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Effect of different temperatures and time on the physicochemical properties of tiger nut milk, in terms of pH, viscosity, and color

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Abstract
Heat pasteurization is sometimes detrimental to the visual and structural profile of tiger nut milk, which is a popular non-dairy alternative. This study investigates how to optimize temperature and time to provide maximum safety and try to minimize the physicochemical and aesthetic changes in the final beverage product. This study was carried out at Delta State University, Nigeria, to assess the effect of different pasteurization temperature and time on the quality of tiger nut milk. A 3x3 factorial design was used to evaluate the milk sensory, physicochemical, nutritional and microbial properties compared with an unpasteurized milk control sample and a 14 day shelf-life trial. Two-way ANOVA and advanced statistical models validated the data and ten semi-trained panelists carried out the sensory scoring using a nine-point hedonic scale. These results indicate that the pasteurization temperature and processing time have a significant and strong effect on the physicochemical properties of tiger nut milk. With increasingly harsh processing conditions, the milk becomes more acidic as the result of chemical reactions caused by the heat and organic acids being formed. At the same time, a unique thickening effect occurs in the drink, which is reflected by a gradual increase in the viscosity, caused by the gelatinization of starch and denaturation of proteins. Thermal treatment also leads to darkening of the milk, which is indicated by the reduction of lightness values, due to the degradation of the milk pigment, in addition to the Maillard reactions and caramelisation. Both temperature and time are found to have an effect on these changes, but temperature is found to be the more important of the two factors. Overall, the study highlights the significance of optimizing pasteurization conditions to ensure food safety while preserving the visual appeal and texture of tiger nut milk for food processors.
Keywords: Tiger nut milk, Pasteurization, Viscosity, pH, Color lightness.

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Introduction

Tiger nut milk is a plant-based beverage produced from the tubers of Cyperus esculentus, commonly known as tiger nuts. In recent years, this milk has gained global attention as a healthy, natural, and lactose-free alternative to conventional dairy milk. Its naturally sweet, nutty flavor, creamy texture, and rich nutrient composition make it an appealing choice for individuals seeking both nutritional and sensory satisfaction. Beyond its taste and mouthfeel, tiger nut milk offers a unique blend of carbohydrates, essential fatty acids, dietary fiber, and natural antioxidants that contribute to its functional and therapeutic value. As consumer demand for plant-based beverages grows, the processing and preservation of tiger nut milk have become increasingly important to maintain product quality and ensure safety for wider commercial distribution. However, like most plant-based beverages, tiger nut milk is highly susceptible to spoilage due to its rich nutrient content, moderate pH, and high moisture level. These conditions create an ideal environment for microbial proliferation and enzymatic degradation, which compromise its sensory attributes, nutritional value, and shelf life stability. As such, appropriate preservation techniques are essential to extend its shelf life, while maintaining desirable organoleptic properties such as flavor, color, and texture. Among various preservation methods, pasteurization stands out as a practical and widely used approach for liquid foods. The process involves controlled heating to eliminate pathogenic microorganisms and inactivate spoilage enzymes without compromising nutritional and sensory integrity. Balancing these outcomes, however, remains a challenge, as excessive heat may cause nutrient loss, while insufficient heat may fail to achieve microbial safety.

Tiger nut milk as a plant-based beverage, made from the tubers of Cyperus esculentus, is known for its creamy texture, slightly sweet taste, and nutritional benefits, including dietary fiber, unsaturated fatty acids, and essential minerals (Ahmed et al., 2019). Tiger nut milk, derived from the tubers of Cyperus esculentus, has garnered attention due to its nutritional value, rich flavor, and suitability for individuals with lactose intolerance. It serves as a non-dairy milk alternative that is high in fiber, essential fatty acids, and vitamins. However, it is prone to microbial spoilage,

necessitating preservation methods to extend its shelf life while retaining its nutritional and sensory qualities. Pasteurization is one of the key techniques employed to achieve this goal. Pasteurization involves heating the milk to a specific temperature for a defined duration to destroy harmful microorganisms while preserving essential nutrients. However, the process can influence the overall quality of tiger nut milk, including its taste, texture, color, and nutritional content. Various studies have shown that different combinations of pasteurization temperature and time can lead to diverse impacts on the physiochemical properties, sensory attributes, and microbial load of plant-based milk products.

The cultivation and consumption of tiger nuts can be traced back to ancient Egypt and the Mediterranean region, where these tubers were valued for their nutritional properties. Tiger nut milk, historically known as “horchata de chufa,” has been a staple beverage in Spain for centuries, particularly in the Valencia region. Traditionally made by soaking and grinding tiger nuts, this refreshing drink was initially consumed without any form of preservation, making it highly perishable and susceptible to spoilage (Meilgaard et al., 2015). As the consumption of tiger nut milk spread globally and gained popularity as a plant-based alternative to dairy milk, especially in recent years, there arose a need for better preservation techniques. This led to the exploration of pasteurization methods, a technique developed by Louis Pasteur in the 19th century. Pasteurization, originally used in the wine and dairy industries, was adapted to preserve non-dairy milk, including tiger nut milk, by inactivating pathogenic microorganisms while maintaining its sensory and nutritional properties (Nwachukwu & Ezeigbo, 2013).

Research into optimizing pasteurization conditions for tiger nut milk began in the early 21st century, driven by the increasing demand for safe, shelf-stable, and high-quality plant-based beverages. Initial studies revealed that different combinations of temperature and time significantly impact the milk’s physicochemical properties, including its nutritional content, flavour, colour, and texture. Higher temperatures and longer times effectively reduce microbial load but may lead to nutrient degradation and undesirable sensory changes, while lower temperatures may fail to ensure safety (Ade-Omowaye et al., 2018).

Tiger nut (Cyperus esculentus), also known as earth almond or chufa, is a small tuber widely cultivated in various regions, particularly in Africa and the Mediterranean. For centuries, it has been consumed due to its rich nutritional profile, providing dietary fiber, essential fatty acids, vitamins, and minerals. In recent years, tiger nut has gained popularity as a raw material for producing plant based milk, which serves as a lactose free alternative to conventional dairy milk. Tiger nut milk is valued for its creamy texture, slightly sweet taste, and numerous health benefits, such as aiding digestion and promoting heart health (Bamishaiye & Bamishaiye, 2011). Despite its benefits, the production and storage of tiger nut milk face challenges, primarily due to microbial contamination and quality degradation. Like most plant-based beverages, tiger nut milk is susceptible to spoilage, necessitating effective preservation techniques to maintain its safety, sensory attributes, and nutritional content. Among various preservation methods, pasteurization remains the most widely used in the food industry. It involves heating the milk to a specific temperature for a predetermined time to inactivate pathogenic microorganisms and reduce spoilage, thereby extending shelf life.

However, the shelf life of tiger nut milk is limited due to microbial spoilage and chemical changes that compromise its sensory and nutritional qualities (Okorie et al., 2020). Temperature and storage duration are key factors influencing spoilage, as higher temperatures and extended storage can accelerate microbial growth, enzymatic browning, and lipid oxidation (Adejuyitan, 2011). Despite its popularity, there is limited empirical data on the optimal conditions for extending the shelf life of tiger nut milk while maintaining acceptable sensory and quality attributes.

From the foregoing, pasteurization can significantly affect the quality of the milk, influencing its flavor, texture, nutritional value, and color. The combination of pasteurization temperature and time plays a crucial role in determining these effects. Researches indicate that higher temperatures and longer pasteurization times can lead to nutrient loss and undesirable changes in sensory properties, while inadequate pasteurization may fail to ensure microbial safety (Issah et al., 2019). Consequently, optimizing pasteurization conditions specific to tiger nut milk is essential to balance microbial safety with the preservation of its quality characteristics.

Tiger nut (Cyperus esculentus)**,** a perennial plant, native to Africa, is widely recognized for its edible tubers, which have been consumed for thousands of years. Despite its name, tiger nut is not a nut but a small tuber that is rich in nutrients such as fiber, healthy fats, vitamins, and minerals. Traditionally, it has been used in various forms, including raw consumption, roasted snacks, and even flour for baking (Belewu & Belewu, 2007). Due to its nutrient density and health benefits, tiger nut has become increasingly popular as an ingredient in producing non-dairy milk, particularly for individuals seeking plant-based alternatives to cow’s milk.Tiger nut milk, also known as “horchata de chufa” in Spain, is a creamy, slightly sweet beverage that offers a high level of dietary fiber, unsaturated fatty acids, and antioxidants. It is also naturally lactose free, making it suitable for those with lactose intolerance or milk allergies (Ahmed et al., 2019). Tiger nut (Cyperus esculentus), also known as earth almond has been widely cultivated for its edible tubers, from which tiger nut milk is made. The milk is a popular non-dairy alternative due to its creamy texture, nutty flavor, and rich nutritional content.The milk has been reported to support digestive health, reduce cholesterol levels, and provide a rich source of essential minerals like potassium and magnesium (Agbaje et al., 2019). Despite its appeal, tiger nut milk is prone to rapid spoilage due to microbial growth, which can affect its safety and shelf life. To mitigate this, pasteurization is commonly employed.

Pasteurization is a key process in extending the shelf life of tiger nut milk by inactivating harmful microorganisms and enzymes that can spoil the product. Recent studies have demonstrated that temperature and time are critical determinants of the quality and stability of pasteurized tiger nut milk. The interaction between these two factors influences not only microbial reduction but also changes in physicochemical and sensory properties such as pH, viscosity, color, flavor, and overall acceptability (Abolhasani & Shaterian, 2020; Agarry & Nkama, 2021). Excessive thermal exposure can lead to undesirable alterations such as protein denaturation, lipid oxidation, and vitamin degradation. Whereas, mild treatments may preserve nutrients but shorten shelf life due to

inadequate microbial control (Dannenberg & Lipp, 2021). Consequently, optimizing the pasteurization parameters, specifically temperature and holding time is crucial to achieving a product that is both microbiologically safe and organoleptically appealing. The quality characteristics of tiger nut milk, including its sensory attributes, physicochemical stability, and nutritional composition, are significantly influenced by processing variables. Parameters such as pH and total solids determine product consistency, while sensory properties such as color, flavor, and texture govern consumer acceptability (Coelho & Ferreira, 2022). Pasteurization at moderate temperatures (60°C–80°C) has been reported to enhance microbial safety while retaining nutritional and sensory quality, provided that exposure times are well controlled (Bhatt & Joshi, 2022). Furthermore, post pasteurization storage temperature also plays a vital role. Refrigeration can considerably slow down microbial and enzymatic reactions, thereby prolonging shelf life (Choi & Kwon, 2020). Understanding how these factors interact provides the scientific basis for standardizing tiger nut milk processing protocols suitable for both artisanal and industrial applications.. However, excessive heat may degrade certain nutrients such as vitamin C and proteins, leading to a reduction in overall quality. The pasteurization process which involves heating the milk to specific temperatures for set duration to destroy harmful microorganisms and extend the product’s shelf life while aiming to retain its nutritional and sensory qualities, however, achieving the optimal balance between microbial safety and the preservation of nutritional content is challenging, as excessive heat can degrade the product's flavor, texture, and nutrient profile (Issah et al., 2019).

Tiger nut milk is one of the emerging non-dairy beverages which is rich in nutritional values and is very attractive in sensory quality. The physicochemical properties of this plant-based beverage are very much influenced by its basic properties, which include a slightly acidic pH of 6.0 to 6.5, high levels of total solids and a variable fat content depending on the extraction process used (between 10% and 25%). The creaminess and thick mouth-feel it has, which are similar to the creaminess and thickness of regular dairy milk, are determined by the physical nature of its native starches and lipids. Moreover, the drink has a very appealing sensorial profile, making it the more pleasant choice compared to other drinks which tend to be more astringent, such as soy milk, without the need for added sweeteners due to its natural sugars and oleic acid content. It is a great functional food with high levels of dietary fibre, monounsaturated fatty acids, potassium, magnesium and antioxidant vitamins E and C. This delicate combination of proteins, lipids and natural sugars, however, makes the beverage very susceptible of rapid microbial spoilage and physical destabilisation during subsequent storage (Ade-Omowaye et al., 2018).

Thermal pasteurization is required to maintain these consumer preferred attributes and to increase market shelf life but the impact of conditions of thermal processing (both temperature and time) on the physical structure of the milk is still poorly researched. The literature is completely lacking in the exact processing limits of the minor tropical tubers namely tiger nut. Although considerable efforts have been directed toward primary production, agronomics and raw biology of local crop resources of West Africa, little attention has been given to the downstream secondary processing optimization. For example, recent research on agriculture has given due consideration to early growth and agronomic responses of indigenous food plants such as Dennettia tripetala (Anozie et al., 2020) as well as management of intercropped field systems containing staple crops such as maize and groundnut (Rotowa et al., 2020). Likewise, in the literature, there is a good amount of information about the use of organic crop residues for altering soil properties and enhancing raw field crop yields (Nweke et al., 2020) or extraction of crude plant juices for initial botanical germination treatments (Akinyele & Ibeh, 2020). Recently released bioresource integration models still only explore the protection of raw bioactive compounds and not the mechanics of liquid food matrices (Aguma et al., 2026).In the context briefly mentioned, how different combinations of pasteurization temperature and time will affect the baseline pH, viscosity and color coordinates of the alternative milks remains entirely unexplored. Food processors cannot safely extend the shelf life of the product without losing its high consumer value without systematic data being created to determine the specific thermal boundaries that cause the formation of organic acids, starch gelatinization, protein denaturation or Maillard browning. This study directly addresses this critical research gap by evaluating a controlled three by three factorial matrix of temperatures and times and giving the exact empirical data needed to optimize the pasteurization parameters to ensure the success of tiger nut milk stabilization.

Research Questions

1. How do different temperatures and time affect the physicochemical properties of tiger nut milk, in terms of pH, viscosity, and color?

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Hypotheses

1. There is no significant effect of varying temperature and time on the physiochemical properties of tiger nut milk.

Method

This study falls within the field of Food and Nutrition, focusing on the sensory evaluation and quality assessment of tiger nut milk as a non-dairy alternative. Conducted at Delta State University in Abraka, Delta State, Nigeria, the research investigated how processing temperatures of 65, 75, and 85 degrees Celsius and processing times of 15, 30, and 60 seconds affect the beverage. The project utilized a 3 by 3 factorial experimental design to analyze the main and interactive effects of these independent variables on the milk's sensory and physicochemical properties. A separate phase of the experiment evaluated shelf life across fourteen days under ambient, refrigerated, and freezing conditions.

For the sensory panel, a purposive sampling technique was used to select fifteen academic staff members from the Vocational Education Department based on established food science standards. Personnel constraints resulted in ten semi-trained panelists performing the final evaluations. The primary research tool was a standard sensory evaluation questionnaire containing a 9-point hedonic scale, which ranged from liked extremely at nine to disliked extremely at one. Panelists scored the samples on color, flavor, texture, taste, mouthfeel, and overall acceptability within a controlled laboratory environment, using water to rinse their palates between assessments. The questionnaire was validated through expert reviews by the project supervisor and an additional sensory analyst, followed by a pilot test with five external individuals. The internal reliability of the panel's scores was verified using Cronbach’s alpha with an acceptable threshold set at 0.7 or higher.

The processing method began by sourcing fresh tiger nuts from local markets, which were cleaned and soaked in distilled water for twenty-four hours to soften. The nuts were blended with distilled water at a 1 to 3 weight-by-volume ratio, and the resulting slurry was filtered through cheesecloth to extract the milk. Certified food-grade dates and coconut were sourced as flavor enhancers. The milk samples were processed using a laboratory pasteurizer under the specified temperature and time combinations, while an unpasteurized sample was kept as a control.

Quality assessment involved proximate, physicochemical, microbiological, and sensory analyses. Proximate testing established the nutritional baseline by measuring moisture via oven drying at 105 degrees Celsius, protein using the Kjeldahl method with a 6.25 conversion factor, fat through Soxhlet extraction, ash via a muffle furnace at 550 degrees Celsius, and carbohydrates by difference subtraction. Physicochemical tracking measured pH changes, viscosity, and color variations using digital laboratory instruments. Microbiological analysis ensured safety by quantifying total viable counts, coliforms, yeasts, and molds, alongside testing for specific pathogens like E. coli, Salmonella, and Listeria.

Statistical analysis was conducted using SPSS version 27.0 and Microsoft Excel 2021. Data were summarized using descriptive statistics, including means and standard deviations. Inferential statistics, specifically two-way analysis of variance, were applied at a 95 percent confidence level to evaluate the impacts of processing conditions. When significant differences were found, mean separation was completed using Tukey HSD and Duncan’s Multiple Range Test. Microbial data were normalized using a log base 10 transformation before evaluation, and the final results were supplemented with partial eta squared effect sizes, Arrhenius shelf-life modeling, and correlation analysis to connect the subjective panel scores with objective laboratory quality markers.

Resuts

The findings are presented according to the research questions and hypotheses guiding the study.

Table 1: Treatment Combinations Used in the Study

Sample Code (tiger nut milk)	Temperature (°c)	Time (s)
T1	65	15
T2	65	30
T3	65	60
T4	75	15
T5	75	30
T6	75	60
T7	85	15
T8	85	30
T9	85	60

The above table 1, shows the different samples of tiger nut milk, represented with "T", ranging from 1-9 and the different treatment combinations of Temperature and Time, used throughout the experimental process.

Research Question 1

How do different temperature and time affect the physicochemical properties (pH, viscosity and colour) of tiger nut milk?

Table 2: Physicochemical properties of tiger nut milk under different pasteurization conditions

Sample Code (tiger nut milk)	Temp (°c)	Time (s)	pH	Viscosity (cP)	Colour (L*)
T1	65	15	6.48 ±0.02	18.5 ±0.4	78.1
T2	65	30	6.44 ±0.03	19.2 ±0.3	77.8
T3	65	60	6.38 ±0.02	20.1 ±0.4	76.5
T4	75	15	6.35 ±0.03	21.3 ±0.5	75.6
T5	75	30	6.31 ±0.02	22.5 ±0.4	74.8
T6	75	60	6.28 ±0.03	23.8 ±0.5	73.9
T7	85	15	6.24 ±0.03	24.6 ±0.6	72.5
T8	85	30	6.20 ±0.02	25.8 ±0.4	71.2
T9	85	60	6.15 ±0.03	27.1 ±0.5	70.3

Table 2 above, shows that pH decreased slightly with increasing temperature and processing time. At temperature of 65°c and processing time of 15 seconds, the pH value of 6.48 was noticed, but as the temperature and processing time increased, (85°c – 30 seconds), the pH value significantly decreased to 6.20. This decrease is attributed to the heat induced chemical reactions and the formation of organic acids during heating. The pH of tiger nut milk varied with pasteurization conditions. Generally, higher temperatures and longer times resulted in a slight decrease in pH, indicating increased acidity. Viscosity increased progressively with higher temperature and longer heating time. At temperature of 65°c and processing time of 15s, viscosity was 18.5, but as the treatment conditions increased, (85°c – 30s), the viscosity increaseds to 25.8. This observation may be associated with protein denaturation and starch gelatinization, which increase the thickness of plant-based milk beverages. Colour values also decreased as temperature increased. At temperature of 65°c and processing time of 15s, the colour value of 78.1 was noticed, but as the temperature and processing time increased, (85°c – 30s), the colour value significantly decreased to 71.2, indicating slight browning reactions and pigment degradation during heat treatment. The colour of tiger nut milk tended to darken with increasing pasteurization temperature and time. This was likely due to Maillard reactions or caramelization.

H_{01}: There is no significant effect of varying temperature and time on the physicochemical properties of tiger nut milk.

Table 3: ANOVA for Physicochemical Properties

Source	Type III Sum of Squares	df	F-value	p-value	Mean Square	Sig.	Partial ⋂2
Temperature	154.72	2	18.45	0.001	77.36	0.001	0.69
Time	88.51	2	12.67	0.003	44.25	0.001	0.54
Temp*Time	31.44	4	5.92	0.021	7.86	0.047	0.28
Error	32.51	12			2.71		
Total	307.18	20					

The above table 3 indicates that: Temperature significantly influenced viscosity $F(2,12) = 28.54$, $p < 0.001$. Processing time also had a significant effect $F(2,12) = 16.32$, $p = 0.001$. The interaction between temperature and time was also significant $F(4,12) = 2.90$, $p = 0.047$. The partial eta squared values (⋂2) show that temperature explained 69% of the variation, indicating a large effect size. Since $p < 0.05$, (0.047), indicating a significant effect of processing temperature and time on the physicochemical properties of tiger nut milk, the null hypotheses is rejected. Temperature and time significantly influenced the physicochemical properties of tiger nut milk.

Discussion

Findings from table 2, revealed that pasteurization temperature significantly affected pH, viscosity, and color ($p < 0.05$). Higher temperatures (85°C) caused slight reductions in pH and increased total soluble solids due to partial concentration effects and heat induced molecular interactions. These findings align with Issah et al. (2019), who reported thermal induced changes in plant based milk systems. Viscosity increased moderately at 75°C due to starch gelatinization and protein interactions but declined slightly at 85°C, possibly due to protein denaturation and structural breakdown (Azevedo et al., 2020). Color changes observed at 85°C may be attributed to Maillard reactions and enzymatic browning mechanisms consistent with enzyme activity theory as postulated by Ashokkumar & Muthusamy (2017). Processing time significantly influenced taste, aroma, and texture ($p < 0.05$). Samples treated for 60 seconds at higher temperatures (85°C), exhibited slightly cooked flavour notes and reduced sweetness perception. This is consistent with Fechner's Law on stimulus perception (Lawless & Heymann, 2010). Moderate exposure (75°C for 30 seconds), maintained optimal flavor release and mouthfeel, supporting flavor release theory by Piggott (2011). The finding confirmed the assertion of Afoakwa (2016), that excessive time led to minor off notes due to lipid oxidation processes.

Conclusion

The results of this study show that the pasteurization temperature and the time have significant and profound influence over the Physicochemical properties of Tiger nut milk, which is statistically significant. The results are quite clear in showing the change of the structural and visual dynamics of the beverage when the thermal increase is increased, this is enough to reject the null hypothesis. In the more intense processing, pH decreases rapidly and is caused by chemical reactions that are induced by the heat, and the milk becomes more acid. At the same time, the beverage experiences a unique 'thickening' effect, which is manifested as a gradual increase in the viscosity of the solution, caused by two phenomena: starch gelatinization and protein denaturation. Thermal processing also results in milky color changes, due to lightness decrease caused by degradation of lightness values in the pigments along with Maillard reactions and caramelization. These changes are effected by both temperature and time, but in this case, the most important factor is the temperature. The findings highlight the significance of optimizing the pasteurization process to ensure microbial safety while maintaining the quality and safety of the tiger nut milk product for food processors to achieve the correct balance of pasteurization parameters.

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