

**CHEMICAL COMPOSITION AND SENSORY EVALUATION
OF TIGER NUT CHEESE**

BY

**Kanayo SUNDAY
AGR2000114**

**DEPARTMENT OF ANIMAL SCIENCE
FACULTY OF AGRICULTURE
UNIVERSITY OF BENIN
BENIN CITY**

NOVEMBER, 2025

**CHEMICAL COMPOSITION AND SENSORY EVALUATION OF TIGER
NUT CHEESE**

BY

**Kanayo SUNDAY
AGR2000114**

**A PROJECT WORK SUBMITTED TO THE DEPARTMENT OF ANIMAL
SCIENCE, FACULTY OF AGRICULTURE, UNIVERSITY OF BENIN, IN
PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD
OF BACHELOR OF AGRICULTURE**

NOVEMBER 2025

CERTIFICATION

This is to certify that the project work was carried out by Kanayo SUNDAY,
Department of Animal Science, Faculty of Agriculture, University of Benin,
Benin City, Nigeria, under the supervision of Dr. (Mrs.) G.O. Egigba.

Dr. (Mrs) G.O. Egigba
Project Supervisor

Date

Dr. N.C. Akaeze
Head of Department

Date

DEDICATION

I dedicate this project to God Almighty, who gave me the strength to go through this academic phase. To him be the glory for ever and ever.

ACKNOWLEDGEMENTS

My Profound gratitude goes to God Almighty, who has helped me throughout my undergraduate program. His love for me is unending.

I extend my appreciation to Dr. (Mrs.) G.O. Egigba, my Project Supervisor, for her motherly love and care. I also extend my appreciation to Dr. N.C. Akaeze, the Head of Department, Animal Science, for his strong leadership capacity in piloting the affairs of the department. I am thankful to Prof. C.O. Emokaro, the Dean, Faculty of Agriculture, and to my lovely lecturers: Prof. J.A. Imasuen, Prof. J.M. Omoyhaki, Prof. M.A. Bamikole, Prof. S.O. Nwokoro, Prof. J. O Oyedeji, Dr. P.A. Ebabhamiegbho, Dr. G.I.O. Odafe, Mr Paul Aduba, Dr. G. Bello-onaghise, Mrs. B.O. Issac, Dr. W.O. Agbonghae, Dr. E.S. Abel, Dr Ekom Udofia, and Mrs. V.E. Ekhurutomwen, for their unrelentless efforts and love towards us. You all are amazing.

I'm also grateful to my Parents, Engr. Edosa Sunday and Mrs. Faith Emedem for their unwavering support, prayers and financial provisions towards me, thank you Dad and Mum. To my siblings, Amaka and Nkiru, thank you for being by my side all the time. To my RCF Family, you all are awesome, you aided my journey in school. Thank you for the memories, love, and prayers. To my friends, Jennifer, Olasubomi, Marvelous, Palmer Faith, DHO Boyi, Pst. Godswill, AMD Oghenemine, Finny Glory and my Media and Organizing family, I love you all. To my fellow project mates, we did it guys. It was worth it. To ANS 20, I'm

grateful to you all; you all are wonderful. The journey was worthwhile with all of you in it. Thank you for the laughter, the smiles and the experiences. Once again, I give God all the glory.

TABLE OF CONTENTS

| | |
|--|-----|
| Title page | i |
| Certification | ii |
| Dedication | iii |
| Acknowledgements | iv |
| Table of Contents | vi |
| List of Tables | vii |
| List of Plates | ix |
| List of Figures | x |
| Abstract | xi |
| CHAPTER ONE | |
| 1.0 Introduction | 1 |
| 1.1 Justification of the study | 3 |
| 1.2 Objective of the study | 6 |
| CHAPTER TWO | |
| 2.0 Literature Review | 7 |
| 2.1 Overview of Tiger Nut | 7 |
| 2.1.1 Botanical Classification and Description | 7 |
| 2.1.2 Varieties | 8 |
| 2.1.3 Geographical Distribution and Availability | 8 |
| 2.1.4 Nutritional and Phytochemical Composition | 10 |
| 2.1.5 Industrial and Traditional Uses of Tiger Nut | 11 |
| 2.2 Tiger Nut Milk | 12 |
| 2.2.1 Production Process | 13 |
| 2.2.2 Physiochemical Properties of Tiger Nut Milk | 14 |
| 2.2.3 Nutritional Composition of Tiger Nut Milk | 15 |
| 2.2.4 Factors Affecting Yield and Quality | 16 |
| 2.3 Cheese | 18 |

| | | |
|----------------------|---|----|
| 2.3.1 | Cheese Production | 19 |
| 2.3.2 | Types of Coagulants used in Cheese Production | 21 |
| 2.3.3 | Types of Cheese | 23 |
| 2.4 | Vegan Cheese | 24 |
| 2.4.1 | Nutritional Benefits of Vegan Cheese | 25 |
| 2.4.2 | Technological Challenges in Texture and Meltability | 28 |
| 2.5 | Chemical Composition of Tiger Nut | 29 |
| 2.5.1 | Proximate Composition | 30 |
| 2.5.2 | Mineral and Vitamin Composition | 30 |
| 2.6 | Sensory Evaluation | 31 |
| 2.6.1 | Importance of Sensory Evaluation in Product Development | 31 |
| 2.6.2 | Sensory Evaluation Methods | 32 |
| CHAPTER THREE | | |
| 3.0 | Materials and Methods | 34 |
| 3.1 | Location of study | 34 |
| 3.2 | Experimental Design | 34 |
| 3.3 | Experimental Treatments | 35 |
| 3.4 | Experimental Materials | 35 |
| 3.5 | Preliminary Trials | 35 |
| 3.5.1 | Trial using Soybean | 36 |
| 3.5.2 | Trial using Coconut | 36 |
| 3.5.3 | Trial using Bambara Nut | 38 |
| 3.5.4 | Trial using Tiger Nut | 39 |
| 3.6 | Production of Tiger Nut Milk | 40 |
| 3.7 | Production of Cheddar Tiger Nut Cheese | 40 |
| 3.8 | Production of Mozzarella Tiger Nut Cheese | 40 |
| 3.9 | Chemical Analysis | 43 |
| 3.9.1.1 | Determination of Moisture Content (MC) | 43 |

| | |
|---|----|
| 3.9.1.2 Determination of Crude Protein (CP) | 43 |
| 3.9.1.3 Determination of Crude Fiber (CF) | 44 |
| 3.9.1.4 Determination of Ash | 45 |
| 3.9.1.5 Determination of Ether Extract (EE) | 46 |
| 3.9.2 Mineral Analysis | 47 |
| 3.10 Sensory Evaluation | 47 |
| 3.11 Statistical Analysis | 47 |
| CHAPTER FOUR | |
| 4.0 Results | 48 |
| 4.1 Proximate Composition of Mozzarella and Cheddar Cheeses Produced from Tiger Nut Using Three (3) Coagulants | 48 |
| 4.2 Mineral Composition of Mozzarella and Cheddar Cheeses Produced from Tiger Nut Using Three (3) Coagulants | 51 |
| 4.3 Sensory Evaluation Analysis of Mozzarella and Cheddar-Type Vegan Cheeses Produced from Tiger Nut Using Three (3) Coagulants | 53 |
| CHAPTER FIVE | |
| 5.0 Discussion | 56 |
| CHAPTER SIX | |
| 6.0 Conclusion and Recommendations | 61 |
| 6.1 Conclusion | 61 |
| 6.2 Recommendations | 62 |
| REFERENCES | 63 |

LIST OF TABLES

| Table | Title | Page |
|--------------|---|-------------|
| 1 | Proximate Composition of Tiger Nut Milk (per 100 mL) | 17 |
| 2 | Proximate Composition (%) and pH of Mozzarella and Cheddar Cheeses Produced from Tiger Nut Using Three (3) Coagulants | 50 |
| 3 | Mineral Composition and pH of Mozzarella and Cheddar Cheeses Produced from Tiger Nut Using Three (3) Coagulants | 52 |
| 4 | Results of Sensory Qualitative Descriptive Analysis of Mozzarella and Cheddar-Type Vegan Cheeses Produced from Tiger Nut Using Three (3) Coagulants | 56 |

LIST OF FIGURES

| Figure | Title | Page |
|---------------|---|-------------|
| 1 | Flow Diagram for extracting tiger nut milk and solids | 41 |
| 2 | Flowchart of the cheese-making process | 42 |

Abstract

The increasing global demand for plant-based dairy alternatives has stimulated research into non-dairy cheese analogues derived from underutilized crops. This study evaluated the chemical composition and sensory characteristics of mozzarella and cheddar-type cheeses produced from tiger nut (*Cyperus esculentus* L.) milk using three coagulants: vinegar, lemon extract, and tamarind extract. A 3 x 2 factorial design resulting in six (6) treatment combinations was adopted. The treatments included mozzarella and cheddar cheeses coagulated with vinegar, lemon, and tamarind extract respectively. Proximate composition, mineral composition, pH, and sensory properties were determined using standard analytical procedures.

The pH values ranged from 4.870 to 5.985, with cheddar cheeses generally exhibiting higher pH values than mozzarella cheeses. Moisture content ranged from 73.10% to 77.53%, while crude protein varied from 1.875% to 2.450%. Ether extract ranged from 3.395% to 4.165%, and ash content ranged from 0.465% to 1.105%. Mineral analysis revealed calcium values between 231.5 and 311.3 mg/kg, magnesium values between 115.5 and 244.2 mg/kg, and phosphorus values between 556.1 and 1254.9 mg/kg. Sensory evaluation showed that mozzarella cheese coagulated with tamarind extract recorded the highest overall acceptability score (3.722), while cheddar cheese coagulated with lemon extract recorded the lowest score (2.944).

The findings demonstrated that tiger nut milk can be successfully utilized in the production of acceptable vegan cheese analogues with desirable nutritional and sensory qualities. Tamarind extract proved to be the most effective coagulant in improving both nutritional composition and consumer acceptability.

CHAPTER ONE

1.0 INTRODUCTION

Cheese is a widely cherished food that also serves as a key ingredient in numerous popular dishes, including pizza, lasagna, enchiladas, and cheeseburgers (Craig *et al.*, 2022). Cheeses are consumed for their high nutritional value and enjoyed for their complex and varied flavor profiles. Some of these nutritional values include: providing a wide range of crucial vitamins like A, B6, B12, D, and K, minerals like calcium, iodine, magnesium, potassium, phosphorus, and zinc, fats and proteins (Delahunty and Drake, 2004; Ballegooijen and Beulens, 2017). Cheese is traditionally produced by converting liquid milk to a semisolid mass by using a coagulating agent such as rennet, acid, heat plus acid, or a combination of these agents (Zheng *et al.*, 2021).

There has been a global surge in demand for plant-based milk and cheese alternatives, driven by health consciousness, ethical concerns regarding animal welfare, and the lower environmental footprint of plant-based foods (Alcorta *et al.*, 2021; Clem and Barthel, 2021; Kraak *et al.*, 2024). These alternatives cater to vegans, vegetarians, individuals with lactose intolerance, and those seeking greater sustainability in food choices (Alcorta *et al.*, 2021). Some of the common reasons that make people tend to follow a plant-based diet include concerns for health, the environment, animal welfare, rejection of meat, and religious beliefs (Crammer *et al.*, 2017). With lactose intolerance as the main

reason, people with this condition are unable to digest significant amounts of lactose due to a genetically inadequate amount of the enzyme lactase. Common symptoms include abdominal pain and bloating, excessive flatus, and watery stool following the ingestion of foods containing lactose (Swagerty *et al.*, 2002).

Plant-based milk substitutes are milk equivalents produced from plant sources. Plant-based milk substitutes comprise a colloidal system of a continuous phase, consisting of water and particles in the dispersed phase. The dispersed particles include starch granules, protein fractions, lipid droplets and solid parts of plant matrices (Briviba *et al.*, 2016; Bocker and Silva, 2022). These plant sources include cereals, legumes, nuts, pseudocereals, seeds, corms, roots and tubers, fruits, and vegetables. The common sources include soy, coconut, tiger nut, almond (Mohanty *et al.*, 2016; Clay *et al.*, 2022; Munekata *et al.*, 2022; Zheng *et al.*, 2021).

With the rising interest in non-dairy products, there has been a surge of interest in consumers seeking plant-based cheese alternatives brought about by a desire to improve individual health and achieve a more sustainable food supply (Craig *et al.*, 2022). Vegan cheese, a plant-based cheese alternative based on nuts, oils, grains, soy, and other plant products, have been developed. Vegan cheese is produced using similar techniques to those of dairy cheese, only differing majorly in the milk source, which is sourced from plant-based materials (Fu and Yano,

2020). Vegan cheese has helped in curbing lactose intolerance or milk allergy (Hopwood *et al.*, 2020).

Tiger nut is a good source of edible oils which contain a lot of monounsaturated fatty acids. The nutritional value of tiger nut oil is similar to that of olive oil (Roselló-Soto *et al.*, 2018). Tiger nut also contains a lot of starch, a renewable and low-cost food ingredient (Silveira Junior and de Francisco, 2020). Its protein content is relatively small, but it has been found to be suitable for people with diabetes or those with digestive dysfunctions and may prevent heart disease after consumption (Adejuyitan, 2011; Bilikis and Olanrewaju, 2015). The dietary fiber present in tiger nut's tuber is very effective in the prevention of colon cancer, obesity and gastrointestinal disorders (Viuda-Martos, 2010). Tiger nuts are widely cultivated around the globe but research on them are insufficient, which greatly limits their application in real life (Adejuyitan, 2011).

1.1 Justification of the Study

Tiger nut (*Cyperus esculentus* L.) is an underutilized crop of high nutritional potential. It contains a wide range of essential nutrients, including protein, dietary fiber, unsaturated fatty acids, minerals, and vitamins (Wu *et al.*, 2024). The tuber is particularly rich in oleic acid, linoleic acid, and linolenic acid, which are beneficial for cardiovascular health (Abdelmontaleb *et al.*, 2023). According to Adejuyitan (2011), tiger nut is also a valuable source of carbohydrates, phosphorus, potassium and vitamins C and E, which support metabolic and

immune functions. The nutritional composition of tiger nut milk makes it a viable non-dairy base for functional food production. Abdelmontaleb *et al.* (2023) demonstrated that substituting up to 30% of water with tiger nut milk in cheese formulation enhanced the protein, ash, and fat content while improving the product's sensory appeal. Staudacher *et al.* (2018) noted that about 68% of adults globally experience lactose malabsorption, particularly in African and Asian populations. This prevalence underscores the demand for lactose-free, plant-based dairy substitutes. These findings highlight its potential to replace animal milk in cheese production without compromising nutritional quality. The health-promoting effects of tiger nut have been documented extensively. It contains bioactive compounds such as phenolics, flavonoids, and phytosterols that exhibit antioxidant, antimicrobial, and anti-inflammatory activities (Wu *et al.*, 2024). These compounds help protect against coronary heart disease, colon cancer, and arteriosclerosis (Adejuyitan, 2011; Abdelmontaleb *et al.*, 2023). Moreover, tiger nut milk serves as an ideal alternative for lactose-intolerant and vegan consumers who avoid animal-based products (Balogun *et al.*, 2019). Its naturally sweet flavor and creamy texture make it suitable for producing plant-based dairy substitutes such as cheese and yogurt with high consumer acceptability. The use of locally available crops like tiger nut for value-added food products holds significant economic promise. In Nigeria and other parts of Africa, the cultivation of tiger nut has increased due to its rising demand and profitability (Falodun and Bakare,

2025). According to Falodun and Bakare (2025), the crop thrives well in Nigeria's rainforest zones and offers profitable returns for small-scale farmers. Small-scale processing of tiger nut-based dairy alternatives such as cheese can create employment, enhance rural income, and reduce dependence on imported dairy products.

According to Sánchez-Zapata *et al.* (2012), the commercialization of Tiger nut and its derivatives provides opportunities for developing food industries that align with local agricultural potential. By fostering local agro-industrial activities, Tiger nut utilization supports economic diversification and food security in developing nations like Nigeria. This study provides valuable data on the chemical composition and sensory characteristics of tiger nut-based cheese, thereby filling a notable gap in existing literatures. Previous works have focused on tiger nut milk, oil, and flour (Wu *et al.*, 2024; Abdelmontaleb *et al.*, 2023), but limited research has examined its integration in cheese production. By assessing the proximate composition and organoleptic properties of tiger nut cheese, this study contributes to the scientific understanding of plant-based dairy equivalents. It also supports ongoing global research into sustainable, functional foods with health-promoting potential.

Tiger nut is a resilient crop that thrives in marginal soils with low fertilizer demand, contributing to environmentally sustainable agriculture (Tan *et al.*, 2023). The use of organic manure in its cultivation not only improves yield but also

reduces the environmental hazards associated with synthetic fertilizers (Falodun and Bakare, 2025). Wu *et al.* (2024) emphasized that tiger nut production aligns with the UN Sustainable Development Goals (SDGs 1, 2, and 3) which are promoting poverty reduction, zero hunger, and good health. Its cultivation and utilization as a plant-based resource support eco-friendly food systems and the global shift towards sustainable diets. Sánchez-Zapata *et al.* (2012), highlighted that transforming tiger nut into milk, oil, and flour enhances its market value while reducing post-harvest waste common in root and tuber crops. Therefore, developing tiger nut cheese not only supports sustainable agriculture but also promotes food security and economic growth.

1.2 Objectives of the Study

The broad objective was to determine the chemical composition and sensory evaluation of cheese produced from tiger nut milk.

The specific objectives of the study were to;

- i. determine the proximate composition (moisture, protein, fat, ash, fiber, and carbohydrate) of tiger nut cheese;
- ii. determine some mineral composition (Calcium, Magnesium, Phosphorus) of Tiger Nut Cheese; and
- iii. assess the sensory characteristics (taste, color, aroma, texture, and overall acceptability) of the cheese.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Overview of Tiger Nut

In recent years, the food industry has shown growing interest in non-dairy milks and cheese alternatives. This development is driven by multiple factors: rising incidence of lactose intolerance and milk-protein allergy, growth in vegan/plant-based diets, heightened consumer demand for functional and sustainable foods, and the environmental pressures of dairy production. Plant-based milks (e.g., soy, almond, oat, tiger-nut) and cheese analogues require ingredients that deliver not just acceptable flavour and texture, but also comparable nutritional value and processability. Within this context, the tuberous crop *Cyperus esculentus* (tiger nut) has attracted attention because it combines favourable nutrient composition (oils, starch, fibre, minerals), functional ingredients (oil, starch) and adaptability in cultivation. Recent reviews highlight that tiger-nut and its derivatives remain under-utilised in food systems despite their potential (Wu *et al.*, 2024).

2.1.1 Botanical Classification and Description

Cyperus esculentus L., commonly called tiger nut, is a monocotyledonous flowering plant belonging to the *Cyperaceae* family (Yang *et al.*, 2022). It develops small, round tubers at the tips of its rhizomes, which are edible and characterized by a naturally sweet, nutty flavor similar to that of almonds. The crop is also referred to by various names, including earth almond, chufa, earth chestnut, edible rush, tiger nutsedge, and Zulu nut (Wu *et al.*, 2024). In Nigeria, tiger nut is commonly referred to as “Ayaya” in Hausa, “Ofio” in Yoruba, and “Akiausa” in Igbo (Oladele and Aina, 2007).

2.1.2 Varieties

In Nigeria, three main varieties of tiger nut—black, brown, and yellow—are cultivated. However, only the yellow and brown types are commonly found in local markets. The yellow variety is generally preferred because of its larger size, appealing color, and fleshy texture. It also produces a higher milk yield during extraction, has lower fat but higher protein content, and contains fewer anti-nutritional compounds, particularly polyphenols (Okafor *et al.*, 2003).

2.1.3 Geographical distribution and availability

Tiger nut (*Cyperus esculentus* L.) has a long and remarkable history that traces back to the Mediterranean region, where it was first domesticated and valued as a staple food source in Ancient Egypt around 4000 BC (Zohari, 1986; Negbi, 1992; De Castro *et al.*, 2015; Maduka and Ire, 2018). Historical evidence suggests that it was among the earliest cultivated crops in Egypt, ranking after emmer wheat and

barley in antiquity (Defelice, 2002). The ancient Egyptians consumed tiger nut in various forms, including as a sweet delicacy and an ingredient in beverages and oils, highlighting its nutritional and cultural importance. During the Middle Ages, the crop was introduced to Southern Europe, particularly Spain, through the Arab expansion across North Africa. It became well established in the region, especially in Valencia, where it remains the primary ingredient for the traditional beverage *horchata de chufa* (Pascual *et al.*, 2000). In 1854, tiger nut cultivation was extended to the United States, from where it gradually spread to other parts of the Americas, including Chile and Brazil (S´anchez-Zapata *et al.*, 2012).

Today, tiger nut is widely distributed across tropical and temperate regions, owing to its high adaptability to different environmental conditions (Pascual *et al.*, 2000; De Castro *et al.*, 2015). It thrives both in natural ecosystems and cultivated fields, and can even be grown in relatively cool climates such as the Netherlands, Switzerland, Germany, Hungary, and Russia (Pascual *et al.*, 2000). Globally, the crop has gained significant prominence, being cultivated in countries such as Spain, Ghana, Nigeria, the United States, China, Ivory Coast, India, Chile, Brazil, and Australia (S´anchez-Zapata *et al.*, 2012; Codina-Torrella *et al.*, 2015). In China, tiger nut was introduced in the 1950s, but large-scale commercial cultivation did not begin until the early 21st century. By 2019, production had expanded rapidly, covering approximately 13,300 hectares and yielding between 79,800 and 266,000 tonnes (dry matter) (Wu *et al.*, 2024). Tiger nuts typically

thrive in riverine areas and are predominantly cultivated on a small scale by local farmers, especially in the northern regions of Nigeria (Suleiman *et al.*, 2018).

Because of its high yield, nutritional richness, and economic value, tiger nut has evolved into both a subsistence and cash crop in many regions. Its versatility in food applications and industrial processing has further increased its importance in agricultural diversification and sustainable food systems worldwide (Wu *et al.*, 2024).

2.1.4 Nutritional and Phytochemical Composition

Tiger nut (*Cyperus esculentus* L.) is recognized as a nutrient-dense tuber capable of accumulating a wide range of essential nutrients and bioactive compounds. The underground tubers store substantial quantities of starch (25–40%), oil (20–30%), sugars (15–20%), protein (5–10%), and dietary fibre (8–10%) (Pascual *et al.*, 2000; S´anchez-Zapata *et al.*, 2012; Maduka and Ire, 2018; Arafat *et al.*, 2009; Bado *et al.*, 2015). These macronutrients contribute to its high energy value and functional versatility in food processing. In addition to macronutrients, tiger nut contains notable levels of vitamins C and E (0.08–0.14 g·kg⁻¹) and essential minerals such as calcium, phosphorus, potassium, magnesium, iron, sodium, and manganese, which play critical roles in bone formation, enzyme activation, and cardiovascular health (Bado *et al.*, 2015; Maduka and Ire, 2018).

The lipid fraction of tiger nut is particularly valuable due to its predominance of unsaturated fatty acids, especially oleic acid, which is comparable in composition

to olive oil and contributes to its recognized cardioprotective properties. This high lipid content reported between 19.79% and 37.83% also makes tiger nut a promising raw material for edible oil (Wu *et al.*, 2024).

From a phytochemical perspective, tiger nut tubers are rich in a variety of biologically active compounds, including alkaloids, tannins, saponins, glycosides, flavonoids, terpenoids, and phytosterols (Edo *et al.*, 2023; Adekanmi *et al.*, 2009; Chukwuma *et al.*, 2010). These constituents are known for their antioxidant, anti-inflammatory, antimicrobial, and antitumor activities, which enhance the crop's potential as a functional food ingredient. For instance, flavonoids and phenolic compounds scavenge free radicals and reduce oxidative stress, while phytosterols contribute to lowering cholesterol levels (Edo *et al.*, 2023)

2.1.5 Industrial and Traditional Uses of Tiger Nut

The synergistic presence of nutrients and phytochemicals underpins the health-promoting benefits associated with the consumption of tiger nuts. The rich presence of nutrients and bioactive compounds in tiger nut tubers highlights its importance as a highly valuable crop, providing significant nutritional and health benefits for both human consumption and animal feed (S'anchez-Zapata *et al.*, 2012; Maduka and Ire, 2018; Chukwuma *et al.*, 2010; Adejuyitan, 2011). Studies suggest that regular intake can support the management of diabetes, obesity, and cardiovascular diseases, while also improving blood circulation, reducing risks of stroke, and protecting against colon cancer (S'anchez-Zapata *et al.*, 2012;

Chukwuma *et al.*, 2010; Adejuyitan, 2011; Borges *et al.*, 2008). In traditional medicine, particularly in Ancient Egypt, China, and India, tiger nut has long been used as a natural remedy for ailments such as stomach pain, mouth and gum infections, and liver disorders, and as an aphrodisiac believed to enhance reproductive health (Maduka and Ire, 2018).

Because of its rich nutrient profile, pleasant taste, and functional properties, tiger nut is often referred to as a “snack food of the gods.” It is considered an ideal food for children, the elderly, and athletes, owing to its high energy content, digestibility, and therapeutic potential (Defelice, 2002). These attributes have spurred the development of diverse tiger nut-based food products, such as *horchata de chufa* in Spain, a refreshing milk-like beverage that exemplifies its versatility and cultural relevance in global diets (Yang *et al.*, 2022).

2.2 Tiger Nut Milk

Tiger-nut milk, commonly referred to as *Kunun aya* in Northern Nigeria, is a traditional non-alcoholic fermented beverage widely appreciated for its refreshing and nutritional qualities. Although it is consumed all year round, its intake is particularly high during the dry season (Okafor & Nwachukwu, 2003). Tiger nut milk is a plant-based beverage extracted from the tubers of *Cyperus esculentus* L., commonly known as tiger nut. It is creamy, naturally sweet, and widely recognized as a non-dairy alternative to cow’s milk. Unlike many plant-based milks, tiger nut milk is free from lactose, gluten, and cholesterol, making it highly

suitable for lactose-intolerant, vegan, and health-conscious consumers (Adejuyitan, 2011; Edo *et al.*, 2023).

This milk can be consumed fresh or flavored with natural sweeteners and spices such as vanilla or cinnamon to enhance its taste and shelf life. In Spain, the beverage is popularly known as “*Horchata de chufa*,” where it holds both nutritional and cultural importance, being traditionally consumed as a refreshing summer drink and an integral part of Mediterranean diets (S´anchez-Zapata *et al.*, 2012). In Nigeria and other African countries, tiger nut milk is widely consumed as a natural beverage and has recently gained attention as a base for developing dairy alternatives such as cheese, yogurt, and ice cream due to its rich nutritional composition and creamy texture (Adejuyitan, 2011; Abdelmontaleb *et al.*, 2023; Edo *et al.*, 2023). Moreover, the milk’s lactose-free and cholesterol-free nature makes it suitable for vegan and lactose-intolerant populations, further increasing its demand globally (Adejuyitan, 2011; Edo *et al.*, 2023).

2.2.1 Production Process

The methods involve four main steps: washing and sorting, soaking, grinding, and filtration. Tubers are first washed to remove soil and contaminants, then soaked in potable water for 6–24 hours to soften tissues (Musa *et al.*, 2013). The softened tubers are wet-milled with water in a 1:4 ratio to produce a slurry. This is followed by filtration using muslin cloth or sieves to obtain the milky extract (Adebayo-Oyetero *et al.*, 2019). The filtrate can be sweetened or flavored with

vanilla, ginger, or dates before consumption (Musa *et al.*, 2013; Ayo & Okaka, 1998). In some cultures, *Kunun aya* is enjoyed with a variety of fruit flavors, whereas others prefer it unsweetened (Adeyemi and Umar, 1994).

2.2.2 Physicochemical Properties of Tiger Nut Milk

Tiger nut milk typically presents a slightly acidic pH, ranging from 6.3 to 6.9, which contributes to its microbial stability and flavor profile (Adedeji *et al.*, 2022; Ismail *et al.*, 2024). The acidity level depends on processing methods, storage duration, and enzymatic treatments. Adedeji *et al.* (2022) reported that surfactant-assisted enzymatic extraction enhanced the stability and viscosity of tiger nut milk, minimizing phase separation and sedimentation during storage. Similarly, Ismail *et al.* (2024) observed that when tiger nut milk was used as a substitute for cow milk in ice cream formulation, it produced emulsions with higher viscosity and improved rheological behavior due to the presence of natural gums and starches in the tuber matrix.

The total solids content of tiger nut milk, ranging between 12% and 18%, depends on the concentration of extracted dry matter and processing intensity (Okafor *et al.*, 2024). The milk's light creamy color and smooth texture are attributed to the natural oil and carbohydrate composition of the tubers, which act as emulsifiers. Its stability during cold storage has been linked to the balanced fat–protein ratio,

which forms a stable emulsion matrix that resists creaming and syneresis (Adedeji *et al.*, 2022). Moreover, thermal treatment (pasteurization at 70–80°C) was shown to enhance microbial safety and shelf stability without significant alteration of physicochemical attributes (Okafor *et al.*, 2024).

2.2.3 Nutritional Composition of Tiger Nut Milk

Tiger nut milk is nutritionally rich and provides an excellent source of macronutrients and micronutrients comparable to conventional dairy milk. On average, 100 mL of tiger nut milk contains 2.8–3.4 g of protein, 2.9–3.5 g of fat, 11–12 g of carbohydrates, and 0.6g of ash (Adedeji *et al.*, 2022). The milk is also energy-dense, providing approximately 80–90 kcal per 100 mL.

Mineral analysis has shown appreciable amounts of potassium (24–30 mg/100 mL), calcium (15–20 mg/100 mL), magnesium (11–14 mg/100 mL), and trace elements such as iron (0.4–0.6 mg/100 mL) (Adedeji *et al.*, 2022). These elements contribute to electrolyte balance and are essential for bone and muscular functions. In comparative studies, tiger nut-based yoghurt demonstrated comparable mineral retention and slightly higher carbohydrate content than cow milk yoghurt, indicating its potential as a nutritional substitute (Okafor *et al.*, 2024).

Tiger nut milk also exhibits significant antioxidant properties due to its phenolic compounds, flavonoids, and vitamin E content. Adedeji *et al.* (2022) reported that the total phenolic content of enzymatically extracted tiger nut milk was 41.8 mg GAE/100 mL, with DPPH radical scavenging activity reaching 68.5%, confirming its role as a natural antioxidant beverage. These bioactive components enhance oxidative stability and may provide health benefits related to cardiovascular protection and lipid metabolism.

Furthermore, studies by Ismail *et al.* (2024) demonstrated that substituting tiger nut milk for cow milk in ice cream improved the nutritional and functional quality, yielding products with higher dietary fiber, better emulsification, and enhanced sensory acceptance among consumers.

2.2.4 Factors affecting Yield and Quality

Soaking time and temperature have a significant influence on milk yield and microbial quality. Prolonged soaking enhances solubilization of solids but increases the risk of microbial growth (Roselló-Soto *et al.*, 2018). Efficient grinding ruptures cell walls, releasing intracellular nutrients and oils. High-speed blending or hammer milling followed by homogenization produces a finer emulsion with better stability and mouthfeel (Yu *et al.*, 2022).

Innovations such as in-situ enzymatic hydrolysis or controlled germination improve sweetness, extractability, and prevent starch gelatinization during heating (Djomdi *et al.*, 2020). Enzymatic treatments (e.g., α -amylase or amyloglucosidase) increase soluble sugar content and reduce viscosity, enhancing process yield (Djomdi *et al.*, 2020).

The slurry obtained from blending is filtered or centrifuged to separate solids. Fine filtration yields a clear beverage but reduces the total solids; coarse filtration, on the other hand, increases turbidity and texture. For commercial stability, homogenization and mild stabilizers (e.g., pectin) are sometimes applied (Adebayo-Oyetero *et al.*, 2019).

Table 1: Proximate Composition of Tiger Nut Milk (per 100 mL)

| Parameter | Traditional Extraction | Enzymatic Extraction | Surfactant-Assisted Enzymatic Extraction |
|------------------|-------------------------------|-----------------------------|---|
| Moisture (%) | 82.45 ± 0.10 | 80.75 ± 0.08 | 79.10 ± 0.05 |
| Protein (g) | 2.85 ± 0.03 | 3.10 ± 0.02 | 3.42 ± 0.03 |
| Fat (g) | 3.25 ± 0.05 | 3.08 ± 0.04 | 2.95 ± 0.04 |
| Ash (g) | 0.52 ± 0.01 | 0.61 ± 0.02 | 0.68 ± 0.01 |
| Carbohydrate (g) | 10.93 ± 0.09 | 11.22 ± 0.06 | 12.05 ± 0.05 |
| Energy (kcal) | 82.8 | 84.3 | 86.4 |

Source: Adedeji *et al.* (2022)

2.3 Cheese

Cheese is one of the most loved and consumed foods around the world. It is a highly nutritious and palatable food that contains almost all the protein, fats, essential minerals, vitamins, and other nutrients of milk (Fox *et al.*, 2017; Walther *et al.*, 2008). Cheese has its origins in early farming societies: evidence from perforated clay sieves in Neolithic Poland and on Croatia's Dalmatian coast dating back as far as 5500 BCE indicates that people were pressing and salting curdled milk to preserve it (Salque *et al.*, 2013). The oldest directly preserved cheese, recovered from Bronze Age mummies in Xinjiang (~3600 years old), was identified as kefir-style cheese, with DNA revealing microbial species closely related to modern kefir cultures and showing how ancient *Lactobacillus* strains evolved over millennia (Fu *et al.*, 2024). While early cheese served primarily as a practical means of preserving milk, today cheese is widely appreciated as a gastronomic delicacy. Over centuries, cheesemaking techniques diversified enormously from rennet coagulation methods to aging in caves, with variations in moisture, salt, and microbial communities producing thousands of distinct cheese types (Banks, 2007; Mayo *et al.*, 2021). In the last two centuries, scientific advances have transformed cheesemaking: developments such as pasteurization, membrane filtration, standardized bacterial starters, and modern biochemical analysis have improved quality, safety, consistency, and flavor control. Genomic and proteomic tools now allow cheesemakers to select microbial cultures for

specific enzyme activities, tailoring taste and texture with precision (McSweeney and Fox, 2018; Mayo *et al.*, 2021). Cheese is made from milk, which can be sourced from either animal or plant-based materials. Cheese is made by curdling milk using rennet or an acid, which separates the curds (solid) from the whey (liquid) (Fox *et al.*, 2017; Bandler, 2023). Consumers have many reasons for choosing plant-based cheese alternatives. These can be related to health concerns such as lactose intolerance or a milk allergy, to concerns about the environment and animal welfare, or to a yearning for variety in their diets that inspires them to try new products (Hopwood *et al.*, 2020). The increase in the number of people following vegan diets and with an interest in vegan foods is also likely to be a factor in the increased production of and demand for plant-based cheese alternatives (Hopwood *et al.*, 2020; Fortune Business Insights, 2022).

2.3.1 Cheese Production

Cheese production is among the oldest and most widely practiced forms of milk preservation and dairy processing, dating back to approximately 7000 BCE (Fox *et al.*, 2017; Sgarbi *et al.*, 2013). The process converts perishable milk into a nutrient-dense, shelf-stable food through controlled fermentation, enzymatic coagulation, and maturation. By concentrating casein, fat, and essential minerals while removing water and lactose, cheesemaking creates a diverse range of products with distinct sensory and nutritional properties (McSweeney, 2017; Walstra *et al.*, 2006). The classical cheesemaking process comprises milk

preparation and standardization, pasteurization (where required), inoculation with starter cultures, coagulation using rennet or acid, curd cutting and cooking, whey drainage, salting, molding and pressing, and, for many varieties, ripening or aging (Fox *et al.*, 2017; Afzal *et al.*, 2020). Although these stages are broadly consistent, variations in milk source, microbial cultures, coagulants, and processing parameters account for the thousands of cheese types produced worldwide (Lucey *et al.*, 2003).

Milk is the principal raw material and determines yield, composition, and texture. Cow's milk is the most commonly used globally, though goat, sheep, buffalo, and camel milk are important regionally (Muehlhoff *et al.*, 2013; Walther, *et al.*, 2008). Starter cultures typically *Lactococcus lactis*, *Streptococcus thermophilus*, and *Lactobacillus helveticus*, acidify milk by converting lactose into lactic acid, assisting in curd formation, flavor generation, and microbial control (Walstra *et al.*, 2006; McSweeney, 2017). Coagulants, such as rennet containing chymosin, are critical for casein gelation; microbial and plant-derived coagulants (e.g., from *Cynara cardunculus*) are increasingly used as alternatives (Kumar *et al.*, 2010). Salt enhances flavor, regulates moisture, inhibits spoilage microorganisms, and affects enzymatic activity during ripening (Fox *et al.*, 2017; Guinee, 2004).

Ripening, the final stage for most cheese types, involves proteolysis, lipolysis, and lactose metabolism, catalyzed by native or added microflora and their enzymes. These reactions generate characteristic aromas, textures, and flavors in

aged cheeses such as Cheddar, Gouda, and Camembert (McSweeney, 2017; Sgarbi *et al.*, 2013). The careful selection of milk type, starter bacteria, and processing techniques allows manufacturers to control both nutritional quality and sensory attributes.

2.3.2 Types of Coagulants used in Cheese Production

1. Enzymatic (Rennet) Coagulants: The most common coagulants in cheese making are enzymatic, particularly rennet, which contains the proteolytic enzyme chymosin. Traditionally, rennet is obtained from the abomasum of unweaned calves, where chymosin specifically cleaves κ -casein at the Phe105–Met106 bond, leading to the destabilization of casein micelles and subsequent curd formation (Fox *et al.*, 2017; Walstra *et al.*, 2006).

Modern cheese industries increasingly use recombinant chymosin, produced via microbial fermentation using genetically modified microorganisms such as *Aspergillus niger* and *Kluyveromyces lactis*, due to its consistency, purity, and suitability for vegetarian consumers (Yun *et al.*, 2022). Enzymatic coagulants produce firm curds with high yields and desirable organoleptic properties, particularly in hard and semi-hard cheeses.

2. Microbial Coagulants: Microbial coagulants are milk-clotting enzymes derived from fungi or bacteria capable of proteolytic activity similar to that of chymosin. Common species include *Rhizomucor miehei*, *Rhizomucor pusillus*, and *Endothia parasitica* (Kumar *et al.*, 2020). These coagulants are valued for being cost-

effective and non-animal-based; however, they may exhibit broader proteolytic activity, leading to potential flavor defects or texture softening if not carefully managed (Guinee & Wilkinson, 2017). Advances in enzyme engineering have improved the specificity of microbial rennets, enhancing their applicability in both traditional and industrial cheese production systems.

3. Acid Coagulants: Acid coagulation occurs when the pH of milk is reduced to the isoelectric point of casein (~4.6), resulting in protein precipitation and curd formation. The acidification can be achieved either through the addition of organic acids such as citric acid, lactic acid, or glucono- δ -lactone (GDL) or by fermentation using lactic acid bacteria (Tamime and Robinson, 2007).

4. Plant-Based Coagulants: Plant-derived coagulants are extracted from various plant sources such as leaves, stems, fruits, and flowers that contain proteolytic enzymes. Examples include ficin from *Ficus carica* (fig tree), papain from *Carica papaya* (papaya), bromelain from *Ananas comosus* (pineapple), and cardosins from *Cynara cardunculus* (wild artichoke) (Roseiro *et al.*, 2003). Plant coagulants have gained renewed attention due to their vegetarian compatibility, cultural acceptance, and unique flavor contributions. However, their activity and specificity vary widely; some may induce excessive proteolysis, resulting in bitterness or soft curd texture. In Mediterranean cheesemaking, *Cynara cardunculus* extracts are traditionally used in ewe's milk cheeses, producing soft, aromatic cheeses with distinctive sensory profiles (Guiné *et al.*, 2019).

2.3.3 Types of Cheese

Cheese is one of the most diverse and ancient fermented dairy products in the world, with over 1,000 varieties globally (Fox *et al.*, 2017). Typically, cheese is classified according to its type (rennet cheese, fresh cheese, processed cheese), its textural properties (soft, semi-soft, medium-hard, semi-hard, and hard), and its origin (e.g., cow, buffalo, or goat) but many more regional cheese classifications are known (Grossmann and McClements, 2021).

Based on the origin of the milk, cheese can be broadly classified as animal milk cheese or plant milk (vegan) cheese (Fox *et al.*, 2017; Grossmann and McClements, 2021; Rinaldi *et al.*, 2021). Animal milk cheeses are traditionally produced from the milk of cows, buffaloes, goats, or sheep and provide a rich source of proteins, fats, minerals, and vitamins (Fox *et al.*, 2017). Plant milk cheeses, on the other hand, are made from protein-rich plant sources such as soy, almonds, cashew nuts, oats, coconut, or tiger nuts. These vegan cheeses exclude all animal products, cater to lactose-intolerant and vegan populations, and are often fortified to compensate for naturally lower calcium and vitamin B12 levels (Grossmann and McClements, 2021; Rinaldi *et al.*, 2021). The development of plant-based cheese has grown significantly in response to dietary preferences, health considerations, and environmental sustainability concerns (Sethi *et al.*, 2016).

2.4 Vegan cheese

Vegan cheese is a plant-based substitute for traditional dairy cheese, designed to mimic its taste, texture, and functionality while eliminating all animal-derived ingredients. It is typically made from plant-based ingredients such as nuts (cashew, almond), soy, legumes, coconut oil, starches, and often uses fermentation and microbial cultures to replicate the umami(savory or meaty taste) and tanginess of aged cheeses (Sethi *et al.*, 2016).

The shift toward plant-based alternatives, including vegan cheese, reflects evolving consumer preferences driven by health, ethical concerns, environmental impact, and dietary needs (McClements and Grossmann, 2021). Lactose intolerance affects approximately 68% of the global population to varying degrees, particularly in non-European ethnic groups (Storhaug *et al.*, 2017). Vegan cheese contains no lactose, making it suitable for individuals who experience bloating, gas, and discomfort after consuming dairy products. Additionally, milk proteins such as casein and whey are among the top eight food allergens. Vegan cheese eliminates these allergens, offering a safer alternative for susceptible populations (Melina *et al.*, 2016).

Dairy cheese is typically high in saturated fat and cholesterol, both of which have been associated with elevated risks of cardiovascular disease (Mensink *et al.*, 2016). Vegan cheese, particularly those based on nuts, seeds, or soy, often contain unsaturated fats and no dietary cholesterol, making them a more heart-friendly

option. A meta-analysis by Li *et al.* (2015) concluded that substituting saturated fats with unsaturated plant-based fats reduces the risk of heart disease significantly.

Industrial dairy farming often leads to deforestation, especially in areas cleared for soybean or maize cultivation used in animal feed. A transition to vegan cheese production reduces the need for such feed crops, thereby protecting biodiversity and limiting habitat loss (FAO, 2019). Vegan cheese is compatible with a wide range of dietary restrictions and preferences, including vegan, vegetarian, kosher, halal, and allergen-free diets. This inclusivity is vital in multicultural societies and institutions such as schools, hospitals, and airlines (Craig and Mangels, 2009).

2.4.1 Nutritional Benefits of Vegan Cheese

Vegan cheese, a plant-based alternative has shown a number of nutritional benefits to man since emergence. These benefits include:

1. **Cholesterol-Free Composition:** One of the major nutritional advantages of vegan cheese is that it is entirely free from cholesterol, as cholesterol is only found in animal-based foods (Harvard T.H. Chan School of Public Health, 2020). Traditional dairy cheese is often high in cholesterol, especially in aged, hard varieties like cheddar and parmesan. Consuming high-cholesterol foods has been linked to increased risk of cardiovascular diseases, although the role of dietary cholesterol is still debated.

2. Lower Saturated Fat (in Some Varieties): Many commercial vegan cheeses, especially those made from legumes or nuts, contain lower levels of saturated fat compared to dairy cheese. Excessive intake of saturated fat is associated with increased levels of LDL cholesterol and a higher risk of heart disease (Astrup *et al.*, 2019).

However, it is essential to note that some vegan cheeses particularly those made from coconut oil can still be high in saturated fat. Consumers seeking heart-healthy alternatives are advised to select vegan cheeses with nut or soy bases, which contain healthier unsaturated fats.

Dairy-Free and Lactose-Free: Vegan cheese is naturally free of lactose, making it suitable for individuals with lactose intolerance, a condition affecting an estimated 68% of the global population (Storhaug *et al.*, 2017). Dairy cheese can cause digestive discomfort, bloating, and diarrhea in lactose-intolerant individuals, while vegan cheese offers a pain-free and dairy free alternative.

Plant-Based Protein Content: Certain vegan cheeses, particularly those made from soy, almonds, or cashews, contain moderate amounts of plant-based protein, which can support muscle maintenance and satiety (Choudhury and Mandal, 2020). While dairy cheese is traditionally rich in casein and whey protein, plant-based versions benefit from diverse amino acid profiles and lower inflammation markers, especially when paired with other plant-based foods.

Fortification with Vitamins and Minerals: Many commercial vegan cheeses are fortified with essential micronutrients, including:

- i. Calcium – crucial for bone health, often added to mimic the calcium content of dairy.
- ii. Vitamin B12 – vital for red blood cell production and neurological function; naturally absent in plants but added to many vegan products.
- iii. Vitamin D – aids calcium absorption and immune function.

Fortification enhances the nutritional parity between vegan and dairy cheeses, particularly for individuals following fully plant-based diets (Craig, 2009).

6. Lower Allergen Risk (for Some Individuals): For individuals with casein allergy (milk protein allergy), vegan cheese offers a safe alternative. While nut- or soy-based vegan cheeses may still be allergenic to some, manufacturers now also offer allergen-friendly varieties made from oats, peas, potatoes, or aquafaba (Lu *et al.*, 2021).

7. Possible Fiber Content and Phytochemicals: Unlike dairy cheese, plant-based cheeses may retain fiber and bioactive plant compounds if minimally processed. For example, nut- and legume-based cheeses can provide:

- i. Soluble fiber, which supports digestive health.
- ii. Polyphenols and antioxidants, which combat oxidative stress.
- iii. Phytoestrogens, particularly from soy, which may support cardiovascular health and hormone balance (Messina, 2010).

8. Gut Health Potential via Fermentation: Some artisanal vegan cheeses are fermented using probiotics like *Lactobacillus* and *Penicillium* strains. These can provide live beneficial bacteria that support gut microbiota diversity and digestive function (Marco *et al.*, 2017). While not all vegan cheeses contain probiotics, this trend is expanding in high-end plant-based cheese markets.
9. Suitability for Special Diets: Vegan cheese is suitable and can fit into a variety of special diets. Some of these diets include:
 - i. Vegan and vegetarian diets, as it contains no animal-derived ingredients.
 - ii. Paleolithic and whole-food plant-based diets, especially when made from whole nuts, seeds, or fermented legumes without additives.
 - iii. Low-sodium diets, as some vegan cheeses (especially homemade or minimally processed ones) contain significantly less sodium compared to aged dairy cheeses (Craig, 2009; Lu *et al.*, 2021).

This makes vegan cheese an inclusive option for individuals with ethical, religious, medical, or lifestyle dietary restrictions.

2.4.2 Technological Challenges in Texture and Meltability

Plant-based cheese alternatives face substantial technological difficulties in achieving the texture, meltability, and flavour of traditional dairy cheese. According to Tekin and Hayaloglu (2025), the absence of a casein-based protein network leads to weaker structural integrity and inferior melt behaviour in many plant analogues. In a detailed investigation of commercial block-style plant

cheeses, it was found that the fat globule stabilization by starch or hydrocolloids rather than an interconnected protein matrix, led to inconsistencies in firmness and melting profiles compared to conventional dairy cheese (Grasso *et al.*, 2023). Furthermore, a formulation study by Grasso *et al.* (2023) in which zein and chickpea proteins were blended demonstrated that increasing the proportion of zein improved meltability and flow at elevated temperatures, highlighting how protein–lipid interactions can influence thermal functionality. Together, these findings highlight how ingredient functionality (protein type, fat blend, starch/hydrocolloid system), microstructure, and processing conditions must be carefully engineered to approach the sensory and functional profiles of dairy cheeses (Lyu *et al.*, 2023).

2.5 Chemical Composition of Tiger Nut

Chemical composition refers to the identification and quantification of the different chemical constituents that make up a substance, material, or biological sample. In food science, it describes the types and amounts of chemical components such as water, proteins, fats, carbohydrates, minerals, vitamins, and other bioactive compounds that collectively determine a food’s nutritional value, functionality, and sensory properties (Belitz *et al.*, 2019).

The chemical composition of tiger nut reflects its nutritional richness and functional potential as both a food and an industrial raw material. Tiger nut, also known as *chufa* or *Aya* in Nigeria, is a nutrient-dense tuber that contains a

balanced mixture of macronutrients, micronutrients, and bioactive compounds contributing to its growing application in plant-based milk and cheese analog formulations (Yu *et al.*, 2022; Adejuyitan, 2011).

2.5.1 Proximate Composition

The proximate composition of tiger nut varies depending on the cultivar, processing method, and environmental conditions. Typically, tiger nuts contain moisture (5–10%), lipid (20–30%), carbohydrate (40–50%), protein (6–8%), fiber (8–10%), and ash (2–3%) (Oladele & Aina, 2007; Belewu and Belewu, 2007). The lipid fraction is dominated by unsaturated fatty acids, primarily oleic (64–73%) and linoleic acids (9–13%), making tiger nut oil comparable to olive oil in its health-promoting properties (Osagie & Eka, 1998). The protein content, though moderate, contains essential amino acids such as arginine, leucine, and glutamic acid, which are beneficial for metabolic functions and cardiovascular health.

2.5.2 Mineral and Vitamin Composition

Tiger nuts are a good source of essential minerals such as potassium, phosphorus, magnesium, calcium, and iron, with potassium being the most abundant (Adekanmi *et al.*, 2009). These minerals support neuromuscular function, bone formation, and enzymatic reactions. The tubers also contain significant levels of vitamins E and C, which contribute to their antioxidant properties, as well as B-complex vitamins like thiamine and riboflavin (Adejuyitan, 2011). Vitamin E, in

particular, enhances the oxidative stability of tiger nut milk, reducing rancidity and extending shelf life (Yu *et al.*, 2022).

2.6 Sensory Evaluation

Sensory evaluation is a scientific discipline used to measure, analyze, and interpret human responses to food characteristics as perceived by the senses of sight, smell, taste, touch, and hearing. In food product development, sensory evaluation serves as a bridge between technological innovation and consumer satisfaction (Lawless & Heymann, 2010). It plays a vital role in assessing the acceptability and quality of both conventional and novel foods such as plant-based milk and cheese analogs. Sensory testing provides insights into consumer perception, guiding formulation adjustments to improve texture, flavor, color, and overall product appeal (Stone & Sidel, 2004). For plant-based cheese products, sensory evaluation is particularly important because consumers often compare them to traditional dairy cheese in terms of meltability, mouthfeel, and flavor intensity (McCarthy *et al.*, 2017).

2.6.1 Importance of Sensory Evaluation in Product Development

Sensory evaluation plays a vital role in the assessment of product quality, particularly for novel foods like tiger nut cheese, which aim to mimic or replace dairy-based products. It helps researchers and manufacturers to:

1. Determine the acceptability of the product by consumers.
2. Identify and quantify key sensory attributes (taste, aroma, texture, color, and mouthfeel).
3. Provide insights into formulation improvements and process optimization (Stone, Bleibaum, & Thomas, 2012).
4. Support product marketing by aligning sensory profiles with consumer preferences (Meilgaard *et al.*, 2007).

According to Lawless and Heymann (2010), the sensory perception of a food product is the ultimate determinant of its success in the marketplace, even when its nutritional and physicochemical properties are favorable.

2.6.2 Sensory Evaluation Methods

Sensory evaluation methods are classified into analytical (objective) and affective (subjective) tests (Stone & Sidel, 2004).

(a) Analytical or Discriminative Tests

These are performed by trained panelists to identify differences between samples and to quantify specific attributes. Common analytical tests include:

- Difference tests: Triangle test, duo-trio test, and paired comparison.
- Descriptive analysis: Quantifies the intensity of specific attributes, often using trained assessors and standardized scales (Lawless & Heymann, 2010). Descriptive sensory analysis is particularly useful in evaluating the

texture, flavor, and aroma of plant-based cheeses derived from tiger nut milk.

(b) Affective or Hedonic Tests

Affective tests are conducted with untrained consumers to assess product preference and acceptability. The most common method is the 5-point hedonic scale (Meilgaard *et al.*, 2007). Panel sizes typically range from 20 to 50 assessors, depending on the study design. This method is widely used in the evaluation of tiger nut-based beverages, yogurts, and cheeses (Sanful, 2009; Obasi & Mani, 2023).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Location of Study

The Experimental work was carried out at Chrisdaz analytical lab located at No. 15, Ekenomawan Street, Old Road, off S & T Barracks, Isihor, Benin City, Edo State.

3.2 Experimental Design

The study employed an experimental research design to assess the impact of two (2) natural coagulants, Tamarind (Tsamiya) and lemon juice and one (1) synthetic coagulant, Vinegar on the chemical composition and sensory attributes of two levels of vegan tiger nut cheese: cheddar and mozzarella and this was produced in triplicate given a total of 18 samples yielding an experimental design of a 3 x 2 factorial design resulting in six (6) treatment combinations. The research involved four (4) trials which was carried out to determine the best method suitable for the final production of the vegan cheese using tiger nut. After this, the final preparation was carried out using the method used in the fourth (4th) trial after which was followed by determination of the chemical composition such as proximate (dry matter, crude protein, crude fibre, ash, ether extract and nitrogen-free extract) and some minerals and sensory evaluation of the final cheese produced using a 5-point hedonic scale.

3.3 Experimental Treatments

Treatment 1 (T₁): Mozzarella + Vinegar; R1, R2 & R3

Treatment 2 (T₂): Cheddar + Vinegar; R4, R5 & R6

Treatment 3 (T₃): Mozzarella + Lemon; R7, R8 & R9

Treatment 4 (T₄): Cheddar + Lemon; R10, R11 & R12

Treatment 5 (T₅): Mozzarella + Tamarind fruit (Tsamiya); R13, R14 & R15

Treatment 6 (T₆): Cheddar + Tamarind fruit (Tsamiya); R16, R17 & R18

3.4 Experimental Materials

Fresh Tiger nuts (*Cyperus esculentus L.*), Bambara nut (plant-base), Soybean (plant-base), Coconut (plant-base), Tamarind (Tsamiya, a locally sourced coagulant), Lemon (*Citrus limon*), Vinegar (5% acetic acid solution), KUNIMED Yeast Powder (Nutritional yeast, for flavour enhancement), Tapioca starch (for stretchiness), Coconut oil (for texture). These were obtained fresh from a local market in Benin City, Edo State, Nigeria. Other materials used for the study include Water, Salt, Sieve cloth, Plastic bowl, Blender, Stainless steel pot, Cooking Thermometer, Weighing balance.

3.5 Pre-liminary Trials

Four Preliminary trials were carried out before the final procedure which was done to get the method best suited for the production of the cheese and also helping to get acquainted with the process and elimination of all controllable errors faced during the trials.

3.5.1 Trial using soybean

The first trial took place on the 22nd of July, 2025.

Materials used: Soybean, Lemon (*Citrus limon*).

Method employed: Curd and whey.

4 cups of soybean were used which weighed 130g. The soybean was boiled for five (5) minutes to remove the bean flavour and was soaked for 12 hours (7 pm-7 am). After soaking, it was washed to remove the hull and then the washed soybean was blended with 1.2 liters of water and the milk extracted from this slurry using a sieve cloth and the milk yield was 900ml. The milk obtained was heated for about five (5) minutes and after heating, it was allowed to cool. After cooling, it was heated again and when boiling began, the juice from the fresh lemon was added to the boiling milk and a separation occurred which led to the formation of whey (the liquid portion) and curd (the solid Portion, consisting of casein proteins, fat and other nutrients).

3.5.2 Trial using Coconut.

This trial was the second (2nd) trial and was conducted on the 9th of August, 2025.

Materials used: Coconut, Garlic, Salt, Corn Starch, three (3) Coagulants (Lime, Tsamiya and Vinegar) and Nutritional yeast.

Method employed: Pasteurized milk.

5 medium size coconut was used which weighed 1250g. The edible part of the coconut was removed from the shell, washed and then blended with 1.5 liters of water to a smooth paste. The milk was then extracted from this paste using a sieve cloth. The milk was then pasteurized for five (5) minutes before it started boiling and was allowed to cool after pasteurization. The pasteurized milk was then divided into three (3) portions, each portion for a type of cheese (Mozzarella, Cheddar and Cream). For mozzarella, garlic and salt were added to the pasteurized milk to enhance taste. Nutritional yeast was added to give it a nutty flavour, a slurry of corn starch (for thickening) was also added. This mixture was heated for 2-3 minutes in a stainless-steel pot and then brought down from the heat source. $\frac{1}{2}$ teaspoon of lime was added and then stirred. The mixture was then poured into a plastic bowl and allowed to cool. The same process was repeated twice using tsamiya and vinegar as the Coagulants for each process.

For Cream cheese, the pasteurized milk was put in a stainless-steel pot and placed on the heat source. $\frac{1}{2}$ teaspoon of lime, a slurry of corn starch, nutritional yeast, salt and garlic were added. The mixture was then stirred for two (2) minutes. Precaution was taken to ensure that it was not as jelly as mozzarella. The heated mixture was then brought down and poured into a bowl and allowed to cool. The process was repeated twice only differing in the use of tsamiya and vinegar as the Coagulants.

For Cheddar cheese, the pasteurized milk was heated to reduce moisture. Then, nutritional yeast, garlic, a slurry of corn starch and salt. The mixture was then stirred until it looked firm. The firm mixture was then brought down and ½ teaspoon of lime was added and stirred. This was then poured into a bowl and allowed to cook. The same process was also repeated twice using tsamiya and vinegar.

This trial failed because we preserved it using a freezer and water was found present in each sample prepared.

3.5.3 Trial using Bambara Nut.

This trial took place on the 22nd of August and was the third (3rd) trial.

Materials used: Bambara Nut, Coagulants (Tsamiya, Lemon and Vinegar).

Method employed: Addition of the materials to the pasteurized milk before heating

2 cups of Bambara nuts were used, which weighed 300g. The bambara nuts were soaked for 9 hours and then washed to remove the hull. This was then blended with 1.0 liters of water and the milk extracted from the paste using a sieve cloth. The milk yield was 850ml. The milk was then pasteurized using high temperature short time (72°C for 15 seconds) and then allowed to cool to about 45°C. Mozzarella, Cheddar and cream cheese were then made using the pasteurized milk with the 3 different coagulants.

To the pasteurized milk was added nutritional yeast, tapioca starch, salt and a coagulant. This mixture was then heated for about 3-5 minutes and then poured into a plastic bowl and stored. This process was repeated for each of the cheeses using the 3 coagulants for all the cheeses. The trial failed because the tapioca starch was used raw without drying and this led to the sample going bad.

3.5.4 Trial using Tiger Nut.

This was the fourth (4) trial and it took place on the 30th of September.

Materials used: Tiger Nut, Coagulants (Tamarind Fruit (Tsamiya), Lemon and Vinegar), coconut oil.

Method employed: Two (2) methods were used to produce only two (2) cheese: Cheddar and mozzarella. For Cheddar: Use of extracted milk.

For mozzarella: use of Tiger nut.

Tapioca starch was sun-dried for 2 days to obtain the flour. Tiger Nut was washed, soaked and then blended to extract the milk. The extracted milk was then used in the preparation of cheddar cheese with the 3 different coagulants. To the milk was added a tablespoon of nutritional yeast, a pinch of salt, a tablespoon of vinegar, 1½ tablespoons of tapioca starch and a tablespoon of coconut oil. The mixture was then heated for 3-5 minutes using moderate heat. The cheddar cheese resulting from this procedure was then poured into a plastic bowl and allowed to cool. This process was repeated twice, only differing in the coagulant used.

For Mozzarella cheese, tiger nut was put in a blender and to it was added a tablespoon of nutritional yeast, a tablespoon of vinegar, a tablespoon of coconut oil, a pinch of salt, 1½ tablespoons of tapioca starch and 250ml of water. This was then blended into a smooth paste. The paste was then heated on moderate heat for about 3-5 minutes, and the process was repeated using the remaining 2 coagulants.

3.6 Production of Tiger Nut Milk

The tubers were first washed to remove soil and contaminants, then soaked in potable water for 6–24 hours to soften the tissues. The softened tubers were then wet-milled with water in a 1:4 ratio to produce a slurry. This was followed by filtration using a sieve cloth to obtain the milky extract as shown in Figure 1.

3.7 Production of Cheddar Tiger Nut Cheese

The milk extracted was put into a stainless steel pot. To it was added a tablespoon of nutritional yeast, a tablespoon of coconut oil, a tablespoon of vinegar, a pinch of salt and 1½ tablespoons of tapioca starch. The resulting mixture was then heated for 3-5 minutes on a moderate heat. The cheese produced was then poured into a plastic bowl and allowed to cool before being covered with the lid. This process was repeated only differing in the coagulants used, ensuring all three (3) coagulants were used.

3.8 Production of Mozzarella Tiger Nut Cheese

To a blender was added tiger nut and 250ml of water. A tablespoon of nutritional yeast, a tablespoon of coconut oil, a pinch of salt, a tablespoon of vinegar and 1½ tablespoons of tapioca starch were added. This mixture was then blended into a smooth paste. The paste was then heated using a stainless-steel pot for about 3-5 minutes on moderate heat. The cheese was then poured into a plastic container and allowed to cool. This process was also repeated, ensuring that all the coagulants were used.

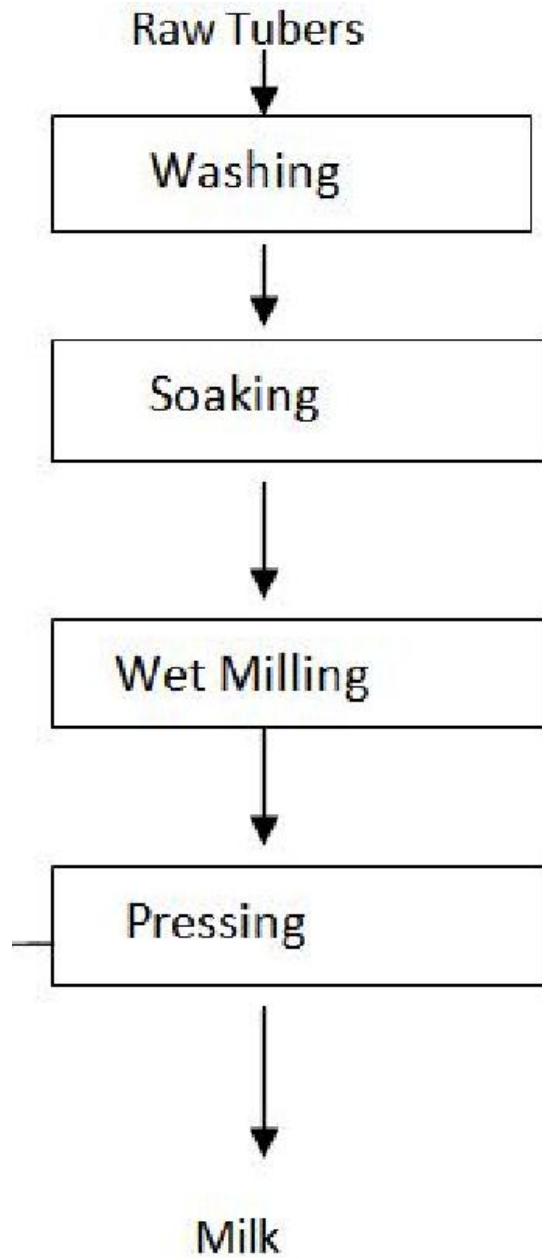


Figure 1: Flow Diagram for extracting tiger nut milk and solids
Source: Asante *et al.* (2014).

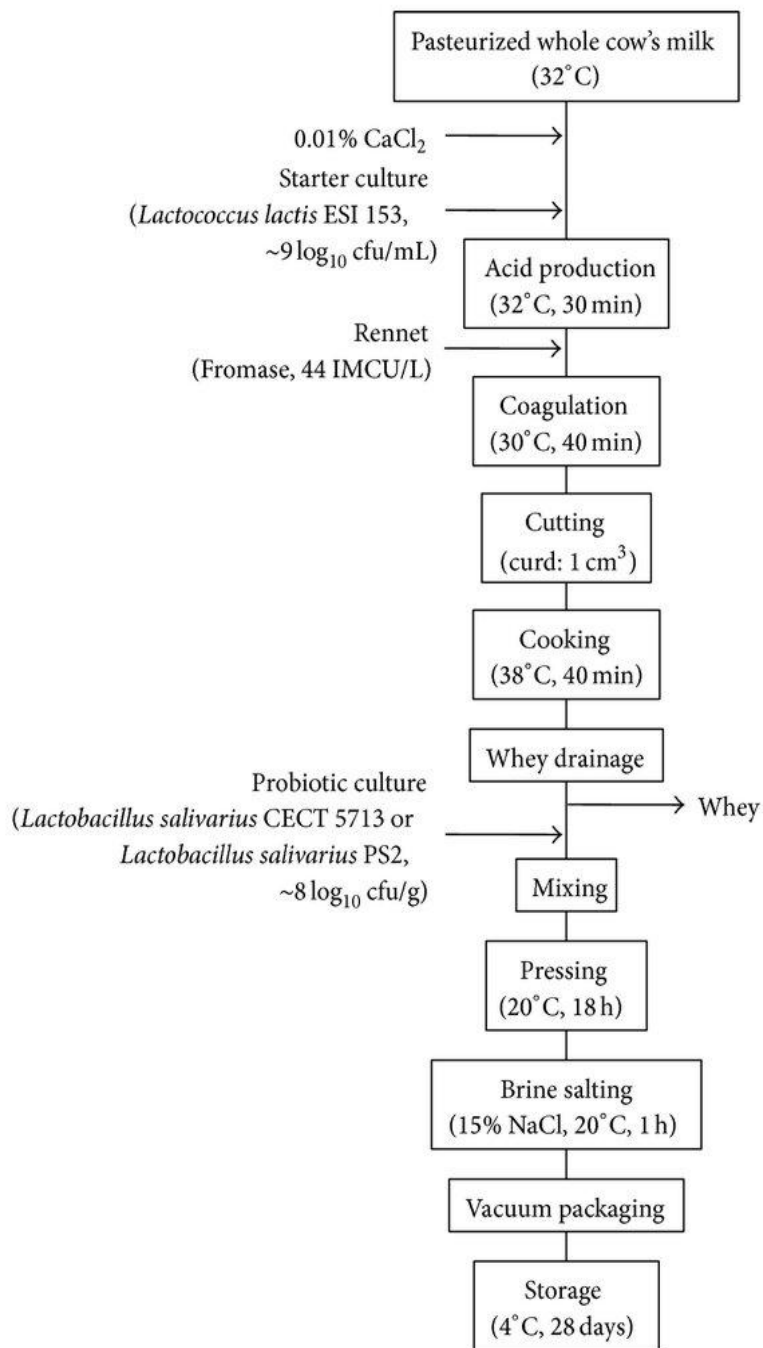


Figure 2: Flowchart of the cheese making process
 Source: Martín *et al.* (2014)

3.9.1 Chemical Analysis

The cheeses produced were then analysed proximately and some mineral content was analysed. The samples were analysed in duplicate.

3.9.1.1 Determination of Moisture Content (MC)

2g of the sample was weighed into a silica dish that had been previously pre-dried and weighed.

Then it was placed in the oven at 100°C for 24 hours and was then dried to constant weight. The sample was then cooled in a desiccator for 30 minutes before weighing again to obtain the final weight.

Calculations:

Weight of moisture = weight of sample before drying - weight of sample after drying.

%Moisture = weight of moisture ÷ weight of sample × 100.

Dry matter = 100 - %moisture.

3.9.1.2 Determination of Crude Protein (CP).

A 2g portion of the dried, moisture-free sample was accurately weighed into a digestion flask. To this, 10 ml of concentrated sulfuric acid (H₂SO₄) and 8g of a digestion catalyst mixture composed of copper sulphate and sodium sulphate in a 1:9 ratio, were added. The contents were swirled gently to ensure proper mixing and uniformity. The mixture was then heated to begin the digestion process and was maintained until a blue-green color appeared, indicating complete digestion.

This process lasted for approximately 2 hours. After digestion, the flask was allowed to cool, and the content was transferred into a 100 ml volumetric flask. Distilled water was added to make up the volume to the 100 ml mark. A distillation was then performed using a Markham still apparatus. For this step, 10 ml of the digested sample was introduced into the distillation tube, followed by the slow addition of 10 ml of 0.5N sodium hydroxide (NaOH). The mixture was left to react for about 10 minutes. During distillation, the released ammonia was trapped as ammonium hydroxide (NH₄OH), which appeared yellow in color. This was collected in a conical flask containing 20 ml of 4% boric acid solution along with a few drops of modified methyl red indicator. The resulting distillate was titrated with standard 0.1N hydrochloric acid (HCl) until a pink endpoint was observed. A blank titration was also carried out using the same acid solution. The nitrogen content obtained from the titration was then used to calculate the percentage of crude protein in the sample by multiplying it by a factor of 6.25.

Calculations:

$\% \text{ Nitrogen} = \text{Normality of acid} \times (14/1000) \times \text{volume of acid} \times (100/\text{volume of digest used}) \times (100/\text{weight of sample}).$

$\% \text{ Crude Protein} = \% \text{ Nitrogen} \times 6.25$

3.9.1.3 Determination of Crude Fibre (CF)

2g of the sample was weighed into a round bottom flask. 100ml of crude fibre reagent that has been boiled was added and then the beaker placed on the crude

fibre apparatus which has been presented to maintain steady boiling. The content was filtered under suction on a piece of close texture linen after refluxing for 1 hour. The residue was rinsed with boiling water until it was free of acid. NaOH solution which had been previously boiled was added, filtered while hot using a filter paper and the residue was allowed to drain and transferred to a pyrex heater and dried, weighed and ashed. The residue was cooled in a desiccator and weighed after 1 hour. The loss on weight due to ashing was calculated as the crude fibre content.

Calculations:

Sample weight = R

Weight before ashing = A

Weight after ashing = K

% Crude Fibre = $(A - K) \div R \times 100$

3.9.1.4 Determination of Ash

2g of the sample was weighed and put into a weighed crucible and was ignited at 550°C for 6 hours in a muffle furnace. The ash was then removed and allowed to cool in a desiccator for about 30 minutes and then reweighed and the value was calculated.

Calculations:

Sample weight = R

Weight before ashing = A

Weight after ashing = K

$$\% \text{ Ash} = (A - K) \div R \times 100$$

3.9.1.5 Determination of Ether Extract (EE)

2g of the sample was weighed into a filter paper. The filter paper was then folded tightly and placed in the extractor. Petroleum Ether was then added until it siphoned over. More Ether was added until the barrel 300ml was half filled. Then the condenser was replaced. The control was adjusted on the apparatus so that the others boiled greatly and was left to siphon for over 2 hours. The apparatus was washed after 3 hours because it was expected that by this time, all the fat present in the sample would have been extracted. The flask was then detached when the Ether was short of siphoning over. The barrel content was drained properly into the bottle and the filter paper removed and dried. The flask was detached while the sample was removed and dried in an oven to constant weight.

Calculations:

$$\% \text{ Ether Extract} = \text{weight of oil} \div \text{weight of sample} \times 100$$

3.7.1.5 Determination of Nitrogen Free Extract (NFE)

This was determined by subtracting the sum of % ether extract, ash, crude protein and crude fibre from 100

$$\text{NFE} = 100 - (\% \text{EE} + \% \text{Ash} + \% \text{CP} + \% \text{CF})$$

3.9.2 Mineral Analysis

1g of the sample was ashed at 550°C in a muffle furnace and then dissolved in deionized water to standard volume. Calcium, Magnesium and potassium were determined using an atomic absorption spectrophotometer.

3.10 Sensory evaluation

A group of 30 panelists were chosen to assess the samples on the appearance, aroma, taste, mouthfeel and overall acceptability using a 5-point hedonic scale.

3.11 Statistical Analysis

Data collected from the study were subjected to analysis of variance using the GENSTAT 12th edition for windows package at 5% significant level ($p < 0.05$). The means with significant difference were separated using Duncan Multiple Range Test (DMRT). SPSS Software was used for the data collected from the sensory evaluation.

CHAPTER FOUR

4.0 RESULTS

4.1 Proximate Composition of Mozzarella and Cheddar Cheeses Produced from Tiger Nut Using Three (3) Coagulants

The proximate composition of Mozzarella and Cheddar Tiger nut Cheeses produced using three (3) coagulants is presented in Table 2.

pH

The pH values ranged from T₁ (5.335) to T₆ (5.985). In general, Cheddar-type cheeses showed higher pH values than the Mozzarella variants, particularly those produced with tamarind extract. The lowest pH value was recorded in T₂, reflecting a more acidic condition typical of vinegar coagulation. The pH of T₂ was significantly different ($p < 0.05$) from those obtained for T₁ (5.335), T₃ (5.605), T₄ (5.195), T₅ (5.775) and T₆ (5.985).

MC ranged from 73.10% (T₆) to 77.53% (T₃). Mozzarella cheeses had higher moisture than Cheddar types. T₆ showed the lowest MC, indicating a drier texture. The MC of T₆ was significantly different ($p < 0.05$) from T₁ (77.46%), T₂ (75.84%), T₃ (77.53%), T₄ (75.72%), and T₅ (77.06%).

CP ranged from 1.875% (T₅) to 2.295% (T₄ and T₆). Cheddar cheeses (T₄ and T₆) had the highest protein content, while Mozzarella types (T₁, T₃, and T₅) had lower protein content. The CP of T₄ and T₆ were significantly different ($p < 0.05$) from T₁, T₂, T₃, and T₅.

EE ranged from 3.395% (T3) to 4.165% (T6). Cheddar cheeses, particularly T6, contained more fat than Mozzarella samples (T1, T3, and T5). The EE of T6 (4.165%) was significantly different ($p < 0.05$) from T1 (3.410%), T2 (3.735%), T3 (3.395%), T4 (3.740%), and T5 (3.480%).

ASH ranged from 0.465% (T1) to 0.780% (T6). The highest ash was found in T6, while the lowest was in T1. The ASH of T6 (0.780%) was significantly different ($p < 0.05$) from T1 (0.465%), T2 (1.105%), T3 (0.520%), T4 (0.725%), and T5 (0.580%).

CF values ranged from 0.145% (T6) to 1.130% (T1). Mozzarella cheeses (T1, T3 and T5) contained more fibre than Cheddar types (T2, T4 and T6). The CF of T1 (1.130%) was significantly different ($p < 0.05$) from T2 (0.200%), T3 (1.025%), T4 (0.180%), T5 (0.755%), and T6 (0.145%).

NFE ranged from 15.52% (T1) to 19.51% (T6). The highest carbohydrate content occurred in T6, while the lowest was found in T2. The NFE of T6 (19.51%) was significantly different ($p < 0.05$) from T1 (15.52%), T2 (16.98%), T3 (15.59%), T4 (17.17%), and T5 (16.25%).

Table 2: Proximate Composition (%) and pH of Mozzarella and Cheddar Cheeses Produced from Tiger Nut Using Three (3) Coagulants

| Parameters | T₁ | T₂ | T₃ | T₄ | T₅ | T₆ | SEM |
|-------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|------------|
| pH | 5.335 ^c | 4.870 ^a | 5.605 ^d | 5.195 ^b | 5.775 ^c | 5.985 ^f | 0.02111 |
| DM (%) | 22.54 ^a | 24.16 ^b | 22.47 ^a | 24.27 ^b | 22.94 ^{ab} | 26.90 ^c | 0.477 |
| MC (%) | 77.46 ^c | 75.84 ^b | 77.53 ^c | 75.72 ^b | 77.06 ^{bc} | 73.10 ^a | 0.477 |
| CP (%) | 2.015 ^{ab} | 2.135 ^{ab} | 1.940 ^a | 2.450 ^c | 1.875 ^a | 2.295 ^{bc} | 0.0928 |
| EE (%) | 3.410 ^a | 3.735 ^b | 3.395 ^a | 3.740 ^b | 3.480 ^a | 4.165 ^c | 0.0667 |
| ASH (%) | 0.465 ^a | 1.105 ^f | 0.520 ^b | 0.725 ^d | 0.580 ^c | 0.780 ^c | 0.01099 |
| CF (%) | 1.130 ^c | 0.200 ^b | 1.025 ^d | 0.180 ^{ab} | 0.755 ^c | 0.145 ^a | 0.01448 |
| NFE (%) | 15.52 ^a | 16.98 ^b | 15.59 ^a | 17.17 ^b | 16.25 ^{ab} | 19.51 ^c | 0.318 |

Note: T₁ = Mozzarella + Vinegar,
T₂ = Cheddar + Vinegar,
T₃ = Mozzarella + Lemon,
T₄ = Cheddar + Lemon,
T₅ = Mozzarella + Tamarind fruit (Tsamiya),
T₆ = Cheddar + Tamarind fruit (Tsamiya),
DM = Dry Matter,
EE = Ether Extract,
CP = Crude Protein,
CF = Crude Fibre,
MC = Moisture Content,
NFE = Nitrogen Free Extract,
SEM = Standard Error of Means.

Mean values with the same letters along the same column are not significantly different at 5% probability level (p>0.05).

4.2 Mineral Composition of Mozzarella and Cheddar Cheeses Produced from Tiger Nut Using Three (3) Coagulants

The mineral analysis of mozzarella and cheddar-type vegan Cheeses produced from tiger nut using three (3) coagulants is presented in Table 3.

Calcium levels ranged from 231.5 mg/kg (T₃) to 311.3 mg/kg (T₄). The highest value was obtained in T₄, while the lowest was in T₃. The Ca content of T₄ was significantly different ($p < 0.05$) from T₁ (307.5 mg/kg), T₂ (278.4 mg/kg), T₃ (231.5 mg/kg), T₅ (288.4 mg/kg), and T₆ (232.1 mg/kg).

Magnesium content ranged between 115.5 mg/kg (T₁) and 244.2 mg/kg (T₆). T₆ showed the highest Mg level, while T₁ had the lowest. The Mg of T₆ was significantly different ($p < 0.05$) from T₁ (115.5 mg/kg), T₂ (178.2 mg/kg), T₃ (150.4 mg/kg), T₄ (131.7 mg/kg), and T₅ (223.6 mg/kg).

Phosphorus values ranged from 556.1 mg/kg (T₃) to 1254.9 mg/kg (T₂). The highest P concentration was observed in T₂, while the lowest was found in T₃. The P content of T₂ was significantly different ($p < 0.05$) from T₁ (720.7 mg/kg), T₃ (556.1 mg/kg), T₄ (1096.0 mg/kg), T₅ (664.9 mg/kg), and T₆ (967.2 mg/kg).

Table 3: Mineral Composition and Ph of Mozzarella and Cheddar Cheeses Produced from Tiger Nut Using Three (3) Coagulants

| Parameters | T₁ | T₂ | T₃ | T₄ | T₅ | T₆ | SEM |
|-------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|------------|
| Ca (mg/kg) | 307.5 ^{bc} | 278.4 ^b | 231.5 ^a | 311.3 ^c | 288.4 ^{bc} | 232.1 ^a | 9.63 |
| Mg (mg/kg) | 115.5 ^a | 178.2 ^c | 150.4 ^b | 131.7 ^{ab} | 223.6 ^d | 244.2 ^d | 7.57 |
| P (mg/kg) | 720.7 ^c | 1254.9 ^f | 556.1 ^a | 1096.0 ^e | 664.9 ^b | 967.2 ^d | 11.83 |

Note: T₁ = Mozzarella + Vinegar,

T₂ = Cheddar + Vinegar,

T₃ = Mozzarella + Lemon,

T₄ = Cheddar + Lemon,

T₅ = Mozzarella + Tamarind fruit (Tsamiya),

T₆ = Cheddar + Tamarind fruit (Tsamiya),

Ca = Calcium,

Mg = Magnesium,

P = Phosphorus.

SEM = Standard Error of Means

Mean values with the same letters along the same column are not significantly different at 5% probability level ($p > 0.05$).

4.3 Sensory Evaluation Analysis of Mozzarella and Cheddar-Type Vegan Cheeses Produced from Tiger Nut Using Three (3) Coagulants

A total of 18 panelists participated in the sensory evaluation. The panel was predominantly female (61.11%) and male (38.89%). 27.9% were self employed and 72.9% were students. A large majority of the respondents (50%) have either never (50%) or rarely (38.89%) consumed vegan cheese, indicating that the panel was composed largely of novice consumers.

Colour ratings ranged from 3.167 (T2, T6) to 3.444 (T3, T4). The best colour appearance was noted in T3 and T4, while T2 and T6 had the lowest ratings. There were no significant differences ($p>0.05$) in colour among all treatments.

Flavour scores varied between 3.111 (T4) and 3.667 (T5). Mozzarella cheese with tamarind (T5) had the strongest cheese-like flavour, whereas Cheddar with lemon (T4) was least rated. The flavour of T5 (3.667) did not differ significantly ($p>0.05$) from T1 (3.556), T2 (3.278), T3 (3.278), T4 (3.111), and T6 (3.167).

Aroma scores ranged from 2.944 (T4) to 3.611 (T3). The most pleasant aroma was associated with T3, while T4 had the lowest score. The aroma of T3 (3.611) showed no significant difference ($p>0.05$) compared to T1 (3.444), T2 (3.111), T4 (2.944), T5 (3.444), and T6 (3.444).

Creaminess scores ranged from 3.111 (T4) to 3.500 (T1). Mozzarella produced with vinegar (T1) was rated the creamiest, while Cheddar with lemon (T4) was

the least creamy. The creaminess of T1 (3.500) was not significantly different ($p>0.05$) from T2 (3.278), T3 (3.333), T4 (3.111), T5 (3.389), and T6 (3.389).

Overall acceptability ranged from 2.944 (T4) to 3.722 (T5). Mozzarella with tamarind (T5) was the most preferred, while Cheddar with lemon (T4) was the least. The overall acceptability of T5 (3.722) was significantly different ($p<0.05$) from T1 (3.444), T2 (3.278), T3 (3.500), T4 (2.944), and T6 (3.444).

Table 4: Results of Sensory Qualitative Descriptive Analysis of Mozzarella and Cheddar-Type Vegan Cheeses Produced from Tiger Nut Using Three (3) Coagulants

| Parameters | T ₁ | T ₂ | T ₃ | T ₄ | T ₅ | T ₆ | SEM |
|--------------------------|---------------------|---------------------|---------------------|--------------------|--------------------|---------------------|--------|
| Colour | 3.222 ^a | 3.167 ^a | 3.444 ^a | 3.444 ^a | 3.222 ^a | 3.167 ^a | 0.2140 |
| Cheese-like flavour | 3.556 ^a | 3.278 ^a | 3.278 ^a | 3.111 ^a | 3.667 ^a | 3.167 ^a | 0.1924 |
| Aromapleasantness | 3.444 ^a | 3.111 ^a | 3.611 ^a | 2.944 ^a | 3.444 ^a | 3.444 ^a | 0.3137 |
| Creaminess | 3.500 ^a | 3.278 ^a | 3.333 ^a | 3.111 ^a | 3.389 ^a | 3.389 ^a | 0.2093 |
| Overall acceptability | 3.444 ^{ab} | 3.278 ^{ab} | 3.500 ^{ab} | 2.944 ^a | 3.722 ^b | 3.444 ^{ab} | 0.2352 |

Note: T₁ = Mozzarella + Vinegar,

T₂ = Cheddar + Vinegar,

T₃ = Mozzarella + Lemon,

T₄ = Cheddar + Lemon,

T₅ = Mozzarella + Tamarind fruit (Tsamiya),

T₆ = Cheddar + Tamarind fruit (Tsamiya),

SEM = Standard Error of Means.

Mean values with the same letters along the same column are not significantly different at 5% probability level ($p > 0.05$).

CHAPTER FIVE

5.0 DISCUSSION

The lowest pH, observed in the vinegar-coagulated Cheddar, indicated a distinctly acidic environment, while the tamarind-coagulated Cheddar showed the highest pH, suggesting a milder acidity. This is in consonance with the findings of Alehosseini *et al.* (2025), which states that the acidity of plant-based or acid coagulants significantly influences the pH and texture of vegan cheese analogues. Similarly, Lomolino *et al.* (2025) reported that lower pH levels produce firmer and tangier cheeses, whereas higher pH results in softer, less acidic textures. Consequently, the type of coagulant used directly determines curd formation, flavor development, and overall texture.

The moisture content also differed with coagulant type and cheese variety. Mozzarella cheeses retained more moisture than Cheddar cheeses, which were drier. This was likely due to firmer curd formation and increased whey expulsion in the Cheddar samples. According to Kumar and Bhattacharya (2024), stronger coagulation and greater acidity generally lead to lower moisture retention in plant-based cheeses, resulting in a denser texture and improved shelf stability.

The crude protein content tended to be higher in Cheddar cheeses than in Mozzarella types, suggesting that coagulants, especially tamarind extract, enhanced protein aggregation and curd strength. Sharma *et al.* (2024) reported that tamarind's naturally acidic polysaccharides promote efficient protein

coagulation, thereby increasing curd yield and protein levels in vegan cheese analogues.

The ether extract (fat content) was influenced by the coagulant used, with Cheddar cheeses showing greater fat retention than Mozzarella samples. This suggested that tamarind extract may have supported better fat emulsification and minimized fat loss during whey separation. Comparable observations were made by Pereira *et al.* (2023), who found that plant-based coagulants with moderate acidity improve fat incorporation and texture uniformity in non-dairy cheese production.

The ash content, representing total mineral concentration, was higher in cheeses coagulated with tamarind extract. This outcome was likely linked to the mineral-binding properties of tamarind's organic acids, which enhance the retention of elements such as calcium and magnesium. Ibrahim *et al.* (2024) similarly found that fruit-based coagulants enhance mineral content and improve the nutritional quality of vegan cheeses.

The crude fibre content was higher in Mozzarella cheeses compared with Cheddar cheeses. This difference may be due to softer curd formation and the presence of unfiltered plant residues in Mozzarella samples. Oseni and Falodun (2023) explained that fibre retention in plant-based cheeses depends largely on the curd's firmness and the filtration efficiency during processing.

The nitrogen-free extract (NFE), which represents the carbohydrate portion, was greatest in cheeses produced with tamarind extract. This could be attributed to lower moisture and higher total solids, which concentrated the carbohydrate fraction. Yusof *et al.* (2024) reported similar results, noting that reduced moisture increases apparent carbohydrate levels in vegan cheese analogues by concentrating soluble nutrients.

The calcium (Ca) content varied among treatments, with Cheddar cheeses containing more calcium than Mozzarella types. Cheeses coagulated with lemon extract had the highest calcium levels, while Mozzarella samples made with lemon or tamarind showed the lowest. This indicated that the coagulant type influenced calcium retention and curd structure. Lemon and tamarind extracts likely improved calcium binding through their organic acids, which aid mineral complex formation during coagulation. These results aligned with Adejuyitan *et al.* (2024), who reported that organic acid coagulants affect calcium solubility and its incorporation into plant-based curds.

The magnesium (Mg) content also varied significantly. Cheddar cheeses coagulated with tamarind extract had the highest magnesium levels, whereas Mozzarella with vinegar had the lowest. This showed that tamarind extract enhanced magnesium retention, possibly due to its chelating acids, such as tartaric and citric, which stabilize minerals during coagulation. Ibrahim *et al.* (2024)

similarly found that fruit-based coagulants increase magnesium bioavailability in vegan cheeses by reducing mineral loss during whey separation.

The phosphorus (P) content followed a similar trend, with the highest values in Cheddar cheese made with vinegar and the lowest in Mozzarella with lemon. The higher phosphorus levels in vinegar-coagulated Cheddar could be linked to increased solids and improved casein-phosphate complex formation under acidic conditions. Lomolino *et al.* (2025) also observed that stronger acid coagulants promote phosphate–protein interactions, enhancing phosphorus retention in the curd.

The colour of the cheeses was largely similar across all treatments, suggesting that the type of coagulant had little influence on visual appearance. This indicates that the natural pigments in tiger nut milk primarily determined the colour, supporting the findings of Yusof *et al.* (2024), who noted that plant-based milk pigments are the main contributors to cheese colour, regardless of the coagulant used.

The cheese-like flavour showed slight variations among the samples. Cheeses coagulated with tamarind extract exhibited a more balanced and pleasant taste, while those made with lemon or vinegar had sharper acidic notes. This is consistent with Pereira *et al.* (2023), who observed that moderately acidic coagulants help improve flavour balance and reduce bitterness in plant-based cheeses.

Aroma pleasantness varied only slightly, with tamarind-based cheeses generally rated higher. While coagulants had a subtle impact on aroma, the overall scent remained largely consistent across treatments, reflecting the intrinsic volatile compounds of tiger nut milk. Yusof *et al.* (2024) similarly reported that natural volatiles in plant-based milks strongly influence aroma, often more than the coagulant.

Creaminess was slightly greater in Mozzarella than in Cheddar, indicating that the cheese type and the natural fat content of tiger nut milk contributed more to mouthfeel than the coagulant itself. Kumar and Bhattacharya (2024) highlighted that oils present in plant-based milks are key determinants of creaminess, independent of the coagulant used.

Overall acceptability was highest for cheeses made with tamarind extract, reflecting their combination of balanced flavour, pleasant aroma, and smooth texture. This aligns with Sharma *et al.* (2024), who reported that tamarind extract enhances sensory appeal in vegan cheeses by promoting mild acidity and improving mouthfeel.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The study shows that tiger nut serves as an excellent raw material for producing acceptable vegan mozzarella and cheddar-type cheeses when used in conjunction with synthetic and natural coagulants such as vinegar, lemon juice, and tamarind fruit extract. Among all treatments, cheeses coagulated with tamarind, particularly Treatment 5 and Treatment 6, displayed the most desirable results in terms of proximate composition, mineral retention, and sensory attributes. The use of tamarind extract enhanced fat emulsification, flavour development, and overall acceptability while maintaining a moderate level of acidity that supported a well-balanced texture.

In contrast, lemon juice produced variable outcomes, improving colour and aroma in mozzarella-type samples but resulting in firmer and less creamy cheddar-type cheeses. Vinegar contributed positively to mineral content and creaminess but achieved only moderate scores in sensory evaluation. Overall, the study confirms that the type of coagulant exerts a significant influence on the nutritional, physicochemical, and sensory characteristics of tiger nut-based vegan cheeses. Therefore, tamarind fruit extract is identified as the most promising natural coagulant for developing high-quality, nutritious, and consumer-acceptable plant-based cheese alternatives.

6.2 Recommendations

- a. Tamarind fruit extract is identified as the most suitable coagulant for producing vegan cheese from tiger nut milk, owing to its positive effects on texture, flavour, and overall consumer acceptance. Therefore, its use should be encouraged.
- b. Future studies should focus on determining the optimal concentration levels of tamarind extract and other natural coagulants to enhance product yield, uniformity, and shelf stability.
- c. Fortifying tiger nut-based vegan cheeses with essential nutrients such as calcium, vitamin B₁₂, and plant-derived protein isolates is encouraged to boost their nutritional value and meet the dietary requirements of consumers.
- d. The flavour of these vegan products should be improved by flavouring with dates or sweeteners.
- e. Small-scale production and consumer testing should be carried out to check how practical, affordable, and appealing tamarind-based vegan cheese would be in the market.

REFERENCES

- Abdelmontaleb, H. S., Hamdy, S. M., and Aït-Kaddour, A. (2023). The effect of replacing water with tiger nut milk on spreadable processed cheese. *Egyptian Journal of Food Science*, 51(2): 258–265.
- Adebayo-Oyetero, A. O., Ogundipe, O. O., Adeyeye, S. A. O., and Olayinka, A. I. (2019). Production and evaluation of tiger nut milk flavoured with Moringa leaf extract. *Food and Nutrition Journal*, 7(2): 105–113.
- Adedeji, O. E., Yohanna, K., Adedeji, O. G., Yunusa, B. M., and Ango, A. N. (2022). Stability, nutritional composition, and antioxidant properties of surfactant-assisted enzymatically extracted tiger nut milk. *Acta Alimentaria*, 51(3): 413–423.
- Adejuitan, J. A. (2011). Tigernut processing: its food uses and health benefits. *American Journal of Food Technology*, 6(3): 197-201.
- Adekanmi, O. K., Oluwatooyin, O. F., and Yemisi, A. A. (2009). Influence of processing techniques on the nutrients and antinutrients of tigernut (*Cyperus esculentus* L.). *World Journal of Dairy & Food Sciences* 4 (2): 88-93
- Adeyemi, T., and Umar, S. (1994). Effect of manufacture on the quality and characteristics of *Kunun zaki*, a millet-based beverage. *Nigerian Food Journal*, 12: 34–40.
- Afzal, M. I., Saeed, F., Arshad, M. S., Nadeem, M. T., and Tufail, T. (2020). Nutritional and therapeutic perspectives of dairy cheese: A review. *International Journal of Dairy Technology*, 73(2): 345–356.
- Alcorta, A., Porta, A., Tárrega, A., Alvarez, M. D., and Vaquero, M. P. (2021). Foods for plant-based diets: Challenges and innovations. *Foods*, 10(2): 293.
- Arafat, S. M., Gaafar, A. M., Basuny, A. M., and Nassef, S. L. (2009). Chufa tubers (*Cyperus esculentus* L.): As a new source of food. *World Applied Sciences Journal*, 7(2): 151-156.
- Asante, F. A., Oduro, I., Ellis, W. O., and Saalia, F. K. (2014). Effect of planting period and site on the chemical composition and milk acceptability of tiger nut (*Cyperus esculentus* L.) tubers in Ghana. *American Journal of Food and Nutrition*, 2(3): 49–54.

- Astrup, A., Magkos, F., Bier, D. M., Brenna, J. T., de Oliveira Otto, M. C., Hill, J. O. and Krauss, R. M. (2019). Saturated fats and health: A reassessment and proposal for food-based recommendations. *Journal of the American College of Cardiology*, 76(7): 844–857.
- Ayo, J. A., and Okaka, J. C. (1998, November 23–26). Interaction effect of Cadaba farinose extract and pH levels on some physiological properties of Kunun Zaki. In *Proceedings of the 22nd Annual Conference of the Nigerian Institute of Food Science and Technology (NIFST)*, (pp. 31–33).
- Bado, S., Bazongo, P., Son, G., Kyaw, M. T., Forster, B. P., Nielen, S., Lykke, A. M., Ouédraogo, A., and Bassolé, I. H. N. (2015). *Physicochemical characteristics and composition of three morphotypes of Cyperus esculentus tubers and tuber oils*. *Industrial Crops and Products*, 65: 405–411.
- Balogun, M., Oyeyinka, S., Kolawole, F., Joseph, J., and Olajobi, G. (2019). *Chemical composition and sensory properties of soy-tiger nut cheese*. *Ceylon Journal of Science*, 48(4): 353–358.
- Bandler, D. K. (2023). Cheese making. *Encyclopedia Britannica*, (1):3
- Banks, J. (2007). Rennet and Cheesemaking, Past and Present. *Journal of Dairy Research*, 74(2): 137-141.
- Belewu, M. A., and Belewu, K. Y. (2007). Comparative physicochemical evaluation of tiger nut, soybean, and coconut milk sources. *International Journal of Agriculture and Biology*, 9(5): 785–787.
- Belitz, H. D., Grosch, W., and Schieberle, P. (2019). *Food Chemistry* (5th ed.). Springer
- Bilikis, A., and Olanrewaju, A. (2015). Chemical compositions, antioxidant capacity of tigernut (*Cyperus esculentus*) and potential health benefits. *European Scientific Journal*, 11:217–224.
- Bocker R. and Silva E. K. (2022). Innovative technologies for manufacturing plant-based non-dairy alternative milk and their impact on nutritional, sensory and safety aspects. *Future Foods*, 5: 100098.
- Borges, O., Gonalves, B., de Carvalho, J.L., Correia, P. and Silva, A.P. (2008). Nutritional quality of chestnut cultivars from Portugal. *Food Chemistry*, 106, 976–984.

- Briviba K., Gräf V., Walz E., Guamis B., and Butz P. (2016). Ultra high pressure homogenization of almond milk: physico-chemical and physiological effects. *Food Chemistry*, 192: 82–89.
- Choudhury, D., and Mandal, S. (2020). Functional and nutritional aspects of plant-based cheeses. *Journal of Food Science and Technology*, 57(12): 4561–4571.
- Chukwuma, E. R., Obioma, N., and Christopher, O. I. (2010). The phytochemical composition and some biochemical effects of Nigerian tigernut (*Cyperus esculentus* L.) tuber. *Pakistan journal of nutrition*, 9(7): 709-715.
- Clay, N., Sexton, A. E., Garnett, T., and Lorimer, J. (2022). Palatable disruption: The politics of plant milk. In *Social Innovation and Sustainability Transition* (pp. 11-28). Cham: Springer Nature Switzerland.
- Clem, J. and Bartel, B. (2021). A look at plant-based diets. *The Permanente Journal*, 25: 21.
- Codina-Torrella, I., Guamis, B., and Trujillo, A. J. (2015). Characterization and comparison of tiger nuts (*Cyperus esculentus* L.) from different geographical origin: Physico-chemical characteristics and protein fractionation. *Industrial Crops and Products*, 65: 406–414.
- Craig, W. J., and Mangels, A. R. (2009). Position of the American dietetic association: vegetarian diets. *Journal of the American Dietetic Association*, 109(7): 1266–1282.
- Craig, W.J.; Mangels, A.R.; Brothers, C.J. (2022). Nutritional profiles of non-dairy plant-based cheese alternatives. *Nutrients* 14: 1247.
- Cramer, H., Kessler, C. S., Sundberg, T., Leach, M. J., Schumann, D., Adams, J., and Lauche, R. (2017). Characteristics of Americans choosing vegetarian and vegan diets for health reasons. *Journal of nutrition education and behavior*, 49(7): 561-567.
- De Castro, O., Gargiulo, R., Del Guacchio, E., Caputo, P., and De Luca, P. (2015). A molecular survey concerning the origin of *Cyperus esculentus* (Cyperaceae, Poales): two sides of the same coin (weed vs. crop). *Annals of botany*, 115(5): 733-745.
- Defelice, M. S. (2002). Yellow nutsedge *Cyperus esculentus* L.—snack food of the Gods. *Weed Technology*, 16(4): 901-907.
- Delahunty, C. M., and Drake, M.A. (2004). Sensory character of cheese and its evaluation. *Cheese: Chemistry, Physics and Microbiology*, 1: 455-487.

- Djomdi, D., Nso, E. J., and Meli, F. M. (2020). Innovation in tiger nut (*Cyperus esculentus* L.) milk production: In-situ hydrolysis of starch. *Polymers*, 12(9): 2153.
- Edo, G. I., Onoharigho, F. O., Jikah, A. N., Oloni, G. O., Samuel, P. O., Rapheal, O. A., Ikpekor, O., Akpogheli, P. O., Agbo, J. J., Ekokotu, H. A., Ugbune, U., Ezekiel, G. O., Abere, G. A., Oghrora, E. E. A., Ojulari, A. E., Okoronkwo, K. A., Owheru, J. O., and Akpogheli, E. O. (2023). *Cyperus esculentus* (tiger nut): An insight into its bioactive compounds, biological activities, nutritional and health benefits. *Heliyon*, 9(12): e21153.
- Falodun, E. J., and Bakare, O., A. (2025). Performance of tiger nut (*Cyperus esculentus* L.) as influenced by row spacing and fertilizer application in a Nigerian rain forest. *Journal of Agroforestry and Environment*, 18(1): 27–36.
- Food and Agriculture Organization of the United Nations (FAO). (2019). The State of the World's Biodiversity for Food and Agriculture. Rome: FAO. 570 pp.
- Fortune Business Inside, Plant-based meal market size, share, and industry analysis, by product type (plant-based dairy, plant-based meat, plant-based milk, others), by distribution channel (Offline, Online), and Regional Forecast, 2022–2029.
- Fox, P. F., McSweeney, P. L., Cogan, T. M., and Guinee, T. P. (2017). Cheese ripening. *Fundamentals of Cheese Science* (2nd ed., pp. 345-450). Springer.
- Fox, P. F., Uniacke-Lowe, T., McSweeney, P. L. H., and O'Mahony, J. A. (2017). *Dairy chemistry and biochemistry* (2nd ed.). Springer International Publishing.
- Fu, Q. M., Liu, Y., Miao, B., Li, W., Hu, X., and Bai, F. (2024). Bronze age cheese reveals human–*Lactobacillus* interactions over evolutionary history. *Cell*, 187(2): 1–14.
- Fu, W., and Yano, H. (2020). Development of “new” bread and cheese. *Processes*, 8(12): 1541.
- Grasso, N., Bot, F., Roos, Y. H., Crowley, S. V., Arendt, E. K., and O'Mahony, J. A. (2023). Plant-Based Alternatives to Cheese Formulated Using Blends of Zein and Chickpea Protein Ingredients. *Foods (Basel, Switzerland)*, 12(7): 1492.

- Grossmann, L., and McClements, D. J. (2021). The science of plant-based foods: Approaches to create nutritious and sustainable plant-based cheese analogs. *Trends in Food Science and Technology*, 118(Part A): 207–229.
- Guinee, T. P. (2004). Salting and the role of salt in cheese. *International Journal of Dairy Technology*, 57(2-3): 99–109.
- Guinee, T. P., and Wilkinson, M. G. (2017). Rennet coagulation and coagulants in cheese manufacture. In P. F. Fox *et al.* (Eds.), *Cheese: Chemistry, physics and microbiology* (pp. 73–106). Academic Press.
- Harvard T. H. Chan School of Public Health. (2020). Cholesterol. *The Nutrition Source*.
- Hopwood, C. J., Bleidorn, W., Schwaba, T., and Chen, S. (2020). Health, environmental, and animal rights motives for vegetarian eating. *PLoS ONE*, 15(4), e0230609.
- Ibrahim, S. M., Yusuf, H. A., and Bello, R. A. (2024). Effect of natural fruit coagulants on mineral composition and quality of plant-based cheeses. *Food Chemistry Advances*, 5(2): 204–213.
- Ismail, H. A., Salama, W. M., Ali, A. A., and Awad, R. A. (2024). *Impact of tiger nut milk as a substitute for cow milk on the rheological, physicochemical, and organoleptic properties of functional ice cream*. *Journal of Food Science and Technology*, 62(8): 1537–1546.
- Kraak, V. I., and Aschemann-Witzel J. (2024). The future of plant-based diets: Aligning healthy marketplace choices with equitable, resilient, and sustainable food systems. *Annual Review of Public Health*, 45: 231-254.
- Kumar, A., Grover, S., and Batish, V. K. (2020). Microbial rennet: Production and application in cheese manufacture. *Comprehensive Reviews in Food Science and Food Safety*, 19(1): 133–148.
- Kumar, D., and Bhattacharya, P. (2024). Role of coagulant acidity in determining the texture and moisture content of non-dairy cheeses. *LWT – Food Science and Technology*, 192: 115246.
- Kumar, P., Sharma, N., and Kumar, R. (2010). Plant rennet: A potential alternative to microbial and animal rennet in cheese production. *Journal of Food Science and Technology*, 47(4): 365–371.
- Lawless, H. T., and Heymann, H. (2010). *Sensory evaluation of food: Principles and practices* (2nd ed.). Springer. 125-147

- Li, Y., Hruby, A., Bernstein, A. M., Ley, S. H., Wang, D. D., Chiuve, S. E. and Hu, F. B. (2015). Saturated fats compared with unsaturated fats and sources of carbohydrates in relation to risk of coronary heart disease. *Journal of the American College of Cardiology*, 66(14): 1538-1548.
- Lim, H.-P., Ho, K.-W., Singh, C. K. S., Ooi, C.-W., Tey, B.-T., and Chan, E.-S. (2020). Pickering emulsion hydrogel as a promising food delivery system: Synergistic effects of chitosan Pickering emulsifier and alginate matrix on hydrogel stability and emulsion delivery. *Food Hydrocolloids*, 103: 105659.
- Lomolino, G., Ragni, L., and Ubertini, M. (2025). Relationship between acidity and phosphate retention in dairy and plant-based cheeses. *International Dairy Journal*, 157: 106202.
- Lu, L., McClements, D. J., and Jafari, S. M. (2021). Plant-based cheese substitutes: Current status and future prospects. *Critical Reviews in Food Science and Nutrition*, 63(12): 1715–1734.
- Lucey, J. A., Johnson, M. E., and Horne, D. S. (2003). Invited review: Perspectives on the basis of the rheology and texture properties of cheese. *Journal of Dairy Science*, 86(9): 2725–2743.
- Lyu, Z., Sala, G., and Scholten, E. (2023). Melting properties of vegan cheese: Effect of emulsion and protein addition on the thermal behaviour of starch gels. *Food Hydrocolloids*, 144: 108917.
- Maduka, N., and Ire, F. S. (2018). Tigernut plant and useful application of tigernut tubers (*Cyperus esculentus*)—A review. *Current Journal of Applied Science and Technology*, 29(3): 1-23.
- Marco, M. L., Heeney, D., Binda, S., Cifelli, C. J., Cotter, P. D., Foligné, B., and Hutkins, R. (2017). Health benefits of fermented foods: microbiota and beyond. *Current Opinion in Biotechnology*, 44: 94–102.
- Martín, R., Olivares, M., Marín, M. L., Fernández, L., Xaus, J., and Rodríguez, J. M. (2014). Probiotic potential of *Lactobacillus salivarius* strains isolated from human milk. *BioMed Research International*, 1:2
- Mayo, B., Rachid, C. T. C. C., Alegría, Á., Leite, A. M. O., Peixoto, R. S., and Delgado, S. (2021). Impact of next generation sequencing techniques in food microbiology. *Current Opinion in Food Science*, 37:61–68.
- McCarthy, K. S., Parker, M., Ameerally, A., Drake, S. L., and Drake, M. A. (2017). Drivers of choice for fluid milk versus plant-based alternatives:

- What are consumer perceptions of fluid milk? *Journal of Dairy Science*, 100(8): 6125–6138.
- McSweeney, P. L. H., and Fox, P. F. (2018). *Advanced dairy chemistry. Proteins: Applied aspects*, pp. 302-318.
- Meilgaard, M., Civille, G. V., and Carr, B. T. (2007). *Sensory Evaluation Techniques* (4th ed.). Boca Raton, FL: CRC Press.
- Melina, V., Craig, W., and Levin, S. (2016). Position of the academy of nutrition and dietetics: Vegetarian diets. *Journal of the Academy of Nutrition and Dietetics*, 116(12): 1970–1980.
- Mensink, R. P., Zock, P. L., Kester, A. D. M., and Katan, M. B. (2016). Effects of dietary fatty acids and carbohydrates on the ratio of serum total to HDL cholesterol and on serum lipids and apolipoproteins: A meta-analysis of 60 controlled trials. *The American Journal of Clinical Nutrition*, 77(5): 1146–1155.
- Messina, M. (2010). Insights gained from 20 years of soy research. *The Journal of Nutrition*, 140(12): 2289–2295.
- Mohanty, D. P., Mohapatra, S., Misra, S., and Sahu, D. P. (2016). Milk derived bioactive peptides and their impact on human health—A review. *Saudi journal of biological sciences*, 23(5): 577-583.
- Muehlhoff, E., Bennett, A., and McMahon, D. (2013). *Milk and dairy products in human nutrition. Food and Agriculture Organization of the United Nations (FAO)*, pp. 175-203.
- Munekata, P.E., Domínguez, R., Budaraju, S., Roselló-Soto, E., Barba, F.J., Mallikarjunan, K., Roohinejad, S. and Lorenzo, J.M. (2020). Effect of innovative food processing technologies on the physicochemical and nutritional properties and quality of non-dairy plant-based beverages. *Foods*, 9(3): p.288.
- Musa, A. A., Lawal, A. O., and Oladimeji, R. A. (2013). Comparative analysis of locally prepared kunun aya (tiger nut beverage) and industrially produced milk in Nigeria. *African Journal of Food Science*, 7(9): 326–331.
- Negbi, M. (1992). A sweetmeat plant, a perfume plant and their weedy relatives: A chapter in the history of *Cyperus esculentus L.* and *C. rotundus L.* *Economic Botany*, 46(1): 64-71.

- Obasi, B. C., and Mani, V. N. (2023). Evaluation of sensory and microbiological quality of tiger nut milk drink sweetened with date palm fruit. *International Journal of Science and Research Archive*, 10(1): 281–288.
- Okafor, C. A., Afunwa, R. A., Ojukwu, M., Onyia, E. C., and Eneh, O. (2024). Comparison of yoghurt attributes prepared from tiger nut (*Cyperus esculentus* L.) and different forms of cow milk. *Asian Food Science Journal*, 23(9): 11–18.
- Okafor, J. N. C., Mordi, J. I., Ozumba, A. U., Solomon, H. M., and Olatunji, O. (2003). Preliminary studies on the characterization of contaminants in tigernut (yellow variety). (pp. 210–211).
- Okafor, T. S., and Nwachukwu, E. (2003). Phytochemical screening of tiger-nut (*Cyperus esculentus*) of three different varieties. *Journal of Biological Sciences*, 81: 115–120.
- Oladele, A. K., and Aina, J. O. (2007). Chemical composition and functional properties of flour produced from two varieties of tiger nut (*Cyperus esculentus*). *African Journal of Biotechnology*, 6(21): 2473–2476.
- Osagie, A.U. and Eka, O.U. (1998). Nutritional quality of plant foods. 1st ed. The Post Harvest Research Unit, UNIBEN Nigeria. pp 62.
- Oseni, T. M., and Falodun, O. J. (2023). Evaluation of fibre retention and curd structure in fermented nut-based cheeses. *Plant Foods for Human Nutrition*, 78(3): 275–284.
- Pascual, B., Maroto, J. V., López-Galarza, S., Sanbautista, A., and Alagarda, J. (2000). Chufa (*Cyperus esculentus* L. var. *sativus* Boeck.): An unconventional crop. Studies related to applications and cultivation. *Economic botany*, 54(4): 439-448.
- Pereira, C. J., Santos, M. F., and Almeida, J. P. (2023). Impact of coagulant type on fat retention and texture development in plant-based cheese formulations. *Food Hydrocolloids*, 145: 108942.
- Rinaldi, M., Paciulli, M., Caligiani, A., and Sforza, S. (2021). Plant-based cheese analogues: A review. *Foods*, 10(12): 2781.
- Roseiro, L. B., Barbosa, M., Ames, J. M., and Wilbey, R. A. (2003). Cheesemaking with vegetable coagulants: The use of *Cynara* L. for the production of ovine milk cheeses. *International Journal of Dairy Technology*, 56(2): 76–85.

- Roselló-Soto, E., Poojary, M. M., Barba, F. J., Lorenzo, J. M., Mañes, J., and Moltó, J. C. (2018). Tiger nut and its by-products valorization: From extraction of oil and valuable compounds to development of new healthy products. *Innovative Food Science & Emerging Technologies*, 45: 306-312.
- S´anchez-Zapata, E., Fern´andez-L´opez, J., and Angel P´erez Alvarez, J. (2012). Tiger nut (*Cyperus esculentus*) commercialization: health aspects, composition, properties, and food applications. *Comprehensive Reviews in Food Science and Food Safety*, 11(4): pp. 366–377.
- Salque, M., Bogucki, P. I., Pyzel, J., Sobkowiak-Tabaka, I., Grygiel, R., Szmyt, M., and Evershed, R. P. (2013). Earliest evidence for cheesemaking in the sixth millennium BC in northern Europe. *Nature*, 493(7433): 522–525.
- Sanful, R. E. (2009). *Production and sensory evaluation of tiger nut beverages. Pakistan Journal of Nutrition*, 8(5): 688–690.
- Sethi, S., Tyagi, S. K., and Anurag, R. K. (2016). Plant-based milk alternatives an emerging segment of functional beverages: a review. *Journal of Food Science and Technology*, 53(9): 3408–3423.
- Sgarbi, E., Bove, C., Tabanelli, G., and Montanari, C. (2013). The microbiology of raw-milk cheeses. *Advances in Microbiology*, 3(5): 419–432.
- Sharma, R., Patel, K., & Mehta, D. (2024). Functional role of tamarind extract in improving protein coagulation and yield in vegan cheese analogues. *Journal of Plant-Based Foods*, 12(1): 56–68.
- Silveira Junior, J. F. D. S., and de Francisco, A. (2020). Unconventional food plants as an alternative in starch production. *Cereals Food World* 65:2.
- Staudacher, H. M., Irving, P. M., Lomer, M. C. E., and Whelan, K. (2018). Country, regional, and global estimates for lactose malabsorption in adults: A systematic review and meta-analysis. *Gastroenterology*, 154(1): 91–107.
- Stone, H., and Sidel, J. L. (2004). *Sensory Evaluation Practices* (3rd ed.). San Diego, CA: Academic Press. 1-9
- Storhaug, C. L., Fosse, S. K., and Fadnes, L. T. (2017). Country, regional, and global estimates for lactose malabsorption in adults: a systematic review and meta-analysis. *The Lancet Gastroenterology and Hepatology*, 2(10): 738–746.
- Suleiman, M. S., Olajide, J. E., Omale, J. A., Abbah, O. C., and Ejembi, D. O. (2018). Proximate composition, mineral and some vitamin contents of tigernut (*Cyperus esculentus*). *Clinical Investigation*, 8(4): 161–165.

- Swagerty, D. L., Jr, Walling, A. D., and Klein, R. M. (2002). Lactose intolerance. *American family physician*, 65(9): 1845–1850.
- Tamime, A. Y., and Robinson, R. K. (2007). *Yoghurt: Science and technology* (3rd ed.). Woodhead Publishing.
- Tan, J., Wu, X., He, Y., Li, Y., Yu, X., and Shi, J. (2023). Mutual feedback mechanisms between functional traits and soil nutrients drive adaptive potential of tiger nuts (*Cyperus esculentus* L.) in marginal land. *Plant and Soil*, 495: 177–194.
- Tekin, A., and Hayaloglu, A. (2025). Overcoming the flavour and textural/rheological problems of plant-based cheese alternatives: Challenges and solution strategies. *Future Foods*, 11: 100531.
- Van Ballegooijen, A. J., and Beulens J. W. (2017). The role of vitamin K status in cardiovascular health: evidence from observational and clinical studies. *Current Nutrition Reports*, 6(3): 197-205.
- Viuda-Martos, M., López-Marcos, M. C., Fernández-López, J., Sendra, E., López-Vargas, J. H., and Pérez-Álvarez, J. A. (2010). Role of fiber in cardiovascular diseases: a review. *Comprehensive reviews in food science and food safety*, 9(2): 240-258.
- Walstra, P., Wouters, J. T. M., and Geurts, T. J. (2006). *Dairy Science and Technology* (2nd ed.) p. 247. CRC Press.
- Walther, B., Schmid, A., Sieber, R., and Wehrmüller, K. (2008). Cheese in nutrition and health. *Dairy Science and Technology*, 88(4–5): 389–405.
- Wu, Y., Mao, Q., Zhao, G., and Ye, F. (2024). Tiger nut (*Cyperus esculentus*) starch: extraction, composition, structure, properties, modification, and uses. *Sustainable Food Technology*, 2(3): 635–651.
- Yang, X., Niu, L., Zhang, Y., Ren, W., Yang, C., Yang, J., Xing, G., Zhong, X., Zhang, J., Slaski, J., and Zhang, J. (2022). Morpho-Agronomic and Biochemical Characterization of Accessions of Tiger Nut (*Cyperus esculentus*) Grown in the North Temperate Zone of China. *Plants (Basel, Switzerland)*, 11(7): 923.
- Yu, Y., Wang, Q., and Li, H. (2022). Tiger nut (*Cyperus esculentus* L.): Nutrition, processing, and applications. *Comprehensive Reviews in Food Science and Food Safety*, 21(6): 4562–4584.

- Yun, S. K., Lee, J. Y., and Park, S. H. (2022). Production of recombinant chymosin and its applications in the dairy industry. *Food Biotechnology*, 36(2): 115–128.
- Yusof, N. A., Ahmad, R., & Nor, A. S. (2024). Effect of moisture reduction on proximate composition and texture of non-dairy cheeses. *International Journal of Food Properties*, 27(5): 713–728.
- Zheng X, Shi X and Wang B (2021) A Review on the General Cheese Processing Technology, Flavor Biochemical Pathways and the Influence of Yeasts in Cheese. *Front. Microbiol.* 12:703284.
- Zheng, B., Zhou, H., and McClements, D. J. (2021). Nutraceutical-fortified plant-based milk analogs: Bioaccessibility of curcumin-loaded almond, cashew, coconut, and oat milks. *Lwt*, 147: 111517.
- Zohari, D. (1986). The origin and early spread of agriculture in the Old World. In *Developments in Agricultural and Managed Forest Ecology* (Vol. 16, pp. 3-20). Elsevier.