Review Article

Contamination of Tigernut Tubers (*Cyperus esculentus*) and Tigernut-Derived Products of Economic Importance: A Review of Some Prevention Strategies

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ABSTRACT

Tigernut is a popular plant because of its sweet tubers (*Cyperus esculentus*) which has numerous benefits. Contamination of tigernut tubers which could be physical, microbial or chemical start in the field through post harvest processes, handling, packaging, storage and retailing. Any form of contamination of tigernut tubers could impact on overall quality and shelf life of tigernut-derived products. Although several studies had been carried out on the nutritional, antinutritional, physicochemical, sensory and microbiological quality of tigernut tubers as well as numerous edible tigernut-derived products, it is important to review recent research findings on contamination of tigernut tubers and popular tigernut-derived products in order to effectively implement prevention strategies. This will promote food safety and food security especially in developing countries such as Nigeria.

Keywords: Contamination; tigernut tubers, tigernut-derived products; prevention strategies; economic importance.

1. INTRODUCTION

Food contamination occurs when food gets in contact with potentially harmful microorganisms and/or substances. This could happen intentionally or unintentionally. As far back as 8,000 years ago, food contamination which affected some persons occurred. Since then till date, instances of food contamination are still occurring with severe casualties being recorded in some incidents [1]. Consumption of contaminated foods usually affect human health and in extreme cases leads to death. As human population is increasing globally, availability of non-contaminated foods at all times in sufficient quantity to guarantee 'food safety' and 'food security' is becoming more challenging [2, 3, 4] .

Food safety as defined by Codex Alimentarius Commission (CAC) is the assurance that food will not cause harm to the consumer when it is prepared and/or eaten according to its intended use [5]. Any unsafe food must not be placed on the market based on general food safety requirements stipulated by Regulation EC No. 178/2002 [6]. Food security is in existence among any group of persons when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life [7].

Nutrient rich diets are insufficient and unaffordable for many low income earners in developing countries like Nigeria [8]. Yet, there are many plants such as tigernut (*Cyperus esculentus*) that produce affordable tubers that are rich in nutrients but still considered as being underutilized. In order to balance population growth with agricultural productivity particularly in tropical and sub-tropical regions where many children are suffering from malnutrition, optimum utilization of tigernut tubers need to be promoted [9, 10, 11].

Tigernut is popular because of the sweet tuber [12]. It is a reliable source of food in times of food scarcity [13]. Since tigernut tubers are readily available in the market almost throughout the year, it is usually processed into different edible products. Maduka and Ire [14] reviewed the useful application of tigernut tubers in development of many edible products. However, several factors predispose these products to contamination. Microbial assessment of 'kunu-aya' which is a popular product of tigernut tubers in Nigeria revealed that the product had a high bacterial count, total coliform count and salmonella-shigella count [15, 16]. Local traders often expose fresh, dried and rehydrated tigernut tubers during retailing. This practice including activities in the field during harvesting and storage of tigernut exposes the tubers to contamination. Three types of contamination of tigernut tubers could occur.

They are physical, microbial and chemical contamination. Retailing contaminated tigernut tubers and/or edible tigernut-derived products poses a public health risk [17, 18].

Therefore, this review article is aimed at categorizing contamination of tigernut tubers and tigernut-derived products, share recent information related to contamination of these products as well as prevention and control measures required to mitigate contamination of these edible products for economic gains.

2. Contamination of tigernut tubers

The physicochemical properties of tigernut tubers as well as existing environmental condition where tigernut is grown and the tubers stored could influence microbial contamination of the tubers. Chemical contamination of tigernut tubers could occur in the field or during storage. Physical contamination of tigernut tubers is very common. Therefore, contamination of tigernut tubers could be conveniently grouped as physical, chemical or microbial.

During harvesting of tigernut tubers, the tubers are usually gathered with foreign materials such as soil, insect or damaged tubers from the field. The part of a growing plant where the edible part is located determines its level of contamination. Generally, the edible part of a plant that develop in the soil as well as the ones that touch the soil surface are more predisposed to contaminants than those located at the aerial parts of the plant. Therefore, tigernut tuber is likely to be contaminated in the field because the tubers develop under the soil [19].

Microbial contamination of tigernut tubers can also occur during handling of the product by vendors. Several studies had been carried out to ascertain the level of microbial contamination of ready-to-eat tigernut tubers retailed in different localities [18, 19]. Table 1 and 2 shows identified parasites in tigernut tubers retailed in different markets. Similarly, Figure 1 shows the total plate count of wash water of tigernut sampled from two states in Nigeria.

Several pathogenic bacteria species have been isolated from exposed tigernut tubers. The presence of *Escherichia coli*, *Streptococcus faecalis* and *Staphylococcus aureus* from exposed tubers is an indication that faecal contamination occurred. This could be traced to irrigation water used in the tigernut farm. According to Chukwu et al. [20], fungi associated with fresh tigernut tubers are *Aspergillus niger*, A. *flavus* and A. *terreus* while that of dried tubers is *Penicillium citrinum* and A. *fumigates*. Table 3 shows the mean microbial loads of washed and unwashed tigernut tubers. The parasite recovery at various washes of tigernuts from different markets is presented in Table 4.

Table 1. Parasites recovered from tigernuts from markets in Calabar

Parasites	Sampling site (Markets)				
	Marian (%)	Ikot Ishie (%)	Watt (%)	CRUTECH Gate (%)	Total (%)
Ascaris lumbicoides (Ova)	2 (18.2)	3 (25.0)	6 (50.0)	4 (44.4)	15 (34.0)
Trichuris trichiura (Ova)	2 (18.2)	3 (25.0)	2 (16.7)	2 (22.2)	9 (20.5)
Strongyloides oocysts	3 (27.3)	3 (25.0)	1 (8.3)	2 (22.2)	9 (20.5)
Cyclospora cayetanensis	4 (36.3)	3 (25.0)	3 (25.0)	1 (11.1)	11 (225)
Total no. (%)	11 (25.0)	12 (27.3)	12 (27.3)	9 (20.4)	44

Source: Ogban and Ukpong [21]

Table 2. Parasites identified on tigernuts from various locations in Accra

Parasites	Locations				
	UTC area	Shangrila area	Madina area	Airport	Total no. (%)
Strongyloides stercoralis larvae	9	-	-	-	9 (22.5)
Ancylostoma duodenale ova	10	-	-	-	10 (25.0)
Cryptosporidium parvum oocysts	7	5	-	-	12 (30.0)
Cyclospora cayetanensis	4	3	2	-	9 (225)
Total no. (%)	30	8	2	0	40 (100)

*No parasites were found in the tiger nuts bought from market places. Source: Ayeh-Kumi et al. [22].

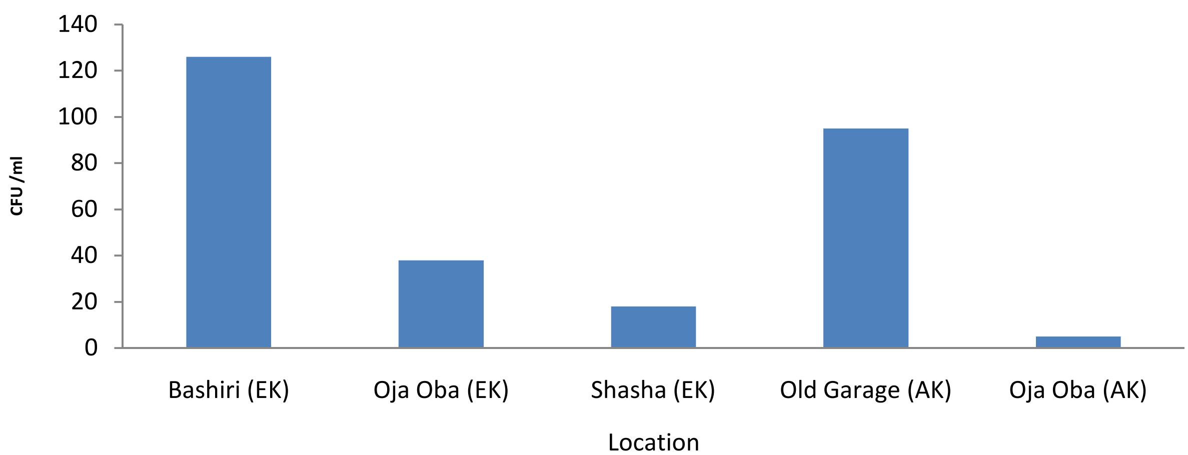

Fig-1
Total plate count of wash water (CFU ml^{-1}) of tigernut sampled in Ado Ekiti and Akure metropolis
EK = Ekiti; AK = Akure; Source: Akomolafe and Awe [19].

Table 3. Mean microbial loads* of the washed and unwashed experimental tiger nuts

Sample	Bacteria (cfu/g x 10^3) at 37 °C, 24 h	Fungi (cfu/g x10^3) at 26 °C, 48 h
Dried (unwashed)	23^a	15^a
Dried (washed)	19^b	9^b
Rehydrated (unwashed)	13^c	9^b
Rehydrated (washed)	7.0^d	5^c

*Values in a column with the same letter are not significantly different (P=0.05).
Source: Ukpabi and Ukenye [18]

Table 4. Parasite recovery at various washes of tiger nuts from different markets

Tigernuts (100 g)	Frequency of wash (% parasite recovery)			Total (%)
	W_1	W_2	W_3	
Dry nuts	14 (70.0)	5 (25.0)	1 (5.0)	20 (45.5)
Fresh nuts	11 (45.8)	10 (41.6)	3 (12.5)	24 (54.5)
Total (%)	25 (56.8)	15 (34.1)	4 (9.1)	44

N/B: $W_1 – W_3$ = 1st to 3rd wash
Source: Ogban and Ukpong [21]

2.1 Physical contamination

This could be considered as the commonest type of contamination of tigernut tubers. Physical contamination of tigernut tubers which usually occur during harvesting of the tubers involves foreign materials such as stone, sand and animal droppings mixed with freshly harvested tigernut tubers. Other sources of contamination could be from composted organic matter, insects and soil. Physical contamination from these sources is most likely to cause microbial contamination of tigernut tubers. Chewing foreign material together with tigernut tubers can cause serious discomfort to the teeth. Therefore, any foreign material gathered with tigernut tubers should carefully be removed before using the tubers to produce edible products. Although physical contamination of tigernut tubers could be considered as being prevalent, the contaminants involved is easy to identify and remove [22]. Ability to design suitable machinery and processing equipment for tigernut tubers based on engineering properties of the tubers could significantly reduce physical contamination of the tubers [23, 24].

2.2 Chemical contamination

Tigernut tubers could be contaminated by chemical substances used in the field. Chemical residues in tigernut tubers could have long term effect in the human body if consumed in large quantity. Results obtained from investigating possible chemical contamination of tigernut tubers are scarce. However, Chukwu et al. [20] in their studies reported that tigernut tubers contain some quantity of lead. According to the result of their analysis, fresh tigernut tubers contain 0.36±0.0895 mg/100 g lead whereas dried tigernut tubers contain 2.05±0.112 mg/100 g lead. According to Al-Shaikh [25], lead is regarded as a major environmental pollutant which is implicated in industrial pollution. The presence of lead in human body inhibits haemoglobin synthesis. Therefore, Chukwu et al. [20] advised people not to eat too much quantity of tigernut tubers in order to reduce intake of large quantity of lead.

One interesting study by Al-Shaikh et al. [25] demonstrated that *Cyperus esculentus* extract had a regenerative effect when administered on male rats which had their testicular histology destroyed by lead acetate. Disinfection of tigernut tubers using 1 % chlorine for a minimum of 30 minutes before using the tubers to produce 'horchata' could result in chemical contamination of the product if excess quantity of the germicide is used [26].

Possible contamination of tigernut tubers by mycotoxins which are secondary metabolites produced by toxigenic species of *Aspergillus* is a health concern because tigernut tubers is commonly eaten as raw tubers without subjecting the tubers to any treatment that will reduce the level of contamination [27]. *Aspergillus flavus* and *A. parasiticus* is largely responsible for aflatoxin production which usually contaminate some stored food products. Shamsuddeen and Aminu [27] reported the presence of aflatoxin in some samples of tigernut tubers evaluated which range between 0.2 - 23.0 µg/Kg. Consumption of stored nuts, cereals and grains contaminated with aflatoxin above allowable limit has serious health implications. Studies have shown that aflatoxin is hepatotoxic and has potential of being hepatocarcinogenic in animals. In other words, aflatoxin could contaminate stored tigernut tubers as well as tigernut-milk [27, 28]. International commission on microbiological specifications for food (ICSMF) recommend that maximum acceptable limit of aflatoxin in foods is 1 x 10^5cfu/g [27]. According to CODEX alimentarius, maximum level of aflatoxins allowable in an edible product must not exceed 4 µg/Kg. A study to evaluate presence of aflatoxins in 'horchata' which is a popular tigernut-milk drink consumed in Spain reported that 4.5 % of the samples were contaminated. In a similar study, 10-120 µg/Kg of aflatoxins was reported in 35 % tigernut samples collected from different locations in Nigeria [28]. Shamsuddeen and Aminu [27] recommended that proper storage condition of raw tigernut tubers will help reduce fungi proliferation and quantity of aflatoxins that could contaminate the tubers [27].

2.3 Microbial contamination

Microbial contamination of tigernut tubers easily occurs and often undetected before the tubers are consumed. The source of microbial contamination could be from infected field workers, contaminated soil, irrigation water, wash tanks, harvesting equipment, fecal materials and transport vehicles. Growth of microorganisms in foods is usually influenced by factors such as product temperature, product-to-headspace, gas volume ratio, initial microbial loads and type of flora, packaging, barrier properties, storage condition and biochemical composition of the food [6]. The water used to apply fungicides and insecticides is a source of microbial contamination of tigernut tubers [19]. According to Okechukwu et al. [29], the use of water polluted with faecal matter to wash knives, polyethene bags and trays could also be a source of microbial contamination of tigernut tubers. Microbial contamination of ready-to-eat-tigernut tubers is largely attributed to unhygienic practices of vendors and inappropriate storage conditions.

Chewing fresh or dried tigernut tubers contaminated with pathogenic microorganisms increases the risk of ingesting mycotoxins such as aflatoxins, ochratoxins and fumonisins [30]. Microorganisms isolated from exposed tigernut tubers are *Bacillus subtilis*, *Staphylococcus aureus*, *Aspergillus flavus*, *A. niger*, *Fusarium solani*, *Saccharomyces cerevisiae*, *S. fibuligera* and *Candida pseudotropicalis*. Isolation of *Proteus vulgaris* from exposed tigernut tubers has a serious health implication in the sense that the bacteria demonstrated some level of multiple drug resistance [22]. An assessment of wholesomeness of tigernut tubers imported into Nigeria as snack food was carried out by Ukpabi and Ukenye [18]. Similarly, Ayeh-Kumi et al. [22] also carried out a survey of pathogens associated with exposed tigernut tubers sold in a Ghanaian city. Findings from the study showed that four different parasites and five bacteria genera were present on tigernut tubers being retailed in the markets. The presence of these pathogens in tigernut tubers sold in the market is a threat to public health [22].

2.3.1 Microbial contamination of tigernut-derived products

Microbial contamination of tigernut-derived products usually occurs as a result of unhygienic processing, handling, transportation and exposure of these products during retailing [18]. Microbial contamination of tigernut-derived products could be traced to microbial contamination of tigernut tubers used for production. A study carried out by

Arranz et al. [28] identified aflatoxin B_1 from samples of 'horchata' sold in Southern Europe. This is an indication that the products were contaminated with fungi that produce mycotoxins. The bacterial load of tigernut juice sold in many localities in Nigeria is quite high [15]. In Spain where tigernut beverages have been commercialized, a comparative study between microbiological quality of commercial and home-made tigernut beverage was determined. Findings from that study revealed that total viable count of all commercially prepared tigernut beverages were below the detection limit. However, *Enterobacteriaceae* (3.41-5.47 log CFU/ml), *Escherichia coli* (2.69 log CFU/ml), *Bacillus* spp. (1.79-2.47 log CFU/ml), yeasts (2.69-4.47 log CFU/ml) and moulds (3.63-4.47 log CFU/ml) were present in home-made tigernut beverages. These values did not exceed legislated levels [31]. In a related study, Onovo and Ogaraku [32] identified microorganisms associated with exposed and unexposed tigernut-milk. Results from their study revealed that frequency of occurrence of *Bacillus subtilis, Staphylococcus aureus*, *Aspergillus flavus*, *A. niger*, *Fusarium solani*, *Saccharomyces cerevisiae*, *S. fubiligera* and *Candida pseudotropicalis* isolated and identified from tigernut-milk samples are 13.04, 17.39, 4.35, 13.04, 13.04, 21.74, 13.04 and 4.35 %, respectively. On average, they reported that bacterial load in exposed and unexposed tigernut-milk samples are 1.2×10^3 cfu mL^{-1} and 0.2×10^3 cfu mL^{-1} , respectively. The presence of these microorganisms in tigernut-milk is considered a threat to public health because they are capable of producing toxic metabolites which can cause ill health in humans. Table 5 shows the microbiological load of tigernut-milk containing different concentration of chemical preservatives during ambient temperature storage for twelve days. Similarly, Table 6 shows the microbial load of tigernut drinks that contain natural preservatives stored at ambient and refrigeration temperature for eight days.

Table 5. Microbiological loads of tigernut-milk during ambient storage

Treatment	Microbial count (cfu/ml) [1,2,3,4]	
	Total viable count	Fungal count
Day one		
Past. Tigernut milk +0.08 % sodium benzoate	$1.33 \times 10^4 \pm 3.33 \times 10^{2b}$	$1.93 \times 10^2 \pm 2.3 \times 10^{1a}$
Past. Tigernut milk + 0.04 % sodium benzoate & 0.01 % sodium azide	$2.26 \times 10^4 \pm 8.71 \times 10^{2b}$	$1.96 \times 10^2 \pm 2.6 \times 10^{1a}$
Past. Tigernut-milk + 0.02 % sodium azide	$7.6 \times 10^1 \pm 8.0 \times 10^{0c}$	$1.3 \times 10^1 \pm 3 \times 10^{0b}$
Past. Tigernut milk without preservatives	$2.03 \times 10^b \pm 2.40 \times 10^{4a}$	$2.3 \times 10^3 \pm 1.85 \times 10^{2a}$
Day seven		
Past. Tigernut milk +0.08 % sodium benzoate	$5.66 \times 10^b \pm 1.45 \times 10^{ba}$	$4.00 \times 10^2 \pm 1.15 \times 10^{2D}$
Past. Tigernut milk + 0.04 % sodium benzoate & 0.01 % sodium azide	$6.70 \times 10^4 \pm 7.23 \times 10^{3a}$	$4.66 \times 10^2 \pm 8.8 \times 10^{1b}$
Past. Tigernut-milk + 0.02 % sodium azide	$1.3 \times 10^1 \pm 3.00 \times 10^{UD}$	$1.3 \times 10^1 \pm 3 \times 10^{Uc}$
Past. Tigernut milk without preservatives	$4.33 \times 10^6 \pm 8.81 \times 10^{5a}$	$7.86 \times 10^6 \pm 6.10 \times 10^{6a}$
Day twelve		
Past. Tigernut milk +0.08 % sodium benzoate	Too numerous to count	$9.5 \times 10^3 \pm 4.2 \times 10^{2b}$
Past. Tigernut milk + 0.04 % sodium benzoate & 0.01 % sodium azide	Too numerous to count	$9.2 \times 10^4 \pm 2.5 \times 10^{2C}$
Past. Tigernut-milk + 0.02 % sodium azide	$3.1 \times 10^1 \pm 1.2 \times 10^D$	$2.1 \times 10^1 \pm 1.5 \times 10^{ud}$
Past. Tigernut milk without preservatives	Too numerous to count	$1.2 \times 1.210^5 \pm 2.7 \times 10^{3a}$

[1]Each value is the mean ± Standard error of triplicate determinations
[2]Different letters within the column subset are significantly different ($p<0.05$)
[3]Bacterial isolates:- *Bacillus* spp., *Lactobacillus* spp., *Pediococcus* spp.
[4]Fungal isolates:- *Aspergillus niger*, *A. flavus*, *A. ochraceus*
Source: Akoma et al. [33]

Table 6. The effect of storage time (day) on the microbial loads of tigernut drinks treated with natural tropical preservatives

Analyses	Storage period (day)	Storage condition	Tigernut extract (control)	Tigernut + garlic	Tigernut + ginger	Tigernut + citric acid	Tigernut + ginger + garlic
Total viable count $\log_{10}$cfu/ml	0		< 1	< 1	< 1	< 1	< 1
	4	28 ^{o}C	1.7±0.022^{a}	1.22±0.044^{b}	1.62±0.058^{a}	1.00±0.051^{b}	1.11±0.115^{bc}
	8		4.68±0.017^{a}	4.28±0.012^{bc}	4.35±0.040^{b}	2.57±0.009^{d}	4.25±0.026^{bc}
Total viable count $\log_{10}$cfu/ml	0		< 1	< 1	< 1	< 1	< 1
	4	4 ^{o}C	1.40±0.009	< 1	1.37±0.033	< 1	1.09±0.018
	8		2.48±0.039^{a}	1.10±0.015^{b}	2.51±0.049^{a}	1.05±0.005^{b}	1.12±0.023^{b}
Fungal count $\log_{10}$cfu/ml	0		<1	<1	<1	<1	<1
	4	28 ^{o}C	1.53±0.027^{a}	1.34±0.031^{b}	1.58±0.015^{a}	1.03±0.014^{c}	1.38±0.016^{b}
	8		2.52±0.012^{a}	2.34±0.031^{c}	2.58±0.012^{a}	2.31±0.021^{c}	2.40±0.009^{b}
Fungal count $\log_{10}$cfu/ml	0		<1	<1	<1	<1	<1
	4	4 ^{o}C	1.25±0.029	< 1	1.25±0.012	<1	< 1
	8		2.71±0.018^{a}	2.16±0.012^{c}	2.56±0.021^{b}	1.09±0.009^{d}	1.06±0.008^{d}

[1]Each data is the mean + standard error of 3 determinations
[2]Different letters within the same row subset are significantly different at $p<0.05$;
[3]< 1 = no growth
[4]Each data is the mean + standard error of 12 member taste panelist determinations using 5-point hedonic scale where 1 = very bad, 2 =bad, 3 =neither good nor bad, 4 = good, 5=very good
[5]Different letters within the same row which are significantly different at $p<0.05$
Source: Nwobosi et al. [16]

3.0 Reduction in level of contamination of tigernut tubers and tigernut-derived products

It is advisable that contamination of tigernut tubers and tigernut-derived products is reduced to a safe level or completely eliminated before the product is consumed. Two methods - removal of foreign materials mixed with tigernut tubers and washing the tubers with potable water were adopted by Akoma et al. [33] before using the tubers to produce tigernut-milk drink. The following subsections highlight the processes recommended for reduction in level of contamination in tigernut tubers and tigernut-derived products.

3.1 Hand-picking of foreign materials

In order to remove foreign contaminants gathered with tigernut tubers, hand-picking of good tubers or careful removal of all foreign materials is recommended. The unwanted materials mixed with tigernut tubers are usually stones, sand, metal objects, plant remains, other grains planted in the field, animal droppings and damaged nuts. Different parts of the tigernut plant such as roots, small sticks, empty and broken nuts as well as the tubers damaged by parasites and insects could also be gathered alongside good tubers. Removal of these physical contaminants is usually done manually and the process is laborious. Recently, an automated system such as sieving systems and wet separating is employed by industries that use tigernut tubers for different purposes [25]. Before tigernut tuber is processed into tigernut-milk, it is necessary to hand-pick foreign materials gathered with the tubers and also remove all bad/cracked tubers. Otherwise, the taste and quality of tigernut-milk might be affected [34]. It is interesting to note that dehulling of tigernut tubers can significantly reduce microbial load of the tubers [35].

3.2 Use of extracts, antimicrobials, water and other solutions

Before raw tigernut tuber is chewed in its raw form, thorough washing of the tubers with potable water is recommended because it significantly reduces microbial load of tigernut tubers. In an attempt to reduce microbial contamination of stored tigernut tubers, Djomdi et al. [35] compared the effectiveness of dehulling and soaking tigernut tubers in $Ca(OH)_2$, 'kanwa' and vitamin C solution at 20 ^oC, 40 ^oC and 60 ^oC in reduction of microbial load in the tubers. The study revealed that soaking dehulled tigernut tubers in vitamin C proved most effective than other solutions. Other solutions such as phosphate buffered water and phosphate buffered water plus 1 % sodium hypochlorite have also been tested and found effective in reducing microbial load of tigernut tubers to a safe level fit for human consumption [36]. The practice of eating raw tigernut tubers stored for a long period without any treatment to reduce the level of aflatoxins in the tubers is not advisable because climatic condition in Nigeria favours fungal growth that result in mycotoxin contamination of stored food products. An interesting study by Omoniyi et al. [37] demonstrated that tigernut samples contaminated with aflatoxin B1 was reduced by 75 % and 67 % when the samples were treated with 50 % and 100 % (v/v) orange juice extract, respectively. Similarly, aflatoxin G2 in the tigernut samples was reduced by 75 % using 100 % (v/v) orange juice. Findings from that study showed that distilled water performed better in reducing the level of aflatoxins B2 and G1 than orange juice extract.

3.3 Use of packaging materials

Vendors usually use polyethylene bags to package fresh or dried tigernut tubers basically to make retailing of the commodity easier. Polyethylene bag is the most widely used and cheapest means of packaging in food and beverage industries [18]. Akomolafe and Awe [18] did a study to determine the effectiveness of using packaging materials such as polyethylene bags to reduce the level of microbial contamination of ready-to-eat fruits and vegetables including tigernut tubers retailed in some states in South Western Nigeria. Their findings was that tigernut tubers that had been washed, disinfected and packed inside polyethylene bags was prevented from being re-contaminated during retailing. Results from the study revealed that tigernut tubers at the wholesale points were heavily contaminated compared with the samples from retail points. Lower microbial load of tigernut tubers sampled at the retail points was attributed to washing of the tubers with water by retailers. However, *Staphylococcus* spp. was isolated from all the samples of tigernut tubers packaged with polyethylene bags from the retail points.

3.4 Industrial processing

Tigernut-derived products could either be home-made or subjected to industrial processing. Microbial assessment of home-made tigernut beverage which is not usually subjected to thermal methods of preservation revealed that it had higher microbial contamination than the ones produced by beverage industries that practice strict good manufacturing practices (GMPs) which also involves thermal methods of treatment. Some beverage industries that produce tigernut-milk drink expose the drink to gamma radiation to guarantee the wholesomeness of the drink. The effect of exposing tigernut-milk drink to gamma radiation in terms of its physicochemical, functional and sensory qualities was reported by Ukpabi and Ukenye [18]. The tigernut-milk drink subjected to gamma irradiation can as well be pasteurized to further reduce microbial load in the drink [38]. Implementation of Hazard Analysis and Critical Control Points (HACCP) plan and GMPs is required to drastically reduce microbial contamination of home-made tigernut beverages. This will improve its bacteriological quality to be like that of commercially-made tigernut beverages sold in Valencia Spain [31].

4. Preservation of tigernut tubers

Preservation of tigernut tubers is aimed at slowing down undesirable changes that occur in the tubers as a result of activities of spoilage microorganisms and chemical reactions. Different storage conditions are employed in preserving fresh tigernut tubers. The use of polyethylene bags by street vendors to retail and store tigernut tuber is a common practice in developing countries like Nigeria. Polyethylene bags have different thickness which could impact on shelf life of tigernut tubers. Akomolafe and Awe [19] reported that tigernut tubers left unpacked for 10 days at ambient temperature (25±1 ^{o}C) were better than the ones sealed inside polyethylene bags which experienced disease severity between 3.00 and 4.25. This result shows that preserving tigernut tubers inside polyethylene bags is not conducive for storage but beneficial in reducing recontamination of the tubers during retailing. Tigernut tubers sealed for 10 days inside polyethylene bag that has a thickness of 1 µm experienced a significant colour change compared with that of 7 µm thickness which experienced no colour change.

Storage of tigernut tubers in a refrigerator or freezer maintained at a constant temperature will prevent the tubers from changing its original colour as well as slow down microbial growth on the tubers which usually result in spoilage. Air tight container filled with tigernut tubers kept at ambient temperature (28±2 ^{o}C) is a suitable storage condition. The use of some artificial preservatives ensures that the unique qualities of tigernut tubers are maintained during storage. Shriveled and wrinkled tigernut tubers that are properly dried can store for a long time without undergoing spoilage. Tigernut tubers soaked inside water changed daily can remain fresh up to 10 days [39].

After fresh tigernut tuber is properly dried, the taste becomes better appreciated by many consumers [40]. Properly dried tigernut tubers can be preserved up to a year or more with minimal risk of being attacked by spoilage microorganisms [39]. The process of reducing moisture content of fresh tigernut tubers is a necessary step that ensures activity of spoilage microorganisms in the tubers are drastically reduced during storage. Therefore, dried tigernut tuber is easier to store than fresh tigernut tubers.

Bulk storage of tigernut tubers under anaerobic warm storage condition is not advisable because it encourages microorganisms that naturally occur on tigernut tubers to rapidly ferment the tubers. Under that condition, chemical spoilage products predominantly mycotoxins is released. However, if the environment where tigernut tubers is stored is well aerated and fumigated every 6 weeks against insects or bugs which cause damage to the tubers, it can be stored up to two years [39].

5. Preservation of tigernut-derived products

Chemical preservatives such as sodium azide has proven to be effective in extending the shelf life of tigernut derived products such as tigernut-milk and still maintain acceptable sensory characteristics of the product [33]. Sá id et al. [41] evaluated the combined effect of different processing treatments and preservation methods on the sensory characteristics and microbial quality of tigernut beverage. Addition of natural preservative to pasteurized tigernut-milk which was stored at refrigeration temperature proved an effective method to extend shelf life of freshly prepared tigernut-milk up to one week [15, 41]. Pasteurization and addition of preservatives reduces microbial load in tigernut-milk which can extend the product shelf life by few days [33]. However, during packaging of the product, recontamination might occur. This might reduce the product shelf life. According to Codex Alimentarius Commission, the acceptance level of microbes in a milk product should be less than 2.0 x 10^{5} cfu/ml [41].

Tigernut-soya milk extract and yoghurt-like products are popular tigernut-derived products that can be stored at room (28±2 ^{o}C) and refrigeration temperature (4±2 ^{o}C). However, *Bacillus* spp., *Saccharomyces* spp., *Staphylococcus aureus, Penicillium* spp., *Aspergillus flavus, Mucor* spp. and *Rhizopus* spp. can survive both storage conditions. Notwithstanding addition of preservatives to tigernut-milk, Nwobosi et al. [15] demonstrated that the products stored at 28±2 ^{o}C had a higher microbial count than similar products stored at 4±2 ^{o}C. Table 7 and 8 shows the total heterotrophic bacterial count of tigernut-soy milk extract stored at 4 ^{o}C and 28 ± 2 ^{o}C, respectively. Similarly, Table 9 and 10 shows the total heterotrophic fungal count of tigernut-soy milk extract stored at 4 ^{o}C and

28 ± 2 °C, respectively. The microorganisms isolated from tigernut-soy milk extract (YSME) during storage at both storage conditions are depicted in Table 11.

Table 7. Total heterotrophic bacterial count in cfu/ml of various tigernut-soy milk extract (TSME) under storage at 4 °C

Sample	Storage period (day)		
	0	7	14
A_R	NG	NG	NG
B_R	NG	NG	NG
C_R	NG	1.21×10^2	1.74×10^2
D_R	1.4×10^2	1.76×10^2	3.6×10^2
E_R	2.4×10^2	2.6×10^2	5.8×10^2
F_R	2.62×10^2	2.8×10^2	7.2×10^2

NG=No growth, Subscript R = Refrigerated; A= 100 % Tigernut milk + 0 % soymilk; B= 90 % Tigernut milk +10 % soymilk; C= 80 % Tigernut milk + 20 % soymilk; D = 70 % Tigernut milk + 30 % soymilk; E=60 % Tigernut milk + 40 % soymilk; F= 50 % Tigernut milk + 50 % soymilk

Source: Udeozor and Awonorin [34].

Table 8. Total heterotrophic bacterial count in cfu/ml of various tigernut-soy milk extract (TSME) under storage at 28±2 °C

Sample	Storage period (day)		
	0	7	14
A_R	1.0×10^2	6.1×10^2	1.31×10^5
B_R	2.1×10^2	9.6×10^2	1.69×10^5
C_R	4.9×10^2	1.28×10^2	1.72×10^5
D_R	6.8×10^2	4.9×10^2	2.01×10^5
E_R	2.8×10^2	8.4×10^2	2.12×10^5
F_R	3.04×10^3	2.51×10^2	2.35×10^5

NG=No growth, Subscript R = Refrigerated; A= 100 % Tigernut milk + 0 % soymilk; B= 90 % Tigernut milk +10 % soymilk; C= 80 % Tigernut milk + 20 % soymilk; D = 70 % Tigernut milk + 30 % soymilk; E=60 % Tigernut milk + 40 % soymilk; F= 50 % Tigernut milk + 50 % soymilk

Source: Udeozor and Awonorin [34].

Table 9. Total heterotrophic fungal count in cfu/ml of various tigernut-soy milk extract (TSME) under storage at 4 °C

Sample	Storage period (day)		
	0	7	14
A_R	7.8×10^2	9.6×10^2	9.8×10^2
B_R	7.7×10^2	8.3×10^2	9.2×10^2
C_R	6.9×10^2	8.7×10^2	8.92×10^2
D_R	3.17×10^2	5.9×10^2	6.3×10^2
E_R	1.48×10^2	1.68×10^2	1.71×10^2
F_R	1.21×10^2	1.81×10^2	1.92×10^2

NG=No growth, Subscript A = Ambient-stored; A= 100 % Tigernut milk + 0 % soymilk; B= 90 % Tigernut milk +10 % soymilk; C= 80 % Tigernut milk + 20 % soymilk; D = 70 % Tigernut milk + 30 % soymilk; E=60 % Tigernut milk + 40 % soymilk; F= 50 % Tigernut milk + 50 % soymilk

Source: Udeozor and Awonorin [34].

Table 10. Total heterotrophic fungal count in cfu/ml of various tigernut-soy milk extract (TSME) under storage at 28±2 °C

Sample	Storage period (day)		
	0	7	14
A_A	9.9×10^2	1.16×10^3	2.01×10^4
B_A	9.2×10^2	9.6×10^3	1.21×10^4
C_A	7.2×10^2	8.1×10^2	1.96×10^4
D_A	4.2×10^2	1.26×10^3	2.41×10^4
E_A	2.6×10^2	1.01×10^3	1.16×10^4
F_A	1.61×10^2	2.7×10^2	2.69×10^4

NG=No growth, Subscript R = Refrigerated; A= 100 % Tigernut milk + 0 % soymilk; B= 90 % Tigernut milk +10 % soymilk; C= 80 % Tigernut milk + 20 % soymilk; D = 70 % Tigernut milk + 30 % soymilk; E=60 % Tigernut milk + 40 % soymilk; F= 50 % Tigernut milk + 50 % soymilk

Source: Udeozor and Awonorin [34].

Table 11. Distribution of microflora isolated from tigernut-soy milk extract (YSME) during storage

Microorganism	Storage condition						
		A	B	C	D	E	F
Bacillus subtilis	Refrigerated	+	+	+	+	+	+
	Ambient-stored	+	+	+	+	+	+
Bacillus cereus	Refrigerated	-	-	-	-	-	-
	Ambient-stored	+	+	-	+	+	+
Staphylococcus aureus	Refrigerated	-	-	-	-	+	+
	Ambient-stored	+	-	+	+	+	+
Penicillium notatum	Refrigerated	_	_	_	+	-	-
	Ambient-stored	-	-	+	-	-	+
Aspergillus flavus	Refrigerated	-	+	+	-	-	-
	Ambient-stored	-	-	+	-	-	-
Rhizopus spp.	Refrigerated	+	+	+	+	+	-
	Ambient-stored	+	+	+	+	-	-
Saccharomyces spp.	Refrigerated	+	+	+	+	+	+

	Ambient-stored	+	+	+	+	+	+
Mucor spp.	Refrigerated	+	+	+	-	+	+
	Ambient-stored	+	+	+	+	+	+

A= 100 % Tigernut milk + 0 % soymilk; B= 90 % Tigernut milk +10 % soymilk; C= 80 % Tigernut milk + 20 % soymilk; D = 70 % Tigernut milk + 30 % soymilk; E=60 % Tigernut milk + 40 % soymilk; F= 50 % Tigernut milk + 50 % soymilk. Source: Udeozor and Awonorin [34]

6. Economic importance of tigernut and tigernut-derived products

The economic value of tigernut is majorly a function of the numerous edible and non-edible products obtained from tigernut tubers. Spain is well known for production of tigernut-milk popularly known as 'horchata de chufa'. Consumption of tigernut-derived products especially tigernut-milk has also gained popularity in many European countries [42]. The 'horchata' industry in Spain has considerable economic importance. Yearly, approximately 40-50 million liters of 'horchata' are manufactured in Spain according to an industrial production survey. In the retail market, this represents about 60 million euros [43]. Due to high demand of tigernut tubers, Spain import tigernut tubers from other countries. Nigeria, Niger, Burkina Faso, Benin, Mali and Ghana export tigernut tubers [28]. Annual tigernut production in Spain is approximately 3.3 million euros [43]. In Nigeria, Asogwa et al. [44] did a study to identify entrepreneurial skills that will enable women farmers in Benue State Nigeria to process tigernut tubers into milk as a strategy to fight poverty.

Cyperus esculentus being listed among top 20 worst weeds which usually result in loss in crop yield up to 50 % should not limit its utilization for economic benefits [45]. Since tigernut is an agricultural byproduct considered as being underutilized, Agbabiaka et al. [46] were able to show that raw and fermented tigernut discard meals have prospects of being incorporated into animal feedstuff because of its nutritional composition. This will translate to economic gain rather than posing a challenge to environmental cleanliness which has cost implication.

As a result of lactose intolerance which has become a major health concern to many individuals, the demand for lactose-free products which largely involves utilization of tigernut tubers has been on the increase. Globally, gluten-free retail market was $ 1.7 billion in 2011. The value increased to $ 3.5 billion in 2016. It is expected to hit $ 4.7 billion in 2020. Therefore, there is great opportunity for farmers and industrialists to increase their income by massive cultivation and large scale processing of tigernut tubers into useful products both for local consumption and export [47].

CONCLUSION

Contamination of tigernut tubers could either be physical, chemical, microbial or a combination of any of them. Consumption of contaminated tigernut tubers and utilization of the tubers to produce edible products will invariably result in contaminated tigernut-derived products if no further treatment to reduce or completely eliminate the contaminant is applied. Based on available information, there has not been any reported casualty as a result of consumption of contaminated tigernut tubers or tigernut-derived products. In order to maximize the potential of tigernut tubers and guarantee safe tigernut-derived products, it is important to prevent tigernut tubers and tigernut-derived products from any form of contamination.

COMPETING INTERESTS

The authors have declared that no competing interests exist.

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