flour possess similar functional properties to wheat flour, it can be combined with wheat flour and reduce its gluten content
viii. Local tigernut processors should be enlightened on the importance of good personal hygiene and other good manufacturing practices as many pathogens were isolated in commercial tigernut milk samples.
ix. Local production of tigernut milk is associated with many safety and quality issues, promoting industrial processing will ensure safer products with better qualities.
x. There is a need for modification in the traditional production methods to incorporate operations that will significantly lower the microbial counts. Application of thermal treatment, though maybe challenging, will reduce the microbial loads.
xi. The potentials of novel techniques in reducing problems associated with conventional processing should be studied.
xii. There is scanty information on tigernut metabolites bioavailability, this area needs to be explore through various approaches including in vivo studies.

CONCLUSION

The presence of numerous phytochemicals with antioxidant potentials account for the health benefits of tigernut. It contains significant amounts of fiber, unsaturated fat and moderate amounts of protein. The high fiber in the tuber and affluent polyunsaturated fatty acids in the oil are crucial in the preparation of healthy recipes. Conventional and novel processing techniques affect the nutritional and functional qualities of tigernut products. It is always important to carefully choose processing operations with minimal negative impacts on the nutritional and functional qualities. Thermal processing, sprouting and fermentation were reported to improve safety, nutrient contents and availability. Sensory properties were reported to be improved through fermentation, the addition of spices, roasting and homogenization. Most of the traditionally processed tigernut milk was reported to be unfit for human consumption due to elevated microbial counts and the presence of pathogens. Awareness on the importance of observing good personal hygiene and implementation of good manufacturing practices will improve the safety of traditionally processed tigernut products. Promoting tigernut consumption will play an imperative role in the health, nutrition and economy of many developing countries.

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