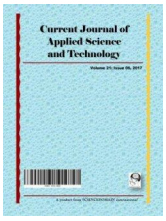

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Tigernut Plant and Useful Application of Tigernut Tubers (*Cyperus esculentus*) - A Review

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Authors' contributions

This work was carried out in collaboration between both authors. Author NM designed the study, wrote the protocol, wrote the first draft of the manuscript and managed the literature searches. Author FSI read the manuscript and made the corrections. Both authors read and approved the final manuscript.

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ABSTRACT

Since thousands of years ago, millions of people enjoy chewing raw tigernut tubers (*Cyperus esculentus*) with less emphasis in processing the tubers into more useful products. Tigernut tuber is very common and abundant in Nigeria. It is always available in both wet and dry season. As global human population is increasing, it is pertinent to fully utilize readily available agricultural products such as tigernut tubers for the production of more useful products. Tigernut tuber is usually processed into three major useful products namely tigernut milk, tigernut flour and tigernut oil which could further be utilized to produce diverse edible and non-edible products. Several studies have been carried out by researchers to develop more useful products from tigernut tubers. The inability to effectively and adequately disseminate recent research findings to the populace as well as massively commercialize tigernut-derived products has been the bane of increased utilization of tigernut tubers in Nigeria and Sub-Saharan Africa. Therefore, this review article is aimed at sharing comprehensively available information on tigernut and recent research findings focused on increasing the utilization of tigernut tubers for the production of useful products.

Keywords: Tigernut plant; Cyperus esculentus; useful application; tigernut tubers.

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1. INTRODUCTION

Tigernut is a perennial monocotyledous plant which has a tough erect fibrous root. The slender rhizomes of tigernut form weak runners above the ground level which develop small-sized tubers at the tip of the stem. Tigernut tubers can reach about six inches depth into the soil. The size of the tubers can be compared with that of peanut. The central erect stem of tigernut is usually covered by sheath of leaves [1].

The botanical name of tigernut is *Cyperus esculentus* L. It has other names depending on the tribe or region where tigernut tuber is cultivated and utilized. The genus name *Cyperus* is derived from an ancient Greek name *Cypeirus* whereas the specie name *esculentus* originate from a Latin word which means edible [2]. Tigernut is also called '*Zulu nut*', '*Yellow nut sedge*', '*Chufa*', '*Flat sedge*', '*Edible rush nut*', '*Water grass*', '*Almond*', '*Northern nut grass*' and '*Nut grass*' [3]. The three most populous ethnic groups in Nigeria which are Hausas, Igbos and Yorubas call tigernut tubers '*Aya*', '*Ofio*' and '*Imumu*', respectively [4,5]. A widely acceptable name given to tigernut tubers in Southern Nigeria is 'Aki Hausa' which literally describes a nut that is largely cultivated and marketed by the Hausas that dominate Northern Nigeria [1,6]. A large portion of tigernut tubers distributed across the country as snacks are cultivated in many states in Northern Nigeria [7,8].

Historically, the cultivation and utilization of tigernut tubers is a practice known to have started with the Egyptians at about 5000 BC [9,10]. Since then, tigernut has spread to other parts of the world. Tigernut is one of the wild edible plants that could be used to improve human nutrition. It contributes significantly towards improving the economy and cultural life of people residing in rural communities in Sub-Saharan Africa [1].

Tigernut is a member of the family *Cyperaceae*. So far, approximately 4,000 species of tigernut plant have been identified. In some countries, tigernut is regarded as a wild plant commonly used as animal feed [3]. *Cyperus esculentus* is very popular because the tubers are directly consumed in its raw form [11].

There are three varieties of tigernut tubers namely yellow, brown and black varieties. The black variety is not common in Nigeria but the tubers are readily available in Ghana [12]. The other two varieties of tigernut tubers are commonly sold in local markets across many states in Nigeria. Generally, the yellow variety tigernut tuber is preferable than the brown variety tigernut tuber [13].

Tigernut tubers have a slightly sweet and nutty flavour. The texture and flavour of tigernut tuber is comparable with coconut. Fresh, semi-dried or dried tigernut tuber is usually consumed as a snack because of its nutty flavour [14,15]. In Nigeria, the primary purpose of cultivating tigernut is because of the sweet tubers [16,17]. Many people who eat tigernut tubers are not well informed about the variety of products that could be derived from the tubers and their benefits. This is one of the reasons tigernut is still regarded as being underutilised [3] despite the fact that large population of inhabitants where tigernut tubers grow chew the raw tubers all year round [18].

Studies on proximate composition, amino acid composition, antinutrient and mineral content of tigernut tubers have been reported extensively by researchers [7]. These parameters are influenced by the tigernut variety, planting site, planting period as well as the method adopted in processing the tubers [19,20].

Tigernut tubers have useful application in food technology [8,21,22]. Three main products derived from tigernut tubers are tigernut milk, tigernut flour and tigernut oil. Tigernut can be pounded and baked [23], used in the preparation of a local drink known as 'kunu' [24] as well as incorporated into other products such as candy, chocolate, biscuits and cookies [8,25,26]. Owing to the usefulness of tigernut tubers and its products, we consider it necessary to review recent research findings on potentials of tigernut in order to provide more information about tigernut tubers for its teeming users. The information shared in this review paper is expected to increase economic gains and guarantee food security in Sub-Saharan Africa [1].

2. TAXONOMY OF TIGERNUT

Tigernut (*Cyperus esculentus*) belongs to the Division *Magnoliophyta*, Class-*Liliopsida*, Order-*Cyperales* and Family *Cyperaceae* [27]. Schippers et al. [28] gathered *Cyperus esculentus* from the continents where they grow in order to carry out an infraspecific taxonomy of the plant. The researchers were able to

distinguish them into four clusters which represent four varieties of *Cyperus esculentus* (yellow nutsedge) which are var. *esculentus*, var. *leptostachyus*, var. *macrostachyus*, and var. *heermannii*. Further assessment of the geographical distribution of the infraspecific taxa of *Cyperus esculentus* (yellow nutsedge) were reported by [28].

There are three varieties of tigernut tubers easily identified based on the colour of the tubers. They are: the yellow, brown and black variety. Only two of the varieties - yellow and brown are commonly seen in most local markets in Nigeria. The yellow variety is further grouped into two - the large yellow variety and the small yellow variety [1]. *Cyperus esculentus* var. *esculentus* is weedy whereas *Cyperus esculentus* var. *sativus* is usually cultivated as a result of its rhizomes which grow into tubers for human consumption. The botanical name *Cyperus esculentus* is commonly used in most literature for both the weedy and the useful sedge. Although the two varieties are closely related, the weedy variety *esculentus* produces more seeds than the variety *sativus* [29]. Other varieties include *Cyperus esculentus* var. *esculentus* (commonly seen around Mediterranean region east of India), *Cyperus esculentus* var. *hermannii* (Florida), *Cyperus esculentus* var. *leptostachyus* (USA), *Cyperus esculentus* var. *macrostachyus* (USA), *Cyperus esculentus* var. *sativus* (Asia) [30]. Figs. 1-4 shows the pictures of four varieties of tigernut tubers.

Fig. 1. Big size black colour tigernut tubers

Fig. 2. Big size yellow variety tigernut tubers

Fig. 3. Small Size Yellow variety tigernt tubers

Fig. 4. Brown variety tigernut tubers

3. ORIGIN AND GEOGRAPHICAL DISTRIBUTION OF TIGERNUT

The origin of tigernut cultivation can be traced to ancient Egypt [31]. The discovery of dry tigernut tubers inside tombs in Egypt which dates back to 6,000 years ago is a strong evidence to support the claim that the cultivation of tigernut started in Egypt. Back then in Egypt, tigernut tubers were roasted and used as sweet meat [3]. According to [32], tigernut tubers originate from Chuf region in Sudan. This could be the reason why tigernut tuber is known as xufa (chufa). Since thousands of years ago, the cultivation of tigernut takes place between Sudan and Egypt on the borders of the Nile River. In Southern Europe and West Africa, the cultivation of tigernut had been practiced since early times [6]. Cultivation of tigernut in Southern Europe was made possible by the Arabs in the middle ages when they travelled beyond Northern Africa. In 1822, Lesant, a French Chemist was the first scientist to analyze tigernut tubers [33]. As far back as 13^{th} century, the consumption of a drink made from tigernut tubers was common among the inhabitants of the Mediterranean. From all indications, this drink can be considered as an ancestor of the modern 'horchata' [3]. In times of old, the Persian and the Arabs were familiar with the nutritive benefits of tigernut tubers [22].

Tigernut is well distributed in Chile, Brazil and USA. It naturally grows in Ghana, Nigeria and Sierra Leone [3]. Cultivation of tigernut takes place in other West African countries such as

Cameroon, Senegal, Guinea and Cote d'ivore. In Nigeria, tigernut is grown mainly in the northern region and the tuber is available in the market all year round [1]. Tigernut can also grow in the middle belt of Nigeria [34]. It grows luxuriantly in wet marshes and areas close to streams [1]. The geographical spread of four varieties of yellow nutsedge was described by [28]. According to their study, variety *esculentus* is abundant in Africa and southern Europe; variety *heermannii* is rarely seen growing in many countries except in south-west region of USA; variety *macrostachyus* grow abundantly in Central America whereas var. *leptostachyus* is present in both the Old and the New World.

4. CULTIVATION OF TIGERNUT

Cyperus esculentus is not a nut considering the literal interpretation of the name tigernut but actually a tuber. During early stage of its development, the immature tubers are whitish and when it matures, it becomes enveloped by a yellow outer membrane [1]. Tigernut tubers share more characteristics with other tubers than nuts and therefore considered as a tuber [17,35]. The proximate composition of tigernut tubers compared with other tubers and nuts is shown in Tables 1 and 2, respectively.

Cultivation of tigernut requires mild climate and sandy soil. Reproduction of tigernut is by seeds and pollination is by wind [1]. Tigernut grows widely as a grass in wet places. Tigernut is planted in April and harvested in November. The planting period is grouped into major (April-July) and minor (September-November). During harvesting of tigernut tubers from the field, foreign materials such as stones, animal droppings and other extraneous materials mix with the tubers. Since the tubers of tigernut can be eaten raw, removal of foreign materials and thorough washing of the tubers with potable water is required before raw tigernut tubers can be chewed [2]. Although the cultivation and utilization of tigernut dates back to many centuries ago in ancient Egypt, the plant had successfully been introduced to other parts of the world through human activity spanning many centuries. Tigernut requires irrigation almost every week until the tubers are due for harvesting [1,36]. It has been established through several researches that mineral contents and acceptability of tigernut-milk drink is affected by the location and planting period of tigernut [20]. In a related study, [12] also investigated the effect of different sites and tigernut variety on the yield of milk and solids of tigernut tubers. Their study revealed that different sites where tigernut tubers are planted affected the yield of milk and solids obtained from the tubers but it did not result in significant differences in flavour, after taste and overall acceptability of the tigenut milk.

5. FRESH AND DRIED TIGERNUT TUBERS

The tubers of tigernut could be utilized when the tubers are fresh, semi-fresh or dried depending on intended use of the tubers. At the time of harvesting tigernut from the farm, the tubers are fresh. During the stage of designing equipment for handling, harvesting and storage of tigernut tubers, the physical properties of the tubers have to be considered. The moisture content of varieties of tigernut tubers especially the black variety affects its physical properties [36]. After sometime, the tigernut tubers harvested from the farm becomes semi-fresh tubers. The tigernut tubers could as well be dried. Due to low moisture content of dried tigernut tubers, it is necessary to soak the tubers in water for some hours to make it soft and also improve its sensory characteristics. Drying of tigernut tubers is usually done by exposing the tubers to direct sun rays with occasional turning which ensures uniform drying. A properly sun-dried tigernut tuber takes about 1-2 months to complete. Dried tigernut tuber is resistant to quick microbial spoilage. The weight of fresh tigernut tuber is 70-900 mg but when it is dried it reduce to 30-350 mg. The length of the fresh tigernut tuber is about 30 mm. The outer covering of fresh tigernut tubers looks brownish with three encircling leaf scars. The inside appears whitish with dark root initials. When soaked in water, the dried tuber can absorb close to three times the weight of water compared with the weight of the dried tuber. Apart from preventing microbial spoilage of tigernut tubers, drying of the tubers ensures that the nutritional quality of tigernut tubers is preserved [1]. A research carried out by [37] compared proximate composition, physicochemical properties, nutritional content as well as level of microbial contamination of fresh and dried tigernut tubers. Their results showed that drying of fresh tigernut tubers increased its carbohydrate and ash content but decreased protein, moisture, lipid and fiber content. Figs. 5 and 6 shows the picture of fresh and dried tigernut tubers, respectively. Table 3 shows the proximate composition of two varieties of wet and dried tigernut tubers. Similarly, the mineral composition of wet and dried tigernut tubers is presented in Table 4.

Table 1. Proximate composition (g/100 g) of tigernut tubers compared with other tubers

Common name	Tigernut	Potato	Yam	Jerusalem artichoke	Yacon	Sweet potato	Cassava
Scientific name	***Cyperus esculentus***	***Solanum tuberosum***	***Dioscorea spp.***	***Helianthus tuberosus***	***Smallanthus sonchinfolius***	***Ipomoea batatas***	***Manihot esculenta***
Moisture	26.00	78.75	62.50	80.00	80.69	70.54	60.00
Lipid	24.49	0.16	0.20	0.21	0.13	3.88	0.30
Fibre	8.91	0.68	1.68	3.12	1.75	0.88	1.18
Protein	5.04	1.97	2.55	1.41	2.22	0.66	1.40
Ash	1.70	0.95	1.50	1.07	1.1	1.49	4.97
Starch	29.90	13.82	18.89	Inulin (16.18)	Inulin (6.94)	10.29	29.40
Reducing Sugar	1.70	0.28	-	2.54	6.09	0.39	5.00
Total Sugar	15.42	0.47	-	4.12	9.90	6.63	7.98
Sucrose	13.03	0.31	-	1.15	3.15	4.77	1.70
Carbohydrate	43.30	18.17	34.60	14.82	13.80	25.74	38

Source: Sánchez-Zapata et al. [3]

Table 2. Proximate composition (g/100 g) of tigernuts compared with nuts

Common name	Scientific name	Moisture	Lipid	Fiber	Protein	Ash	Total Sugar	Carbohydrate
Tigernut	*Cyperus esculentus*	26.00	24.49	8.91	5.04	1.70	15.42	43.30
Almonds	*Prunus dulcis*	9.51	43.36	8.80	21.30	2.48	1.10	6.10
Hazelnuts	*Prunus amigdalis*	4.19	60.80	10.40	15.00	2.28	1.20	4.70
Walnuts	*Junglans regia*	2.70	65.20	6.40	15.20	1.82	0.70	3.0
Pistachios	*Pistachia vera*	5.74	44.40	9.00	20.60	3.21	2.20	7.80
Pine nuts	*Pinus pinea*	1.47	68.40	3.70	13.70	2.50	1.00	3.70
Peanuts	*Arachis hyogaea*	3.53	49.20	8.50	25.80	2.27	1.10	7.48

Source: Sánchez-Zapata et al. [3]

Fig. 5. Fresh tigernut tubers (*Cyperus esculentus*)

Fig. 6. Dried tigernut tubers (*Cyperus esculentus*)

Table 3. Proximate composition (%) of wet and dried tigernut tubers (*Cyperus esculentus*) varieties

Composition	Wet *C. esculentus* (L)	Dried *C. esculentus* (L)	Wet *C. esculentus* (S)	Dried *C. esculentus* (S)
Ash	1.80±0.01	2.68±0.20	1.75±0.10	1.79±0.0
Moisture	42.80±0.20	32.16±0.20	24.22±0.1	9.7±0.1
Crude fiber	18.0±0.1	21.36±0.0	15.27±0.10	15.60±0.0
Crude lipid	14.10±0.0	19.67±0.1	11.50±0.0	27.54±0.0
Crude protein	4.82±0.1	7.94±0.1	3.65±0.20	3.94±0.1
Carbohydrate	18.44±0.2	16.19±0.2	16.39±0.1	15.60±0.0
Energy (KJ)	213.90	317.61	183.50	326.02

L represents 'large sized tigernut tubers'; S represents 'small sized tigernut tubers'
Source: Nwaoguikpe [34]

Table 4. Mineral composition (mg/100 g) of fresh and dried tigernut (*Cyperus esculentus)*

Mineral	Fresh *Cyperus esculentus*	Dried *Cyperus esculentus*
Fe	41.75±1.104	158.49±0.124
Zn	34.77±0.0877	22.763±0.727
Cu	41.05±0.112	52.35±0.112
Pb	0.36±0.0895	2.05±0.112

Source: Chukwu et al. [37]

Table 5. Proximate composition (%) of yellow, brown and black varieties of *Cyperus esculentus*

Composition	*C. esculentus* (Yellow variety)	*C. esculentus* (Brown variety)	*C. esculentus* (Black variety)
Ash	3.97	4.25	2.57
Moisture	3.50	3.78	3.73
Crude fiber	6.26	5.62	7.02
Crude lipid	32.13	35.43	8.94
Crude protein	7.15	9.70	12.00
Carbohydrate	46.99	41.22	65.66
Energy (KJ)	1343	1511	1652.53

Source: Nwaoguikpe [34]

6. NUTRITIONAL COMPOSITION OF TIGERNUT TUBERS

Several studies had been carried out on the nutritional composition of varieties of tigernut tubers grown in different geographical locations [34]. Since utilization of tigernut tubers for development of diverse edible products is being prioritized, more attention on the nutritional composition of tigernut-derived products have been attracting strong interest from researchers. Chinma et al. [38] reported that protein and ash content of tigernut flour separately obtained from two varieties of tigernut tubers increased after the tigernut tubers were subjected to germination. In terms of proximate composition, [39] compared flour obtained from two varieties of tigernut tubers and reported that the brown variety tigernut tuber has higher protein, fat, ash, potassium, magnesium, manganese and iron content than the yellow variety. On the other hand, the yellow variety contains higher amount of carbohydrate, crude fibre, calcium, sodium and copper. In appearance, the yellow variety of tigernut tubers looks bigger and has a more attractive colour than the brown and black variety tigernut tubers. The quantity of tigernut-milk produced by yellow variety tigernut tubers as well as its fat and protein content is higher than the tigernut-milk drink prepared using the black variety tigernut tubers. The antinutritional factors especially polyphenols present in yellow variety tigernut tubers are lower than what is obtainable in the black variety tigernut tubers [15]. However, the black variety tigernut tubers contain more quantity of oil than the yellow variety tigernut tubers [1]. Interestingly, the yellow variety tigernut tubers contain lower antinutritional factors such as polyphenols compared with the brown variety tignut tubers [15].

Bado et al. [40] compared the tuber characteristics of three morphotypes of tigernut namely big size and yellow colour, small size and yellow colour and big size and black colour. As a result of unpopularity of black variety tigernut tubers, limited studies have been carried out on it. It is not enough to differentiate tigernut tubers based on morphological parameters but to also relate it with their nutritional composition which is beneficial to human health. Aremu et al. [41] in their studies examined the proximate composition, metabolizable energy, amino acid profiles and isoelectric point of black variety of tigernut tubers. Their research findings is that site and planting period of brown and black varieties of tigernut tubers have significant effects on the fat, protein, mineral and energy content of tigernut milk produced from the two varieties of tigernut tubers. Also affected is the sensory characteristic of tigernut milk produced from the two varieties of tigernut tubers planted in different sites and planting periods [20]. Interestingly, [42] reported that tigernut tuber is considered as a famine food by some individuals from different races. Four varieties of tigernut tubers were separately used to produce tigernut-milk drink and [43] did a comparative study of their nutritional composition. Olaoye [43] reported that 2.51% and 2.34% protein and carbohydrate content, respectively in tigernut juice was the maximum value obtained after evaluating the nutritional composition of four different tigernut nut juice produced from four different varieties of tigernut tubers. The moisture content of each of the tigernut juice is above 90%. Table 5 shows the proximate composition of black, yellow and brown variety *Cyperus esculentus*.

The starch, dietary fibre and digestible carbohydrate (monosaccharides, disaccharides and polysaccharides) content of tigernut tubers are quite high. The moisture content is about 50%, fat 12%, crude fibre 8%, protein 4%, ash 1.80% and carbohydrate 34%. Tigernut tuber is also rich in minerals. Because of its rich nutrient

composition, tigernut tuber can be used to fortify other food materials. The nutritional composition of tigernut tuber is the reason behind its increased utilization. However, different processing methods affect the nutritional composition of tigernut tubers [23]. Oguike et al. [44] reported that tigernut tuber contain 932.8 g/Kg dry matter, 245.0 g/Kg crude lipid, 256.8 g/Kg starch, 14.3 g/Kg ash, 50.5 g/Kg protein, 89.1 g/Kg crude fibre, 17.1 g/Kg reducing sugar, 154.3 g/Kg total sugar and 130.4 g/Kg sucrose. Regarding the fatty acid composition, it contains 689.20-732.90 oleic acid, 125.5-141.2 palmitic acid and 99.6-154.6 linoleic acid. Tigernut tubers contain vitamins and minerals such as zinc, sodium, potassium, magnesium and minute quantity of copper [1,45]. According to [31], some researchers reported that tigernut tubers contains low quantity of magnesium, manganese, phosphorus, iron, zinc and copper but has a high content of calcium, sodium and copper. The physical characteristics, vitamin content, mineral and carbohydrate composition of three *Cyperus esculentus* morphotypes is depicted in Table 6 while the amino acid composition of two varieties of tigernut tubers is presented in Table 7.

Table 6. Physical characteristics, vitamin content, mineral (mg/100 g) and carbohydrate composition of *Cyperus esculentus* morphotypes

Parameters/Minerals	Morph. 1	Morph. 2	Morph. 3
Mean length (cm)	1.24±0.05^{a}	0.98±0.06^{b}	1.31±0.06^{a}
Mean width (cm)	0.97±0.005$^{a, b}$	0.90±0.08 ^{b}	1.19±0.05^{a}
1000 dried tubers (g)	814.3±184.1^{a}	598.00±115.00^{b}	1044.00±34.60^{a}
Moisture (g 100 g^{-1})	5.19±0.18^{a}	4.56±0.22^{a}	4.99±0.78^{a}
Crude oil (g 100 g^{-1})	26.14±0.71^{b}	28.94±0.37^{a}	24.91±0.94^{c}
Protein (g 100 g^{-1})	3.47±0.71$^{a, b}$	4.33±0.6^{a}	3.3±0.26^{b}
Ash (g 100 g^{-1})	1.81±0.24$^{a, b}$	1.69±0.21 ^{b}	2.21±0.39^{a}
Carbohydrate (g 100 g^{-1})	68.24±1.28$^{a, b}$	68.24±1.28$^{a, b}$	69.21±1.30^{a}
Starch (g 100 g^{-1})	30.54±2.75^{a}	33.21±1.1^{a}	30.54±0.5^{a}
Sucrose (g 100 g^{-1})	18.99±0.56^{b}	17.98±1.03^{b}	20.39±1.15^{a}
Fructose (g 100 g^{-1})	3.02±0.37^{a}	3.59±0.72^{a}	1.6±0.69^{a}
Glucose (g 100 g^{-1})	6.79±1.34^{a}	6.33±0.97^{a}	0±0^{b}
Vitamin C (mg 100 g^{-1})	5.48±1.05^{c}	26.78±2.51^{a}	8.33±1.83^{b}
Vitamin E (µg 100 g^{-1})	209.71±1.30^{b}	270.56±1.74^{a}	149.86±1.94^{c}
β-Carotene (µg 100 g^{-1})	7.3±0.57^{b}	6.13±0.62^{c}	10.05±1.79^{a}
Al	34.35±2.55^{b}	43.37±6.13^{a}	39.86±0.74^{a}
Ca	32.27±5.66^{a}	19.09±3.22^{b}	22.13±1.64^{b}
Cd	0.01±0.01^{a,b}	0.02±0.01^{a}	0.01±0^{b}
Cl	167±0.53^{a}	155.4±2.83^{b}	167.2±5.51^{a}
Cr	1.65±0.05^{a}	1.12±0.31^{b}	0.18±0.01^{c}
Cu	0.71±0.003^{a}	0.48±0.05^{b}	0.43±0.01^{c}
Fe	11.44±0.48^{a}	8.25±1^{b}	3.57±0.17^{c}
K	608.3±97.84^{b}	556.9±80.4^{b}	845.8±7.94^{a}
Mg	100.50±1.79^{a}	107.3±8.2^{a}	102.2±2.86^{a}
Mn	1.55±0.44^{a}	1.44±0.15^{a}	0.38±0.02^{b}
P	229.60±51.54^{a,b}	283.7±14.96^{a}	236.4±16.53^{b}
S	164.3±18.23^{a}	194.1±61.62^{a}	148.8±8.39^{a}
Si	181.6±50.35^{b}	242.5±35.89^{a}	220.3±47.32$^{a, b}$
Sr	0.36±0.009^{a}	0.17±0.02^{b}	0.19±0.02^{b}
Zn	2.34±0.31^{b}	1.88±0.22^{b}	2.7±0.03^{a}

Values are means ± standard deviation for n=3. Data in the same row followed by different letters are significantly different (p<0.05). Morph. 1 represents big size yellow colour Cyperus esculentus; Morph. 2 represents small size and yellow colour Cyperus esculentus; Morph. 3 represents big size and black colour Cyperus esculentus. Source: Bado et al. [40]

Table 7. Amino acid composition of yellow and black varieties of tigernut tubers (*Cyperus esculentus*)

Amino acid	Yellow variety tigernut tubers (mg/16 g)	Black variety tigernut tubers (g/100 g)
Histidine	4.43±1.10	3.03
Isoleucine	4.84±0.90	3.55
Leucine	8.03±0.83	3.87
Lysine	6.50±0.67	6.24
Methionine	11.83±2.50	1.85
Phenylalanine	4.27±1.00	5.06
Threonine	3.59±0.50	4.09
Valine	5.93±0.81	4.20
Serine	4.96±0.91	3.37
Tyrosine	3.31±0.49	3.18
Alanine	9.24±1.90	3.34
Arginine	5.79±1.23	9.32
Aspartic acid	14.79±3.00	10.12
Cysteine	0.69±0.15	1.32
Glutamic acid	12.14±2.38	19.70
Glycine	6.35±0.80	4.30
Proline	4.00±1.00	3.66

Source: Aremu et al. [41]; Arafat et al. [46]

7. NUTRITIONAL BENEFITS OF TIGERNUT TUBERS

Tigernut tuber contains digestive enzymes such as catalase, lipase and amylase. These enzymes help to alleviate indigestion, flatulence and diarrhoea. High oleic content of tigernut tubers helps to reduce cholesterol level in the human body which prevents heart attacks and thrombosis. Tigernut tubers are rich in vitamin B1 which helps central nervous system to function properly and also help the human body undergo stressful condition. Regular consumption of tigernut tubers improves men and women fertility as a result of vitamin E present in the tubers. That is why in the Middle East, tigernut tuber is known as 'Hab Al-zulom' which is an Arabic word. The meaning of the word 'Hab Al-zulom' is 'the seeds of men'. The reason tigernut tubers is called 'Hab Al-zulom' by inhabitants in the Middle East is because tigernut tubers have the ability to enhance sexual activity both in animals and humans [9]. The vitamin E present in tigernut tubers delay aging in human cells, bring about improvement in the elasticity of the skin and get rid of wrinkles, acne and undesirable changes that may affect the skin [1]. It was reported that coeliac disease affects approximately 1% of the population of some countries [29]. The pathology of coeliac disease affects the upper small intestine mucosa due to an inappropriate immune response to gluten protein fractions which are mainly present in wheat, barley and rye. Ahmed and Hussein [31] advised people suffering from this disease to avoid cereals that contain gluten throughout their lifetime because there is no available treatment for coeliac disease. Such persons can consume tigernut-derived products because it does not contain gluten.

8. ANTINUTRITIONAL FACTORS IN TIGERNUT TUBERS

Although tigernut tubers are rich in nutrients, it still contains some quantity of antinutritional factors. Krichène et al. [33] reported that antinutrients such as tannins, saponins, phytate, oxalates and cyanogenic glycosides are present in raw tigernut tubers in considerable quantity. If tigernut tuber is roasted, the quantity of alkaloids, steroids and resins in the tubers becomes higher than unroasted tigernut tubers. This is an indication that processing methods influence antinutritional content of tigernut tubers [22]. The presence of antinutritional factors (ANF) in food substances interfere with digestive processes and prevent efficient utilization of protein [47]. Consumption of foods that contain high quantity of antinutrients over a long period could be harmful to the body. The harmful effects include toxicity, hyperlipidaemia, excessive weight gain, hyperglycaemia, carotenemia, constipation, kidney stones, body odour, bad breath, allergies, diarrhoea, frequent urination and acne. Due to the effect of antinutrients in human health and

Table 8. Phytochemical composition (%) of two varieties of *Cyperus esculentus*

Parameter	*Cyperus esculentus* (Large)	*Cyperus esculentus* (Small)
Oxalate	0.50±0.20	0.42±0.1
Phytate	2.35±0.20	2.12±0.1
Saponin	0.76±0.20	0.65±0.1
Tanins	9.50±0.20	7.22±0.1
Cyanogenic glycoside	1.07±0.20	0.85±0.20

Source: Nwaoguikpe [34]

Table 9. Antinutritional factors (mg/100 g) in raw, soaked and toasted tigernut tubers

Sample	Constituents				
	Tanins	Polyphenols	Phytates	Oxalates	Alkaloids
RTGN	$2.37 \pm 0.20_{d}$	$1.00\pm0.07_{d}$	$21.42\pm0.67_{c}$	$13.20\pm0.10_{a}$	$2.63\pm0.04_{f}$
TGSR	$2.02\pm0.05\ (15)_{cd}$	$0.85\pm0.10(15)_{cd}$	$15.65\pm0.67(27)_{cd}$	$8.28\pm0.15(37)_{c}$	$2.55\pm0.04(3)_{e}$
TGS1	$1.65\pm0.08(30)_{bc}$	$0.58\pm0.03(42)_{b}$	$14.97\pm0.52(0.30)_{bc}$	$7.90\pm0.15(40)_{c}$	$2.48\pm0.03(6)_{d}$
TGS2	$0.93\pm0.007(61)_{a}$	$0.52\pm0.07(48)_{ab}$	$11.95\pm0.58(44)_{a}$	$5.46\pm0.08(58)_{b}$	$2.29\pm0.02(13)_{c}$
TGOV	$1.10\pm0.19(54)_{ab}$	$0.48\pm0.15(52)_{ab}$	$16.75\pm0.38(22)_{d}$	$5.55\pm0.43(58)_{b}$	$1.93\pm0.04(27)_{a}$
TGP1	$1.51\pm0.17(36)_{b}$	$0.75\pm0.005(25)_{c}$	$12.90\pm0.38(40)_{ab}$	$5.67\pm0.51(57)_{b}$	$2.05\pm0.02(22)_{b}$
TGP2	$0.70\pm0.10(71)_{a}$	$0.35\pm0.01(65)_{a}$	$13.87\pm0.19(35)_{b}$	$2.97\pm0.07(77)_{a}$	$2.30\pm0.01(13)_{c}$

**Values are means of triplicate determinations. Values in parenthesis are reductions in percentage while the values followed by different alphabets in a column are significantly different (P=0.05) RTGN-Raw tigernut; TGSR-Tigernut soaked in distilled water at room (28±2°C) temperature for 12 h; TGS1-Tigernut soaked in distilled waterat 60°C for 6 h; TGS2-Tigernut soaked in distilled water at 60°C for 7 h; TGOV-Tigernut toasted in the oven at 120°C for 30 min; TGP1-Tigernut toasted in an open pan for 10 min; TGP2-Tigernut toasted in an open pan for 30 min. Source: Adekanmi et al. [30]*

nutrition, some researchers have studied the effect of antinutrients on blood glucose, serum albumin, protein, cholesterol, erythrocytes, leukocytes, haemoglobin, erythrocyte sedimentation rate (ESR) and packed cell volume (PCV) [48]. Despite the presence of antinutrients in tigernut tubers, experimental studies demonstrated that administering raw tigernut tubers on rats did not cause any negative effect. Interestingly, some antinutrients have positive effects. For example, alkaloids, saponins and tannins possess antimicrobial properties. Chukwuma [48] in collaboration with other researchers reported that useful natural compounds such as flavonoids, steroids, tannins and saponins possess therapeutic properties that can help in the treatment of some diseases. Table 8 depicts the phytochemical composition of two varieties of *Cyperus esculentus* while Table 9 depicts the effect of different treatments on antinutritional factors present in tigernut tubers.

9. HEALTH AND THERAPEUTIC BENEFITS OF TIGERNUT TUBERS

The consumption of tigernut tubers does not only bring about nutritional benefits to the body but also health benefits. Egyptians and Chinese consume soaked tigernut tubers as a liver tonic. Its consumption brings about healing of stomach pain, mouth and gum ulcers. Other health benefits associated with tigernut tuber is that it promotes normal menstruation and enhances the production of breast milk in nursing mothers. In order to cause menstruation to start early in life, Zulu girls are advised to eat tigernut tubers. Fertility is enhanced through the consumption of tigernut tubers. That is why tigernut tuber is regarded as an aphrodisiac [42]. It is suggested that consumption of tigernut tubers might bring about improvement of human reproductive system to its maturity [44,49]. In the practice of folk medicine, tigernut tuber is used as a colon evacuator [50]. Consumption of tigernut tubers help in the treatment of boil, common cold and poliomyelitis [23]. Its use as sedative and also as a stimulant has also been reported [42]. The consumption of tigernut tubers enhances digestion process. Treatment of diarrhoea and intestinal inflammation (colitis) can be achieved through consumption of tigernut tubers [42]. Tigernut extract play some vital role in preventing heart diseases, thrombosis and activates blood circulation. Consumption of tigernut tubers goes a long way in prevention and treatment of urinary tract infections as well as other bacterial infections.

Oyedepo and Odoje [51] carried out a study to investigate the protective effects tigernut tubers will have in the liver of experimental rats that is damaged by a dose of carbon-tetrachloride (CCl_4). At the end of that study, they observed that hepatic oxidative stress induced by CCl_4 in the rats was prevented possibly as a result of intake of tigernut tubers. This suggests that tigernut tubers could function as a natural antioxidant. Treatment of ailments caused by oxidative stress using tigernut extract is as a result of its antibiotic/antifungal property [52]. Some substances present in tigernut tubers have high antisickling capability and inhibit gelation of sickle cell haemoglobin which improves oxidant status of erythrocytes. What makes tigernut tubers suitable for diabetics is as a result of sucrose and starch it contains in reasonable quantity as well as high level of arginine which stimulates insulin production in the human body [32]. Tigernut extract is effective in the management of anaemia and kwashiorkor which are nutritionally related syndromes. Tigernut tuber being a source of antioxidant makes it a useful therapy for diseases that involves cell or tumor growth. *Cyperus esculentus* is very useful in traditional medical practice [52]. After pounding tigernut tubers with tobacco leaves, it can be used in the treatment of athlete's foot. This practice is common among Paiute Indians [53]. Tigernut tubers can be used in medicine and cosmetic industry to scavenge and remove free radicals resulting from metabolic body reactions and environmental pollutants because of the antioxidant activity of dry, raw and roasted tigernut [54]. Furthermore, the phytochemical composition of tigernut tubers bring about biochemical effects which translate to enhanced health condition in humans [45,55].

According to studies conducted by feeding animals with tigernut tubers, it was observed that the phytochemicals present in the tubers exhibited diverse pharmacological and biochemical actions [3]. The consumption of tigernut tubers help in the prevention of heart diseases. According to [48], consumption of tigernut tubers over a long period reduces the risk of people developing colon cancer. The highly nutritious composition of tigernut tubers, its health benefits and therapeutic effect makes it suitable to be used in supplementing or fortifying other food materials including dairy products [56]. Hassan [14] and [57] listed several therapeutic benefits the body can derive as a result of consuming tigernut tubers. According to [14], therapeutic potentials of tigernut are antimalarial, analgesic, antipyretic, astringent, demulcent, diuretic, hypoglycemic, diaphoretic, hepatoprotective, stomachic, hypotensive effects. Tigernut extract administered on Wistar rats result in delayed manifestation of diarrhea symptoms suggesting anti-diarrhea property of tigernut tubers linked to flavonoids and tannins present in the tubers [31].

Cyperus esculentus can be described as a healthy food material. This is as a result of numerous health benefits associated with regular consumption of tigernut tubers [3]. According to Ukpabi and Ukenye [58], tigernut tuber assigned a probiotic status could be attributed to resistant starch and soluble fiber content, mono-saturated fatty acid content, anti-sickling effect as well its antioxidant characteristics associated with general health benefits. The antioxidant characteristics of tigernut tubers and its ability to bring about anti-sickling effect in those patients suffering from sickle cell anemia give tigernut tubers the status of a healthy food.

Although there are numerous health benefits attributed to consuming tigernut tubers, there is still some concern about its health effect in the liver. Ebojele and Ezenwanne [18] revealed that tigernut tubers possess heptatotoxic properties that could be of health concern when tigernut tubers or any of its products is consumed in large quantities for a lengthened period. In a related study carried out by Akpojotor et al. [59], the liver functions of rats were tested as to determine the effect of feeding the rats with ethanol extract of tigernut tubers. Their research findings revealed that tigernut extract could be detrimental to the liver. Hence, they cautioned consumers against consuming large quantity of tigernut over a long period.

10. ANTIMICROBIAL ACTIVITY OF TIGERNUT EXTRACT

Tigernut extract exhibit some level of antibacterial effect against numerous human pathogenic microorganisms such as *Escherichia coli*, *Staphylococcus aureus, Klebsiella pneumonia, Proteus vulgaris, Pseudomonas aeruginosa* and *Citrobacter freundii*. The amount of alkaloids, saponins and tannin present in tigernut is quite high. These antinutrients are responsible for the antimicrobial activity associated with tigernut extract. Krichène et al. [33] suggested that purification of bioactive compounds in tigernut could result in the development of novel antibiotic against

Salmonella typhi. The study carried out by [60] demonstrated that phenolic extracts of tigernut tubers possess antimicrobial activity against some bacteria. In essence, antimicrobial property of tigernut tubers is as a result of phytochemicals such as alkaloids, phenol, flavonoids and glycosides present in the tubers [49]. Hassan [14] reported that tigernut possess antibacterial and antimicrobial properties.

11. EDIBLE PRODUCTS OBTAINED FROM TIGERNUT TUBERS

Three main products obtained from *Cyperus esculentus* are tigernut milk, tigernut flour and tigernut oil. Development of other products involves any of the three main products of tigernut tubers or its combination. A ready-to-eat crunchy snack called gurundi can be produced using tigernut flour [24,42,61]. A highly nutritious beverage known as bambaranut-tigernut-coconut milk was prepared by [62] using tigernut-milk derived from tigernut tubers. Tigernut is used to produce 'kunuaya' which is a non-alcoholic, low viscous, sweet-sour beverage that has milky and creamy appearance. Tigernut milk is a common drink prepared locally in northern Nigeria. It has also gained huge popularity in southern Nigeria in recent times. Conventionally, kunu is prepared using cereals such as millet and sorghum but due to its low protein content, tigernut milk can be added to fortify it. A blend of tigernut tubers with millet or sorghum result to a product that has higher consumer acceptability than conventional kunu [24]. Using tigernut tubers, it has been possible to develop phyto milk of acceptable quality [8].

Yoghurt is a drink prepared by partially fermenting milk. Different flavorings can be added to yoghurt depending on consumer's choice [15,63]. Tigernut tubers used to prepare tigernut milk can further be used to prepare yoghurt-like drink [64]. Conventionally, skimmed cow milk is used for yoghurt production. Yoghurt from pure cow milk share similar quality attributes with yoghurt prepared using tigernut milk and cow milk composite. The use of tigernut milk and cow milk composite to prepare yoghurt is aimed at reducing the cost of yoghurt production without compromising its nutritional composition and therapeutic effects. Adgidzi et al. [15] was able to develop yoghurt-like products from tigernut tubers. It is possible to manufacture probiotic yoghurt using tigernut extract as a functional dairy food [56]. Products such as tigernut extract blended with yoghurt starter and tigernut milk blended with soybean milk is yet to be commercialized in Nigeria. The product tigernut-soymilk extract (TSME) is a source of high quality energy, protein, minerals and vitamins. Since tigernut tuber is a food suitable for children, grown-ups and sportsmen, TSME is also ideal for them. As a result of high energy content (starch, fat, sugars and protein) of tigernut tubers, it is recommended for sportsmen [6]. A product known as cyper-coconut yoghurt can be prepared using coconut milk blended with tigernut milk and commercially available starter used as source of lactic acid bacteria [63].

Obasi and Ugwu [65] in their study used a blend of vegetable milk obtained from tigernut tubers and melon seeds instead of cow milk to produce candy. Okudu and Ogbuike [26] also used tigernut milk to produce candy. In some countries, probiotic chocolate products are well known but it is still unpopular in Nigeria [66]. In order to diversify utilization of tigernut tubers as a snack, [46] were able to develop a chufa coated chocolate just like peanut coated with chocolate as children's food. The consumption of horchata is widespread as a soft drink in Spain. In horchata production, co-products can be separated into liquid (52.88%) and solid residue (47.12%) for other uses in the food industry. Similarly, sweetened tigernut extract are usually bottled and sold in Ghana. Ice cream production from blend of tigernut milk and cow milk was subjected to proximate, physicochemical and sensory evaluation by Umelo et al. [67]. Tigernut tubers can be used to add flavour to ice cream and biscuits during manufacturing of the product [45]. Fermentation of tigernut drink can yield some quantity of alcohol [53]. Tigernut tubers can replace maize completely or partially used in the production of *dakuwa* which is food popular among the northerners in Nigeria [22]. Studies on substituting tigernut flour with some quantity of flour from other sources such as wheat and the use of the composite flour to produce gluten-free biscuit, cake and bread had been carried out [29, 68]. In fact, tigernut tuber is regarded as one of the top rated nutritional crops used to supplement other diets. That is why tigernut tubers when processed can be used to fortify less nutritious drink like kunu [24].

Different treatment methods affect the quality of tigernut flour, tigernut oil and tigernut-milk. Okoye and Ene [69] reported that fermentation and germination of tigernut tubers used in preparation of tigernut flour resulted in higher protein, and

ash content than the flour obtained from tigernut tubers that were not subjected to the two processing methods. In a related study, [70] reported that different processing treatments also affected the sensory characteristics and microbiological quality of tigernut beverage. In terms of oil extraction from tigernut tubers, [71] reported that n-Hexane extraction efficiency is 86 %, its oil yield is 17.10 g or 19.01±0.11 cm^3 and the tigernut oil has a brighter and golden yellow colour compared with tigernut oil extracted using petroleum ether which resulted in 75% extraction efficiency, oil yield of 15.05 g or 16.72±0.12 cm^3 and the colour of the tigernut oil is brownish yellow tint. Tigernut in combination with coconut which grows abundantly in Nigeria were combined and used to produce yoghurt [72]. An interesting result from a combination of tigernut flour and tigernut milk was reported by [73] when they used both materials to prepare cookies. According to Akajiaku et al. [73], cookies made using tigernut flour enriched with cow milk had less acceptability than that made from tigernut flour enriched with tigernut-milk [73]. A natural energizing drink called tigernut juice is produced when tigernut tubers are crushed and the slurry is mixed with cinnamon, sugar and vanilla. This drink gives consumers a feeling that is so refreshing [3,32]. Figs. 7, 8 and 9 shows the picture of three main products obtained from tigernut tubers. Other edible products that could be developed using tigernut tubers are listed in Table 10. Also listed in Table 10 are useful applications of tigernut tubers as non-edible products.

11.1 Tigernut Milk

Tigernut milk is an edible light brown coloured liquid extract obtained from tigernut tubers. In Spain and Ghana, tigernut milk is known as 'chufa de horchata' and 'Atadwe' respectively [42]. Tigernut milk is a sweet, non-dairy, nutritious, energetic and diuretic drink. It contains reasonable quantity of minerals predominantly phosphorus and potassium. Tigernut milk also contains vitamins C and E [22]. Tigernut milk also contains reasonable quantity of carbohydrate, fats and proteins required to meet daily human nutrition needs.

Interestingly, tigernut milk contains higher quantity of iron, magnesium and carbohydrate than cow milk. However, the protein content of cow milk is higher than that of tigernut milk. The protein content of tigernut milk is 6.05% [1]. The low protein content of tigernut milk can be boosted by blending it with milk from other sources. Bambaranut-tigernut-coconut milk beverage blends had been developed and its proximate composition and consumer acceptability determined by Adedokun et al. [74].

Due to increasing cost of cow milk in developing countries, attention is shifting to non-dairy milk such as tigernut milk [75]. More consumer acceptability and in-depth knowledge about

Fig. 7. Tigernut-milk

Fig. 8. Tigernut flour

Fig. 9. Tigernut oil

Table 10. Edible and non-edible uses of tigernut tubers (*Cyperus esculentus*)

Edible uses of tigernut	Non-edible uses of tigernut
Dakuwa, tigernut kunu, gurundi, tigernut-kunu, gurundi, bambaranut-tigernut-coconut milk, tigernut milk yoghurt, cyper-coconut yoghurt, horchata, ice cream, biscuits, chocolate, candy and tigernut-soymilk	Soap, perfumes, biofuel/biodiesel, starch, bait for fish, feeding livestock and cockerel starter (mash)

non-dairy milk is increasing due to factors such as dietary limitations, allergens, religious beliefs and moral principles of people of different tribes and races. In fact, tigernut milk is not only known for its nutritional benefits because recently it is also being considered as a medicinal drink [22]. Tigernut milk help control heart attacks and thrombosis; cause improvement in blood circulation and contribute in reducing risk of developing colon cancer [8]. Asante et al. [76] were able to compare expected milk solids (EMS) from tigernut-milk from brown and black variety tigernut tubers for industrial applications.

It is interesting to note that tigernut milk does not contain lactose and casein. As a result of this, tigernut milk is recommended to individuals who do not have the ability to tolerate gluten or lactose present in cow milk. Tigernut milk without refined sugar added to it is a suitable drink for people suffering from diabetes. Tigernut milk contains arginine which liberates the hormone that produces insulin. This makes tigernut milk suitable for people suffering from diabetes. In recent times, more individuals are becoming increasingly concerned about excessive consumption of foods and beverages that have high fat and cholesterol content. Therefore, products low in fat and cholesterol is highly recommended to the general public. As for those individuals that are lactose intolerant, non-dairy products such as tigernut milk is strongly recommended. Tigernut milk is preferred by diabetics because it does not contain sodium, lactose sugar, casein protein, gluten and cholesterol. Apart from being a drink for everyone, tigernut-milk is a special drink suitable to meet the nutritional requirements of certain category of people such as diabetics, lactose intolerance individuals, sports men and women [26,77,78].

Tigernut-milk drink can be subjected to fermentation using yoghurt starter to produce tigernut-milk yoghurt. Varieties of non-dairy products are derived from fermentation of tigernut milk. They are naturally prepared tigernut-milk drink, pasteurized tigernut-milk drink subjected to pasteurization, tigernut-milk drink subjected to sterilization, tigernut-milk subjected to ultra-high temperature sterilization and condensed tigernut-milk drink [50,78,79]. Concentrated and condensed tigernut milk is subjected to pasteurization, sterilization or ultra-high temperature sterilization in order to reduce or completely eliminate microbial contamination of the product so that the shelf life of the product is prolonged [33,50].

In a related study, three varieties of tigernut tubers were separately used to prepare tigernut milk that were subjected to spontaneous fermentation. Wakil et al. [50] determined the nutritional composition of a fermented tigernut-milk drink prepared using a starter culture comprising lactic acid bacteria isolated from spontaneously fermenting tigernut-milk drink. The researchers also carried out microbial analysis of the product. Although fermented tigernut milk contains some level of alcohol, it is generally considered as a non-alcoholic beverage because its alcohol content is very low [80].

A probiotic yoghurt manufactured with tigernut extract as a functional dairy food was formulated by El-Shenawy et al. [56] using a conventional yoghurt starter together with *Bifidobacteria bifidum* as a probiotic strain. Oligosaccharides, sucrose, amino acids and peptides contained in soybean stimulate microbial growth. Sensory characteristics of probiotic fermented soybean beverages are comparable with traditional yoghurt [81]. Table 11 compares the physicochemical and proximate composition of tigernut milk and a popular brand of dairy milk in Nigeria. The mineral content of tigernut milk is depicted in Fig. 10.

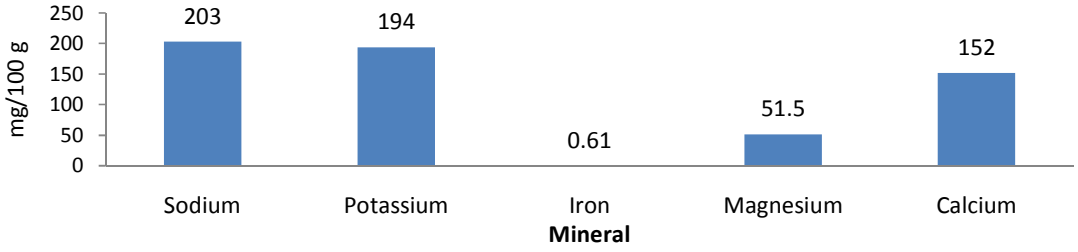

Fig. 10. Mineral content of tigernut-milk drink
Source: Obasi and Ugwu [65]

Table 11. Physicochemical and proximate composition of tigernut milk and a brand of dairy milk

Parameter	®Peak milk	Tigernut milk
Moisture (%)	96.00±0.14	84.60±0.41
Crude protein (%)	8.50±0.19	8.19±0.11
Crude fibre (%)	0.50±0.19	7.50±0.19
Crude fat (%)	9.70±0.20	25.50±0.60
Total ash (%)	1.50±0.01	1.80±0.02
Carbohydrate (%)	13.0±0.58	58.01±1.24
pH	6.63±0.03	6.64±0.13
Total titratable acidity (%)	0.17±0.02	0.15±0.05
Total solids (%)	14.21±0.10	12.28±0.25
Total Energy (Kcal)	173.58±0.01	501.55±0.25

Source: Chima et al. [82]

11.1.1 Fermented Tigernut-milk drink as alcoholic beverage

Fermentation of tigernut milk results in some quantity of alcohol such as ethanol to be released into the product. Alcohol is a product of fermentation which impact flavour to the product. Alcoholic drink is intentionally consumed by millions of people globally. Some people consume alcohol moderately by consuming certain diets which contain alcohol. Although excessive intake of alcohol has negative effects, it also has some health benefits. Recent studies have revealed that moderate alcohol consumption can give some level of protection against heart disease [83]. In fact, alcohol is used in preparation of cough syrups and some medications. Ethanol is a volatile compound effective as an olfactory and trigeminal stimulus which is used in preparation of dairy products such as eggnog and rum-raisin ice cream. Flavour enhancement and organoleptic attributes is associated with ethanol present in some products and can also function as a preservative in such products. A study to determine the effect of ethanol on yoghurt culture- *Lactobacillus delbrueckii ssp. bulgaricus* (LB-12) and *Streptococcus thermophilus* (ST-MS) was carried out by Mena and Aryana [84]. Their research findings is that ethanol incorporated in yoghurt did not have any influence in the *Lactobacillus bulgaricus* and *Streptococcus thermophilus* count. Therefore, therapeutic yoghurt that contains some quantity of ethanol could offer the human body some probiotic benefits. Ndubisi [85] monitored ethanol content of tigernut wine at different fermentation periods. The researcher reported that ethanol content of tigernut wine between 24-48 hr fermentation increased from 3.17-7.13%. Maduka [86] in a related study monitored ethanol content of spicy and non-spicy lactic fermented tigernut-milk drink during storage of the product at ambient and refrigeration temperature. The lactic culture involved in fermenting the spicy and non-spicy tigernut-milk drink is *Streptococcus thermophilus*, *Lactobacillus plantarum*, L. *acidophilus* and L. *brevis*. That study revealed that ethanol content of non-spicy lactic fermented tigernut-milk drink is higher than that of spicy lactic fermented tigernut-milk drink.

11.2 Tigernut Flour

Tigernut flour is a dry and fine powdery material obtained after grinding and sieving dried tigernut tubers. It has useful application in food formulations [7]. In fact, production of tigernut flour increases usefulness of tigernut tubers. A blend of tigernut flour in different proportions with other types of flour for the development of different products had been carried out by many researchers. The composite flour can be used to develop bakery products. Tigernut flour is a good replacement of wheat flour in the confectionery industry because its natural sugar content is reasonably high which makes the quantity of sugar that need to be added to the product to be reduced. The natural sugar content of tigernut flour makes it appropriate to be used in flavouring ice cream and biscuits as well as used as an additive in the bakery industry. Since tigernut flour does not contain gluten, it is ideal for people who restrain themselves from diets that contain gluten because of health challenges linked to gluten. Tigernut flour obtained from brown variety tigernut tubers contain higher protein, fat, ash, potassium, manganese, magnesium and iron content than the flour obtained from yellow variety tigernut tubers. On the other hand, the flour obtained from the yellow variety tigernut tubers contain higher

carbohydrate, crude fibre, calcium, sodium and copper than the flour obtained from the brown variety tigernut tubers [39]. Fermentation of tigernut tubers before the dried tuber is ground into flour improves the nutritional content of tigernut flour [7]. Processing methods such as boiling and toasting of tigernuts before grinding it into flour also bring about a reduction in antinutritional factors such as phytate, tannin, oxalate, total polyphenols and alkaloids present in tigernut flour [50] Tigernut flour is very attractive to fish and therefore it is used in formulating bait [1]. A blend of pigeon, tigernut and wheat flour is a strategy that can be used to fortify protein content of biscuits [25,68]. The result presented in Table 12 shows the mineral content and proximate composition of tigernut flour obtained separately from yellow and brown tigernut varieties.

11.2.1 Tigernut tubers used as a weaning food

A very important requirement for weaning foods is for it to be highly nutritious because during weaning period, breast milk becomes inadequate to meet the nutrient requirement of a growing child. In developing countries, poor families and low income earners find it difficult to purchase highly nutritious commercially formulated brands of weaning food. Therefore, they resort to patronizing high starchy gruels which contain low protein and essential minerals as weaning diet. In order to meet the nutritional requirements of a growing child considering the purchasing power of most families in developing countries, the use of cheap and highly proteinous weaning food formulated using underutilized readily available raw materials such as tigernut becomes a good alternative. Tigernut can be used as a replacement for cereals to function as a weaning formula [63]. A blend of soybean and tigernut was used by Ikpeme-Emmanuel et al. [87] to develop a cheap proteinous weaning food which is of good quality. Since tigernut tubers is abundant in Nigeria, its utilization for preparation of weaning foods that majorly comprise cereals by low income earners in mostly rural areas is advocated for the wellbeing of growing children.

11.3 Tigernut Oil

Tigernut oil obtained from tigernut tubers has a golden brown colour and nutty taste [1]. The oil present in tigernut tubers contribute in making products developed using tigernut tubers have consistency and specific binding characteristics [11]. El-Naggar [88] studied the physicochemical characteristics of tigernut oil. Further studies to compare the quality of oil from two varieties of *Cyperus esculentus* L. tubers was carried out by [89,90]. Several studies had been carried out on the nutritional values, organoleptic properties, oil content as well as medicinal properties of tigernut oil [91]. In times of scarcity, tigernut oil can be used as a replacement for corn, soybean, olive and cotton seed oil. Comparative analysis of oil obtained from two varieties of *Cyperus esculentus* (yellow and brown) shows that oil yield from the yellow variety tigernut tubers is slightly higher than that of brown variety tigernut tubers. In a related study, [90] noted that free fatty acid (FFA) of oil from the brown variety tigernut tuber is higher than that of yellow variety tigernut tuber. For the edible purpose, tigernut oil with low free fatty acid (FFA) content is recommended but not for technical purposes [90].

Traditional method is used to extract oil from tigernut tubers for domestic use. In terms of production process, it is quite easy and involves natural cold pressing. From rhizome of tigernut, a non-drying oil (known as chufa) is obtained. Preference of tigernut oil to olive oil which has been the practice among Egyptians for thousands of years is because it is healthier oil [92]. The suitability of using tigernut oil in making salad is because the oil stays in a liquid form at refrigeration temperature [93].

The saturated fatty acids content of tigernut oil range between 170-180 g/Kg of which 120-140 g/Kg is palmitic acid and the rest mainly stearic acid. Considering the saturated fatty acids present, about 75 g/Kg of it is oleic acid and 90-155 g/Kg is linoleic acid. Essential fatty acids such as omega-3 (linolenic), Omega-6 (linoleic acid) and Omega-9 (oleic acid) are richly present in tigernut oil [94]. The oleic acid content of tigernut oil is high and due to its low polyunsaturated fatty acid (linoleic and linolenic acid), it has a higher oxidative stability compared to some other vegetable oils. The physical and chemical properties as well as fatty acid composition of tigernut oil were determined by Patrick et al. [95]. According to [21], rats fed tigernut oil experienced significant increase in their body weights and probably had lower accumulated lipids in its vital organs. Tigernut oil is ideal for cooking because at high temperature the oil is resistant to chemical decomposition. Tigernut oil has this property because during oil extraction, external heat is not required. Other uses of tigernut oil include manufacturing of body and hair creams [21].

Table 12. Mineral content and proximate composition of flour obtained from two varieties of tigernut tubers

Mineral element/constituent	Yellow tigernut flour	Brown tigernut flour
Calcium (mg/100 g)	155	140
Sodium (mg/100 g)	245	235
Potassium (mg/100 g)	216	255
Magnesium (mg/100 g)	51.2	56.3
Manganese (mg/100 g)	33.2	38.41
Phosphorus (mg/100 g)	121	121
Iron (mg/100 g)	0.65	0.80
Zinc (mg/100 g)	0.01	0.01
Copper (mg/100 g)	0.02	0.01
Moisture (%)	3.5	3.78
Fat (%)	32.13	35.43
Protein (%)	7.15	9.70
Ash (%)	3.97	4.25
Carbohydrate (%)	46.99	41.22
Crude fiber (%)	6.26	5.62
Energy scale (KJ)	1343.00	1511.00

Source: Oladele and Aina [39]; Adejuyitan [7]

Table 13. Effect of different preparation methods on physicochemical properties of tigernut oils

Parameter	Untreated	Soaking	Blanching	Roasting
Refractive index	1.464±0.16	1.4642±0.08	1.465±0.12	1.4651±0.24
Colour (as absorbance at 420 nm)	0.20±0.06	0.28±0.27	0.21±0.33	0.22±0.22
Acid value (mg/g oil)	7.23±0.35	10.78±0.28	8.48±0.11	8.97±0.42
Acidity (as % oleic acid)	3.64±0.33	5.42±0.25	4.26±0.17	4.51±0.21
Saponification value (mg/g oil)	200.71±0.44	198.98±0.58	199.14±0.38	201.24±0.30
Ester value (mg/g oil)	193.48±0.18	188.20±0.12	190.66±0.09	192.27±0.28
Iodine value (gI_2/100 g of oil)	72.35±0.33	71.82±0.38	71.89±0.40	72.94±0.52
Peroxide value (meq O_2 /Kg oil)	0.79±0.18	1.52±0.12	1.12±0.24	0.80±0.20
Unsaponifable matter (%)	1.71±0.18	1.26±0.28	1.52±0.24	0.46±0.36

Source: Adel et al. [11]

The phytochemical screening of tigernut oil from large (yellow) and small (brown) tigernut tuber varieties revealed that tigernut oil contain steroid, alkaloids, saponin and glycosides. The study further revealed that phenols, anthraquinone, terpenoids, tannins, flavonoids and phlobatanin were not present in the tigernut oil obtained from the two varieties of tigernut tubers [95]. The phytochemical composition of tigernut oil is an indication that the oil could have pharmacological benefits. In other words, tigernut oil could have various medicinal applications. The hepatoprotective effect of essential oils from tigernut explains why tigernut is used in folk medicine [94]. Optimization of tigernut oil extraction takes into account processing parameters required for efficient oil extraction to take place. Therefore, it is recommended that tigernut tubers should not be heated above 100 ^{o}C prior to oil extraction for optimum oil yield and reduction in peroxide value [92]. Mohammed et al. [96] reported that within a regulated temperature and concentration, *Cyperus esculentus* oil can be an effective corrosion inhibitor for Al-Si-Mg alloy. Since tigernut tuber approximately contains 36% oil, this oil crop can be used for biodiesel production [27]. Table 13 above shows the effect different preparation methods could have on the physicochemical properties of tigernut oil.

12. INDUSTRIAL APPLICATION OF TIGERNUT TUBERS

Since early times, utilization of tigernut tubers for the development of different products has always been done domestically until a few decades ago when the industrial application of tigernut tubers started in many countries. Tigernut tubers can be used to prepare starch. This biomaterial is useful

in some industries [97]. Tigernut can be used to manufacture soap, perfumes and biofuel in an industrial scale [38]. The starch obtained from tigernut in a solution forms a good paste, has stability, clarity and impressive adhesive strength. The characteristics of starch derived from tigernut tubers have useful application in the cosmetic industry [1]. The starch obtained from tigernut is affected by extraction method adopted. The starch gotten from tigernut is a non-hygroscopic powder. It is odourless and has a brilliant white colour. The size of tigernut tubers to a large extent determines the quantity of starch that could be obtained from the tubers. The variations in chemical composition of amylopectin and amylose which constitute the structure of starch determine the physicochemical properties of starch. The solubility of starch, the extent of swelling, the temperature at which starch will gelatinise, its water absorption capacity, pH and viscosity are physicochemical properties of starch [97]. Consideration of tigernut tubers as oil crop source for biodiesel production is as a result of its oil content. Biodiesel can be produced using tigernut oil blended with petro-diesel [98]. From the study, a blend of petro-diesel with tigernut diesel revealed that B10 and B20 are similar with the results of B100. In other words, tigernut oil blended with petro-diesel is suitable for biodiesel engines.

13. USE OF TIGERNUT TUBERS AS ANIMAL FEED

Tigernut tubers are majorly used as an edible plant material in Nigeria. It is also used for the purpose of feeding livestock. Because wild turkey likes tigernut tubers which serve as natural scratchers, the plant is used to attract and feed game. Ducks are fond of diving in wetland field where tigernut is planted [1]. Similarly, pigs are attracted to a field where tigernut is planted. Consumption of tigernut tubers by pigs makes the animal look fatter and enhances the taste of pork. Tigernut meal can be used to substitute maize in the diets of broiler starter and in catfish [99,100]. Tigernut tubers can be used to formulate a diet for cockerel starter (mash) [32]. Sourcing for cheaper, nutritious and readily available alternative materials for animal feed is for the economic benefit of poultry farmers. Tigernut tuber can serve this purpose [98]. It can also be used directly or combined with other food materials in feeding animals [101]. Tigernut meal can function as a potential source of energy to poultry and livestock. It can also be combined with ogi and incorporated into basal feed animal to function as animal growth enhancer [102]. In addition to using tigernut to feed animals, it can also be used as bait for fish because of its lysine content. Fish is attracted to tigernut after it has been ground into a smooth creamy powder [1].

14. CONCLUSION

Tigernut is popular because of its small-sized tuber which has a sweet nutty taste when it is chewed in its raw form. Further processing of the raw tubers yields three main products which are tigernut flour, tigernut milk and tigernut oil. Apart from the usual utilization of tigernut tubers and tigernut derived products for edible purposes, there are non-edible uses of products from tigernut tubers. Although utilization of tigernut tubers for different purposes had been practised since many centuries ago, this review has highlighted recent improvements in utilizing tigernut and tigernut derived products in order to massively drive utilization and commercialization of tigernut tubers in Nigeria and beyond.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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