



ORIGINAL RESEARCH ARTICLE

**THIN LAYER DRYING KINETICS AND INFLUENCE OF DRYING
TEMPERATURE ON THE PROXIMATE COMPOSITION OF TIGER-NUT
MILK POWDER**

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ABSTRACT

Milk derived from animal sources often contains anti-nutrient elements such as α -lactoglobulin, β -lactoglobulin, lactose and cholesterol, which can contribute to various health challenges. Plant-based milk alternatives, such as tiger-nut milk, offer a healthier option but often face limitations like short shelf life and high storage costs. This study aimed to investigate the drying kinetics and proximate composition of tiger-nut milk powder. Tiger-nut tubers were processed into milk from brown varieties and subsequently dried at 50, 60, and 70°C. Data obtained were fitted to five commonly applied drying mathematical models (Newton, Logarithmic, Page, Henderson and Pabis) to determine the one which predicted the drying kinetics of the milk more accurately. The dried powder was then analyzed for its proximate composition, including moisture content, crude fiber, carbohydrates, protein, lipids, ash, and pH using standardized procedures developed by Association of Official Analytical Chemists (AOAC). The best fit model for the drying kinetics analysis was determined using the coefficient of determination (R^2), with the Page model having the highest R^2 values of 0.998-0.999. This analysis revealed that the Page model accurately describes the drying behavior, with both drying time and equilibrium moisture content decrease as the drying temperature increases. The results also indicated that tiger-nut milk powder contains a moderate protein content (7.12-7.26%), a high carbohydrate content (63.68-64.17%), and relatively low levels of lipids (6.12-6.24%) and ash (1.42%). These findings suggest that tiger-nut milk powder has the potential to be a valuable plant-based food alternative. Future research should focus on determining its specific mineral composition, bioactive compounds, and potential health benefits.

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1.0 Introduction

Milk, an essential food for many people, is produced by mammals like cattle, sheep, goats, and buffalo and provides essential nutrients. Cow milk, which is the most consumed milk worldwide is reported by (Bouglé and Bouhallab, 2017) and (Paul et al., 2020) to provide essential nutrients including proteins (whey and casein protein), fat (palmitic acid, conjugated linoleic acids (CLA), α -linolenic acid (ALA), milk polar lipids (MPL), vitamins (vitamin A, vitamin B complex) and minerals (iron, calcium, magnesium, phosphorus) which have been described to have indispensable functions in the body's growth (both adults and adolescences), metabolism and maintaining health or well-being.

Milk is used daily in coffee, breakfast cereals and as an ingredient in cooking and baking (Sebastian and Davis, 2019). Unfortunately, milk from animal sources contain anti-nutrient elements such as α -lacto globulin and β -lacto globulin which causes food allergies in infants (Ah-Leung et al., 2007), lactose and cholesterol which are associated with some health challenges such as dietary disorders, milk-protein allergy and/or lactose intolerance which have been reported to affect about 70 to 75 % of the human population due to genetically decreased lactase enzyme production (Heine et al., 2017; Sebastian and Davis, 2019) and dietary constraints such as vegan diet and milk allergy (Helsing, 2019; Osthoff et al., 2010). It is also not accessible by the poor owing to its high cost and scarcity. Animal milk consumption is also linked with the increase in low-density lipoprotein as it contains saturated fatty acid and cholesterol (Lordan et al., 2018).

Owing to these and other problems associated with milk from animal sources, international organizations such as the WHO (World Health Organization), the FAO (Food and Agriculture Organization of the United Nations), and the IPCC (Intergovernmental Panel on Climate Change) urge a global shift to plant-based diets among which is plant base milk and reported by (2021) to be of high health benefits.

Plant-based milk is milk that is extracted from legumes (soya, lupins, peanuts, among others), cereals (oats, rice, spelt, corn, etcetera) pseudo cereal (quinoa, amaranth, teff, etcetera) nuts (almonds, hazelnuts, coconut, macadamia nuts, pistachios) and/or seeds (hemp seeds, flax seeds, sesame seeds, sunflower seeds) (Romulo, 2022), diluted in water, and similar to animal milk in appearance, texture, and use. Such milk has been reported to have different nutritional composition and taste depending on the raw material, method of production, and type of fortification (Sebastian and Davis, 2019). Sebastian and Davis (Sebastian and Davis, 2019) stated that all the nutrients provided by cow's milk can be obtained from suitable plant-based alternatives. Plant milk can also be obtained from other crops such as lupin, cashew, quinoa, flax, hemp, walnut, hazelnut, and tiger nut.

Because of its numerous nutritional and health benefits as well as its ever-increasing market potential, plant-based milk has been referred to as white gold by the Guardian in a report on the unstoppable rise of alternative milk. Among the sources of plant-based milk, tiger nut is one of the commonly available and underutilized ones found in Nigeria (Adebayo-Oyetero et al., 2019; Ayuba et al., 2020; Ogori et al., 2022). It contains an appreciable amount of healthy nutrients and has so many health benefits.

Tiger-nut (*Cyperus esculentus* L.) is a root tuber that is a member of the family Cyperaceae found in the Eastern Hemisphere, including Southern Europe, Africa, and Madagascar, as well as the Middle East and Indian subcontinent (Adebayo-Oyetero et al., 2019). It is also known as earth almonds or Zulu nuts (Okudu and Ogubuike, 2016). In Nigeria, it is called Ofio in Yoruba, Aya in Hausa, and Akiaawusa in Igbo (Bamishaiye and Bamishaiye, 2011). Three varieties namely black, brown, and yellow, are easily obtainable in the Country (Bamishaiye and Bamishaiye, 2011). Ayuba et al and Swati et al reported that the nuts help in the prevention and/or treatment of many diseases such as heart attacks, thrombosis, colon cancer and other cancers, obesity, diabetes, and gastrointestinal diseases. Tiger nuts are rich in protein, starch glucose, essential minerals such as phosphorus, potassium, vitamins E and C, fat, and sugar (Gambo and Da'u, 2014). They are also high in fiber, myristic, linolenic, and oleic acid which is heart-friendly and can help to prevent cardiac arrest (Adebayo-Oyetero et al., 2019; Asante et al., 2014). (Ayuba et al., 2020) found that regular consumption of tiger nuts could reduce the frequency of illness, particularly in sickle cell patients.. The nuts also aid the internal body mechanisms and prevent both constipation and diarrhoea (Adebayo-Oyetero et al., 2019; Bamishaiye and Bamishaiye, 2011).

Tiger-nut is a very useful raw material in such industries as gastronomic, pharmaceutical/medicinal, confectionery, and the biofuel. It is applicable in the manufacture of many useful products including food additives, coffee substitutes, malt caramel, beverages, fermented foods, flour for baking and vegetable oil, and it can be eaten as a snack (Asante et al., 2014; Frank, 2015). A very nutritional beverage called "horchata de chufa" in Spain, "atadwe" in Ghana, and "kunun aya" in Northern Nigeria is produced from Tiger-nut by soaking, milling, sieving and sweetening with flavors and sugar is gaining acceptability. But the Tiger-nut liquid milk has very low shelf life and its storage is energy intensive as the milk has to be stored in a temperature range of 40 to 70 °C making the use of such milk expensive as a result of the increase in the cost of electricity which is the main source of energy for running refrigerators (Paul et al., 2020; Torna et al., 2020). Even in favorable storage conditions, the shelf life

of such milk is very short as (Abdulfatai et al., 2013) reported that the shelf life of beverage drinks from Tiger-nut tuber is 24 hours. To increase the shelf life of Tiger-nut milk, reduce the cost of storage, and for ease of storage and transportation, the milk needs to be converted into powdered form as reports show that the shelf life of powder milk is far longer than that of liquid milk, and there is no need for refrigeration (Pal et al., 2016).

The process of converting liquid milk to powder is through drying which is achieved by reducing the moisture content of the milk to a level that prevents the growth and reproduction of spoilage-causing microorganisms and thus, minimizing many of the moisture-mediated deterioration reactions (Famurewa and Olumofin, 2015). Drying also lead to reduction in the bulkiness of the product thereby minimizing packaging, storage, and transportation costs and enabling storage of the product under ambient temperature to be achieved (Orishagbemi et al., 2000). But the drying process especially under high temperatures, does not only reduce the moisture content of the product but also affects some of its physical, proximate, and chemical compositions as well as its sensory properties.

The drying process involves the movement of moisture from the core of the products to the outer surface and then to the surroundings. The rate of moisture removal from produce is dependent on factors such as the initial moisture content of the product, the drying temperature, and the velocity of the drying medium among others. Chukwuma and Ozoma, (2006) reported that the characteristics and behaviour of the drying material can be described and represented using mathematical models. These models are used in designing and analysing drying systems (Famurewa and Olumofin, 2015). Several drying models such as Empirical Models among which include (page, Henderson and Pabis, Newton, Logarithmic and Two-term Models among others) (Akpınar, 2006), Semi-Empirical Models (modify page and Midilli Models) (Bryś et al., 2021) and Theoretical Models (Diffusion-Based Models, Capillary Theory and Film Theory) (Erbay and İcier, 2010) were developed by many researchers which are suitable to explain the drying behaviours of different products.

Therefore, this study is aimed at studying the drying kinetics of Tiger nut milk in a thin layer dryer, and investigating the effect of drying temperature on the proximate composition of milk powder. The study will therefore, provide the appropriate drying temperature for drying Tiger-nut milk to powder as well as the best-fit Empirical drying model for the drying process.

2. Materials and Methods

2.1 Materials Used

The Materials used in this study include: Brown Tiger-nut, Weighing Balance (aeAdam model number AE7681116, 2000g ×0.01g), Blender (EuroSonic Model Number: ES-910, Capacity: 1.8 Litres), Digital thermometer (Custom model number: CT-220 measuring range: -50 to +200 °C, Resolution: 0.1 °C), Modular Cold Room (Riva Cold, Model: MCRI, Temperature Range -50C to 5 °C), Drying Pan (Aluminum tray 25 by 40 cm by 3 cm deep), Hot Air Electric Oven (Genlab, Model OV/200/F/DIG-R38, 2 kW, temperature Range: 30 to 250 °C).

2.2 Sample Preparation

Brown Tiger-nut (*Cyperus esculent*) was procured from a Tiger-nut whole seller in the central market Bauchi metropolis, Bauchi State. The Tiger nuts were then sieved using a 12 mm sieve to remove sand, impurities, and other materials and then washed several times with clean water, sun dried, and stored in air-tight polythene bags for use in producing the milk. The initial moisture content of the Tiger nut was determined to be 32.4% wet basis using oven drying method at 105 °C.

2.3 Milk Extraction and Drying

The Tiger-nut milk was extracted following the procedure described by (Romulo, 2022) with some modifications. From the clean dried Tiger-nut, 450 g were soaked in twice its volume of water at 40 °C for 12 hours placed inside Genlab Hot Air oven (Model OV/200/F/DIG-R38) to maintain the temperature. The sample was then drained and washed in clean water. The moisture content of the sample was then determined using oven drying method at 105 °C to be 38.7%.

The soaked Tiger-nut was then ground using the kitchen blender (EuroSonic Model Number: ES-910) at high speed of 9,645 rpm for 5 minutes and filtered through cheesecloth to obtain Tiger-nut milk.

The quantity of water used in grinding the Tiger-nut and filtering the milk was twice the volume of the Tiger-nut after soaking. The liquid Tiger-nut milk was then pasteurized in a non-stick pan at 72 °C for 15 sec and stored in a refrigerator at 4 °C for 24 hrs before drying.

The liquid milk was dried in a hot air oven (Genlab, Model OV/200/F/DIG-R38) using shallow drying trays at three different temperatures: 50, 60, and 70 °C. The milk samples were weighed hourly to determine weight loss following the method described by (Abano *et al.*, 2021), which was used to study drying kinetics and drying time. The drying process continued until the milk was completely dry, as indicated by three consecutive weighs showing no change in weight.

At the end of the drying process, the equilibrium moisture content (m_e) was determined using oven drying method at 105 °C for 24 hours. The dried milk was then blended to powder using a blender and stored for proximate analysis. The whole process of milk production and drying was replicated 3 times to reduce error in the results.

2.4 Drying Kinetics of the Tiger Nut Milk

Data obtained from the drying tests as described in section 2.3 were used in analyzing the drying kinetics of the Tiger-nut milk powder thus:

2.4.1 Drying rate

The rate of drying of the Tiger-nut milk was determined using the Equation 1 (Abano *et al.*, 2021)

$$DR = \frac{M_{t+\Delta t} - M_t}{\Delta t} \quad 1$$

where: DR is drying rate, g H₂O/min, $M_{t+\Delta t}$ and M_t are moisture contents, g H₂O /g of dry solid at drying time t, Δt is drying time, min

The original moisture content of the milk, the moisture content during the drying process and the equilibrium moisture content were determined using Equation 2 and the data obtained were used to determine the moisture ratio.

$$M_t = \frac{W_0 - W_1}{W_1} \quad 2$$

where: M_t is Product moisture content at a specified time during the drying operation, g of water, W_0 is the weight of the sample before drying, g, W_1 is the weight of after dry, g

The moisture ratio was calculated using Fick's diffusion equation (Equation 3), as presented by Eunice (Eunice, 2018). The equilibrium moisture content was achieved by continuous monitoring of weight change until no further changes occurred. The calculated moisture ratios were then plotted against drying time to create a drying curve, from which regression equations for the drying of tiger-nut milk were developed

$$MR = \frac{M_t - M_e}{M_o - M_e} \quad 3$$

where: M_t is moisture content at time t, % dwb, M_e is equilibrium moisture content, % dwb, M_o is initial moisture content, % dwb.

2.4.2 Mathematical modeling of the drying process

The data obtained from the computation of moisture ration MR at different drying periods were used to develop an empirical model based on the assumption that resistance to water movement to the surface of the sample was negligible and that the resistance to water evaporation was concentrated on the surface of the sample (Abano *et al.*, 2021). This phenomenon is similar to Newton's law of cooling.

Five empirical drying models applicable to thin layer drying shown in the Equations 4 to 8 (Table 1) were used to study the drying behaviour of the Tiger-nut milk. The drying rate constant k , k_o and k_1 and drying coefficients a , b , c and n were determined using a nonlinear regression procedure on SPSS version 25 following the procedure described by Rasmussen *et al* 2021 and Yi *et al*, 2012 The goodness of the fit of each drying models was assessed using the coefficient of determination (R^2) as shown in Equation 9 and the model with the highest R^2 was selected to best describe the drying of the Tiger-nut milk.

Table 1: Mathematical models fitted to the drying data

Model Name	Equation	Reference
Newton	$MR = \exp(-kt)$... 4	(Jahanbakhshi <i>et al.</i> , 2020)
Logarithmic	$MR = a \exp(-kt) + c$... 5	(Coşkuner <i>et al.</i> , 2002)
Page	$MR = \exp(-kt^n)$... 6	(Eunice, 2018)
Handerson and Pabis	$MR = a \exp(-kt)$... 7	(Aviara and Igbeka, 2016)
Two term	$MR = a \exp(-k_o t) + b \exp(-k_1 t)$... 8	(Famurewa and Olumofin, 2015)

Where: t is time (min), k , k_o and k_1 are drying rate constant (min^{-1}) and a , c and n are drying coefficients.

$$R^2 = 1 - \frac{\sum(MR_{pre} - MR_{act})^2}{\sum(MR_{act} - MR_{act.avg})^2} \tag{9}$$

Where: R^2 is coefficient of determination, MR_{pre} is predicted moisture ratio, MR_{act} is Experimental moisture ratio, $MR_{act.avg}$ is the Average experimental moisture ratio

2.5 Validation of the Model

To validate the predictive accuracy of the selected models, the predicted moisture ratios were plotted against the experimental drying time for each of the three drying temperatures. Additionally, a plot of predicted moisture ratio against observed moisture ratio was created, and the R^2 value of the linear trend line fitted to this plot was evaluated. A closer R^2 value to 1 indicates a better fit between the predicted and observed data.

2.6 Proximate Analysis

The proximate composition of the dried Tiger-nut milk was determined using standard methods as follows: Crude protein content, mineral ash content, and crude fiber content were determined following the procedure given by the Association of Official Analytical Chemists (AOAC) (2000), crude fat content was determined using the Soxhlet method as reported by (Ndubuisi, 2009). Carbohydrate content of the milk was obtained by difference as reported by (Frank, 2015). The carbohydrate content was calculated by subtracting the sum of the protein, fat (lipid), fiber, and ash from the total dry matter. While the energy value of the milk was calculated by multiplying the mean values of the crude protein, fat, and carbohydrates by the At water factors of 4, 9 and 4 respectively (FAO, 2006) as reported by (Frank, 2015) and represented in Equation 10. The obtained energy values were converted to kilojoule (KJ) using a conversion factor of 4.184 (approximately 4.2) to multiply the energy values given in Kcal (Ndubuisi, 2009).

$$\text{Energy Value} = (4 \times \text{protien} + 9 \times \text{fat} + 4 \times \text{carbohydrate}) * 4.184 \tag{10}$$

2.7 Statistical Analysis

All the experiments were carried out in replications. The drying data and proximate analysis results were subjected to Analysis of variance (ANOVA) using SPSS version 23 to investigate the effect of drying temperature on the drying time and the various proximate composition of the milk.

3. Results and Discussions

The effects of drying temperature on the drying kinetics and proximate composition of tiger-nut milk powder were investigated. The results are presented below:

3.1 Drying Kinetics

Table 2 presents the results of modeling the drying behavior of tiger-nut milk at varying temperatures (50, 60, and 70°C) using five drying models: Newton, Logarithmic, Page, Henderson and Pabis, and Two-term. The table includes drying rate constants (k , k'), drying coefficients (a , b , c , n), and coefficient of determination (R^2) values for thin-layer drying.

All five models demonstrated a good fit for describing the thin-layer drying of tiger-nut milk, aligning with the findings of (Famurewa and Olumofin, 2015). A model with an R^2 value greater than 0.9 is generally considered to accurately represent the drying characteristics of a product. The R^2 values for all models in this study ranged from 0.936 to 0.999. The Newton model exhibited the least fit, with R^2 values between 0.936 and 0.945 for all three temperatures. The Henderson and Pabis model followed with R^2 values ranging from 0.857 to 0.962. The Page model demonstrated the best fit for all three temperatures, with R^2 values of 0.998 to 0.999.

Figure 1 illustrates the relationship between moisture ratio and drying time for both experimental data and the Page model at 50, 60, and 70°C. The plots indicate that moisture reduction begins after the first hour of drying for all three temperatures, suggesting a falling rate period. Drying at 50°C required 22 hours to complete, likely due to the lower energy of water molecules at lower temperatures. In contrast, drying at 60 and 70°C took 20 and 15 hours, respectively, as the higher temperatures increased the energy of the water molecules. The equilibrium moisture contents of the milk were determined to be 8.23%, 6.95%, and 5.78% for drying at 50, 60, and 70°C, respectively.

Table 2: Fitting of Thin Layer Drying of Tiger-nut Milk to Three Selected Drying Models

Drying Temperature °C	Newton Model		Logarithmic Model				Page Model			Handerson and Pabis			Two-term				
	k	R ²	A	k	C	R ²	K	N	R ²	a	k	R ²	a	k ₀	b	k ₁	R ²
50	0.115	0.936	1.394	0.077	-0.309	0.986	0.024	1.689	0.998	1.147	0.131	0.957	0.831	0.131	0.316	0.131	0.957
60	0.156	0.945	1.254	0.126	-0.158	0.982	0.040	1.679	0.999	1.141	0.175	0.962	30.563	0.080	-29.469	0.077	0.984
70	0.124	0.938	1.288	0.153	-0.190	0.980	0.052	1.756	0.999	1.142	0.223	0.957	34.791	0.096	-33.693	0.094	0.982

k, k₀ and k₁ are drying rate constants, a, b, c, and n are model constants and R² is the Coefficient of determination.

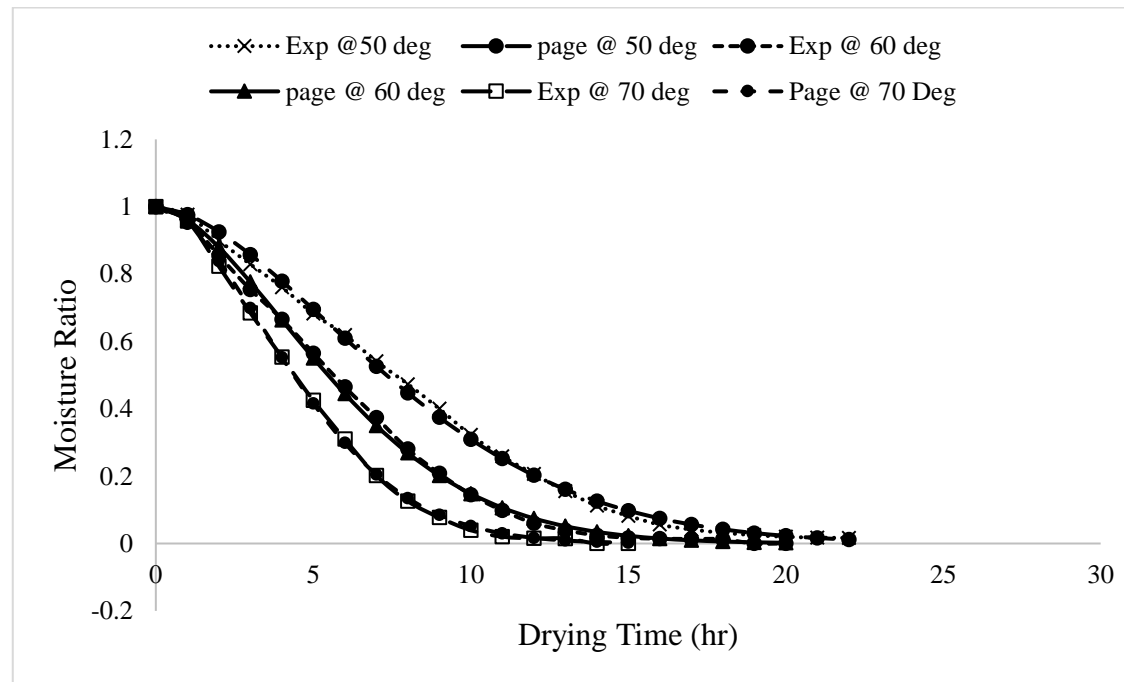


Figure 1: Experimental and Page Model Drying Curves for Tiger-nut milk dried at 50, 60 and 70 °C.

3.2 Proximate Composition Results

The analysis of variance (ANOVA) for the effect of drying temperature on the proximate composition of the tiger-nut milk powder is presented in Table 3. The ANOVA indicates that drying temperature significantly influences all the determined proximate components. Among the proximate compositions, carbohydrate content was most affected by temperature, as evidenced by the highest F-value of 61600.522. Other proximate components significantly impacted by temperature included crude fibre (F-value = 29606.173), pH (F-value = 9408.129), energy (kcal) (F-value = 7192.206), moisture content (F-value = 3433.836), energy (kj) (F-value = 2403.589), lipid content (F-value = 1444.895), ash content (F-value = 688.345), and crude protein content (F-value = 620.794).

Table 3: ANOVA for the effect of Temperature on the Proximate Composition of Tiger-nut Milk Powder

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Drying	Moisture Contain (%)	200.765	3	66.922	3433.836	<0.001
	Ash (%)	18.379	3	6.126	688.345	<0.001
Temperature (°C)	Crude Protein (%)	445.937	3	148.646	620.794	<0.001
	Lipid (%)	343.500	3	114.500	1444.895	<0.001
	Crude Fiber (%)	1382.608	3	460.869	29606.173	<0.001
	pH	159.938	3	53.313	9408.129	<0.001
	Carbohydrate (%)	36617.404	3	12205.801	61600.522	<0.001
	Energy (kcal)	1038790.258	3	346263.419	7192.206	<0.001
	Energy (kj)	17949558.582	3	5983186.194	2403.589	<0.001

Table 4 presents the mean proximate composition per 100 g of Tiger-nut milk powder for milk dried at 50, 60, and 70 °C with their respective standard deviations in parenthesis. The results indicated that drying temperature influences all the proximate elements.

Table 4: Proximate Composition of Tiger-nut Milk Powder per 100 g Dried at Various Temperatures

Drying Temperature (°C)	Moisture Contain (%)	Ash (%)	Crude Protein (%)	Lipid (%)	Crude Fiber (%)	pH	Carbohydrate (%)	Energy (kcal)	Energy (kj)
50	4.84	1.43	7.12	6.12	12.42	4.21	64.17	340.24	1423.56
	(0.15)	(0.1)	(0.3)	(0.29)	(0.11)	(0.06)	(.062)	(4.97)	(29.08)
60	4.81	1.41	7.22	6.18	12.39	4.23	63.76	339.54	1420.64
	(0.18)	(0.09)	(0.65)	(0.33)	(0.15)	(0.08)	(0.3)	(8.05)	(56.68)
70	4.51	1.42	7.26	6.24	12.36	4.2	63.68	339.92	1422.23
	(0.07)	(0.1)	(0.46)	(0.2)	(0.11)	(0.09)	(0.34)	(7.42)	58.39)

Values in the parenthesis are standard deviations of three replications

The moisture content of the Tiger-nut milk powder dried at 50 °C was 4.84% and is slightly higher than that of the milk dried at 60 and 70 °C which was of 4.81 and 4.51%, respectively. The moisture content range (4.84 to 4.51%) of the Tiger-nut powder milk was close to 4.15 ± 0.03 % obtained by Aidoo et al. (2010) for skimmed milk powder, 4.32 % and 4.89 % for Soymilk powder and Okara (soy pulp), respectively, reported by Osthoff et al. (2010). The moisture content of the Tiger-nut milk powder was found to fall within the safe and ideal storage moisture content of powder milk reported by Osthoff et al. (2010) and recommended by Codex Alimentarius (Marie et al., 2004).

The crude fiber content of the Tiger-nut milk powder was found also to be inversely affected by drying temperature to a lesser extent as the highest crude fiber content of 12.42% was found in milk dried at 50 °C which decreased to 12.39% for the milk dried at 60 °C while the least crude fiber content of 12.36% was obtained for milk dried at 70 °C. The fiber content of the Tiger-nut milk was found to be higher than 0.26%, and 2.58% found for skimmed milk powder, and dehydrated peanut-cowpea milk reported by Aidoo et al. (2010).

The Tiger-nut powder milk was found to have an average carbohydrate content of 63.76% for milk dried at 60 °C with a minimum and maximum values of 63.68% for milk dried at 70 °C and 64.17% for milk dried at 50

°C, respectively. Indicating that the milk contains large amount of energy. Closer carbohydrate content of 65.10% is reported for tiger-nut microencapsulation powder milk by Neto et al. (2019) but a far lower value of 2.21 and 10.73 % were reported by Ogori et al. (2022) and Abdulfatai et al. (2013) respectively for Tiger-nut milk. Protein is a vital component for living organisms, regulating body metabolism and serving as a storage form of carbon and nitrogen (Famurewa and Olumofin, 2015). The crude protein content of the tiger-nut milk powder in this study ranged from 7.12 to 7.26%.

Drying temperature was found to influence protein content, with lower temperatures resulting in lower protein levels and higher temperatures yielding higher protein content. This finding suggests that drying conditions can be optimized to maximize protein retention in the final product.

The protein content of the tiger-nut milk powder was comparable to the 7.69% reported by Frank (2015) for a similar product. However, it was lower than the 11-15% range for oat milk (Swati et al., 2016) and significantly lower than the 37.81% and 29.90% reported for soymilk powder and okara milk, respectively Osthoff et al. (2010). Additionally, the protein content was higher than the 4.43% reported for almond milk powder (Bueno, 2018) and exceeded the minimum recommended level of 2.2% for plant-based milk according to Drewnowski et al. (2021). While tiger-nut milk powder may not be as protein-rich as some other plant-based milk alternatives, its moderate protein content can contribute to a balanced diet. The influence of drying temperature on protein content provides opportunities for optimizing production processes to enhance the nutritional value of tiger-nut milk powder.

The lipid content of tiger-nut milk was found to increase with an increase in drying temperature as the least lipid content of 6.12% was found in the milk dried at 50 °C followed by 6.18% in milk dried at 60 °C with the highest lipid content of 6.24% found in the milk dried at 70 °C. The lipid content of the tiger-nut powder milk was found to be lower than 23.70% obtained by Neto et al. (2019) for tiger-nut milk produced by microencapsulation process and 22.44% for soymilk powder obtained by Osthoff et al. (2010) but is within the range of 9.01% for okara milk obtained by Osthoff et al. (2010) and 5–9 % for oat milk reported by Swati et al. (2016). Tiger-nut milk powder offers a relatively low-lipid content compared to some other plant-based milk alternatives, making it a suitable option for individuals seeking to reduce their dietary fat intake

The Ash content of the milk was found to remain around 1.42% which is below 3.16% for okara milk powder, 6.53, 7.5 and 8.11 % for soymilk powder, high milk protein powder and skimmed milk powder respectively reported by Osthoff et al. (2010), Marie et al. (2004) and Aidoo et al. (2010), respectively. The ash content of the tiger-nut milk powder was found to be within the same range as 2.43% obtained by Frank (2015) for tiger-nut milk powder and close to that of cow milk powder (5.72 %) reported by El- Sara (2009). The pH of the milk was found to be around the acidic range of 4.21 which is below 6.68 for soymilk powder (Osthoff et al., 2010), 6.73 for tiger-nut milk (Abdulfatai et al., 2013) and 6.70 to 7.03 for reconstituted tiger-nut milk (Neto et al., 2019). The pH of the tiger-nut milk was also lower than those of goat milk 6.80, cow milk 6.80 and camel milk 6.25 (El- Sara, 2009) but is higher than those of most fruit juices such as apple juice (3.61) and pineapple juice (3.67) (Abdulfatai et al., 2013).

Generally, the acidic nature of the milk may aid in digestion. Some studies suggest that acidic beverages can contribute to digestive processes (Wang et al., 2017). The energy content of the milk calculated using the At water factors remained around 339.92 kcal (1422.23 kJ) per 100 g of the milk as the drying temperature increased. This energy is above 170–200 kcal minimum energy recommended by (Drewnowski et al., 2021) for plant-based milk indicating that the milk has high energy content.

4. Conclusion

This study investigated the proximate composition and drying behaviour of tiger-nut milk powder, a promising plant-based milk alternative. Key findings include a balanced nutritional profile with a moderate protein content (7.12-7.26%), high carbohydrate content (63.68-64.17%), and relatively low lipid (6.12-6.24%) and ash (1.42%) levels. The Page model accurately represents the drying kinetics of tiger-nut milk powder, while drying time and equilibrium moisture content decreased with increasing temperature. These findings suggest that drying conditions can be optimized to improve the quality and efficiency of tiger-nut milk powder production. Tiger-nut milk powder offers a valuable addition to the plant-based food market. Its unique nutritional composition and potential health benefits warrant further research to explore specific mineral content, bioactive compounds, and their implications for consumer health.

References

- Abano, EE., Akanson, J. and Kizzie-hayford, N. 2021. Drying Kinetics and Quality of Whole, Halved , and Pulverized Tiger Nut Tubers (*Cyperus esculentus*). *International Journal of Food Science*, 2021: 1–11. <https://doi.org/https://doi.org/10.1155/2021/8870001>
- Abdufatai, J., Saka, AA., Afolabi, AS. and Kadiri Diana. 2013. Development and Characterization of Beverages from Tigernut Milk , Pineapple and Coconut Fruit Extracts Development and Characterization of Beverages from Tigernut Milk , Pineapple and Coconut Fruit Extracts . *Applied Mechanics and Materials*, 248: 304–309. <https://doi.org/10.4028/www.scientific.net/AMM.248.304>
- Adebayo-Oyetero, AO., Ogundipe, OO., Adeyeye, SAO., Akande, EA. and Akinyele, AB. 2019. Production and Evaluation of Tigernut (*Cyperus esculentus*) Milk Flavoured with Moringa oleifera Leaf Extract. *Current Research in Nutrition and Food Science*, 07(1): 1–7. <https://doi.org/10.12944/CRNFSJ.7.1.26>
- Ah-Leung, S., Bernard, H., Bidat, E., Paty, E., Rance, F., Scheinmann, P. and Wal, JM. 2007. Allergy to goat and sheep milk without allergy to cow's milk. *Allergy*, 61(11):1358–1365.
- Aidoo, H., Sakyi-Dawson, E., Tano-Debrah, K., and Firibu Kwesi Saalia. (2010). Development and characterization of dehydrated peanut–cowpea milk powder for use as a dairy milk substitute in chocolate manufacture. *Food Research International*, 43(1): 79–85.
- Akpınar, EK. 2006. Determination of suitable thin layer drying curve model for some vegetables and fruits. *Journal of Food Engineering*, 73(1): 75–84. <https://doi.org/https://doi.org/10.1016/j.jfoodeng.2005.01.007>
- Asante, FA., Ellis, WO., Oduro, I. and Saalia, FK. 2014. Effect of Soaking and Cooking Methods on Extraction of Solids and Acceptability of Tiger Nut (*Cyperus Esculentus* L) Milk. *Journal of Agricultural Studies*, 2(2): 76–86. <https://doi.org/10.5296/jas.v2i2.5991>
- Association of Official Analytical Chemists, (AOAC). 2000. *Official Methods of Analysis* (17th Editi). Association of Official analytical Chemists.
- Aviara, NA. and Igbeka, JC. 2016. Modeling for drying of thin layer of native cassava starch in tray dryer. *Journal of Biosystems Engineering*, 41(4): 342–356. <https://doi.org/10.5307/jbe.2016.41.4.342>
- Ayuba, LO., Bolarin, FM. and Chukwu, U. 2020. Effects of Conditioning on the Proximate/Chemical Composition of Tiger Nut Milk. *Global Scientific Journals*, 8(2): 3187–3196.
- Bamishaiye, El. and Bamishaiye, OM. 2011. Tigernut: As a plant, its derivatives and benefits. *African Journal of Food, Agriculture, Nutrition and Development*, 11(5): 5157–5170.
- Bouglé, D. and Bouhallab, S. (2017). Dietary bioactive peptides: human studies *Crit. Rev. Food Sci. Nutr*, 57: 335–43.
- Bryś, A., Kaleta, A., Górnicki, K., Głowacki, S., Tulej, W., Bryś, J. and Wichowski, P. (2021). Some Aspects of the Modelling of Thin-Layer Drying of Sawdust. *Energies*, 14(3): 726. <https://doi.org/https://doi.org/10.3390/en14030726>
- Bueno, F. 2018. *Almond Milk Powder Fortification with Flaxseed Oil (Linum usitatissimum) as an Alternative Non-Dairy Milk Powder for Infants and Toddlers*. Louisiana State University and Agricultural and Mechanical College.
- Chukwuma, P. and Ozoma, RT. 2006. *Tropical plant perishables, handling, storage and processing of food commodity series* (2nd ed.). Silicon valley publishers.
- Coşkuner, Y., Ercan, R., Karababa, E. and Nazlıcan, AN. 2002. Physical and chemical properties of chufa (*Cyperus esculentus* L) tubers grown in the Çukurova region of Turkey. *Journal of the Science of Food and Agriculture*, 82(6): 625–631.
- Drewnowski, A., Henry, CJ. and Dwyer, JT. 2021. Proposed Nutrient Standards for Plant-Based Beverages

Intended as Milk Alternatives. *Frontiers in Nutrition*, 8(761442): 1–9.
<https://doi.org/10.3389/fnut.2021.761442>

El- Sara, TESA. 2009. *Properties of Milk Powder Made From the Milk of Cow, Goat and Camel*. University of Khartoum.

Erbay, Z. and Icier, F. 2010. A Review of Thin Layer Drying of Foods: Theory, Modeling, and Experimental Results. *Critical Reviews in Food Science and Nutrition*, 50(5): 441–464.
<https://doi.org/https://doi.org/10.1080/10408390802437063>

Eunice, AM. 2018. *Modelling of Drying Kinetics and Quality Characteristics of Solar Dried Beef*. University of Nairobi.

Famurewa, JAV. and Olumofin, KM. 2015. Drying Kinetics and Influence on the Chemical Characteristics of Dehydrated Okra (*Abelmoschus esculentus*) Using Cabinet Dryer. *European Journal of Engineering and Technology*, 3(2): 7–19.

FAO, C. D. R. 2006. *Calculation of the Energy Content of Foods- Energy Conversion Factors*.

Frank, AA. 2015. *Process Development and Evaluation of Tiger Nut Based Chocolate Products*. Kwame Nkrumah University of Science and Technology, Kumasi.

Gambo, A. and Da'u, A. 2014. Tiger Nut (*Cyperus Esculentus*): Composition, Products, Uses and Health Benefits – A Review. *Bayero Journal of Pure and Applied Sciences*, 7(1): 56–61.
<https://doi.org/doi.org/10.4314/bajopas.v7i1.11>

Heine, RG., AlRefaee, F., Bachina, P., De-Leon, JC., Geng, L., Gong, S., Madrazo, JA., Ngamphaiboon, J., Ong, C. and Rogacion, JM. (2017). Lactose intolerance and gastrointestinal cow's milk allergy in infants and children - common misconceptions revisited. *World Allergy Organ J*, 10(41).

Helsing, L. 2019. *Comparison between conventional (animal origin) milk and milk from plant kingdom*.

Jahanbakhshi, A., Kaveh, M., Taghinezhad, E. and Sharabiani, VR. 2020. Assessment of kinetics, effective moisture diffusivity, specific energy consumption, shrinkage, and color in the pistachio kernel drying process in microwave drying with ultrasonic pretreatment. *Journal of Food Processing and Preservation*, 44(6): e14449.

Lordan, R., Tsoupras, A., Mitra, B. and Zabetakis, I. 2018. Dairy fats and cardiovascular disease: do we really need to be concerned. *Foods*, 7(29).

Marie, ECT., Joël, S., Sylvie, DB. and Stéphane, D. 2004. Milk Powders Ageing: Effect on Physical and Functional Properties. *Critical Reviews in Food Science and Nutrition*, 44(5): 297–322.
<https://doi.org/10.1080/10408690490464041>

Ndubuisi, LC. 2009. *Evaluation of Food Potentials of Tigernut Tubers (Cyperus Esculentus) and its Products (Milk, Coffee and Wine)*. University of Nigeria, Nsukka.

Neto, JJG, Gomes, TLM., Amaral, PFF., Leão, MHMR. and Gizele. C. Fontes Sant'Ana. 2019. Optimization of Tiger Nut Milk Microencapsulation Process : Evaluation of Solubility and Oxidative Stability. *International Journal of Advanced Engineering Research and Science (IJAERS)*, 6(12): 251–260.
<https://doi.org/https://dx.doi.org/10.22161/ijaers.612.22>

Ogori, AF., Julius, A. and Eche, OM. 2022. Quality property of beverage drink from Tiger nut milk , malted yellow maize blend. *Food Therapy and Health Care*, 4(2): 1–6.
<https://doi.org/10.53388/FTHC20220501011>.Executive

Okudu, HO. and Ogubuike, LA. 2016. Evaluation of chemical composition of candy developed from tigernut (*Cyperus esculentus*) milk. *African Journal of Food Science and Technology*, 7(1): 027–031.
<https://doi.org/http://dx.doi.org/10.14303/ajfst.2016.006>

- Orishagbemi, C. ., Ozumba, A. U., & Olatunji, O. 2000. Effect of Stimulated Shaded drying on the colour stability of dehydrated Okra. *20th Annual NIFST Conference, Federal Polytechnic Bauchi*, 103–105.
- Osthoff, G., Hugo, A., Wyk, P. Van, Wit, M. De and Meyer, S. 2010. Characterization of a Spray-Dried Soymilk Powder and Changes Observed During Storage. *Food Sci Tech Int*, 16(2): 169–178. <https://doi.org/10.1177/1082013209353236>
- Pal, M., Alemu, J., Mulu, S., Karanfil, O., Parmar, BC. and Nayak, JB. 2016. Microbial and Hygienic aspects of Dry Milk Powder. *BEVERAGE & FOOD WORLD*, 43(7): 28–31.
- Paul, AA., Kumar, S., Kumar, V. and Sharma, R. (2020). Milk analog: plant based alternatives to conventional milk, production, potential and health concerns *Crit. Rev. Food Sci. Nutr*, 60: 3005–3023.
- Rasmussen, LV., Hall, C., Vansant, EC., den Braber, B., and Olesen, RS. 2021. Rethinking the approach of a global shift toward plant-based diets. *One Earth*, 4(9): 1201–1204. <https://doi.org/https://doi.org/10.1016/j.oneear.2021.08.018>
- Romulo, A. 2022. Nutritional Contents and Processing of Plant-Based Milk: A Review. *5th International Conference on Eco Engineering Development. IOP Conf. Series: Earth and Environmental Science* 998: 1–9. <https://doi.org/10.1088/1755-1315/998/1/012054>
- Sebastian, J., & Davis, B. 2019. *Plant milk report*.
- Swati, S., Tyagi, SK. and Rahul, KA. 2016. Plant-based milk alternatives an emerging segment of functional beverages: a review. *Journal of Food Science and Technology*, 53(9): 3408–3423. <https://doi.org/10.1007/s13197-016-2328-3>
- Torna, E., Mendoza, D. R., & Wendy, J. D. 2020. *Plant-Based Milks: Almond*.
- Wang, X., Ye, A., Lin, Q., Han, J. and Harjinder, S. (2017). Gastric digestion of milk protein ingredients: Study using an in vitro dynamic model. *J. Dairy Sci.*, 101: 6842–6852. <https://doi.org/https://doi.org/10.3168/jds.2017-14284>
- Yi, XK., Wen-Fu, W., Zhang, Y. Q., Li, JX. and Luo, H. P. 2012. Thin-Layer Drying Characteristics and Modeling of Chinese Jujubes. *Mathematical Problems in Engineering*, 386214. <https://doi.org/10.1155/2012/386214>