



**An-Najah National University  
Faculty of Graduate Studies**

**INNOVATING DAIRY ALTERNATIVES:  
THE PRODUCTION AND EVALUATION OF  
PLANT-BASED YOGURT SUBSTITUTES**

**By  
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## **Dedication**

This thesis is dedicated to the individuals who have provided me with the most encouragement and support over my academic career. First and foremost, I want to sincerely thank Dr. Ola Anabtawi and Dr. Mohammad Sabbah, my supervisors. This research has been greatly influenced by their priceless advice, unbreakable support, and unceasing encouragement. Their knowledge and tolerance have taught me not just how to conduct research but also how to be persistent and passionate about learning. Their mentoring has been crucial to my intellectual and personal development, and for that I am incredibly grateful.

I owe my family everything. Their sacrifices, love, and understanding have been a continual source of support. I will always be appreciative of their support and their unwavering faith in me, even when I had doubts. Their assistance has been the cornerstone of this accomplishment.

I want to express my heartfelt gratitude to a dear friend whose encouragement and presence have made this journey even more meaningful. Their unwavering belief in me has been a source of inspiration, and I sincerely appreciate the help they have provided me with during all of my periods of happiness and sadness.

Last but not least, I dedicate this essay to the resilient Gaza people who still face indescribable difficulties and awful conditions. I am inspired daily by their strength, courage, and commitment in the face of hardship and conflict. This thesis is a tiny homage to their unwavering hope and tenacity, and they are never far from my thoughts and prayers.

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## Declaration

I, the undersigned, declare that I submitted the thesis entitled:

# **INNOVATING DAIRY ALTERNATIVES: THE PRODUCTION AND EVALUATION OF PLANT-BASED YOGURT SUBSTITUTES**

I declare that the work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

Student's Name Ayah Anwar Mohammad Ibrahim

Signature:  \_\_\_\_\_

Date: 26/03/2025

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# **INNOVATING DAIRY ALTERNATIVES: THE PRODUCTION AND EVALUATION OF PLANT-BASED YOGURT SUBSTITUTES**

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## **Abstract**

**Background:** The demand for plant-based food alternatives has grown due to increasing health awareness and environmental concerns. Among these alternatives, plant-based yogurt has gained popularity as a dairy substitute.

**Objectives:** This study evaluates the impact of blending four plant-based milks—oat (OM), almond (AM), coconut (CM), and quinoa (QM)—in different ratios on the physicochemical, sensory, and nutritional properties of plant-based yogurt following fermentation with lactic acid bacteria.

**Methodology:** Five formulations (T1–T5) were prepared:

- T1: 30% OM, 30% AM, 20% CM, 20% QM
- T2: 30% OM, 20% AM, 40% CM, 10% QM
- T3: 50% OM, 25% AM, 15% CM, 10% QM
- T4: 30% OM, 30% AM, 10% CM, 30% QM
- T5: 25% OM, 20% AM, 35% CM, 20% QM

The blends were fermented with *Lactobacillus bulgaricus* and *Streptococcus thermophilus* at 45°C for 6 hours. Stabilizers (pectin, xanthan gum, or both) were added to prevent syneresis. Formulations were analyzed for pH, acidity, zeta potential, particle size, viscosity, sensory attributes, and nutritional composition.

**Results:** Fermentation ended at pH 4.6, with acidity increasing from 0.04%–0.6% to 0.15%–0.2%. T1 had the highest acidity due to its high oat and almond content, while T2, with more coconut milk, had the lowest.

Xanthan gum improved zeta potential and reduced particle size in T1 and T2, while pectin-xanthan combinations enhanced stability in T3, T4, and T5. T5, with 35% coconut milk, had the highest viscosity, while T1 was the least viscous.

Sensory evaluation showed T3 and T5 had the best appearance and viscosity, with T5 achieving the highest overall acceptance. T1 had the lowest calorie content (49 kcal), while T1, T3, and T4 had the highest protein content (.2%–1.3%).

**Conclusions:** Blending plant-based milks successfully produced yogurt with diverse properties. T1, T2, and T3 optimized acidity, viscosity, and stability. This yogurt could be a viable dairy alternative, especially for vegans and lactose-intolerant consumers. Future research should refine formulations for commercial production.

**Keywords:** Plant-based yogurt; Sensory evaluation; Nutritional composition.

# Chapter One

## Introduction and Theoretical Background

### 1.1 Overview of Plant-Based Yogurt Production

Plant-based yogurt is becoming more and more popular as a dairy substitute due to increasing demand from consumers for lactose-free, vegan, and environmentally friendly food options. Selecting the appropriate plant-based components is the first step in creating plant-based yogurt. The nutritional profiles, flavors, and textures of a wide range of plant-based foods, such as soy, almond, coconut, cashew, oat, and pea, vary. These ingredients are combined, filtered, and, if necessary, soaked to create a homogenous, smooth liquid that is used to make plant-based milk (1–3).

Several ingredients, such as vitamins, minerals, stabilizers, and emulsifiers, are added to plant-based milk to improve its nutritional profile and functional properties. Natural flavors and sweeteners can also be utilized to enhance flavor. To provide a consistent and smooth consistency, prevent separation, and improve mouthfeel, homogenization is then applied to the enriched plant-based milk. The combination is then heated to remove harmful germs and prepare it for fermentation, a process known as pasteurization (2,4).

Fermentation, which involves adding specific lactic acid strains of bacteria to pasteurized plant-based milk, is the main process in the creation of yogurt. Throughout the fermentation process of the carbohydrates, these bacteria produce lactic acid, which thickens the mixture and lowers its pH, giving yogurt its characteristically sour flavor and creamy consistency. The infected mixture is maintained under controlled circumstances until the desired acidity and texture are achieved. Once fermentation has started, the milk yogurt has been refrigerated to halt the process and stabilize the finished product (1,2,5).

When yogurt cools, it can be mixed with additional flavors, fruits, or sweeteners. Following that, the final product is packaged in several ways, using a seal to maintain freshness and prevent contamination. To ensure that the finished plant-based yogurt meets safety, nutritional, and sensory standards, it undergoes a rigorous quality control testing procedure. Refrigeration is used to maintain its quality and extend its shelf life (1,2,5).

Plant-based yogurt is made using a number of strictly regulated procedures, all of that are necessary to ensure the product's quality, safety, and acceptance. By addressing the

unique challenges of making plant-based yogurt and leveraging advancements in food science and technology, producers can meet the evolving needs of health-conscious consumers by creating delicious, nourishing, and sustainable alternatives to traditional dairy yogurt.

## **1.2 Historical Plant-based Yogurt Market**

### **1.2.1 Plant-based Yogurt Market Outlook from 2023 to 2033**

The global market for plant-based yogurt is expected to be worth US\$4,489.87 million in 2023. Expectations point to a steadily rising trend as more and more people learn that plant-based substitutes can provide dairy products with just as much, if not more, protein and minerals. With a predicted Compound Annual Growth Rate (CAGR) of 13.1%, the market is therefore expected to surpass US\$ 15,398.39 million by 2033 (1).

Plant-based yogurt is expected to experience significant growth between 2023 and 2030 of 20% due to several causes, including growing demand for dairy substitutes because of people adopting plant-based diets and increasing health and well-being awareness (2). While other studies showed that between 2022 and 2023, the size of the worldwide market for plant-based yogurt increased by US\$471.76 million. A shift toward a more plant-based (PB) diet is seen as essential to restricting environmental and climate impacts and maintaining the sustainability of world food systems, given that the world's population is predicted to increase to nearly 9.8 billion people by 2050 and that demands for meat and dairy products are rising. Specifically, producing high-protein foods without animal protein is critical to saving water and land resources and improving human health (1,3).

### **1.2.2 Key Factors Influencing the Growth of the Plant-Based Yogurt Market**

Even while dairy products still rule the market, plant-based substitutes have become more and more well-known recently. Consumers are searching for dairy alternatives as their health concerns grow. From 2018 to 2022, the market for plant-based dairy products grew at a 7.9% CAGR. There is evidence of a long-term trend toward plant-based substitutes: around half of customers who already eat plant-based products want to increase their intake in the future. One of the main factors influencing the market's potential expansion is consumers' growing awareness of the benefits and applications of vegan yogurt.

Veganism and plant-based diets have been more popular in recent years, which has opened up a market for businesses that sell vegan yogurt (2).

The present theoretical shift in dietary preferences reflects a multifaceted confluence of causes, including health, environmental, and ethical concerns as well as changing consumer tastes (9,10). The growing acceptance of plant-based diets, which demonstrate vegetables, fruits, legumes, nuts, and grains whereas avoiding or reducing animal-derived products, has gained significant popularity among people of all ages worldwide in recent years, primarily due to the growing amount of scientific data linking plant-based diets to numerous health advantages. Numerous studies have demonstrated the many positive health effects of plant-based diets, including a decreased risk of chronic conditions like diabetes and cardiovascular disease, when they are well planned (10,11). Additionally, a higher concentration of plant-based foods enables individuals with lactose intolerance, milk allergy, and vegetarianism to consume more essential nutrients, fiber, antioxidants, and phytochemicals, which all of that improve general health and raise nutritional and flavor satisfaction (11,12).

Veganism and plant-based diets are growing in popularity for a variety of ethical, the environment, and health-related reasons. Many consumers search for dairy substitutes because of lactose intolerance, milk allergies, and vegetarianism and other dietary restrictions. Plant-based diets have also been linked to a number of health benefits, including a lower risk of chronic conditions including diabetes and cardiovascular disease. Additionally, nutrient-dense foods like grains, legumes, and nuts, which provide vital minerals, fiber, and antioxidants—are emphasized in plant-based diets.

In many nations, the vegan yogurt sector is still in its infancy. Nonetheless, in industrialized countries like Europe and North America, it is a well-known industry. In industrialized countries, yogurt flavors with added protein, like chocolate, strawberry, and blueberry, have gained popularity. For many years, milk consumption has been steadily falling, with each generation drinking less than the one before it. In the future, the main factor driving demand for vegan yogurt and other plant-based food items is anticipated to be the rise in the vegan population worldwide (2,4).

As more people become aware of the negative environmental implications of animal agriculture, a growing number of individuals are switching to plant-based diets. Yogurt made from plants is said to be a more environmentally friendly option because it requires fewer natural resources to produce. Producers of vegan goods are focusing on increasing the sustainability of their manufacturing processes. Furthermore, consumers' consumption of conventional cattle has declined recently as they have grown more conscious of the issues it causes. Yogurt that is friendly to the environment is therefore growing in popularity. Berrywell, a trademark of Wellme, a recently established Chinese firm, is a line of vegan yogurt that is beneficial to the intestines. The company uses peas, coconuts, and chickpeas to manufacture 100% vegan yogurt products, catering to consumers' desire for nutritious, immunity-boosting meals (1).

As part of efforts to lessen their negative effects on the environment and enhance public health, governments in many areas are passing laws and regulations that promote plant-based substitutes. The Food and Drug Administration (FDA) of the United States is looking at the identity rules set forth for using dairy names for non-dairy products. To learn more about how consumers use dairy substitutes and comprehend concepts like milk, yogurt, and cheese, the regulatory authority has released a request for information. The poll will be used by the FDA to promote developments in the production of plant-based products such as vegan yogurt. This encouragement helps the market for yogurt made from plants grow (1).

Considerable progress has been made in plant-based food technology thanks to ongoing developments. The development of plant-based probiotic alternatives has produced products that remarkably resemble the nutritional profile, flavor, and texture of traditional dairy yogurt. Due to this, the market has expanded beyond vegetarians and vegans. The digestive benefits of vegan yogurts with live bacteria and cultures are equivalent to those of dairy-based yogurts; in some circumstances, vegan yogurts also provide nutrients that dairy-based yogurts do not. Hemp and flax yogurt, for instance, naturally contain fiber and omega-3 fatty acids. To make them healthier, several different varieties of vegan yogurt are fortified with vitamins and minerals. For many customers, vegan probiotics have helped them get past taste obstacles (3,5).

Consumer interest in Plant-Based Yogurt (PBY) is growing because it is still healthful but has less of an adverse effect on the environment and ethics. Nevertheless, it has been challenging to produce PBYM with the appropriate texture and sensory aspects due to the lack of precise design requirements (3,6). The examination of PBY's unique formulation methodologies, unit operations, and raw ingredients, as well as their effects on arrangement, nutrition, and sensory aspects, are covered in detail in the manuscript. The paper also addresses strategies for reducing negative aspects like soft structure, off-flavor, syneresis, and anti-nutritional elements. The kind of plant-based milk utilized in the formulation and the unit operations employed significantly impact the structural and sensory characteristics of PBY. Legumes, cereals, and nuts soaked and blanched before aqueous extraction yield a more robust, viscous, and firm yogurt substitute (7–9). Odors can be eliminated by roasting, altering pH, using deodorizing agents, or treating with enzymes. Probiotic lactic acid bacteria and ultra-sonication can also enhance flavor. Lactic acid bacteria fermentation lowers the amount of  $\alpha$ -galactosidase and increases the bioavailability of minerals (6,10).

In the case of dietary modification, limiting lactose intake in the diet by eliminating lactose-containing products helps with symptoms of the condition. Recent research showed that lactose-free and low-lactose dairy products allow lactose-intolerant people to benefit from the numerous vitamins and minerals in milk, which is one of the most effective approaches for enhancing the malabsorption of lactose and lactase intolerance. Lactose-free milk can be processed further to make lactose-free/low-lactose yogurt, cheese, milk powder, ice cream, and other dairy products. Therefore, a lactose-free milk product will be developed from plant milk, and its effect will be studied from several aspects later (11,12).

Yogurt made from plants has become a key component of sustainable and health-conscious diets. Because it uses fewer natural resources than traditional dairy, it is seen as an environmentally friendly substitute. Plant-based yogurt's appeal has grown beyond vegan consumers thanks to innovations in its recipe, such as the addition of probiotics. Protein-rich flavors, such as chocolate and berries, have become popular, especially in developed countries like North America and Europe. Yogurt's nutritional profile, texture, and sensory appeal have all enhanced as a result of the addition of legumes, grains, and nuts in its manufacturing.

### **1.3 Recent advancements in the production of plant-based yogurt**

Recent developments in plant-based yogurt manufacturing have sparked an increase in innovation aiming at improving both texture and flavor characteristics, replicating the sensory traits typically associated with dairy-based competitors (3,8,9). Manufacturers and researchers have worked hard to overcome the inherent difficulties in plant-based yogurt recipes, notably in obtaining a creamy texture and pleasing mouthfeel. Food technology advancements have resulted in the creation of unique approaches that use components such as coconut, almond, quinoa, and oat bases, as well as the incorporation of probiotics and emulsifiers, leading to amazing improvements in texture simulation. Significant advancements have also been made in the production of taste, with fruit combinations, natural additives, and fermentation methods collaborating to replicate the familiar and appealing flavors of conventional yogurt variations (1,4,14,17).

Understanding the history of the plant-based dairy sector identifies fascinating opportunities for growth that desire more research and innovation. The market reach has significantly expanded with the introduction of plant-based dairy products, yogurts, and ice creams as well as a wider range of product offerings beyond milk substitutes. Additionally, there is a discernible shift in focus toward enhancing nutritional profiles, flavor authenticity, and product quality in order to better meet consumer expectations (8,15). Innovations in food science and technology, such as the creation of improved fortification techniques, taste enhancers, and texturizing agents, will be essential to the company's continued expansion. Additionally, there is an untapped potential to serve niche markets, such as those who prefer organic, gluten-free, or allergy-free foods (18,19).

### **1.4 Nutritional value and nutritional benefit of plant-based yogurt**

Plant-based yogurts offer a variety of nutritional benefits compared to traditional dairy yogurts. While protein content in plant-based yogurts might be lower, they often contain essential vitamins, minerals, and probiotics. Many are fortified with nutrients like B12, calcium, and vitamin D to compensate for potential deficiencies in a plant-based diet (13–15). Probiotics in both types support gut health, and plant-based yogurts can be an excellent option for those with lactose intolerance or seeking a dairy-free alternative (7).

Full-fat dairy yogurt had fewer calories per 100 g in terms of energy density than low- and nonfat dairy yogurt (16). Coconut yogurt had many more calories than both dairy categories when it came to plant-based yogurts. While oat yogurt was similar to low- and nonfat dairy, it had many fewer calories than full-fat dairy (15). Plant-based yogurts made from almonds did not differ significantly from full-fat dairy products, but they did differ considerably from low- and nonfat dairy yogurts. Among the macronutrients, we found the least variation in the concentration of carbohydrates (10,15). Compared to full-fat dairy, low- and nonfat yogurts had noticeably higher carbs. Yogurt made with coconut and almonds did not differ significantly from full-fat dairy, nor did yogurt made of oats from either type of dairy. Put otherwise, it found no discernible variation in the carbohydrate content amongst the four types of plant-based yogurts, and they were all similar to the full-fat dairy yogurts. Dairy yogurts had an average protein level of about 4.2 g per 100 g. The protein composition of full-fat, low-fat, and nonfat dairy yogurts was the same (15). Almond yogurts were shown to have a protein concentration that was comparable to full-fat dairy yogurts when compared to low- and nonfat dairy yogurts, but much lower than both. The protein content of all other plant-based yogurts was considerably lower, with coconut having the lowest protein content of any product (around 1.2 g per 100 g). The highest fiber content was found in almond yogurts, which differed greatly from the other yogurt bases. Less than 1.2 g of fiber per 100 g was found in dairy yogurts, which differed greatly from all other plant-based yogurts. Yogurts made of cashews, coconut, and oats had intermediate fiber content (7,8,16).

Since plant-based yogurt is naturally free of lactose, the sugar present in dairy products that may upset stomachs, it's a great substitute for people who are lactose intolerant. Plant-based yogurt is a smooth and readily digestible alternative to traditional yogurt, which can cause bloating, gas, and diarrhea in people who are lactose intolerant. Dairy avoiders can still achieve their nutritional needs thanks to the fact that many types are fortified with vital elements like calcium and vitamin D. Furthermore, plant-based yogurts produced from oats, almonds, or soy frequently have healthy fiber that promotes digestion and intestinal health.

Plant-based yogurt is not only lactose-free but also high in probiotics, which support a balanced gut flora. Probiotics increase general immunological function, aid in better digestion, and improve nutrient absorption. Numerous plant-based yogurts are also a rich

source of plant-based protein, especially those produced from pea or soy protein, which can support general health and muscle maintenance. Additionally, they frequently include heart-healthy unsaturated fats, especially those derived from nuts and seeds, which promote cardiovascular health. For those who are lactose intolerant and seeking a dairy-free option, plant-based yogurt offers a tasty and nutritious substitute in a range of tastes and textures.

As dairy yogurts, plant-based yogurt substitutes usually include various kinds of live, active cultures. As a component of their health messaging, some of the products even claim to include probiotic microorganisms. The yogurt substitutes in our study had an average of four to six probiotic living cultures. *Streptococcus thermophilus*, *Lactobacillus acidophilus*, *Bifidobacterium species*, *Lactobacillus delbrueckii*, *Lactobacillus rhamnosus*, *Lactobacillus casei*, and *Lactobacillus bulgaricus* are common cultures added to yogurt substitutes. Better gut health has long been linked to fermentation's viable microorganisms and bioactive byproducts. Their effects on the gut microbiota may also enhance immunological response and general health . By altering the gut microbiome, probiotics and bioactive compounds found in fermented non-dairy products have been linked to enhanced immunological function and general intestinal health, even though the viability of probiotic microorganisms may be more challenging to maintain in a non-dairy matrix [44]. This has made it possible for producers of plant-based yogurt substitutes with active cultures to make health claims comparable to those of dairy-based yogurts.

### **1.5 Plant-Based Yogurt and its Production**

Plant-based yogurt is made from aqueous extracts of legumes, cereals, and oilseeds, which have diverse characteristics compared to single-composition milk-based yogurt. Additionally, plant-based yogurts are naturally low in cholesterol and benefit consumers who are lactose intolerant or allergic to dairy protein (7,8). Various plant-based raw materials, including quinoa, almonds, coconuts, and oats, are used to make yogurt. Yogurts are easy to digest and have lower bloating effects than plant milk due to the bacterial  $\alpha$ -galactosidase breaking down oligosaccharides during fermentation (17). Moreover, compounds such as arabinose and tocopherol in plant milk have the potential to act as free radical scavengers, and plant milk sterols have anti-inflammatory and anti-

diabetic properties. PBYM with increased omega-3 fatty acids and fiber can be developed by incorporating hemp or flax proteins during fermentation (7,8).

Plant milk includes a variety of macro- and micronutrients. Cereal milk is high in starch. Optimal treatment with heat is thus advised for starch gelatinization before fermentation. This minimizes phase separation and may provide a simple carbon source for endogenous microbial multiplication. Yogurt's sensory/nutritional functioning can be enhanced further by choosing probiotic cultures capable of producing exopolysaccharides in situ (7,18). Proteins, fibers, and bioactive substances abound in legumes and grains; yet, anti-nutritional factors (ANFs) such as tannins, saponins, phytic acid, resistant galactosidase, and trypsin inhibitors may diminish their nutritious value, and they are reduced by fermentation (7).

The yogurts produced by the brands listed below are exclusively made without any animal ingredients. You could prefer some brands to others because of the differences in their bases and flavors. Such as oats, silk's vegan yogurt, forger's vegan yogurt, etc. (19).

Extracting plant-based milk substitutes from foods like grains, legumes, seeds, and nuts is the initial stage. After that, this milk substitute is homogenized, standardized, and pasteurized to help with sterilization and gelatinization. After the plant-based milk has cooled, the chosen bacterial culture (*Lactobacillus Bulgaricus* and *Streptococcus Salivarius subsp. Thermophilus*) is introduced, and it ferments at a particular temperature. Even though these bacterial species are less suitable for fermentation than those found in cow's milk, research has been done to enhance the manufacture of plant-based yogurt by analyzing various raw ingredients, processing methods, and bacterial strains (7).

Zannini et al. used quinoa aqueous extract with 10% sucrose, homogenization at 180 MPa, pasteurization at 110°C for 10 minutes, and inoculation with *Weissella cibari MG1*. After 24 hours of fermentation at 30°C, the mixture was cooled to 4°C. A critical stage that needs to be completed at 60°C is homogenization, which melts fat crystals that could jam the homogenizer's valve (7). The quantity of protein complexes denatured during high-temperature treatment may have an impact on the characteristics of gels that develop in coconut milk. Heat-induced denaturation of proteins increases hydrophobic interactions and strengthens covalent disulfide connections, creating a larger protein network that aids in immobilizing more water (6, 7).

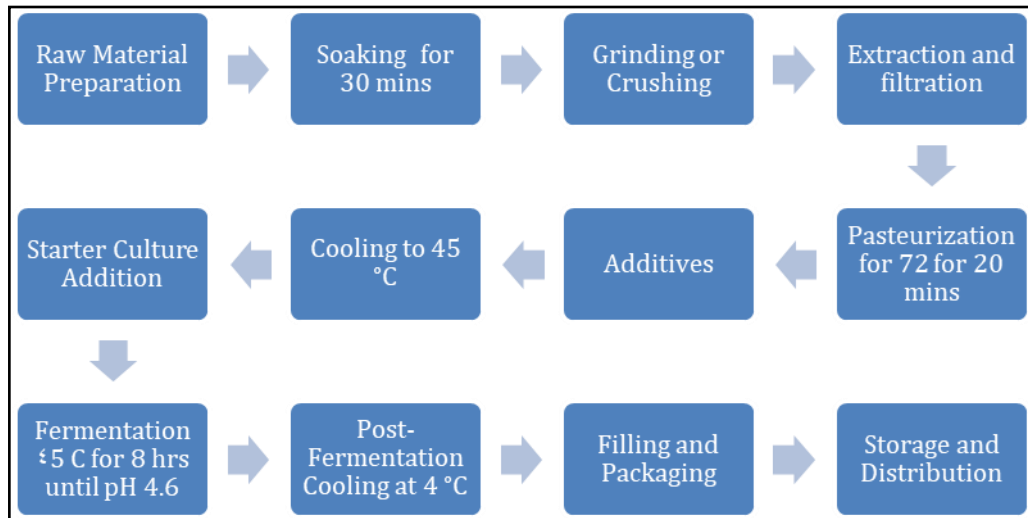
In the Demir et al. study, oat milk that had been cooked to 70°C was used to make oat milk yogurt. After being inoculated at 45°C, a 2% w/v culture (YC-350 Yoflex®) was cultured for 8 hours at 37°C, or until pH 4.6 was attained. After that, the yogurt was chilled and kept for 21 days at 4°C. The globulin protein has an isoelectric point of 3.5 and the albumin protein of oats ranges from 4 to 7.5. Electrostatic repulsion results from a drop in net positive charge, which in turn causes a decrease in steric stabilization, coagulates the protein and forms a three-dimensional gel network (20). Choosing the right plant-based components is the first step in making plant-based yogurt. Almonds, cashews, coconuts, oats, peas, and soy are common bases for plant-based yogurt. These ingredients all have different tastes, textures, and nutritional profiles.

The first step in making plant-based yogurt is choosing a base, such as soy, almond, cashew, coconut, oat, or pea; each has a unique flavor and nutritional profile. Hard components (such as almonds or cashews) are soaked to soften them, then blended with water to get a milk-like consistency, and strained to get rid of any solids. To improve the nutritional profile and texture, further ingredients are added, including flavors, sweeteners, emulsifiers, stabilizers, vitamins, and minerals. The enriched plant-based milk is homogenized to ensure consistency, then pasteurized to eliminate any potentially harmful germs and prepare it for fermentation as reported in figure 1 (1).

Fermentation, a critical step in the production of yogurt, involves the addition of lactic acid bacteria, such as *Lactobacillus Bbulgaricus* and *Streptococcus Salivarius subsp. Thermophilus*, to pasteurized milk. By fermenting the milk's carbohydrates, these bacteria thicken the mixture and lower the pH of the milk, giving the yogurt its unique creamy texture and sour flavor. To get the proper acidity and texture, the mixture is incubated at controlled temperatures. To stop the fermentation and stabilize the yogurt, it is then cooled. By lowering the pH and inhibiting the bacteria that cause spoilage, this process improves the yogurt's flavor and texture while also increasing its safety and shelf life (4,5,17).

**Figure 1**

*The process of production of plant-based milk*



### 1.6 Selection of Raw Materials

Choosing the right kind of plant milk is critical for PBYM performance. Higher fat and protein content in milk is desired since it improves the taste as well as the texture of the final product. Proteins are primarily responsible for physiochemical properties like water retention, gel strengthening, and flavor precursor generation, whereas fats contribute to textural and sensory characteristics (flavor and mouth feel). In contrast to dairy-based yogurt, whose flavor is varied through the inclusion of synthetic or natural flavors or fruit extracts, the flavor of plant-based yogurt can vary depending on the raw ingredients utilized. Plant-based raw materials fall into five categories: legumes, nuts, cereals, pseudo-cereals, and seeds. Because of its high protein level, calcium, phosphorus, and potassium, almond dairy has a long history of usage (7,10). Almonds have a high concentration of monounsaturated and polyunsaturated fatty acids, fiber, polyphenols, minerals, and antioxidant vitamins, all of which contribute to their nutritional and health advantages. Approximately 65-70% of the total protein in almonds originates from globulin protein, which has a hexameric structure connected by disulfide bonds to acidic and basic polypeptides. This leads to increased gel strength and water retention in almond yogurt. The effect of thermal treatment and fermentation by bacteria on the structure and physical-chemical properties of almond proteins is unknown, but higher heat treatments (85-90°C) are thought to cause greater denaturation and gelation, resulting in protein

connections that trap fat droplets. This qualifies almonds for the production of yogurt with a jelly texture (7).

Mechanically extracting fluids from ripe coconut flesh yields coconut milk. Aqueous molecules of protein hold a water-in-oil emulsion together. The most common proteins in coconut skim milk are globulin 75% and albumin 25%. Globulin is more stable during yogurt manufacture because of its charged amino acids (aspartic acid, glutamic acid, arginine, and lysine) (7,21,22).

The globulin fraction, unlike the albumin fraction exhibits high emulsifying capabilities when combined with oil in water. This discrepancy might be attributed to the varied amino acid content, which includes polar and non-polar amino acids, as well as non-polar side chains, including hydrophobic proteins that are more emulsifying. As a result, nuts serve an important role as elements in yogurt mimics, each with specific functional qualities (7).

Oats have a high protein content when compared to other crops, although they are mostly starch. Oats have higher soluble dietary fiber ( $\beta$ -glucans) than many other cereals, which has been linked to improved health. Oat milk, in addition to being lactose- and gluten-free, has excellent emulsifying and gelling capabilities, resulting in firm gels with acceptable water retention (7,9)

Quinoa is a nutrient-dense pseudo-cereal with a high protein content. Quinoa is high in globulins 37%, albumins (35%), and prolamins 0.5-7%. These proteins provide solubility, gel formation, foaming, and emulsifying qualities in food applications. Protein hydrophobicity, moisture retention capabilities, and interfacial layer characteristics determine the properties. Water, tastes, other food components, and sugars can all be retained by gel formation (7).

Yogurt substitutes may be made from a variety of plant-based source components. Plant-based yogurt is often produced with high-fat or high-protein raw components to increase texture and flavor. Yogurt is typically created from legumes, nuts, and cereals, which all have excellent nutritional content, although tubers, pseudo cereals, and seeds are inexpensive and underused. As a result, a base material produced from legumes, nuts, cereals, or a mix of legumes and cereals can be created (7,17).

Creating high-quality plant-based yogurts that mimic the qualities of dairy-based counterparts presents several challenges. Achieving a similar creamy texture without dairy fats and proteins can be technically demanding. Substituting for casein and whey proteins, which contribute to the structure and texture of traditional yogurts, requires innovative plant protein sources and processing techniques (3,7,23).

Nutritionally, ensuring adequate protein content in plant-based yogurts can be challenging, as some plant proteins lack certain essential amino acids found in dairy proteins. Fortification becomes crucial to address nutritional gaps. Additionally, achieving the right balance of probiotics and ensuring their stability throughout production and shelf life pose additional hurdles. Manufacturers frequently use ingredients like coconut, soy, and almond to further improve the nutritional profile of plant-based yogurts. These additives increase the protein content and enhance texture. To fill in nutritional deficits, fortification with vitamins and minerals, like calcium and vitamin D, is frequently used (14).

Overcoming these issues demands continual research and development, researching novel plant ingredients, improving processing methods, and refining compositions to enhance both the technological and nutritional features of plant-based yogurts (4,19). Plant-based yogurt requires specific ingredients to achieve the desired viscosity, texture, mouth feel, and appearance. To achieve this, natural and modified starch, pectin and gum, sugars like sucrose, glucose, and maltose, and other ingredients like fats, emulsifiers, flavors, and fruit particles are used. The plant pretreatment system involves soaking plant components, wet grinding/extracting, filtering, enzymatic treatment, and decanter separation. This process converts raw plants into slurry or pulp, similar to producing plant-based milk products. The milk imitation is standardized, homogenized, and pasteurized for gelatinization and sterilization. The substances are mixed with plant-based products to provide specific viscosity and taste. Different plant-based products require different components, which are dissolved in a high-shear mixing tank. For oat-based yogurt, the enzymatic hydrolysis process can break down carbohydrates into sugar, allowing less sugar to be included. For almond yogurt, enough sugar and thickener are added to achieve viscosity due to the low starch/high-fat composition of almonds. Overall, the process of formulating and processing plant-based yogurt is crucial for achieving the desired results (7,9).

**Table 1**

*Protein, fat, carbohydrate, and fiber content of plant-based raw materials (all values are expressed on a g/100 g dry basis)*

| Raw Material | Protein (g) | Fat (g) | Carbohydrates (g) | Fiber (g) | Properties  | Reference |
|--------------|-------------|---------|-------------------|-----------|---|-----------|
| Almonds      | 21.9        | 50.6    | 19.9              | 12.5      | Slightly sweet and nutty flavor. Low in calories.         | (7)       |
| Coconut      | 3.95        | 20.8    | 13.05             | -         | Creamy texture and subtle coconut flavor. Higher in fat.  | (7)       |
| Oats         | 13          | 7.5     | 51                | 10.3      | Natural sweetness and creamy texture. Pleasant mouthfeel. | (7)       |
| Quinoa       | 14.5        | 5.2     | 64.2              | 14.2      | Distinct, slightly earthy flavor. Rich in protein.        | (24)      |

Furthermore, the emulsifiers and stabilizers are employed to maintain the desired consistency, addressing the absence of natural stabilizers found in dairy. Additionally, optimizing fermentation conditions with plant-based cultures is crucial to ensure the production of probiotics, fostering a healthy gut microbiome. Despite these advancements, taste and flavor complexities remain a focal point. Balancing the inherent flavors of plant ingredients while achieving a taste profile comparable to traditional yogurt requires careful formulation and sensory analysis (7,9,23).

Plant-based diets and dairy substitutes present a far more complex set of food safety challenges. For instance, raw milk is the primary ingredient in the dairy business and is largely consistent in terms of its nutritional makeup, physical attributes, and presence of microbiological contamination. However, because there is a greater variety of bacteria and a wide range in the number of bacteria, plant-based yogurts are more likely to become contaminated by bacteria. Harvesting practices, protein extraction procedures, the kind of soil used to grow the source plant, and even how the plant and its by-products are handled and stored can all have an effect (19). Fermentation and heat treatment are essential processes in the creation of plant-based yogurt products. The thickeners and stabilizers employed affect the temperature and holding time of these goods; the most popular is 90°C for 5 minutes. Protein can be denatured during this process, which also enhances

the final yogurt's texture. The product is sterilized, then chilled to 40°C before being transferred into tanks for fermentation (19).

A culture of bacteria, such as *Streptococcus Salivarius subsp. Thermophilus* and *Lactobacillus bulgaricus*, is added during fermentation to convert carbohydrates into lactic acid, which lowers pH and alters flavor. By suppressing bacteria and other metabolites that cause spoiling, this treatment improves the biological parts and changes the flavor. Protein concentration, initial and ultimate pH levels, oxygen content, and other variables all affect the temperature and length of fermentation (1,2,4). Various studies have shown that pasteurization, homogenization, and inoculation with *Weissella Cibari MG1* in quinoa aqueous extract with 10% sugar results in full quinoa meal yogurt imitation. Other studies have also investigated the manufacture of oat milk yogurt using heated oat milk at 70 degrees Celsius. The composition and quantity of exopolysaccharides (EPS) produced by bacteria can vary depending on parameters such as *Lactic Acid Bacteria* (LAB) strains, pH, temperature, minerals, vitamin availability, and carbon source. LAB fermentation reduces antinutritive chemicals in legumes, cereals, and grains, such as -galactosides, trypsin inhibitors, condensed tannins, and phytic acid. Fermentation may enhance protein concentration, solubility, and bioavailability. Since *Lactobacillus* species alter polypeptide quality by controlled proteolysis, protein fermentation is a viable method for obtaining bioactive peptides. The versatility and nutritional benefits of plant-based yogurt substitutes make them a promising substitute for conventional dairy products. They have a special structure made up of crosslinked proteins, lipids, and carbohydrates, and they have the capacity to hold a significant amount of liquid phase. Innovative methods like heat treatment, gelatinization, and high-voltage pulsed electric fields have been employed to raise the product's quality (1).

In plant-based yogurt, a process known as syneresis occurs when a phase separates from the ongoing network of protein, fat, and carbohydrates. Inadequate heat and homogenization procedures, improper bacterial culture selection, improper component composition, and other reasons can all contribute to this. Modifications to the raw materials and technique can lessen syneresis and enhance texture.

Stabilizers or hydrocolloids can be added to plant-based yogurt to enhance its rigidity and texture. In order to reduce syneresis, long and branching hydrocolloid chains help bind

water and restrict water flow into the matrix region. Plant-based yogurt uses tapioca, potatoes, water yam, kudzu, and maize to lessen syneresis. Ethanol and supercritical CO<sub>2</sub> are two chemical deodorization techniques that have been studied to lessen off odors in plant-based yogurt alternatives. Additionally, researchers are looking into ways to lower the nutritional value and anti-nutritional components in plant-based yogurt substitutes. Pre-fermentation enzyme therapy has been found to increase dietary fiber in imitation oat yogurt, while fermentation processes can decrease tannins, cyanides, and phytates. Despite the potential for plant-based dairy mimics, further research is needed to determine the best ways to extract plant-based ingredients, formulate the yogurt imitation, add structure, and lessen sensory flaws. A thorough investigation is required to provide design guidelines for manufacturing plant-based dairy yogurt substitutes (7,10,23). Because of their adaptability and nutritional advantages, dairy-free derivatives of dairy products present a viable substitute for dairy yogurts and have the potential to expand the market quickly. With a particular focus on yogurt mimics, we have outlined the present state, promise for the future, and unanswered questions surrounding plant-based dairy mimics in this paper (7).

Creating plant-based foods that have the right amount of nutrients. While satisfying customer demand requires preserving sensory qualities. Further research is still required to determine the best ways to extract plant-based ingredients, formulate the yogurt imitation, add structure, and lessen sensory flaws. A thorough investigation is required to provide design guidelines for manufacturing plant-based dairy yogurt substitutes (7,9).

### **1.7 Background of the Study**

A major shift in consumer tastes towards environmentally friendly, health-conscious, and ethically produced products is causing a substantial transformation in the global food sector. Of all the food groups going through this transition, plant-based substitutes are becoming the most popular. This change is not just a passing trend but also a reflection of a heightened awareness of the relationships between environment, health, and diet. Particularly plant-based yogurt has drawn a lot of interest as a dairy-free substitute that satisfies these changing customer preferences (23).

Plant-based dairy substitutes are no longer limited to specialty stores; they are now widely available in most supermarkets, moving from the periphery to the mainstream. The

availability of a wider range of plant-based alternatives and a tidal change in consumption have supported this. The market for plant-based substitutes has grown outside of the vegetarian and vegan diets, thanks to several shifts in consumer views and habits (10,24).

First, the demand for plant-based yogurt has grown dramatically as people become more conscious of intolerance to lactose, dairy allergens, and the advantages of plant-based diets. For instance, while lactose intolerance is estimated to affect over 50% of people in South America, Africa, and Asia and nearly 100% in some Asian nations, it may only affect between 5 and 17% of white North Europeans, North Americans, and Australasians (11,25). Customers are looking for products that satisfy their nutritional requirements without sacrificing quality. Plant-based yogurt substitutes are frequently supplemented with essential nutrients including calcium, vitamin D, and vitamin B12, to rival dairy-based varieties. The inherently reduced protein level of plant-based yogurts, particularly those produced from oat, coconut, or almond bases, is one of the difficulties. In order to improve texture and appeal to consumers who are health-conscious, producers are combining protein-rich bases like soy or pea with functional additives like xanthan gum or pectin (9). Furthermore, dairy products made from plants contain lower levels of cholesterol and saturated fat, two factors linked to chronic illnesses (7,10).

Second, consumers are still primarily influenced by taste when it comes to plant-based yogurt; it is challenging to replicate the creamy texture, sour flavor, and overall sensory experience of conventional yogurt, and the distinct scents of plant-based bases, like the grassy tones of oats, can cause consumers to be less satisfied. Manufacturers are utilizing cutting-edge flavor-masking technology and mixing bases, such as coconut and almond, to produce a more enticing taste profile in order to get over these obstacles. In order to accommodate a variety of palates and further cover up the natural flavors of the plant basis, flavored choices such as vanilla, berries, and tropical fruits have been introduced (9).

Third, because plant-based products are thought to be more environmentally friendly and sustainable than animal products, customers are becoming more concerned about how their purchases may affect the environment. As they use less water and have a smaller carbon impact. Some ingredients like oats, almonds, and coconut appeal to people who care about the environment. However, other bases, like almonds, can still cause issues

with water use during production. In order to comply with eco-friendly principles and minimize waste, businesses are concentrating on sustainable packaging options, such as recyclable or biodegradable materials, in addition to ingredient sourcing. Plant-based yogurt's reputation as a more environmentally friendly option is strengthened by this dual emphasis on sustainable manufacturing and packaging (1,5,9).

By 2026, the non-dairy alternatives industry is expected to have grown from its 2020 valuation of \$22.6 billion to \$40.6 billion worldwide. Consumers' changing views on environmental sustainability, animal welfare, and personal wellness are the main drivers of this astounding growth. In the upcoming years, dairy-free products are anticipated to see a significant increase among the several plant-based substitutes (5,24).

Eighty percent of the dairy substitute market is made up of plant-based milk. Sales of plant-based milk rose between 2014 and 2019, whereas traditional milk sales fell by \$3.1 billion in Western Europe and \$4.4 billion in North America. Plant-based milk is already more affordable than conventional milk thanks to US production expansion; several European nations are also getting close to this mark, bringing the product to a wider consumer base (24).

China continues to be the world's biggest user of plant-based milk, notwithstanding its expansion in Western markets. Sales of milk substitutes in China were more than four times higher than those in the US in 2016, and by 2019, the Chinese market was worth \$8 billion, or 44% of worldwide retail sales. About 70% of plant-based milk sales worldwide came from the US and China combined, demonstrating their dominance in this growing business (24).

New plant-based milks have flooded European supermarket shelves, making up half of all UK product debuts in the milk and cream category in 2019 and 2020. Since cow milk is a mainstay in Western households, there is less room for innovation. However, as plant-based milk sales rise, both new and existing businesses are becoming involved (24).

Plant-based diets have been increasingly popular over the last ten years. Numerous factors, such as rising awareness of the health benefits of plant-based diets, animal welfare concerns, and the environmental impact of livestock farming, are driving this dietary trend. Diets based mostly on plants, which are frequently higher in fiber, vitamins, and

phytonutrients and lower in cholesterol and saturated fats, have been shown to provide possible health benefits. Reduced chances of chronic illnesses like diabetes, heart disease, and some types of cancer have been associated with these diets (26,27).

Plant-based yogurt is not a completely new idea; plant-based ingredient fermentation has been practiced for a long time by many different cultures. However, thanks to advancements in food science and technology, the plant-based yogurt market has undergone a substantial evolution in recent years. The main ingredient of the first plant-based yogurts was soy, a legume high in protein and easily fermented. Plant-based yogurts manufactured from almonds, cashews, coconuts, oats, peas, and other ingredients are widely available in the market today. In terms of flavor, texture, and nutritional value, each of these bases offers certain potential as well as obstacles (28,29).

Plant-based yogurt sales have been significantly shaped by consumer tastes. More knowledgeable and discriminating than previous generations, modern customers look for goods that not only fit their nutritional requirements but also their moral principles. Yogurt made from plants meets a wide range of nutritional needs, such as lactose intolerance, vegetarianism, and allergy issues. The market has produced a wide range of cutting-edge goods in response to this demand, emphasizing minimal processing, organic components, and clean labels. The market for plant-based yogurt is expanding quickly, which is evidence of its growing acceptance and appeal (8,24).

To produce plant-based yogurt of superior quality, several technological obstacles must be addressed. It might be challenging to get the appropriate consistency, flavor, and texture when using plant-based raw ingredients because of their diversity. The protein concentration, lipid content, and other important characteristics of plant-based ingredients can fluctuate greatly, in contrast to dairy milk, which has a constant composition. Food scientists have developed a number of methods to get around these issues, including the use of stabilizers, emulsifiers, and fermentation techniques. For plant-based yogurts to meet customer expectations for stability and smoothness, the well-known hydrocolloid xanthan gum is crucial (1,2).

## **1.8 Problem Statement**

lant-based yogurt's growing appeal is a sign of a broader shift in dietary tastes toward more sustainable and health-conscious options. To create high-quality plant-based yogurt, a number of significant difficulties still need to be thoroughly addressed. Unlike regular dairy yogurt, plant-based yogurt requires alternative ingredients, many of which are devoid of the natural stabilizers and emulsifiers found in milk. This results in issues with texture, homogeneity, and overall consumer acceptability.

Despite the wide variety of plant-based yogurt products on the market, many still struggle to get the creaminess and consistency that consumers want. Xanthan gum is a well-known hydrocolloid that has shown promise in improving the texture and stability of plant-based yogurts. However, not much research has been done on the optimal xanthan gum concentrations required to deliver the best physicochemical and sensory qualities in different plant-based yogurt compositions.

This knowledge gap is a significant barrier to the development of exceptional plant-based yogurt products. If these problems are not fixed, manufacturers may still struggle to make plant-based yogurts that meet consumer standards, which might hinder the growth of this market segment and limit the adoption of healthier eating practices.

Therefore, the goal of this study is to investigate how the physicochemical properties, nutritional compositions, and consumer acceptance of plant-based yogurt are impacted by varying quantities of milk combination. By identifying the optimal conditions for plant-based yogurt production, this study seeks to offer significant insights that can enhance the quality and appeal of plant-based yogurts. This study aims to fill these gaps by investigating the nuances of formulation, processing, and fermentation unique to plant-based yogurt.

## **1.9 Study hypothesis**

The study hypothesis is that a plant-based yogurt that complements the sensory qualities of traditional dairy yogurt while surpassing it in terms of nutritional value and versatility can be produced by carefully selecting plant-based ingredients and employing innovative processing methods. The key characteristics of viscosity, texture, flavor, and nutritional

content are anticipated to be significantly enhanced by careful formulation and processing changes.

### **1.10 Significance of the Study**

The current rise in popularity of plant-based dairy alternatives can be attributed to dietary restrictions, greater awareness of lactose sensitivity, and concerns about environmental sustainability. Plant-based yogurts have emerged as a competitive alternative to traditional dairy yogurt, with potential health and environmental benefits.

Despite their growing popularity, plant-based yogurts have several disadvantages over traditional dairy yogurt, including poor texture, strange aromas, and inadequate nutritional profiles. Many plant-based formulations suffer from phase separation, lack of creamy texture, and lack of ability to achieve the sensory and functional qualities that customers expect from yogurt products. In addition to limiting consumer acceptance, these barriers also make it more difficult for plant-based yogurt to compete and serve as a sustainable dairy product alternative.

The study is aimed at helping the food industry in developing plant-based yogurts with enhanced flavor, texture, and nutritional value in order to satisfy the rising need for solutions that are both health-conscious and environmentally responsible.

In order to solve typical problems, including off-flavors, phase separation, and insufficient texture in plant-based yogurt recipes, the study will combine various plant-based milk types, including almond, oat, and coconut, with xanthan gum being used as a stabilizer. This method offers guidance on how to achieve desired functional and sensory qualities, like enhanced mouthfeel, stability, and creaminess. The study also looks at how consumers view and accept these developments, providing insightful advice for product development in the expanding market for plant-based dairy substitutes.

Although several studies have investigated individual plant-based milks in yogurt compositions, few have explored the synergistic benefits of combining different plant-based milk sources to enhance sensory and nutritional properties. Additionally, there is limited research on the use of xanthan gum as a stabilizer in plant-based yogurt to improve texture, consistency, and shelf life. Addressing these gaps is essential for developing

premium plant-based yogurts that meet consumer expectations and support the global shift toward inclusive and sustainable food systems

### **1.11 Research objectives**

To create high-quality plant-based yogurt that satisfies consumer needs for sustainability, texture, stability, and nutrition by applying creative formulation, innovative processing, fermentation, and thorough nutritional analysis.

Sub-Objectives:

1. Optimize the formulation of plant-based yogurt by strategically incorporating pectin, and xanthan gums to enhance viscosity and stability.
2. Apply innovative processing techniques including plant pretreatment, standardization, homogenization, and pasteurization, tailored to plant-based ingredients.
3. Explore the effect of xanthan gum, pectin, and their mixture on zeta potential, viscosity, and particle size to optimize the texture and stability of plant-based yogurt.
4. Perform nutritional analysis to assess protein content, sugar levels, vitamins, and minerals, comparing the results with traditional dairy yogurt.
5. Perform physicochemical analysis as texture, viscosity, pH, acidity, color, water-holding capacity, and syneresis. Each of these properties plays a crucial role in determining the overall quality and acceptability of the yogurt.

This thesis aims to set the stage for an exciting future in plant-based yogurt production by addressing these goals and advancing our knowledge of non-dairy fermentation processes as well as the development of nutrient-dense, appealing, and stable plant-based yogurt products.

## Chapter Two

### Methodology

#### 2.1 Materials

Raw almonds, coconuts, quinoa, and oats were procured from the local market in Palestine (Saleh Khalaf, supermarket Shini). Yogurt starter culture, containing *Lactobacillus subsp. Bulgaricus* and *Streptococcus Salivarius subsp. Thermophilus*, was used in this study, YC-X11 (Batch No: 3665973) as detailed in Appendix A. This strain was obtained from Silva Extracts s.r.l. (Gorle, BG, Italy). The strain was stored in a freezer at  $-18^{\circ}\text{C}$  until use. Xanthan gum and pectin were purchased from Sun pharm Drug Store Ltd. (Nablus, Palestine) and natural sweeteners such as stevia sugar. The plastic containers from the Jabareen Plast Company (Jenin, Palestine) were purchased.

#### 2.2 Methodology

##### 2.2.1 Plant sampling

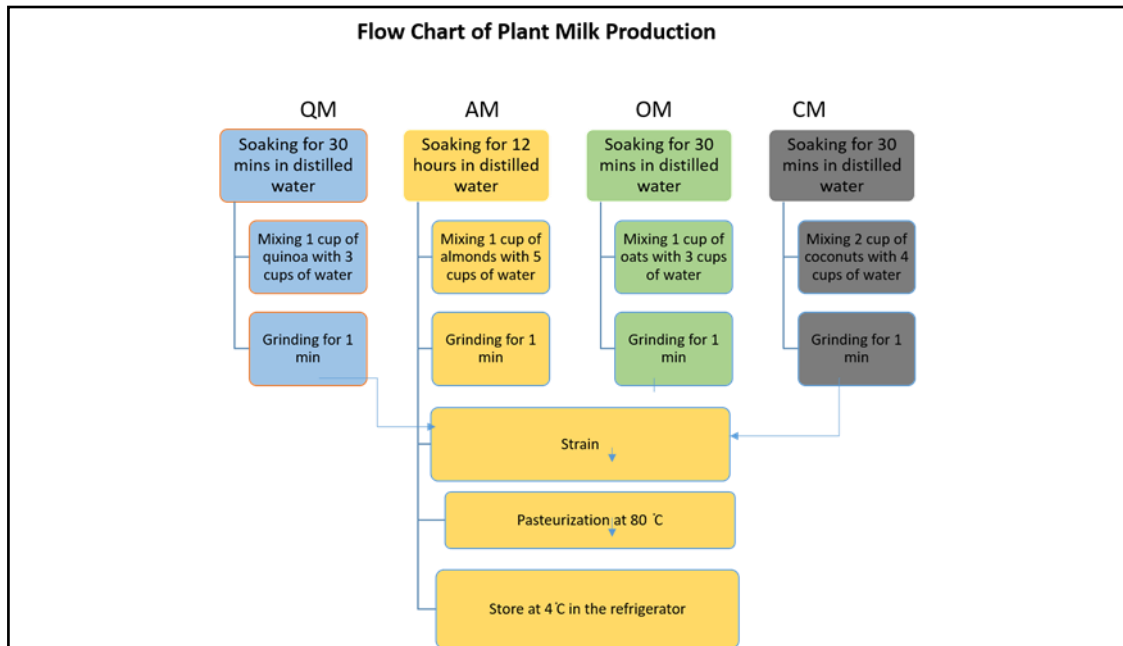
During this study, four different types of plant milks were used: almonds (made from nuts), oats and coconuts (made from seeds), and quinoa (made for pseudo-cereals).

##### 2.2.2 Plant Milk Preparation

For the preparation of almond milk: Almonds were soaked in sterile distilled water for 12 h in a fridge  $4^{\circ}\text{C}$ , followed by a draining step. Then, the almonds were ground with sterile distilled water in a blender (in a ratio of 1:5 w/w) for 2 min, followed by straining through a two-layer muslin cloth to obtain almond milk. Oat milk was prepared by soaking oat flakes in sterile distilled water (in a ratio of 1:3 w/w) for 30 minutes at  $25^{\circ}\text{C}$ . Then, the oat flakes were ground in a blender for 2 min, followed by straining through a two-layer muslin cloth. Coconut milk was prepared by soaking (2:4 w/w) for 30 minutes at  $25^{\circ}\text{C}$  in distilled water and draining the solution afterward. Quinoa milk was prepared by soaking (2:4 w/w) for 30 minutes at  $25^{\circ}\text{C}$  in distilled water and draining the solution afterward. The plant milks were pasteurized  $75^{\circ}\text{C}$  for 20 min and subsequently cooled down to  $37-40^{\circ}\text{C}$  (fermentation temperature) as illustrated in Fig. 2.

**Figure 2**

*Flow chart of plant milk production*



Develop different formulations of plant-based yogurt substitutes using selected ingredients. Conduct small-scale trials to optimize the ratio of ingredients for taste, texture, and nutritional profile as mentioned in Table 2 and as detailed in appendix B.

**Table 2**

*Formulation development for different types of milk\**

| Target properties            | Oat Milk<br>OM | Almond Milk<br>AM | Coconut Milk<br>CM | Quinoa Milk<br>QM |
|------------------------------|----------------|-------------------|--------------------|-------------------|
| High protein focus           | 30%            | 30%               | 20%                | 20%               |
| Creamier Texture             | 30%            | 20%               | 40%                | 10%               |
| Balanced flavor and texture  | 50%            | 25%               | 15%                | 10%               |
| Low fat, high protein        | 30%            | 30%               | 10%                | 30%               |
| Nutrient-dense and flavorful | 25%            | 20%               | 35%                | 20%               |

Note: \* The selected concentrations are based on the previous published results.

## 2.3 Plant Milk Characterization

### 2.3.1 PH

The pH of the plant-based milk was measured with a pH meter (OHAUS Starter 3100 at 11.7°C).

### 1.3.2 Total Titratable Acidity

To ascertain the acidity of a milk sample, begin by adding N/10 NaOH solution to a burette. Make sure the milk sample is well combined without including any air. Ten milliliters of the milk (ten milliliters) should be pipetted into a conical flask along with the same amount of glass-distilled water. Add three to four drops of the phenolphthalein indicator solution, then use a glass rod to stir the mixture. At the meniscus's lowest position, note the alkali's initial reading in the burette. Titrate the milk mixture quickly using the 0.1 NaOH solution, stirring constantly as you add the alkali drop by drop. When a distinct pink color emerges and holds for ten to fifteen seconds, stop the titration. Make sure the titration is finished in twenty seconds. The acidity of the milk can be calculated using the formula (8):

$$\text{TitrateableAcidity} = \frac{V \times 0.105 \times 90.08}{10 \times 1000} \dots\dots\dots(1)$$

### 2.3.3 Zeta potential

Zeta potential analysis plays a crucial role in characterizing plant-based milk alternatives, like emulsions made of almond and coconut milk. Over time, these colloidal systems may flocculate and coalesce, necessitating the inclusion of stabilizing chemicals to change the product's electro-kinetic potential (30,31). Zeta potential is the differential in charge repulsion/attraction between the stationary layers of ions that have adhered to the surfaces of insoluble nanoparticles distributed throughout the medium and the mobile particles in a dispersion fluid. It is carried out by distributing nanoparticles in a liquid medium with different pH values and distributing an electrical field throughout the colloid. The dynamic light scattering (DLS) equipment was used to measure it (30).

The zeta potential of the samples was determined by particle size and zeta potential analyzers are based on the principles of (DLS) for particle sizing and distribution, and based on Doppler velocimetry for zeta potential measurement using the NanoBrook

Series size and zeta potential analyzers. All samples were diluted with ultrapure water at a ratio of 1:199 (v/v) and then placed into the sample cell. Before measurement, the samples were maintained for 1 min at 25°C (32).

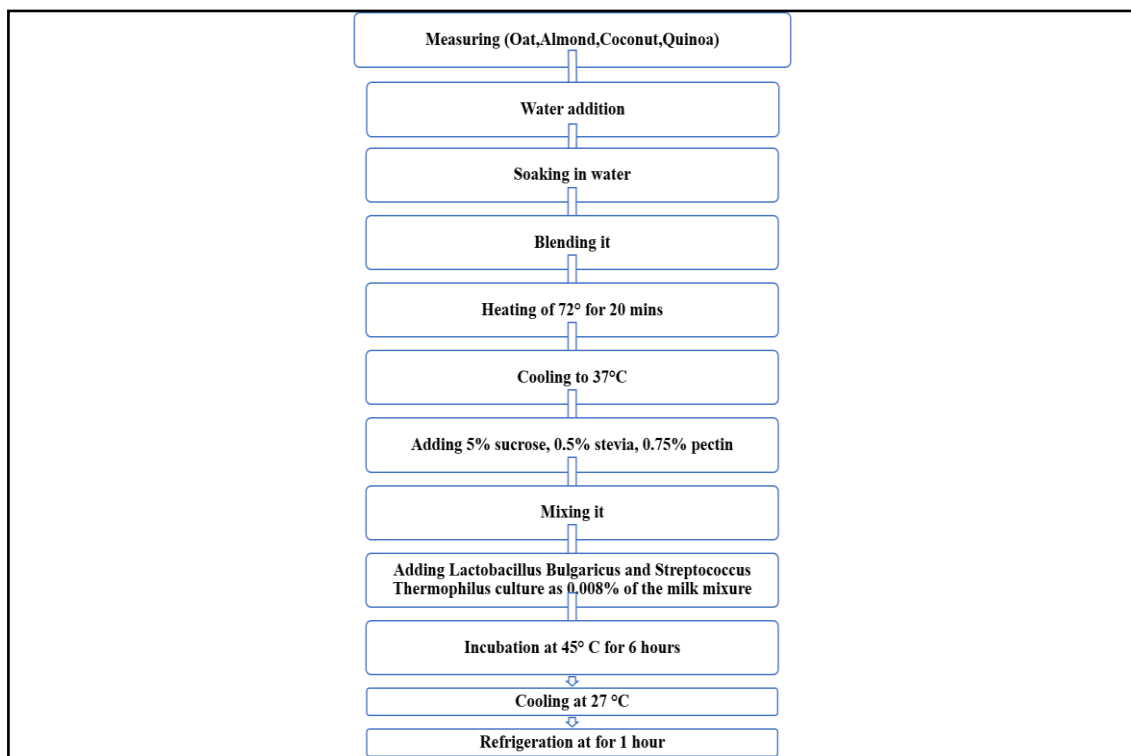
## 2.4 Plant-based yogurt Characterization

### 2.4.1 Plant-based yogurt production

The PBY will be obtained according to (33) as described in Fig 3 , oat, almonds, coconuts, quinoa will be used to extract their milk and then mixed according to the specific concentration reported in Table 1. Then the sugar and stevia 5%, and 0.5% respectively were added to the mixtures and shaken then the pectin (0.375g/50ml) was added and shaken by mixer. In addition, based on the manufacturer's instructions, the plant milk samples (100 mL, preheated to 40°C) the starter cultures were added as 0.008 g of the milk mixture weight. Then, the samples were vigorously shaken (in tightly closed glass bottles) to distribute the culture homogeneously in the milk. Fermentation was carried out at 45°C for 8 h (33).

**Figure 3**

*Flow chart of the plant based yogurt manufacturing (33)*



## **2.4.2 Viscosity of plant-based yogurt**

Viscosity has a direct impact on the texture, mouthfeel, and customer acceptability of plant-based yogurt, making it a crucial quality factor. Due to variations in protein structure, lipid content, and the lack of casein, plant-based yogurt substitutes frequently struggle to reach the appropriate viscosity in comparison to dairy yogurt. The development of the viscosity of plant-based yogurt is significantly influenced by the addition of stabilizers, the conditions under which fermentation occurs, and the choice of bacterial cultures (8,34). Thickening agents were used to improve the texture and viscosity of plant-based food products, as viscosity is one of the primary quality factors determining consumer approval. It was measured by a rotational viscometer (8,28). They were measured at 23.1°C using a Brookfield DV-1 Viscometer with a 03 spindle. After the instrument's calibration, samples of 150 ml were loaded into the cup and were measured at 50 PRM (35).

## **2.4.3 Proximate Analysis of plant-based yogurt**

### **2.4.3.1 Determination of Moisture Content**

The moisture balance (EB-340MOC) was used to measure the total solids in plant-based yogurts. The aluminum sample pan was loaded into the warming unit after a 5 g sample of the yogurt was weighed and put inside. The sample was heated to the proper temperature (usually 105°C) for three hours. Based on the weight loss during the heating process, the moisture balance automatically determined the proportion of total solids. Following the three-hour drying time, the sample pan was taken out and cleaned for later use, and the unit's screen showed the percentage of total solids (36,37).

$$\text{MoistureContent} = 100\% - \text{totalsolids} \dots\dots\dots(2)$$

### **2.4.3.2 Determination of Protein Content**

Each yogurt sample's total protein content was ascertained using the Kjeldahl procedure. In conclusion, the organic matter must first be demineralized using sulfuric acid, and then the reaction products must be alkalized. The milk was stirred into a beaker using a VELP magnetic stirrer for 60 sec. at 700 rpm. The 5 ml sample was put into a 250 ml test tube by using a pipette. For each sample, 2 catalyst tablets of VCM (0.1 g CuSO<sub>4</sub>), 20 ml of concentrated sulfuric acid 96-98%, and 5 ml of hydrogen peroxide were added. The

digestion unit was connected to a proper aspiration pump and a fume neutralization system to neutralize the acid fumes created during the digestion phase. The samples were digested for 15 minutes at 150°C (40). The coefficient of conversion of organic azote to proteins is 6.25 (41).

**2.4.3.3 Determination of Fat Content**

Lipid content was ascertained by weighing 10 g of samples, and then 9 ml of HCl and 10 ml of H2O were added and heated for 5 minutes. Then 1.5 ml NH4OH was added and mixed. Then it was poured into solution in a separatory funnel. 25 ml of diethylene ether was added and shaken for 2 minutes. 250 ml flasks were weighed (w1) and were collected in an organic layer, letting the solvent evaporate and then weighed (w2) after coiling the flask at room temperature (41).

$$\%fat = \frac{W2 - W1}{Wt.of\ sample \times 100} \dots\dots\dots(3)$$

**2.4.3.4 Determination of Carbohydrate Content**

Carbohydrate was calculated by difference, using the equation (FAO, 2003) presented below: Carbohydrate (g/100 mL) = 100 – moisture content – total protein content – total fat content – ash content (37,38).

**2.4.3.5 Energy content**

Energy was calculated with the standard conversion factors (9.0 kcal/g for fat, and 4.0 kcal/g for protein and carbohydrate) (28,37).

**2.4.3.6 Determination of Ash Content**

The ash content was determined by the direct heating method. Briefly, 2 g of each of the yogurt samples was weighed in dried glass crucibles separately. The samples were then incinerated to ash in a muffle furnace for 3 hours at 550°C. The crucibles were then removed and cooled in a desiccator, and the weight of the ash was determined. The percentage ash content was calculated by the following formula (39).

$$\% \text{ ash} = \frac{Z-X}{Y-X} \times 100 \dots\dots\dots(4)$$

Where; X=weight of empty crucible; Y=weight of crucible+sample; Z=weight of crucible+ash

#### **2.4.4 Sensory Evaluation of Plant-Based Yogurt**

The 35 panelists aged 25-40 years from AN-Najah University in Palestine were randomly selected and informed about the evaluation process before the test. Twenty grams of samples were served randomly in clear plastic cups with three-digit codes at 4°C. They were scored on a nine-point rating system that included appearance, viscosity, color, sweetness, sourness, mouthfeel, odor, flavor, texture, and overall acceptability, with 0 denoting "extremely dislike" and 9 denoting "extremely like" (8). The acceptability index (AI) was calculated as  $AI \% = (\text{Average score}/\text{highest score}) \times 100$  (40). The sensory evaluation was conducted in a laboratory with standard lighting and a temperature of 25°C, where each panelist was provided an isolated booth.

#### **2.4.5 Statistical Analysis Methods**

A one-way ANOVA analysis of variance was performed using SPSS Statistics. At  $p < 0.05$ , the acceptable level for significant variation was established. The post-hoc Tukey test was used to compare the samples in pairs, defining the significant differences between samples. The variations in means were examined (7,8). The Kruskal–Wallis non-parametric test, an alternative to one-way analysis of variance, was used to make conclusions about the equality of medians between the samples, which were not normally distributed. Frequency statistics were used to summarize and describe (mean  $\pm$  SD) of macronutrients (total fats, protein) per serving and other variables like zeta potential, viscosity, and sensory scores (7).

## **Chapter Three**

### **Results and Discussion**

#### **3.1 pH of different plant-based milk**

The concentration of hydrogen ions ( $H^+$ ) in a solution is used to calculate the pH scale, which indicates how acidic or alkaline a substance is. A pH value of 7 is considered neutral, while values below 7 indicate acidity and above 7 suggest alkalinity. Regarding food and drink, including plant-based milk, pH is a critical factor in determining product attributes like flavor, stability, and component interactions. Acidity has a significant impact on taste, microbiological stability, and the entire sensory experience, making it crucial for preserving the quality of plant-based milk (41).

A key determinant of plant-based milk's alkaline or acidic level, which affects its flavor, stability, and applicability for particular uses, is its pH. As shown in Figure 4, panel A the average pH values of the compared milk ranged from 6.41 to 6.52. The CM has the highest pH value. Because of its limited fermentable sugars and low protein content. Furthermore, fats do not become acidic like proteins and carbs do. A comparison of these plant-based milks revealed significant ( $P = 0.00$ ) differences in the average value of (a-d) between OM, AM, CM, and QM. The pH values of oat milk and almond milk in our investigation were 6.43 and 6.52, respectively. Which are in accordance with typical plant-based milk characteristics and have a slight acidity (42). However, these values are lower than those found in research by Jemaa et al. (2021) (41), which showed comparable pH values of 6.72 and 6.61, respectively.

The type of plant matter used, the water quality, or the preparation methods used can all affect pH variations between experiments. For instance, due to their innate metabolic contents, various almond cultivars or oat processing techniques may cause slight variations in pH. While the results showed that the quinoa milk in our investigation had a little lower pH (6.41), compared to the milk in the other study (43). Adding enzymes to quinoa (to improve its emulsifying properties) might not be the ideal choice due to the proteins in the cereal. The pH differences across different quinoa milks may be explained by the fact that alpha-amylase and protease require an acidic pH to properly perform their proteolysis, as shown in this research (43). In addition to that, the previously mentioned variations in the ingredient composition and production technology of plant-based milk

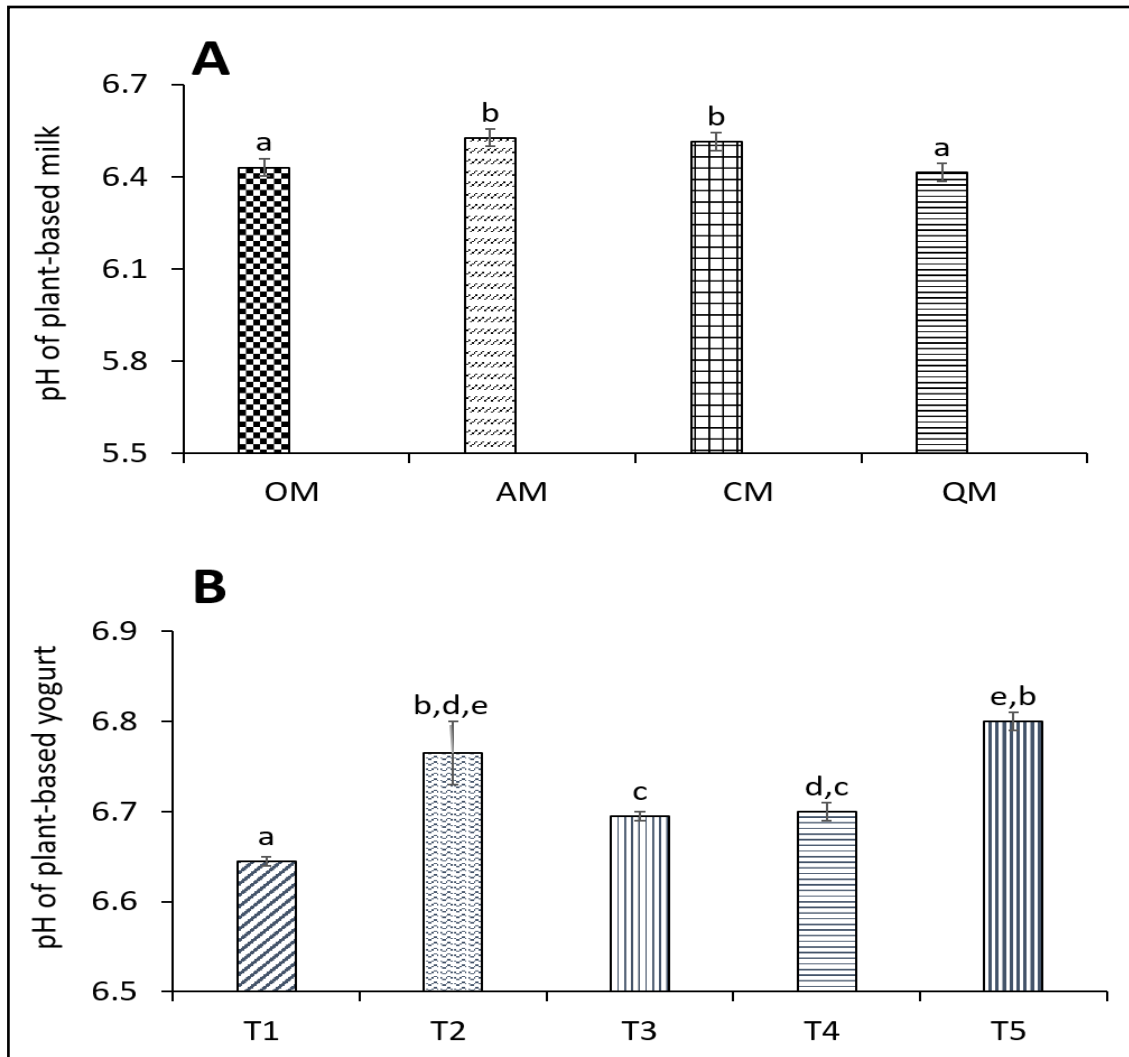
substitutes examined by various researchers are probably the reason why the results of the aforementioned studies are inconclusive and the pH values of products made from various raw materials do not follow a clear pattern (44).

The pH values of blended plant-based yogurts (T1 to T5) are shown in Figure 4, panel B. The average pH values of the compared yogurts ranged from 6.6 to 6.8. Specifically, T1 had a pH of 6.64, T2 had a pH of 6.74 and T3 had a pH of 6.69, T4 had a pH of 6.7, and T5 had the highest pH of 6.8. When comparing these values, no statistically significant differences were observed between T1, T2, and T3 at  $p < 0.05$ . However, significant differences were detected between T1 and T4 ( $p < 0.05$ ) as well as between T1 and T5 ( $p < 0.05$ ). In addition, T5's average pH was significantly higher than the other samples' ( $p = 0.00$ ).

The pH of plant-based milk may be impacted by external variables such as production processes, additional additives, and storage conditions. Particularly important factors are the acidity of the water and the presence of stabilizers, sweeteners, or preservatives. Our study found that a slightly acidic pH is beneficial for shelf life, but it can also have an impact on consumer acceptance and sensory qualities. According to Grasso and colleagues (2020), the purpose of plant-based yogurts' diverse pH ranges is to maximize the activity of different gelling agents. Since the inclusion of hydrocolloids probably contributes to the viscoelastic qualities of yogurts, these additional thickeners have an impact on the viscosity of the yogurt (43,45).

**Figure 4**

*The pH values of the different plant-based milk oat milk (OM)*



Note: almond milk (AM), coconut milk (CM), and quinoa milk (QM) Panel (A). The pH values of blended plant-based milk yogurts Panel (B). The different blended plant-based milk as following (T1: 30% OM, 30% AM, 20% CM, 20% QM, T2: 30% OM, 20% AM, 40% CM, 10% QM, T3: 50% OM, 25% AM, 15% CM, 10% QM, T4: 30% OM, 30% AM, 10% CM, 30% QM, T5: 25% OM, 20% AM, 35% CM, 20% QM). Comparison of these plant-based milk yogurts revealed significant ( $P = 0.00$ ) differences in the average value of (a-e) between T1, T2, T3, T4, and T5. The values followed by the same letter are statistically different at ( $p < 0.05$ ) for Panel (A) ( $P = 0.00$ ) for Panel (B).

### **3.1.2 Effect of incubation time on the pH value of plant-based yogurt**

For many years, fermentation has been employed to create plant-based products while encouraging the growth of microorganisms, especially LAB. In addition to generating metabolites like organic acids that improve flavor and biological components, LAB also breaks down antinutritional chemicals and produces bacteriocins, which fight spoilage bacteria. Protein gelation results from LAB's reduction of pH to 4.6 as well. Their exopolysaccharides enhance flavor, mouthfeel, freeze-thaw stability, and water-holding

capacity, rheology, and gel hardness. LAB strains, temperature, pH, minerals, vitamins, and carbon sources, however, all affect the formation of exopolysaccharides (7).

Yogurt contains *L. bulgaricus* and *S. thermophilus* as starting cultures. The amount of acidity in the yogurt is determined by the fermenting duration. Yogurt that ferments for a longer period is extremely acidic. Low plant milk sugar inhibits the synthesis of acid by carboxylic acid bacteria, necessitating the addition of sucrose (7,46).

Figure 5 shows how the pH of blended plant-based milk during fermentation for 6 h at 45°C. Interestingly, the pH values steadily dropped for every treatment (T1, T2, T3, T4, T5), suggesting that the acidity increased as fermentation began. This pattern is common in the fermentation of plant-based milk and in dairy milk fermentation, where fermentable carbohydrates are converted to lactic acid by LAB, which lowers the pH. The blended plant-based milk have a pH of 6.0 to 6.5 at started point of fermentation, which is typical for plant-based milk yogurts before fermentation.

Figure 5 shows that some milk treatments (such as T1 and T3) showed a faster pH drop than others, which may be a sign of a higher quantity of fermentable carbohydrates. For example, T1 contains high amount of oats and almonds 30% & 30%, respectively, which support rapid microbial growth and fermentation. The Previous study showed that the amount of carbohydrates in oat yogurt was slightly higher; 7.8g/100g. The presence of polysaccharides like  $\beta$ -glucan in oats may be the cause of this (47). T3 contains the highest amount of oats, 50%. On the other hand, slower rates in the initial stages of fermentation were observed in T2 and T4, which may indicate lower fermentable carbohydrates. However, T4 had a greater amount of QM 30% has 3.7 g/100 g lesser than oat which contains 23g/100 g, there is less substrate for microbial action, which may explain the slower fermentation. And other research revealed in their findings that the initial pH was lower the more quinoa there was (48).

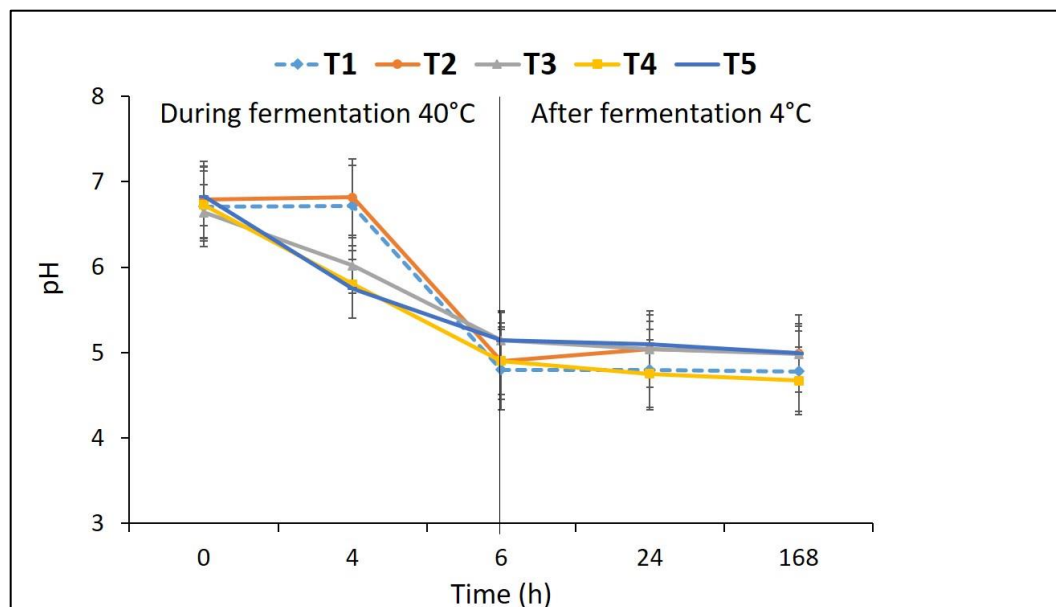
The quantities of coconut milk (CM) in T2 40% and T5 35% also appeared to have an impact on the fermentation speed; T2 had a more moderate pH drop, presumably because of contains 30% of OM and 10% of QM. In addition, it contains the higher content of coconut milk, which is heavy in lipids. (8). In addition to that, the study showed that by adding tapioca starch to the coconut yogurt increase the bacterial viability in plant-based yogurt during storage (49).

Additionally, the final pH values obtained are crucial for assessing the fermented the blended plant-based milk's quality. In general, a lower pH increases shelf life and improves microbiological stability, both of which are critical for commercial items. However, lower pH levels might produce sourer flavors, which can or might not be preferred depending on the product's intended function. Thus, a crucial factor in the blended plant-based milk fermentation is maximizing the fermentation conditions to get the required pH while preserving flavor and texture.

Figure 5 displays the pH dynamics of various plant-based milks (T1-T5) during fermentation 40°C and after fermentation 4°C. All treatments show a quick reduction in pH during fermentation, which is indicative of effective microbial activity and acid generation. Following fermentation at 4°C, the pH stabilizes, indicating that it inhibits microbial activity. Differences in the protein and carbohydrate content of plant-based milks, which affect acidification rates and fermentation efficiency, could be the cause of treatment variations. This demonstrates how plant-based milks can be used for probiotic purposes and how crucial it is to maximize the fermentation conditions for every kind of milk.

**Figure 5**

*The pH value of five samples*



Note: T1 (OM 30%, AM 30%, CM 20%, QM 20%); T2 (OM 30%, AM 20%, CM 40%, QM 10%); T3 (OM 50%, AM 25%, CM 15%, QM 10%); T4 (OM 30%, AM 30%, CM 10%, QM 30%) and T5 (OM 25%, AM 20%, CM 35%, QM, 20%) over time, from the initial measurement (zero time) through intervals of 4 hours, 6 hours during fermentation and 24 hours, one week at refrigerated temperature.

### **3.2 Total Titratable Acidity for plant-based milk and plant-based yogurt**

Total titratable acidity (TTA) measurement is a crucial metric for assessing the efficacy of plant-based milk and plant-based yogurt. TTA, or the total acid content of a sample, is a critical factor on sensory qualities, stability, and shelf life of the product. By measuring TTA, producers can make sure that the process of fermentation goes as planned and that the finished product has the right amount of acidity (3,8).

As shown in Figure 6. Panel A, the plant-based milk varieties differed significantly in their levels of lactic acid. QM had the highest lactic acid concentration 0.16% due to its natural organic acids, which include phenolic chemicals and phytic acid. A previous study showed that quinoa is a nutrient-rich substrate for lactic acid bacteria (50). In addition to that, the researchers showed that the acidity of QM was 0.23% which is higher than our result (51).

On the other hand, because of its high fat content, CM showed the lowest lactic acid concentration. The amount of lactic acid produced by OM was moderate (~0.08%).

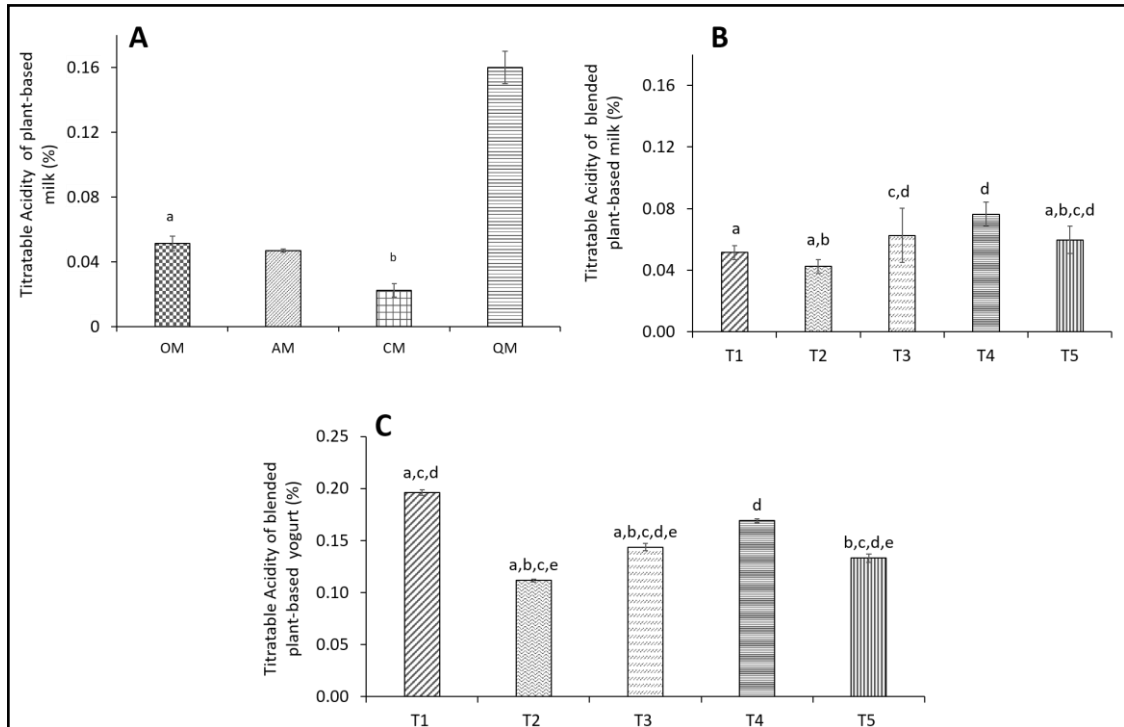
As shown in Figure 5. Panel B, lactic acid generation varied not significantly throughout the mixture formulations (T1–T5), with T4 obtaining the greatest concentration 0.1% and T1 the lowest (~0.05%). Which demonstrates the beneficial effects of a well-balanced mix of OM, AM, and the highly fermentable QM. Conversely, T2 (30% OM, 20% AM, 40% CM, 10% QM) produced the least amount of lactic acid, most likely due to the higher CM content.

As shown in Figure 6, Panel C, the range of TTA for blended plant-based yogurt is from 0.112 to 0.17%. The efficiency of fermentation during plant-based yogurt manufacturing was demonstrated by the fact that the lactic acid content in plant-based yogurt was often higher than in the blended milk. The formulation with the greatest lactic acid concentration (~0.20%) was T1 (30% OM, 30% AM, 20% CM, 20% QM), followed by T4 (~0.18%) and T5 (~0.16%). The greater amounts of lactic acid in T1 imply that this formulation supported vigorous bacterial growth by offering an ideal balance of nutrients and fermentable substrates. However, T2 (30% OM, 20% AM, 40% CM, 10% QM) showed the significant low lactic acid concentration (~0.12%), confirming that a large

CM proportion had an inhibitory impact and it lacks fermentable sugars, which are necessary for lactic acid bacteria (LAB) to produce lactic acid.

**Figure 6**

*Total titratable acidity of plant-based milk*



Note: (A), plant-based mixtures (B) and plant-based yogurt after fermentation (C). The values that are followed by the same letter are not statistically different at  $p < 0.05$ .

### 3.3 Zeta potential, partial size, and polydispersity index for different plant-based milks and different treatments

Zeta potential is a crucial parameter for assessing colloidal stability. Greater absolute values imply more stability by limiting the agglomeration of particles. One method used to determine the charge on the surface of the droplets in the dispersion medium is to use the zeta potential, which is the potential between the droplet surface and the dispersing liquid medium (35).

Zeta potential is frequently employed to measure droplet stability (52). The zeta potentials more than +30 mV or less than -30 mV are considered strongly cationic, whereas those with zeta potentials between -10 and +10 mV are considered generally neutral (73). Thus, particles having zeta potentials more than +30 mV or less than -30 mV are stable (i.e., do not aggregate). The droplets' electrophoretic motion is measured to estimate the zeta

potential. Because plant-based yogurts typically have textural problems due to phase separation, the main obstacles addressed by makers of these products are related to the appearance and texture features. Serum separation occurs when these plant-based systems become acidic because the destabilization of the proteins causes a weak, non-continuous gel to form (53).

Table 3 shows how different additions, including xanthan gums and pectin, affect the physical properties and colloidal stability of plant-based milk. These characteristics are essential because they have a direct impact on the mouth feel, texture, and shelf life of the final product.

### **3.3.1 Zeta Potential**

Research indicates that pectin and other additions can alter the surface charge of particles (54). According to Table 3, the results show that AM has a stable, negatively charged colloidal system, is indicated by the baseline zeta potential of -20.6 mV. The zeta potential shifts toward neutrality (-0.1 mV) when pectin is added, indicating that pectin adsorbs onto the particle surfaces and neutralizes their negative charge (54). This result is not consistent with prior research showing that pectin alters electrostatic interactions to stabilize colloidal systems, resulting in a more stable system (30). On the other hand, xanthan gum causes a little positive shift (0.6 mV), most likely because of charge interactions between the milk particles and xanthan gum molecules. Pectin and xanthan gum together produce a more noticeable negative zeta potential (-26.8 mV), which is probably the result of the two biopolymers working together to promote colloidal stability and electrostatic repulsion. In addition, when compared to AM, the zeta potential of OM without additions is less negative (-9.3 mV), indicating a less stable system. A degree of charge neutralization is indicated by the minor reduction of the negative charge (-0.6 and -0.2 mV, respectively) caused by the addition of pectin or xanthan gum. Combining the two biopolymers results in a significantly negative zeta potential (-11.4 mV), which shows some increase in colloidal stability but a less noticeable charge change than in AM.

Without additions, CM exhibits a significantly negative zeta potential (-32.9 mV), indicating a very stable colloidal system compared to other plant-milks. The zeta potential is raised to positive values by pectin and xanthan gum (11.2 and 12.4 mV, respectively), indicating that the biopolymers may change the CM particle's surface charge and cause

instability. When pectin and xanthan gum are combined to CM, the zeta potential shifts toward a less positive value (-6.6 mV). Due to a complex interaction between the pectin and xanthan gum, possibly altering the structure of the emulsion in such a way that leads to a more neutral charge. While QM alone has a moderately stable zeta potential of -18.9. The negative zeta potential is further decreased by pectin and xanthan gum (-24.4 mV and -21.9 mV, respectively), indicating that both biopolymers aid in charge neutralization. Especially in quinoa-based milk, the combination of pectin and xanthan gum produces a strongly negative zeta potential (-26.9 mV), which increases electrostatic repulsion and improves colloidal stability (55).

### **3.3.2 Particle Size**

According to table 3, the results show that AM without additives, the particle size is 816.8 nm. When pectin is added, the particle size increases to 1565.3 nm, indicating that pectin can encourage particle growth or aggregation. On the other hand, xanthan gum produces particles that are smaller (958.7 nm), possibly as a result of its stabilizing properties. Due to interactions between the two biopolymers and their combined effect on particle dispersion, the combination of the two biopolymers produces a moderate particle size (1025.1 nm) (30).

Compared to OM, without additives, OM has a high particle size of 6164.9 nm. Particle size is greatly decreased by the addition of pectin and xanthan gum (1255.4 nm and 1412.4 nm, respectively), indicating that these biopolymers aid in particle stability and size reduction. When both biopolymers are mixed, the particle size is further decreased (1056.3 nm), indicating better stability and dispersion. Without additions, the particle size of CM is 976.7 nm. The little increases in particle size upon the addition of pectin and xanthan gum (1119.3 nm and 1025.3 nm, respectively) indicate a certain degree of aggregation. Nevertheless, the particle size decreases to 675.9 nm when both pectin and xanthan gum are combined in CM, suggesting that they cooperate to enhance dispersion and reduce aggregation. Furthermore, QM particles have a size of 935.9 nm. When pectin and xanthan gum are introduced to QM, the particle size rises, indicating that both biopolymers that may promote aggregation. However, combining pectin and xanthan gum in the same milk results in a lower particle size (988.5 nm), suggesting a synergistic effect on particles stabilization and aggregation reduction.

### 3.3.3 Polydispersity Index (PDI)

The type and concentration of hydrocolloids have a significant impact on the rheological and stability properties of plant-based beverages, according to polydispersity index (PDI) studies on the use of stabilizers in plant-based milk. These studies found that low quantities of hydrocolloids can successfully avoid sedimentation and phase separation, which is in agreement with the lower PDI observed with certain additives in this study (58,59). AM has a narrow particle size distribution, as seen by its low 0.1 PDI when additives are not added. Because pectin and xanthan gum affect particle aggregation, their addition results in a higher PDI (0.3 and 0.3, respectively), indicating a wider distribution. Because of the interaction between pectin and xanthan gum, the combination of both biopolymers yields an even wider PDI 0.5. However, in OM without additives, the PDI of 0.4 indicates a limited particle size distribution. The inclusion of pectin and xanthan gum considerably lowers the PDI 0.3, which denotes a homogeneous particle size distribution. The PDI 0.2 further decreases with combining the two biopolymers, suggesting improved stability and a more uniform particle dispersion (60). Furthermore, the PDI of 0.3 in CM without additions indicates a rather narrow particle size distribution, according to the results. Particle aggregation is likely caused by bridging flocculation, a process in which pectin molecules join many particles to form clusters, as pectin and xanthan gum do not significantly increase the PDI 1.9 and 4.7, respectively when added (61).

Quinoa milk's (QM) polydispersity index (PDI) varies not significantly between treatments. Pectin lowers the PDI to  $0.3 \pm 0.0$ , indicating a much narrower distribution, while xanthan gum results in a larger PDI of  $3.3 \pm 0.6$ , reflecting enhanced particle size heterogeneity. Pure quinoa milk (none) has a PDI of  $1.6 \pm 0.5$ , suggesting a moderately wide particle size distribution (56).

**Table 3**

*Effect of using different stabilizers (pectin and xanthan gum) and their mixture on zeta potential, particle size and polydispersity index of plant-based milk\**

| Type | added material | Zeta potential (mV)      | Particle size (nm)          | Polydispersity index (PDI) |
|------|----------------|--------------------------|-----------------------------|----------------------------|
| AM   | none           | -20.6± 5.6 <sup>a</sup>  | 816.8±66.9 <sup>a</sup>     | 0.1 ± 0.04                 |
|      | Pectin         | -0.1 ± 0.6 <sup>b</sup>  | 1565.3± 70.6 <sup>b</sup>   | 0.3 ± 0.01                 |
|      | Xanthan gum    | 0.6 ± 1.5 <sup>c</sup>   | 958.69 ± 30.63              | 0.3 ± 0.0                  |
|      | mix            | -26.8 ± 4.9 <sup>d</sup> | 1025.1 ± 156                | 0.5 ± 0.3                  |
| OM   | none           | -9.3± 2.7                | 4289.7± 582.2 <sup>a</sup>  | 0.4 ± 0.1                  |
|      | Pectin         | -0.6± 1.1 <sup>a</sup>   | 1255.42 ± 71.6              | 0.3 ± 0.0                  |
|      | Xanthan gum    | -0.2 ± 1.2 <sup>b</sup>  | 1412.4 ± 167.2              | 0.3 ± 0.0                  |
|      | mix            | -11.4 ± 2.1              | 1056.3 ± 131.6 <sup>d</sup> | 0.2 ± 0.0                  |
| CM   | none           | -32.9 ± 1.8              | 976.7 ± 123.7               | 0.3 ± 0.0                  |
|      | Pectin         | 11.2 ± 7.4 <sup>a</sup>  | 1119.3 ± 276.2              | 2.7 ± 1.2                  |
|      | Xanthan gum    | 12.4 ± 8.5 <sup>b</sup>  | 1025.3 ± 270.9              | 2.3 ± 1.8                  |
|      | mix            | -6.6 ± 4.0 <sup>c</sup>  | 675.9 ± 114.6               | 2.2 ± 0.9                  |
| QM   | none           | -18.9 ± 0.5              | 935.9 ± 58.7 <sup>a</sup>   | 1.6 ± 0.5                  |
|      | Pectin         | -24.4 ± 4.3              | 1515.9 ± 116                | 0.3 ± 0.0                  |
|      | Xanthan gum    | -21.8 ± 5.8              | 1826.1 ± 489.5 <sup>b</sup> | 3.3 ± 0.6                  |
|      | mix            | -26.9 ± 3.8              | 988.5 ± 130.9 <sup>c</sup>  | 0.8 ± 0.7                  |

Note: \*Means ± SD (n = 3). Values followed by different superscript letters (a–d) in the same column are significantly different (p < 0.05).

**Table 4**

*Effect of using different stabilizers (pectin and xanthan gum) and their mixture on zeta potential, particle size and poydispersity index of blended plant-based milk treatments*

| Types of treatments | Added material | Zeta potential (Mv)      | Diameter (nm)  | Polydispersity index (PDI) |
|---------------------|----------------|--------------------------|----------------|----------------------------|
| T1                  | None           | 0.04 ± 0.9               | 1066.3 ± 67.5  | 0.1 ± 0.09 <sup>a</sup>    |
|                     | Pectin         | -17.6 ± 5.7              | 925.7 ± 192.3  | 2.4 ± 1.3 <sup>b</sup>     |
|                     | Xanthan gum    | -30.4 ± 4.3 <sup>d</sup> | 723.6 ± 71     | 0.5 ± 0.4                  |
|                     | Mix            | -21.5 ± 6.9 <sup>c</sup> | 2065.2 ± 375.1 | 3.8 ± 2.5 <sup>c</sup>     |
| T2                  | none           | -17.8 ± 1                | 1280.8 ± 25.7  | 0.2 ± 0.03 <sup>a</sup>    |
|                     | Pectin         | -26.5 ± 7.6 <sup>b</sup> | 1768.7 ± 464   | 5.3 ± 4.4 <sup>b</sup>     |
|                     | xanthan gum    | -32.2 ± 3.0 <sup>c</sup> | 813.6 ± 75.7   | 0.1 ± 0.05 <sup>c</sup>    |
|                     | mix            | -9.3 ± 12.2 <sup>d</sup> | 2246.5 ± 402.4 | 1.5 ± 0.8 <sup>d</sup>     |
| T3                  | none           | -14.9 ± 1.7              | 1477.9 ± 73.2  | 0.3 ± 0.03                 |
|                     | Pectin         | -25.5 ± 2.5              | 1217.7 ± 893.1 | 1.4 ± 0.1                  |
|                     | xanthan gum    | -17.4 ± 1.2              | 1438.3 ± 266.7 | 0.79 ± 0.8                 |
|                     | mix            | -24.0 ± 5.3              | 1105.5 ± 186.2 | 2.1 ± 0.6                  |
| T4                  | none           | 0.29 ± 1.4               | 1511.6 ± 188.6 | 0.2 ± 0.04                 |
|                     | Pectin         | -31.2 ± 5.8              | 1320.9 ± 128.4 | 1.2 ± 0.8                  |
|                     | xanthan gum    | 0.5 ± 8.5                | 762.3 ± 112.7  | 0.2 ± 0.1                  |
|                     | mix            | -42.0 ± 1.9              | 1321.8 ± 277.7 | 0.5 ± 0.3                  |
| T5                  | none           | 0.5 ± 1.5 <sup>a</sup>   | 1569.9 ± 229.4 | 0.2 ± 0.05                 |
|                     | Pectin         | 0.2 ± 1.5 <sup>b</sup>   | 1262.8 ± 109.9 | 0.1 ± 0.02                 |
|                     | xanthan gum    | 1.4 ± 1.7 <sup>c</sup>   | 930.8 ± 73.7   | 0.1 ± 0.09 <sup>c</sup>    |
|                     | mix            | 11.1 ± 16.6 <sup>d</sup> | 221.9 ± 326.7  | 1.5 ± 1.9 <sup>d</sup>     |

Note: \*Means ±SD (n = 3). Values followed by different superscript letters (a–d) in the same column are significantly different (p < 0.05).

### 3.4 Viscosity of different plant-based yogurts

Viscosity is one of the primary quality factors that determine consumers acceptance of plant-based yogurt items (56).

The viscosity of different blended plant-based yogurt was evaluated at 50 paddle rotation rates (PRM) and reported in Table 5. According to the data, T5 had the highest viscosity

value, reaching 16723.3 mPa.s. At the same PRM, however, the T2 reported the lowest viscosity value, reaching 2806.7 mPa.s. Also, T2 continuing to have much less viscosity than T4 ( $p = 0.022$ ), T3 ( $p < 0.001$ ), and T5 ( $p < 0.001$ ). Furthermore, there was a significant difference ( $p = 0.039$ ) between T1 and T3, with T3 showing a higher viscosity. Nonetheless, there were no significant variations between T1 and T4 ( $p = 1.000$ ).

The addition of gelling agents and hydrocolloids such as agar, starch, gums and/or pectin was found to significantly affect the rheological properties of the yogurt products. Combinations of these additives are frequently used either in the food industry to obtain a desirable texture, directly or through polysaccharide-protein interactions (34).

During preparation and storage, plant-based yogurt is known to undergo changes in viscosity and syneresis. When a phase (serum) in yogurt splits off from the continuous network, syneresis takes place. The gelation and multi-component networks of protein, lipid, and carbohydrate cause plant-based milk to change from a Newtonian fluid to a semi-solid product (7).

The viscosity of the majority of plant-based yogurts reduces as the shear rate rises ( $n < 1$ ), a phenomenon known as shear-thinning (pseudoplastic) behavior. This characteristic is crucial for yogurt since it keeps it thick when it's at rest, giving it a desired texture, but it also makes it easier to stir and pour when it's combined or eaten. The components utilized, such as plant proteins (including almond, and coconut), starches, gums, and other stabilizers, affect the consistency index ( $m$ ) and give the yogurt its thickness and mouthfeel (33). This is consistent with our results for T4 and T5 only, and is also likely to be because they contain a high percentage of coconut.

The findings indicated that T5 had the highest viscosity of 50 PRM level and a comparatively high CM concentration 35% in our study. A denser network of connections is formed in part by the medium-chain triglycerides (MCTs) and total lipids found in coconut milk. These lipids produce stable colloidal structures that generate a creamier texture and increase viscosity (32). The findings of this study align with those of Kosterina and colleagues, 2020, who reported that coconut milk-based yogurt, exhibited increased viscosity, associating its apparent viscosity with thixotropic behavior (36).

Likewise, T3, which had 50% (OM), also displayed high viscosities, highlighting the contribution of the natural total solids (such as beta-glucans) in oat milk to viscosity enhancement (57). Research has indicated that hydrocolloids such as pectin and xanthan are important components of yogurt recipes. Pectin strengthens the protein network by interacting with positively charged proteins, whereas xanthan increases the viscosity of the continuous phase. Protein coagulation is facilitated by decreased electrostatic repulsion in oat milk-based yogurts, creating a three-dimensional gel network. Furthermore, starch granule swelling increases water retention and viscosity, decreasing syneresis and promoting a stable yogurt structure (7).

**Table 5**

*Plant-based yogurt viscosity at different paddle rotation rates at 21.2°C*

| Treatment | PRM | Viscosity mPa·s                   |
|-----------|-----|-----------------------------------|
| T1        | 50  | 3481.7 ± 92.2 <sup>a</sup>        |
| T2        | 50  | 2806.7 ± 318.6 <sup>b</sup>       |
| T3        | 50  | 4232.3 ± 59.4 <sup>c</sup>        |
| T4        | 50  | 3609.7 ± 153.5 <sup>a,b,c,d</sup> |
| T5        | 50  | 16723.3 ± 105.9 <sup>e</sup>      |

Values followed by different superscript letters (a–d) in the same column are significantly different ( $p < 0.05$ ) at same PRM between different plant-based yogurts.

### 3.5 Sensory Evaluation of Different Treatments

The variations in how consumers perceive treatments (T1 to T5) across a range of qualities are highlighted by the sensory assessment data as reported in Figure (7). Ten sensory attributes (taste, texture, aroma, appearance, color, sweetness, sourness, mouthfeel, viscosity, and overall liking) were used to evaluate the sensory qualities of five blended plant-based yogurt formulations (T1, T2, T3, T4, and T5). A 9-point rating system is used for each attribute, with higher scores indicating better sensory function. According to the statistics, there is a not significant amount of variation among the formulations, with most features having scores between 3 and 7. Some characteristics, including sweetness and sourness, exhibit more variation between formulations, indicating that they might be important factors influencing sensory variance. T1 and T5,

for example, exhibit comparatively higher ratings for criteria like sweetness and aroma, indicating that these formulations may have been tailored for consumer-pleasing flavor profiles. T3 and T4, on the other hand, score lower on sourness and overall like, suggesting possible issues with balancing acidity or consumer appeal.

According to the acceptability index, T1 (62%) was the most favored, most likely because of its well-balanced constituent composition, which improved the flavor. T4 (47.5%), on the other hand, had the lowest acceptance index, which may have been caused by an unbalanced composition or the use with less appealing substances.

The Acceptable Index (AI) values for the five treatments (T1, T2, T3, T4, and T5) show a wide range of variations across numerous sensory attributes. T1 had the highest taste score 62%, followed by T5 (57.6%), and T4 (47.5%) received the lowest. In terms of texture, T4 received the lowest score 53.1%, while T3 and T5 had the greatest scores 56.6% maybe because of the ideal ratios of OM and AM. The viscosity data for these treatments is in good agreement with the consistency of the sensory texture.

T1 once more had the greatest aroma value 55.85%, while T4 had the lowest 47.5%. This could be because it's a larger QM or CM which usually has a strong smell. T5 has the greatest appearance characteristic 67.3%, followed by T4 (57.9%), and T2 45.5%. In the same way, T5 had the highest color score 68.4%, followed by T4 (68%), while T1 and T2 had the lowest 61.1%. This implies that the composition of T5 produced a product with a desirable color and visual appeal. Despite its lower scores in other sensory qualities, T2 received the lowest appearance score.

T1 distinguished not significantly out the most in terms of sweetness, indicating that its well-balanced composition improved the feeling of sweetness. T4 received the lowest score, most likely as a result of a more bitter profile brought on by a higher QM or CM content. On the other hand, T2 (58.4%) and T5 (54.6%) had the strongest sourness, which may have been caused by their higher CM level, which could have intensified the formulations' acidic overtones.

T5's mouthfeel and viscosity, which scored 66.4% and 65.2%, respectively, were noteworthy qualities. These findings are consistent with the viscosity values of T5, which were the highest of the treatments. This implies that T5's composition offered an attractive

structure that satisfied customers' tactile perception. Because of their excellent performance across a variety of sensory qualities, T3 and T5 were the most preferred in terms of overall liking. T4 received the lowest score, suggesting that its shortcomings in terms of mouthfeel, taste, and scent exceeded its advantages in terms of color and appearance. The study's main conclusion was that there is a low level of general acceptability for plant-based yogurts (treatments), which results in negative attitudes and a low inclination to eat them. Despite being designed to resemble dairy yogurt in terms of appearance, flavor, texture, and nutritional value, these products typically contain little protein and frequently have unsatisfactory sensory qualities. For instance, prior research has highlighted undesired texture characteristics (such as watery, thin, and "separated") and flavors (such as acidic, beany, nutty, and painty flavors) (49)

**Table 6**

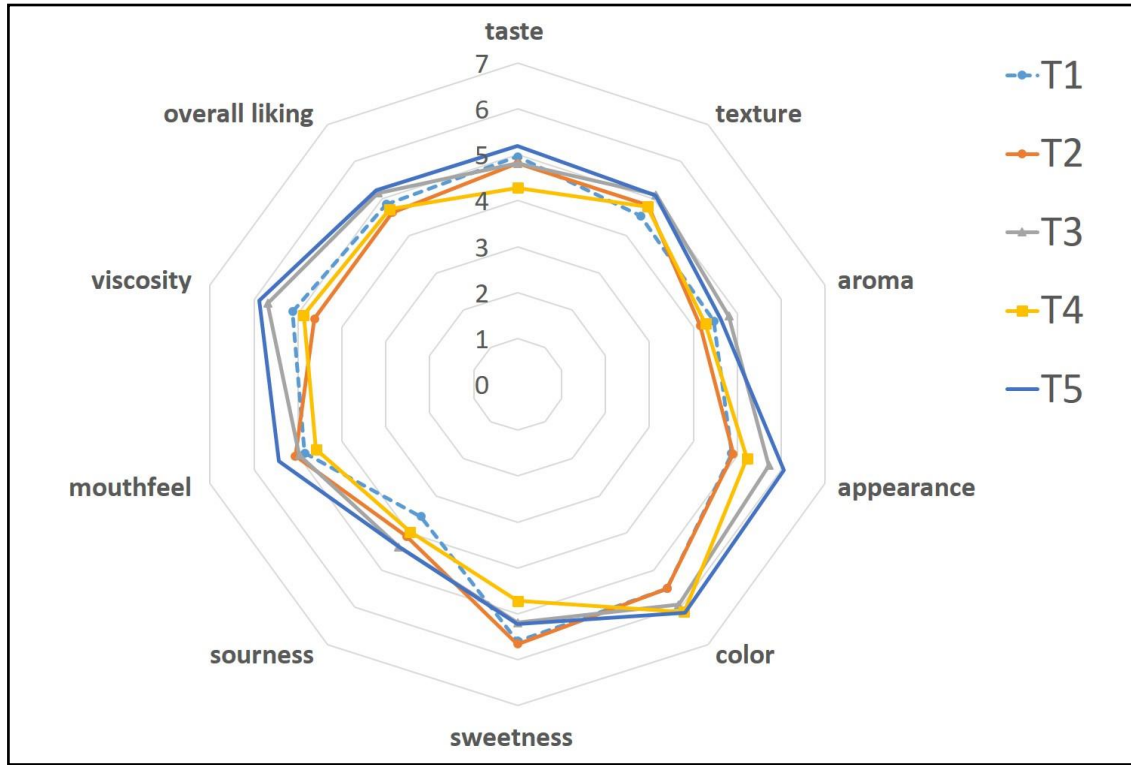
*Acceptable index (AI) of the blended plant-based yogurt for (taste, texture, aroma, overall liking, appearance rating, odor) rating, and taste rating by consumers*

| Acceptable index (AI) (%) | Treatment         |      |      |      |      |
|---------------------------|-------------------|------|------|------|------|
|                           | T1                | T2   | T3   | T4   | T5   |
| Taste                     | 62                | 53.4 | 53.4 | 47.5 | 57.6 |
| Texture                   | 54.3              | 53.4 | 56.6 | 53.1 | 56.6 |
| Aroma                     | 55.85             | 51.9 | 53.4 | 47.5 | 51.3 |
| Appearance                | 54.1              | 45.5 | 63.5 | 57.9 | 67.3 |
| Color                     | 61.1              | 61.1 | 66   | 68   | 68.4 |
| Sweetness                 | 92.1 <sup>a</sup> | 62.7 | 57.6 | 52.4 | 57.9 |
| Sourness                  | 44.5              | 58.4 | 48.6 | 44.1 | 54.6 |
| Mouthfeel                 | 53.8              | 56.2 | 55.2 | 51   | 66.4 |
| Viscosity                 | 56.9              | 51.3 | 63.1 | 54.1 | 65.2 |
| Overall liking            | 53.7              | 51.3 | 57.2 | 52.4 | 57.9 |

No statistically significant ( $p < 0.05$ ) changes were found across the parameters in the one-way ANOVA results for the various treatment groups (T1–T5). The absence of significant pairwise differences between the treatment groups was further supported by the post-hoc Tukey's HSD test. The letter “a” indicated the highest AI score where it reached the acceptance threshold, “acceptable” ( $\geq 70\%$ ) or “not acceptable” ( $\leq 70\%$ ).

**Figure 7**

*Radar chart of sensory evaluation test of the different blended plant-based yogurt*



### 3.6 Nutritional composition of plant-based yogurts

The nutritional composition of the blended plant-based yogurts is provided in Table 5. The protein content varied from 0.44 to 1.34 g/100 g for blended plant-based yogurts, with the T3 having the highest protein content of 1.34 g/100 g, which contains the highest amount of OM as OM is a good protein source. Conversely, T5 contains low QM, OM which are considered sources of protein and high CM content. These results highlight the crucial role that OM and QM plays in boosting the nutritional value of treatments intended for greater protein content by indicating that it is the main source of protein in the formulations.

Furthermore, the blended plant-based yogurt differed in their fat content; T2 had the highest value (1.61 g/100 g), whereas T1 had the lowest (0.68 g/100 g). Given that, CM may contain lipophilic components, T2's high CM content (40%) probably explains its higher fat levels. As shown in a previous study the saturated fat content was considerably higher for the coconut yogurt (4.2 g/g fat) than the other yogurts (0.2–1.0 g/g fat) (8).

A formulation with higher OM and AM, which probably contribute less to the fat fraction, is reflected in T1's lower fat content. These differences imply that CM has a substantial impact on the formulations' fat content, which affects their texture and energy density.

Furthermore, T4 had the greatest energy value 66.2 kcal, which was probably caused by its increased fat and carbohydrate content, which were caused by its higher QM content and total solids. The energy content varied throughout treatments. In line with its lower quantities of fat and protein, T1 had the lowest energy content 48.2 kcal.

The previous study which showed that the almond yogurt had the highest (7.9 g/100 g) and the high fat content in some plant-based yogurts (i.e., almond and coconut) resulted in higher caloric density 79 and 97 kcal, respectively compared to the other yogurts (38–70 kcal) (8) in addition to that, other study showed that the coconut yogurts contain the highest fat compared with other plant yogurts (14). T1 had the highest ash content (0.2 g/100 g), a measure of mineral composition, whereas T4 had the lowest (0.003 g/100 g). The discrepancies may result from different ingredient compositions; for example, T1 may have more minerals from OM and QM than T4, which has lower ash values. This suggests that treatments with higher quantities of OM and QM may contribute more minerals, improving the product's nutritional value.

While moisture content fluctuated inversely, from 85.98% T4 to 87.74% T1, total solids ranged from 12.26% T1 to 14.02% T4. T4's higher fat and carbohydrate composition is consistent with its low moisture content and high total solids, indicating a denser and more concentrated formulation. On the other hand, T1's more balanced but less concentrated composition is reflected in its higher moisture content and lower total solids. According to these results, total solids can be adjusted to provide the appropriate texture and shelf stability; greater solids may result in a lower moisture content and a longer shelf life.

**Table 7***Nutritional comparison of the plant-based yogurts (mean  $\pm$ SD)*

| Type of treatments | Energy (kcal/100g) | Carbohydrate (%) | Protein (%)                  | Fat (%)       | Ash (%)                            | total solids (%) | Moisture content (%) |
|--------------------|--------------------|------------------|------------------------------|---------------|------------------------------------|------------------|----------------------|
| T1                 | 48.2               | 9.5 $\pm$ 0.7    | 1.2 $\pm$ 0.1                | 0.6 $\pm$ .20 | 0.203 $\pm$ 0.048 <sup>a</sup>     | 12.2 $\pm$ 0.8   | 87.7 $\pm$ 0.8       |
| T2                 | 60.0               | 10.7 $\pm$ 2.4   | 0.7 $\pm$ 0.2                | 1.6 $\pm$ 1.2 | 0.160 $\pm$ .006 <sup>a,b</sup>    | 13.3 $\pm$ 1.9   | 86.6 $\pm$ 1.9       |
| T3                 | 60.4               | 11.1 $\pm$ 2.3   | 1.3 $\pm$ 0.0 <sup>a</sup>   | 1.2 $\pm$ 0.4 | 0.126 $\pm$ 0.026                  | 13.7 $\pm$ 2.6   | 86.2 $\pm$ 2.6       |
| T4                 | 66.2               | 12.2 $\pm$ 0.6   | 1.2 $\pm$ 0.0 <sup>b</sup>   | 1.4 $\pm$ 1.5 | 0.005 $\pm$ 0.0 <sup>d</sup>       | 14.0 $\pm$ 0.5   | 85.9 $\pm$ 0.5       |
| T5                 | 58.4               | 11.5 $\pm$ 1.0   | 0.4 $\pm$ 0.0 <sup>a,c</sup> | 1.2 $\pm$ 0.2 | 0.025 $\pm$ 0.002 <sup>b,d,e</sup> | 13.2 $\pm$ 0.5   | 86.7 $\pm$ 1.5       |

Values are mean scores of triplicate determinations  $\pm$ SD. Value with different superscripts in the same column differed significantly ( $P \leq 0.05$ ).

## Chapter Four

### Conclusion

Plant-based yogurts provide a sustainable substitute for dairy yogurts and, because of their variety and nutritional advantages, have an abundance of opportunity to grow as a market. The development and assessment of blended plant-based yogurt substitutes as sustainable and healthful substitutes for conventional dairy products was the main objective of this work. Making novel formulations with plant-based components such as coconut, almond, quinoa, and oat milk and evaluating their functional, nutritional, and sensory qualities were the main goals.

The results showed that when important ingredients like natural thickeners such as pectin and xanthan gum are added to blended plant-based yogurt alternatives enhanced their sensory properties of the product. To ensure the quality and feasibility of these alternatives, a number of tests and studies were conducted. These included pH analysis to monitor the acidity levels in plant-based milks and yogurts, and total titratable acidity to assess the fermentation process and detect acidity fluctuations during yogurt manufacturing. Important details regarding the metabolic alterations occurring during production have been provided by these assays.

To ascertain consumer approval, sensory evaluations were conducted on the taste, texture, scent, and appearance of the various treatments. The results showed that T1 had the highest taste and sweetness scores. In addition to that, T5 was chosen as the most favorable treatment based on sensory evaluations. This demonstrates its ability to successfully mimic the smooth texture and appealing look of conventional dairy yogurt. T5 also had the highest viscosity 65.2%, which contributed to its enticingly creamy texture. The fact that participants thought the plant-based yogurt recipes would work is indicative of this.

Nutritional composition analysis was also used to determine the amounts of protein, fat, and carbohydrate. According to the data, T5 had a balanced nutritional composition with 58.4 kcal of energy, 11.5% carbohydrates, and 1.2% fats. Because of its balanced nutritional profile, excellent viscosity, and higher sensory acceptance, T5 was the optimum formulation. These findings indicate that it could become a highly well-liked and nutrient-dense plant-based yogurt alternative.

In conclusion, a thorough investigation of plant-based yogurt substitutes shows that they have the potential to be practical options for vegans, those who are lactose intolerant, and environmentally conscious consumers. Well-balanced nutritional profiles, enhanced product durability, and positive sensory attributes all demonstrate how viable these goods are to meet the growing need for sustainable and healthful food alternatives.

Although this study provides useful information about the development and evaluation of plant-based yogurt substitutes, it is crucial to acknowledge many limitations. The quality and composition of the plant-based ingredients used, such as almond, coconut, quinoa, and oat milk, can vary, which may affect the results' repeatability between brands or regions. Additionally, the sensory evaluations were conducted on a somewhat small and restricted demographic, which may not fully represent the 9-hedonic testing of a larger group of consumers.

Future research should look into new ingredients to enhance texture and nutritional value, such as plant-based protein isolates or substitute stabilizers, to make plant-based yogurt substitutes more appealing and helpful. To gain a more comprehensive understanding of consumer preferences and cultural influences on acceptability, cross-regional sensory evaluations should be conducted. Research ought to look at the possibility of fortifying products with useful components like vitamins, probiotics, or antioxidants to produce goods with added value.

## List of Abbreviations

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| Abbreviation | Meaning                      |
|--------------|------------------------------|
| AI           | Acceptability Index          |
| AM           | Almond Milk                  |
| CM           | Coconut Milk                 |
| CAGR         | Compound Annual Growth Rate  |
| DLS          | Dynamic Light Scattering     |
| EPS          | Exopolysachhride             |
| FDA          | FOOD and Drug Administration |
| LAB          | Lactic Acid Bacteria         |
| OM           | Oat Milk                     |
| PB           | Plant-Based                  |
| PBYM         | Plant-Based Yogurt Mimic     |
| PDI          | Polydispersity               |
| QM           | Quinoa Milk                  |
| TTA          | Total Titrable Acidity       |

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# Appendices

## Appendix A

### (FD-DVS YC-X11 Yo-Flex ®Product Information)



(FD-DVS YC-X11 Yo-Flex ®Product Information)

Product Information Version: 1 PIEU EN 02-25-2015

Description Thermophilic YoFlex® culture.

Taxonomy *Lactobacillus delbrueckii* subsp. *bulgaricus* *Streptococcus thermophilus*

Packaging Material No: 713506 Size: 30X50 U

Type Pouch(es) in box Dietary status kosher: Kosher Dairy Excl. Passover

Halal: Certified

Physical Properties Application

Color: Off-white to slightly reddish or brown

Form: Granulate

Usage The culture will produce yoghurt with mild flavor, high viscosity and low post-acidification. Suitable for cup set, stirred and drinking yoghurt.

Recommended inoculation rate Directions for Use

Remove cultures from the freezer just prior to use. Sanitize the top of the pouch with chlorine. Open the pouch and pour the freeze-dried granules directly into the pasteurized product using slow agitation. Agitate the mixture for 10-15 minutes to distribute the culture evenly.

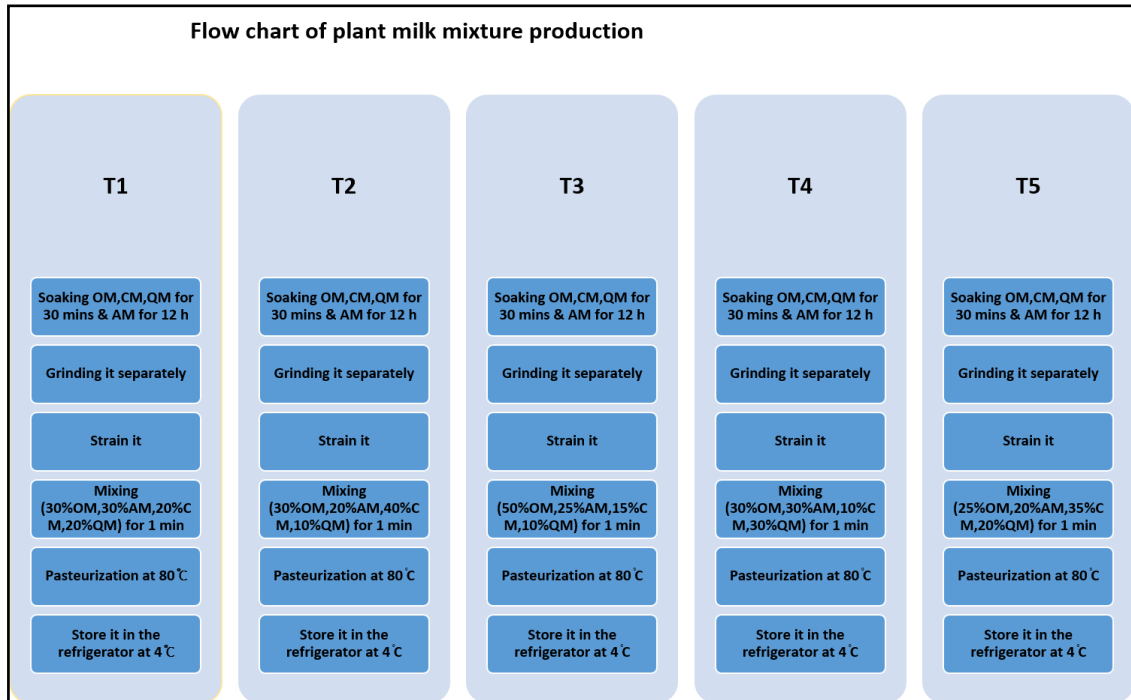
The recommended incubation temperature is 35-45°C (95-113°F). For more information on specific applications see our technical brochures and suggested recipes.

## Appendix B

### Flow chart of plant milk mixtures production

Figure 6

#### *Flow chart of plant milk mixtures production*





جامعة النجاح الوطنية  
كلية الدراسات العليا

## ابتكار بدائل الألبان: إنتاج وتقييم اللبن النباتي

إعداد

آية أنور محمد إبراهيم

إشراف

د. محمد الصباح

د. علا عنبتاوي

قدمت هذه الرسالة استكمالاً لمتطلبات الحصول على درجة الماجستير في التغذية وتكنولوجيا الغذاء  
بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس، فلسطين.

2025

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### الملخص

**الخلفية:** زاد الطلب على البدائل الغذائية النباتية بسبب الوعي الصحي والمخاوف البيئية، ويعد الزبادي النباتي من البدائل الشائعة للألبان.

**الأهداف:** تهدف هذه الدراسة إلى تقييم تأثير مزج أربعة أنواع من الحليب النباتي (الشوفان، اللوز، جوز الهند، والكينوا) بنسب مختلفة على الخصائص الفيزيائية والكيميائية والحسية والتغذوية للزبادي النباتي بعد التخمير باستخدام بكتيريا حمض اللاكتيك.

**المنهجية:** تم تخمير الحليب النباتي المخروط (T1–T5) باستخدام *Lactobacillus bulgaricus* و *Streptococcus thermophilus* عند 45 درجة مئوية ولمدة 6 ساعات. لتجنب ظاهرة الانفصال، أضيفت مثبتات البكتين وصمغ الوانثان وخليطهما. تم تقييم الجودة من خلال قياس الرقم الهيدروجيني، الحموضة، الجهدزيتا، حجم الجسيمات، اللزوجة، والتحليل الحسي، بالإضافة إلى التحليل الغذائي.

**النتائج:** انتهى التخمير عند pH 4.6، وزادت الحموضة من 0.04%–0.6% إلى 0.15%–0.2%. كانت T1 الأعلى حموضة لاحتوائها على 30% من حليب الشوفان واللوز، بينما كانت T2 الأقل حموضة بسبب ارتفاع نسبة حليب جوز الهند 40%. حسن صمغ الوانثان الجهدزيتا وخفض حجم الجسيمات في T1 وT2، بينما عزز خليط البكتين والوانثان استقرار التركيبات في T3–T5. كانت T5 الأكثر كثافة ولزوجة لاحتوائها على 35% حليب جوز الهند و25% حليب الشوفان، بينما كانت T1 الأقل لزوجة.

أظهر التقييم الحسي أن T3 و T5 حصلتا على أعلى درجات في المظهر والزوجة، وكانت T5 الأكثر قبولاً بمزيج متوازن من الحليب النباتي. غذائياً، كانت T1 الأقل سعوات (49 ك. كال)، بينما سجلت T1 و T3 و T4 أعلى محتوى بروتين 1.2-1.3%.

**الخلاصة:** نجحت الواسة في إنتاج زبادي نباتي بتوكيبة متوازنة، مما يجعله بديلاً مناسباً للأشخاص الذين يعانون من عدم تحمل اللاكتوز أو بروتين الألبان، أو الذين يتبعون نظاماً غذائياً نباتياً. يجب أن تركز الواسات المستقبلية على تحسين التوكيبات والتوسع في الإنتاج التجري.

**الكلمات الرئيسية:** الزبادي النباتي؛ التقييم الحسي؛ التوكيبة الغذائية.