# EFFECT OF DIFFERENT STORAGE CONDITIONS ON THE STABILITY AND FUNCTIONALITY OF DAIRY POWDERS: A CASE STUDY WITH LABNEH PRODUCTION

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# ABSTRACT

## EFFECT OF DIFFERENT STORAGE CONDITIONS ON THE STABILITY AND FUNCTIONALITY OF DAIRY POWDERS: A CASE STUDY WITH LABNEH PRODUCTION

Dairy powders are frequently used in the food industry because of their distinctive nutritional profile and long shelf life. They are popular food ingredients due to their texturizing, emulsifying, and nutritional properties. Nevertheless, each product exhibits distinct attributes that confer unique functionalities to them. The purpose of this study is to comprehend the impact of storage temperature and time on the functionality and stability of dairy powders and their use in labneh production to see how storage conditions of an ingredient affect final product attributes. The study employs four different dairy powders, namely Milk Protein Concentrate (MPC85), Skim Milk Powder (SMP), Whey Protein Concentrate 80 (WPC80), and Whey Protein Concentrate 80 -S (WPC80S). The mentioned powders were subjected to storage conditions of 10 °C, 25 °C, and 37 °C for a duration of 4 months. Prior to subjecting them to any temperature conditions, the analysis on day zero (D0) was performed. On a monthly basis dairy powder properties were assessed using color analysis using the L*, a*, b* system, particle size distribution, Fourier Transform Infrared Spectroscopy (FTIR), water activity, and turbidity analysis. After 4 months, the powders were removed from their storage environments and used in labneh recipes. For each resulted labneh sample, various analytical techniques were employed, including Color analysis, Fourier Transform Infrared Spectroscopy (FTIR), Texture analysis, Rheology measurements, and Sensory evaluations. The findings indicate that alterations in the functionality of dairy powders may greatly impact the quality of the final product.

# ÖZET

## FARKLI SAKLAMA KOŞULLARININ SÜT TOZLARININ STABİLİTESİ VE FONKSİYONELLİĞİ ÜZERİNE ETKİSİ: LABNE ÜRETİMİ ÜZERİNDE ÖRNEK BİR ÇALIŞMA

Toz süt ürünleri, zengin besin profilleri ve uzun raf ömürleri nedeniyle gıda endüstrisinde sıklıkla kullanılmaktadır. Tekstürize edici, emülsifiye edici ve besleyici özellikleri nedeniyle popüler gıda bileşenleridir. Fakat her bir toz ürün, kendilerine benzersiz işlevler kazandıran farklı özelliklere sahiptir. Bu çalışmanın amacı, bu süt tozlarının çeşitli sıcaklıklarda ve değişik saklama sürelerinde saklama koşullarının süt tozlarının işlevselliği ve stabilitesi üzerindeki etkisini anlamak ve ayrıca bu değişimlerin kullanıldıkları nihai ürünün (labne) niteliklerini nasıl etkilediğini incelemektir. Çalışma süresince, Süt Protein Konsantresi, Yağsız Süt Tozu, Peynir Altı Suyu Protein Konsantresi 80 ve Peynir Altı Suyu Protein Konsantresi 80-S olmak üzere dört farklı süt tozu kullanılmıştır. Söz konusu tozlar 10°C, 25°C ve 37°C'de 4 ay süreyle depolama koşullarına tabi tutulmuştur. Tozları herhangi bir sıcaklık koşuluna tabi tutmadan önce, sıfırıncı depolama günlerinde (D0) tüm analizleri yapılmıştır.Aylık bazda, L*, a*, b* renk analizi sistemi, Parçacık Boyutu Dağılımı, Fourier Dönüşümü Kızılötesi Spektroskopisi (FTIR), su aktivitesi ve bulanıklık gibi çeşitli analizler kullanılarak süt tozlarının özellikleri değerlendirilmiştir. Tozlar 4 aylık raf ömrünün ardından ilgili sıcaklık koşullarından alınmış ve her bir toz bir labne formülasyonunda kullanılmıştır. Elde edilen her labne örneği için, renk analizi, Fourier dönüşümü kızılötesi spektroskopisi (FTIR), tekstür analizi, reoloji ölçümleri ve duyusal değerlendirmeler dahil olmak üzere çeşitli analizler uygulanmıştır. Bulgular, süt tozlarının işlevselliğindeki değişikliklerin kullanıldıkları nihai ürünlerin kalitesini büyük ölçüde etkileyebileceğini göstermektedir.

# TABLE OF CONTENTS

# LIST OF FIGURES

**Figure** **Page**

**Figure** **Page**

# LIST OF TABLES

**Table** **Page**

# LIST OF ABBREVIATIONS

SMP: Skimmed Milk Powder

MPC85: Milk Protein Concentrate 85

WPC80: Whey Protein Concentrate 80

WPC80S: Whey Protein Concentrate 80S

L-SMP: Labneh that has been prepared with SMP

L-MPC85: Labneh that has been prepared with MPC85

L-WPC80: Labneh that has been prepared with WPC80

L-WPC80S: Labneh that has been prepared with WPC80S

L-SMP-10°C: Labneh that has been prepared with 4-month-old SMP from 10°C storage conditions

L-SMP-25°C: Labneh that has been prepared with 4-month-old SMP from 25°C storage conditions

L-SMP-37°C: Labneh that has been prepared with 4-month-old SMP from 37°C storage conditions

L-MPC85-10°C: Labneh that has been prepared with 4-month-old MPC85 from 10°C storage conditions

L-MPC85-25°C: Labneh that has been prepared with 4-month-old MPC85 from 25°C storage conditions

L-MPC85-37°C: Labneh that has been prepared with 4-month-old MPC85 from 37°C storage conditions

L-WPC80-10°C: Labneh that has been prepared with 4-month-old WPC80 from 10°C storage conditions

L-WPC80-25°C: Labneh that has been prepared with 4-month-old WPC80 from 25°C storage conditions

L-WPC80-37°C: Labneh that has been prepared with 4-month-old WPC80 from 37°C storage conditions

L-WPC80S-10°C: Labneh that has been prepared with 4-month-old WPC80S from 10°C storage conditions

L-WPC80S-25°C: Labneh that has been prepared with 4-month-old WPC80 from 25°C storage conditions

L-WPC80S-37°C: Labneh that has been prepared with 4-month-old WPC80 from 37°C storage conditions

# CHAPTER 1

# INTRODUCTION

## 1.1. General View of The Dairy Powders

Milk powders have a wide range of applications in the food sector because of their ease of transportation, processing, storage, and product development. Furthermore, milk powders are one of the finest ways to preserve milk without significantly reducing its quality and nutrients and extending its shelf life. Their exclusive application is not for reconstitution or recombination, but they are also known to be used in a variety of items such as bread and meat products (Pugliese et al. 2017, Sharma, Jana and Shavan 2012).

There are various commercial dairy powders, such as whole and skim milk powders, and isolates, which all have varied protein concentrations. They can be grouped as protein concentrates (35–89% protein), like milk protein concentrates (MPC), whey protein concentrates (WPC), and micellar casein concentrates (MCC). These concentrates can also be distinguished by their protein content, which includes MPC70, MPC85, and WPC80. Dairy powders that contain at least 90% protein are classified as protein isolates, such as milk protein isolates (MPI), whey protein isolates (WPI), and micellar casein isolates (MCI). With regard to their protein content, each dairy powder has a unique functionality that has a desirable impact on the end use of the products. Apart from these, they have one thing in common: heat treatment was used throughout production. Furthermore, these thermal treatments can alter the characteristics of the powders and increase their functionality (Hazlett, Schmidmeier, and O'Mahony 2021, McCarthy et al. 2022).

In this study, the effect of different storage time and temperature conditions on the stability and functionality of SMP, MPC85, WPC80, and acidified WPC80-S were inverstigated. Also, to understand the impact of these alterations on the final product which these powders were utilized, a labneh production was performed for each of the powder after 4 months of storage at each temperature conditions, namely 10 °C, 25 °C and 37 °C.

## 1.2. Global Milk Powder Market

Convenient, functional, and simple-to-use products are always desirable in the food industry. Milk powders are one of the most convenient ingredients because they have a long shelf life and very specific functional properties. As a result, the global milk powder market grows year after year.

The Global Milk Powder Market size reached 27.78 USD billion dollars in 2022, and it is expected to rise to 38.08 USD billion dollars by the year 2028. Aside from the convenience and functionality of milk powders, another important factor is their nutritional value. Milk powders are an excellent source of protein. They are also high in essential minerals such as magnesium, potassium, zinc, and phosphorous, as well as calcium. They also contain some micronutrients such as nicotine amide riboside, which aids in body strength and the prevention of obesity (Forecast ltd nd).

## 1.3. Leading Markets of Dairy Powders

Beginning with the covid 19 pandemic, consumers' health consciousness grew. They expect food products that satisfy them, making them feel full while providing necessary nutrients such as protein. As a result, dairy powders have begun to be used in a variety of applications to improve product functionality (such as emulsification, flavoring, thickening, and foaming) while also increasing nutritional value (Forecast ltd nd). They have been used all over the world, but some regions of the world lead the dairy powder market. The main regions can be categorized as (Milk Powder Market 2022) :

Asia Pacific – including India, Japan, China, Australia, Singapore, Malaysia, Southeast Asia, New Zealand, and South Korea.

North America – including the United States and Canada

Europe- including the United Kingdom, Germany, Italy, Spain, and France

Latin America – including Brazil, Argentina, Mexico, and other Latin American countries like Chile

The Middle East and Africa – including Middle East countries like UAE, Oman, Lebanon, Jordan, and Saudi Arabia, and Africa

Across all the regions, New Zealand is a significant dairy powder exporter. They have high-quality milk, which gives a reputation to the region. The consumption of milk in the region has higher rates compared to other regions in the world. Also, they are one of the biggest exporters of whole milk powder in the world (Forecast ltd nd, Statista nd). Asia-Pacific is expected to see significant growth in the milk powder industry due to advancements in processing and shipping technology. Moreover, fairly low transportation costs and the use of trade policies are expected to propel the region's milk powder industry forward (Milk Powder Market 2022).

### 1.3.1. Key Players in the Market

According to the study that is conducted by Market Data Forecast (2023), the key players are :

Nestle, Lactalis, Arla Foods, Danone, FrieslandCampina, Fonterra, Kraft Foods, Dairy Farmers of America, Dean Foods and Saputo.

They are the main key players in the industry including leading activities of production and export of the products (Forecast ltd nd).

## 1.4. Leading Applications of Dairy Powders in the Market

Dairy powders have various functional properties that can give benefits to different products. They have texturizing, and foaming. Emulsifying and thickening properties that can be used by industries like the dairy industry. Also, they can be used as a fortificant to produce functional products like protein-fortified milk, yogurts, etc. Furthermore, they are very important ingredients in the bakery and confectionary sectors.

According to a Future Market Insights study, bakery professionals use dairy powders extensively, and the bakery and confectionary sector governs application segments, accounting for more than 40% of market share in 2022 and expected to grow at a 4.3% CAGR in the future (Syndicated Market Research Reports | Business Analysis | FMI. Nd).

## 1.5. Overview of Dairy Powders Processing

There are different processing techniques for dairy powders. The most common and popular ones can be categorized as spray drying, drum drying, freeze drying, vacuum drying and fludized bed drying.

### 1.5.1. Spray Drying

Spray drying is a common method used by various industries to produce dry products from a liquid or slurry material. The system’s main principle is that liquid is atomized into hot air, and the resulting droplets evaporate in the drying chamber. Furthermore, the main goal of this method is to produce powders quickly and at low temperatures to minimize heat damage. This method is used in a variety of industries, including agriculture, mineral processing, pharmaceuticals, food, and dairy products. Also, it is a very common method in the dairy industry to produce various milk powders (Hazlett, Schmidmeier, and O'Mahony 2021, Sefidan et al. 2022).

Powder breakage, size, and stability of the powders can all be impacted by spray drying process conditions. Powder breakage is common after spray drying all through production and transportation, especially for agglomerated powders. Powder breakage occurs when particles are subjected to mechanical load via particle equipment and different particle-particle interactions like collisions and friction effects. Moreover, it is an important parameter to keep stable, as it directly affects the stability of the product and the rate of chemical reactions.  The type of emulsion, its concentration, and particle size are important during spray drying since they may directly affect the particle size of the resulting powders. The bigger particle size of emulsions means a smaller number of particles, which might contribute to the lower viscosity of emulsions and then resulted in smaller particles during the atomization stage of spray drying. Moreover, as the inlet and outlet air temperatures of the spray dryer are around 180°C and 80°C, some of the whey proteins might face denaturation, and form protein aggregates (Han et al. 2022). Spray drying is one of the pioneering methods for producing dry dairy products, in accordance with the research of Baldelli et al (2022), In their study, the authors assessed the impact of dairy product formulation on dispersibility, and their outcomes suggested that spray drying has far shorter operating times than other technologies including vacuum frying or freeze drying, and it is also less expensive than other options available like as drum drying. Another important finding from the study was that the operating temperatures are indeed relatively low, with outlet air temperatures for dry cow milk ranging between 150°C and 180 °C.

Furthermore, as well other studies (Han et al. 2022) have highlighted the importance of particle breakage, Baldelli et al (2022) stated that spray drying could indeed control particle structure and size distribution more easily than other alternative methods. Spray-dried products will have more consistent values of important parameters such as water content, water activity, insolubility index, dispersibility, and solubility, which really is essential for production purposes since it's going to help to have products with the same functionality among each batch of production. Spray drying conditions such as temperature, liquid flow, atomization pressure, feed viscosity, and feed rate, on the other hand, should be optimized for each process since those parameters may have a direct effect on the quality of the goods.

Besides the numerous advantages of spray drying, there are some limitations. According to Zhang et al. (2022a), the majority of energy is consumed in the spray-drying stage of milk powder production. High energy consumption tends to raise concerns about environmental impact alongside production costs. As a result, lowering the environmental impact while retaining the product's high quality and nutritional composition is absolutely vital once operating this process. Many of the authors have carried out different technology solutions; for example, Ogolla et al. (2019) studied cow and camel milk powder production by investigating the important aspects of wettability, compressibility, dispersibility, and lightness parameters. They evaluated the effect of inlet drying temperatures and feed rates on the physicochemical properties, rehydration and thermal properties of the powders. As according to their conclusions, inlet drying temperatures and feed rates of spray drying systems are remarkably significant since they directly affect the color properties of the product, moisture content, and reconstitution properties which are primarily influenced by the milk flow rate.

There are a variety of approaches to implement to enhance the efficacy of the spray drying process in addition to adjusting technical parameters to minimize energy usage and conducting sustainability studies to reduce energy consumption and environmental impact. Prior to spray drying, McSweeney et al. (2021) looked at the potential advantages of injecting high-pressure nitrogen gas into the dryer system on the rehydration properties of various milk protein concentrate powders. According to their investigation, powder dispersibility is enhanced for all types of powders, including regular and agglomerated powders. Additionally, they came to the conclusion that nitrogen gas injection improved powder solubility.

Combining new, promising technologies with already-existing ones is another way to improve the process' effectiveness. To determine whether this type of emerging technology has a positive impact on the functionality of the product, Voronin, Hettiarachchi, and Harte (2021) attempted to develop a prototype of a continuous high-pressure jat spray drying system. High-pressure technologies are increasingly being used in industry to preserve product quality while minimizing heat damage and to reveal various functional characteristics of the products because they can withstand higher pressures than conventional ones. Their objective was to comprehend the impact of combination with a promising technology on the rehydration properties of the products. Through the use of a high-pressure jet spray dryer system with varying pressure values between 100 and 500 Mpa, the authors developed skim milk powder products. They discovered that, in comparison to other powder samples, the samples produced under high pressure (500 Mpa) had higher particle densities. Although there is no discernible difference between the products' D[4,3] values, the powders produced under high pressure had a lower solubility than other powder samples. Moreover, skimmed milk powder produced under high pressure also showed excellent foam stability, whereas samples produced under low pressure performed poorly in this test. As a result, the authors demonstrated that desired functional properties of products can be achieved if an rabictive production system for spray drying can be adjusted in conjunction with different technologies, and according to their findings, this process can be used as an effective tool to increase product functionality and produce novel powders.

There are also different innovations strategies and methods that imply the production processes every day. As spray drying is an open process for innovations, there are many of opportunities to apply. Samborska et al (2022) conducted a study to give insights into recent innovations in the spray drying process for the food and pharma industries. The authors first discussed some current drawbacks and restrictions of the traditional spray drying systems, such as a withdraws on the production of high-sugar products in dried form because these products may make the surface material of the system sticky. Protein-based materials may also experience some denaturation issues when dried using a spray system. Another drawback of the system is its high energy consumption, which limits process efficiency. As a result, various innovations are urgently needed to make the system more efficient. Implementing a vacuum system is one of the most popular innovations used in spray drying systems.The authors also demonstrated that in rabic spray drying systems, lower drying temperatures and pressure has been used. Lower drying pressures and temperatures have been used in vacuum spray drying systems. In addition to limiting bioactive compound oxidation and degradation, the system also reduces product heat damage, which makes the process attractive. The system is suitable for making functional protein products, encapsulation studies, and probiotic powders. However, one limitation of vacuum systems is cost, but it can still be used as an alternative method to freeze drying because it is less expensive than freeze drying .

Another novel approach is to incorporate demudified air into the spray drying system. As previously stated, there are issues such as stickiness due to the products' glass transition temperatures in conventional spray drying systems. Some implementations to lower the drying temperature are required to address these issues.

Dehumidified air can be used as a medium to lower the temperature, in accordance to that. The authors concluded that implementing this step improved powder yield when compared to conventional spray drying (Samborska et al. 2022).

Other cutting-edge technologies include nano spray drying systems, ultrasound-assisted spray drying systems, and flame spray drying systems. Nano spray drying systems are capable of producing submicron powder samples in milligram quantities. This technology makes it possible to achieve high yields for relatively small quantities of products and is ideal for sensitive products like biological materials, some functional proteins, amino acids, etc. Additionally, by providing suitable routes for poorly soluble materials to fully complete drug delivery in the human body, this technology solves some of the problems in the pharmaceutical industry. Ultrasound-assisted spray drying systems use ultrasonic-type atomizers in place of conventional ones; these atomizers operate at a slower speed than conventional ones. Because of the system's low speed, the powder doesn't build up on the dryer system, thus increasing the product's effectiveness. They can also create particle distributions that are narrower and come in a variety of sizes. Another technology, known as flame spray drying, was developed to improve the energy efficiency of the traditional process. Energy is created in this system through the burning of liquid fuel. The system offers some advantages like the use of renewable resources like biofuels and lower environmental impact (Samborska et al. 2022).

As the application types of spray drying is discussed earlier, one of them is doing encapsulation studies. Kandasamy and Naveen (2022) published a review paper on the encapsulation of bioactive compounds using spray and freeze-drying techniques. Due to the bioactive compounds' ease of degradation, encapsulation is one of the best methods for maintaining their activity. They claimed that while freeze drying required low temperatures and lengthy processing times, spray drying was quick and required high temperatures. They experimented with a variety of parameters, including feed rate, airflow rate, and temperature, to understand the impact of drying on the stability of the encapsulated products. According to their research, the authors came to the conclusion that the type of product and its formulation has a significant impact on the effectiveness of these two drying techniques for encapsulation. The efficiency and yield of the encapsulated products with spray drying, were lower than those of the freeze-dried samples. Nonetheless, one major disadvantage of freeze-drying systems is their high cost and lengthy processing times. They concluded, however, that encapsulation yield is limited in terms of bioactive compound stability when compared to freeze drying. Therefore, rather than relying solely on freeze drying, the method known as spray freeze drying which combines both technologies could help to improve the process by shortening the time and maintaining the stability of the products.

Another valuable encapsulation study is conducted by Altay et al (2022) , which they aimed to understand the encapsulation of essential oils by spray drying. Essential oil products have numerous advantages for the food industry, including antimicrobial and antioxidant activity. However, they are highly susceptible to degradation and can easily lose their stability due to factors such as processing and storage conditions. Among the best methods to maintain their quality and retain their potentially beneficial effects on health is encapsulation. In their study, The authors adjust the process parameters based on product characteristics such as dry solid amount and moisture content. For example, they made an encapsulation of oregano oil with different wall materials like modified starch and gum rabic. They found that encapsulation efficiency has reached higher values in gum rabic than in modified starch. Therefore, they stated that to increase the stability of end products, protective and efficient wall material and proper inlet temperature should be applied. They also came to the conclusion that an oil-in-water emulsion should be fed into the system for the purpose of encapsulating essential oils. Additionally, they recommended that spray drying technology be combined with other technologies in future studies to boost the effectiveness and yield of the encapsulated particles.

Aside from encapsulation techniques, one of the main goals of spray drying is to produce shelf-stable products in dried form. One of the common food products in the food industry, honey, has some drawbacks when it is in its original form, such as crystallization during storage. In order to understand whether honey can be produced in powder form or not, Toniazzo et al (2023) studied the spray drying kinetics to produce honey powder by using an isolated rice protein as a carrier. According to their findings, using a spersion to produce a commercial-scale honey powder is a useful tool. Additionally, they claimed that using spray drying technology, they were able to recover more than 60% of the protein and obtain more than 50% of the yield. These results also indicated that spray drying with some modifications might be a practical method for producing honey powder products on a commercial scale.

Different drying kinetics have the ability to show various characteristics of the product. One of these characteristic properties is including in vitro digestibility. To see the effect of drying techniques on this aspect, Zhang et al (2022b) studied goat milk powder samples that produced by spray drying and freeze-drying. In this study aspect, they aimed to see how these drying techniques impact the lipid profile of the products and as well as their digestibility. As per their findings, freeze-dried goat milk powders showed lower cholesterol and higher amount of monounsaturated fatty acids. Also, some of the polyunsaturated fatty acids retain their stability longer in this process. The authors made a statement that these freeze-dried samples have a better membrane structure, and these samples took longer to digest in gastric system.

### 1.5.2. Drum Drying

To produce dairy powders, a variety of drying methods can be utilized. One of the most widely known dryer types in these categories is spray dryers and drum dryers, which are commonly used for producing dried dairy products. Regarding energy usage for continuous processing operations, the drum dryer is regarded as the most effective type. The method uses less space and is less expensive than spray drying. They are also known as roller dryers and have been used to preserve and produce liquid food products in dry form since the early 1900s. However, when it comes to technical aspects like operation, application, and configuration, roller dryers and drum dryers couldn't be more dissimilar from one another (Karthik, Chhanwal, and Anandharamakrishnan 2017).

Drum drying is a continuous process that employs steam to heat all of the drums and rotates them all at the same speed to dry the liquid or paste medium. Conduction is the main process that drives heat transfer during this process while the product is in contact with the drums for a constant rotation speed. After the liquid or paste substrate has been applied to the rotating drum, the dried or film-formed product is scraped from the surface using knife blades. This process is also referred to as having high compatibility with gelatinized or starch-based products and has the capacity to impart distinctive functional characteristics of the gelatinized products. Another crucial aspect of this process is the potential for interactions like "boiling-like" drying, which gives the finished product a porous structure, as a result of the high heat present (Karthik, Chhanwal, and Anandharamakrishnan 2017).

Since each method differed from the others in terms of the conditions, steps, etc. during processing, the final products have different functional aspects. Aalei et al. (2016) studied how much maillard reaction products was present in skim milk powders produced using spray drying, freeze drying, and drum drying. They search into the amount of available lysine in the products during the study's shelf life in order to reveal their findings. According to their findings, the authors have determined that the choice of drying technique has a big impact on product characteristics. Their findings indicated that products produced using the freeze-drying method lost the lowest amount of available lysine during shelf life, while products produced using the drum drying method lost the most. The availability of lysine was least affected by the drying process in freeze-dried powders, which were then followed by spray-dried and drum-dried powders .

In order to determine the effects of various drying techniques and controlled storage conditions on the formation of AGE products in skim milk powders, Aalei et al. (2017) conducted a study. The authors made a different analysis to understand the extent of the maillard reaction by analyzing a different glycation end product called CML, or carboxymethyl lysine. They performed an isotope dilution ESI-LC-MS/MS analysis after various product drying processes and at various intervals over the course of 200 days. According to their research, samples produced using spray drying developed double as much CML after 200 days as compared to samples produced using freeze drying, and for the products that produce by drum drying, the amount of CML was still lesser than spray dried products, but higher than freeze-dried products. In conclusion, based on their findings, the importance of different drying techniques is understood, as it can directly impact the quality and functionality of the products. Also, since every product has a different characteristic, each drying technique can be adjusted based on those properties. As it is clear, the drum drying method is not particularly effective at reducing the degree of the Maillard reaction; however, based on other advantages, such as compatibility with the production of gelatinized products, it can be modified to meet the standards of the desired products.

As was already stated by Zhang et al. (2022a), the food industry situates great importance on processes that are more environmentally friendly, less costly, and more sustainable. As a result, there are various methods to accomplish those goals.

Almena et al (2019) conducted a study to optimize food dehydration processes and they tried to create an optimized drum drying process. The authors created a model for breakfast porridge production by double drum drying, they focused on the optimization of steam temperature and rotation speed of the drums, and they stated that these parameters are of vast importance to reducing energy consumption in dehydrating processes. Additionally, they mentioned that each process parameter will change depending on the final product's formulation, thickness, and smoothness.

They evaluate various components of the procedure, including such product thickness, formulation, final moisture content, and feed slurry temperature in their model to figure out the ideal paths for steam temperature and double drum dryer rotation speed. Their study showed that the thickness of the feed slurry and the water content of the feed slurry and final product are critical drivers in modifying the system's energy consumption. The authors have determined that thicker feed slurries requires for higher steam temperatures and longer processing times. In contrast, thinner feeds necessitate lower temperatures and shorter processing times, which is advantageous for a production because it reduces heat damage and energy use (Almena et al. 2019).

Therefore, it can be concluded that the thickness of the feed is significant for drum drying and should be adjusted in a way to save energy, improve production effectiveness, and maintain product quality in accordance with standards.

As well as producing dried form of the products, there are different purposes to use drum drying processes. One of these purposes to create encapsulated products. Desobry, Netto, and Labuza (1997) used the spray, freeze, and drum drying methods to study the process of encapsulating pure beta-carotene in 25 Dextrose Equivalent maltodextrins. The stability of the products was evaluated in the study at various relative humidity and temperature levels. They came to the conclusion that drum drying, followed by spray and then freeze drying, caused the B-carotene to degrade more quickly. But when compared to other methods, drum drying has been found to produce particles with a larger size that are more stable and a lower surface of carotenoids. On the other hand, authors demonstrated that the color changes of drum-dried powders under the influence of relative humidity were more significant than those of the other powders, which leads to the conclusion that drum-dried powders under various relative humidity values were more particularly prone to the changes.

There are highly valuable agro-industrial waste products that contain high levels of antioxidants and can be converted into high-value end products through the use of drying technologies. Galaz et al. (2017) conducted a study to assess the effect of drum drying temperature on the polyphonel content of pomegranate peel powders, as well as the effect of temperature on the dynamic of production. Because general drum drying temperatures range from 100 to 120 degrees Celsius, with short rotation times, the authors demonstrated that under these conditions, both antioxidant activity and polyphenol content of the products were not highly affected, and their stability in aspects of microbial stability and water activity remained stable. As a result, the authors concluded that drum drying is an appropriate method for producing high-quality end products from various biowaste products such as pomegranate peel, thereby adding value to agro-industrial waste.

Understanding the dynamics of the process and identifying key parameters are crucial for improving process efficiency, just like with any other drying technique. Qiu et al (2019) investigated the drying kinetics of a drum drying process using a conductive thin film. They attempted to provide insight into direct dynamics, but there were some difficulties in the process because mass and temperature are not stable enough to monitor. The authors created two profiles in their study by drying maltodextrin and starch suspensions. They classified process into three stages: heating, boiling, and conduction. Their research revealed that film thickness directly influences the heating process' initial stage.

The bubbles that formed during the boiling stage prevented heat from being transferred, keeping the drying rate constant. Because each product has unique characteristics, the results have varied. Larger bubbles have formed in starch suspensions due to the product's different viscosity and elasticity profile. Consequently, during the drying process of starch suspensions, larger temperature gradients were observed between the feed film and heating medium. Furthermore, because starch suspensions are more elastic and viscous, they produce more stable bubbles and a matrix with a large number of pores. However, the buildup of so many bubbles on the surface limited drying and increased product non-homogeneity. Therefore, authors concluded that a thin film is required during the drying process to prevent any loss of quality and increase the process efficiency (Qiu et al. 2019).

Nevara et al. (2018) conducted another study to produce high-value end products from bio-wastes. The purple sweet potato powder which has a high anthocyanin content was produced using the drum drying technique. However, browning and some other reactions like the degradation of important compounds (like anthocyanins) may be an issue during the manufacturing process of this product. As a result, authors investigated various pre-treatments prior to drum drying in order to comprehend how these pre-treatments affected the physicochemical, color, and antioxidant properties of this product. In this study, the efficacy of two pre-treatments—steaming and boiling—was examined. Results showed that both treatments contributed to keeping the product's distinctive purple color.

In terms of maintaining significant product constituents like total anthocyanin content and resistant starch content, steaming performed better. And furthermore, steaming produced more consistent results in terms of powder yield and product color change extent. As conclusion, the authors recommended using different pretreatment methods for improving product characteristics and production dynamics (Nevara et al. 2018).

As is mentioned earlier that drum drying technique has better compatibility to produce dried products from starch-based products, another valuable study is conducted by Roman et al. (2022) to reveal the swelling behavior of a pregelatinized wheat starch that produced by drum drying technique and to see the opportunity of abelling this product as a oil replacer. According to their research, pregelatinized starch has a high capacity to absorb water and swell under room temperature conditions. Also, because it is not commonly studied, the authors attempted to provide insight into the suitability of this product as an oil replacer in oil-in-water emulsions. Their research suggests that the substance used to replace the oil affects the functional properties of oil-in-water emulsions, such as rheology and stability. They also suggested that the swelling behavior of the substituted material is important in maintaining the emulsions' stability and consistency index. According to their findings, the drum-dried pregelatinized starch with a high swelling capacity are more suitable for use as an oil replacer.

Another study that reveals the importance of adjusting technical parameters to have a better product quality had been conducted by Córdova et al (2020) , which aimed to see impact of drying conditions on the degradation level of bioactive compounds of broccoli pulp. In the study, they looked at three different factors—drum temperature, rotation speed, and water-to-pulp ratio—to understand how these factors affect the rate of degradation of bioactive substances like glucoraphanin and phenolic compounds. They claimed that the drum drying parameters did not significantly affect all of the bioactive compounds, but the outcomes showed that some of the products had non-homogeneous shapes and mixed colors as a result of the broccoli pulp's poor adhesion.

They stated that antioxidant activity is affected by drying conditions in an inconsistent manner. Furthermore, ascorbic acid and phenolic compounds are impacted by rotation speed and frequency in a manner that is consistent. Ascorbic acid is significantly reduced after drying, and the factor is highly dependent on process conditions.

As conclusion, the authors demonstrated that drum drying has many advantages and is highly promising for creating a variety of functional ingredients. The advantages of drum drying include lower costs compared to other drying techniques like freeze and tunnel drying and little heat damage, which reduces the rate of degradation of key bioactive compounds (Córdova et al. 2020).

### 1.5.3. Freeze Drying

As stated earlier in two previous process techniques (spray and drum drying), freeze-drying is one of the most common drying techniques which ensures better and longer microbial stability to the products and gives high quality by applying lower temperatures and higher-pressure values (Oyinloye and Yoon 2020).

Freeze drying is a method whose main mechanism is based on the products' sublimation transition. Frozen products have undergone dehydration during this transition, which results in the immediate formation of gas from a solid state. The thermal characteristics of the products are crucial for freeze drying because they help us understand how the process works and estimate how quickly heat is transferred throughout the system. Two important thermal characteristics are the specific heat and thermal conductivity of the products. Every product has unique thermal properties, so the temperature, pressure, and processing time may change depending on those differences. Additionally, knowing these characteristics is crucial for equipment development and for estimating product shelf life. Particularly for products that are highly dependent on oxidation and easily degraded under thermal conditions, freeze-drying is a common and effective technique. Because these products can lose their quality and stability under harsh temperature conditions, low operating temperatures in freeze drying are ideal for retaining their stability during the process. The freeze-drying system has a lot of benefits, but there are some drawbacks as well. For instance, if the process has not been properly designed based on the products' characteristics, there is a high likelihood that the products will lose their rigid structure and become shrunk. Therefore, it can be inferred that even though freeze drying has advantages for the products, it is a sensitive process that needs to be carried out correctly (Oyinloye and Yoon 2020).

The freeze-drying process consists of three major steps: initial freezing, primary drying, and secondary drying. During the initial freezing stage, ice nuclei began to form in the system. If there is a faster freezing rate that is applied to the system in that stage which depends on lots of factors like the morphology of the products, smaller ice crystals will be seen in the product structure. Due to the size and buildup of the ice, the rate of sublimation is higher during primary drying than it is during secondary drying. At this point, ice has been directly transformed into gas without melting. The viscosity has begun to rise as the system loses moisture, and once it reaches its saturated state, it stays stable. As a result, one of the most important parameters to consider during freeze drying, glass transition temperature, has begun to emerge. Glass transition temperature is related to the highest extent of freeze concentration In the system; it is an especially important term to understand the dynamics of drying of carbohydrate-based products because their glass transition temperatures are so different that they can be simply identified (Oyinloye and Yoon 2020).

There are different studies for carbohydrates in freeze-drying areas, either understanding the glass transition effect on their collapse time or retention time and their positive effect as a cryoprotectant to preserve the stability of other freeze-dried products. Guowei et al (2019) conducted a study to understand the cryoprotectant profile of carbohydrates that contains various carbohydrates, namely lactose, trehalose, and sodium glutamate, on the *Saccharomyces boulardii* during the freeze-drying process. According to their research, different cryoprotectant contents for S. boulardii, primarily a higher amount of lactose, nearly the same amount of trehalose, and a lower amount of sodium glutamate, have a positive impact on the viability of S. boulardii cells as well as the survival rate after freeze drying. Additionally, authors concluded that the product's stability was acceptable and preferred when these powders were used to produce goat milk powder because inactivation rate constants were within acceptable limits.

In primary drying, the process of sublimation has begun, and the water vapor is eliminated from the system with the help of low vapor pressure at the ice particles' surfaces. After this stage, the product has only partly dried. To remove any systemic mass transfer resistance and maximize the primary drying period, large crystal particle sizes are required. Otherwise, the small ice particles will cause low efficiency and a high level of opposition (Guowei et al 2019, Oyinloye and Yoon 2020).

Secondary drying requires more energy than primary drying because it is more closely related to higher vapor flow rates. However, because it takes up more than 30% of the processing time and only removes a maximum of 10% of the moisture from the system, this step is regarded as the least effective step in the freeze-drying systems. This stage is initiated by raising the product temperature once all of the ice has completed sublimation. In this step, the most important food products to take into account are heat-sensitive food products such as protein. Due to the removal of bound water from the structure, a collapse of the protein products is likely to occur if high temperatures (higher than Tg) have been used in this step (Oyinloye and Yoon 2020). In contrast to primary drying, the secondary drying step should be accelerated by using smaller ice crystals to promote the penetration of water to the system's porous matrix. If the secondary drying is taking longer than necessary, it can be sped up by changing the freezing conditions so that the system receives smaller ice crystals (Guowei et al. 2019).

In other sections related to drum drying and spray drying, the benefits of freeze-drying systems with some more promising results than other methods have been discussed. For example, Kandasamy and Naveen (2022) stated that encapsulated bioactive compounds by freeze drying were more stable than the ones that are produced by spray drying. Zhang et al (2022b) stated that the goat milk powder samples produced by freeze-drying have been found to have better membrane structure than the spray-dried samples. Aalei et al (2016) tried to express the effect of drying techniques on the extent of Maillard reaction products. They found that the available lysine amount was at least in freeze-dried samples compared to spray and drum-dried samples. Also, Desobry, Netto, and Labuza (1997) stated that the lowest degradation of the β-Carotene has been seen in freeze-dried samples, compared to spray and drum-dried samples. As it is understood, freeze drying has a better ability than other drying techniques to preserve the stability and integrity of the products, as well as their nutritional composition.

With all those advantages, there are many different application types of freeze-drying technologies. For example, Deshwal et al (2020) studied the impact of spray and freeze-drying systems on the functional, chemical, and physical properties of camel milk powder samples. They claimed that compared to the freeze-dried samples, the powders that are spray-dried have a higher moisture content. Additionally, a notable degradation in the calcium and iron content of spray-dried powders has been observed. While camel milk powders that had been spray-dried demonstrated good flow characteristics, freeze-dried samples displayed the best rehydration characteristics, including solubility, dispersibility, and wettability. When they examined the microstructural characteristics of the samples, they discovered that spray-dried samples had more agglomerates than freeze-dried samples. Additionally, their research showed that when compared to freeze-dried samples, spray-dried samples had higher L* values. Spray-dried samples had greater porosity and surface fat than freeze-dried samples. Freeze-dried samples were discovered to be smoother and to contain fewer pores. Furthermore, it was discovered that samples that were freeze-dried had a higher water-holding capacity than samples that were spray-dried .

As was previously mentioned, combining various drying technologies can enhance product qualities and streamline the process. As spray drying alone has some limitations in terms of maintaining product stability for a longer period of time, Kandasamy and Naveen (2022) demonstrated that the combination of these two technologies as spray freeze drying improved the encapsulation of bioactive compounds.

Another study of spray freeze-drying technology has been conducted by Ren et al (2022), to understand the impact of spray freeze-drying on the characteristics of micellar casein powders. In contrast to conventional spray-dried samples, they discovered that spray-freeze-dried samples have a very porous structure. Additionally, they claimed that these samples gave off more calcium colloidal phosphates into the system. The authors altered the atomization level during their process to produce small, medium, and large particles. They claimed that small droplets have prolonged wetting times and better dissolution and dispersibility. As there are no extreme conditions that could affect the structure of the protein powders, the authors came to the conclusion that this technology is practical for producing highly functional protein powders. However, they also mention that the cost of those processes at production scales is a problem.

As stated, that there are many other applications of freeze-drying technology, one of them being for encapsulation studies Obradović et al (2022) studied the microencapsulation of probiotic starter culture with aid of protein-carbohydrate carriers by using spray and freeze-drying systems, and the possibility to use these encapsulates in whey-based beverages. They made the encapsulation process with whey, sodium alginate, and whey protein concentrate. The freeze-drying process was found to have the highest stability and production yield in their study. Using a freeze-drying system also allowed for the highest encapsulation efficiency and cell survival rate. Because the protein at the outer surface is denaturized and the inner cell culture is protected, spray drying has, however, produced the best cell viability in beverages. The authors also came to the conclusion that the microencapsulation process kept the number of viable cells by more than 50%, and freeze drying is an effective method for encapsulation purposes of sensitive materials.

One of the other common applications of freeze drying is producing dried food products to develop new food products, to improve the existing products scales, etc. Setiawan et al (2022) studied the development of a powdered coconut drink by using freeze-drying technique. To make the beverage, they use both coconut water and meat from coconuts.They tried to comprehend how freeze-drying helped to preserve quality characteristics that were as close to those of fresh coconut as possible. They discovered that freeze-drying preserves sensory qualities that are remarkably similar to those of fresh coconut, with only a negligible loss of sweet notes and a small amount of fermented aroma taste. The author’s conclusion that the product’s shelf life in a freeze-dried form significantly increases, especially at 25°C, is another crucial point.

Another study of product development using freeze-drying technology has been conducted by R et al (2022) , and they tried to develop an innovative and new herbal bio yogurt powder by using freeze drying technology. In their study, different cultures were added to the yogurt samples at various concentrations, and freeze-drying was used to create yogurt powder. In order to increase the number of viable cells in the yogurt samples, they also included a prebiotic concentrate. Authors have used a variety of carbohydrates as cryoprotectants during freeze drying, and they claim that trehalose has an excellent capacity to preserve the stability of the product. The study's authors concluded that yogurt powders can be successfully produced by freeze drying and used as a ready source of starter for domestic yogurt applications.

To produce food products with a long shelf life, more stability, and higher nutritional value, emerging technologies must be used because there are numerous demands and expectations from the food industry. There are numerous technical aspects to implement in the freeze-drying process, including microwave technology and infrared systems. Because other conventional drying techniques have limitations, combining different technologies may help to maintain food structure stability and increase processing efficiency. Du et al. (2021) evaluated the various inventive applications of freeze-drying to create instant formulas. Foam mat freeze-drying technology is the first technology they have mentioned in their study. The products in this technology have been foamed to improve drying efficiency and increase drying surface space. This technique is best suited for products that are thermally sensitive as well as those with a high sugar content, and thus a high risk of sticking to the drying wall material.  The biggest disadvantage of this system is that it is difficult and impractical to produce a foamy structure from every food product. However, this problem is solved by adding certain edible foaming agents and stabilizers to the feed product.

Du et al. (2021) also mentioned the use of microwave-assisted freeze-drying technology as an innovative technique. They claimed that using microwave generators in the system in place of conventional heating plates has the potential to improve the process because the microwave can quickly and easily heat the product and produce a uniform heated area. The successful application of this combined technology to the drying of various products, including lettuce and okra. This technology can be used to process thermally sensitive functional formula food products in addition to providing a faster drying rate with a homogeneous heating environment and superior product quality.

### 1.5.4. Vacuum Drying

Vacuum drying is a widely used technology that is ideal for thermally sensitive food products. Additionally, the chemical, food, and pharmaceutical industries frequently employ this technology. Low pressures are applied during this process, and indirect heat is applied via radiation or a metal call contact. Low temperatures may also be used during this process to avoid any color diminishing or chemical degradation brought on by harsh temperature conditions. Vacuum drying has many benefits, the most notable of which are the ability to process in extreme temperatures, the removal of air as a potential source of oxidation, and the acceleration of drying due to a lower boiling point and greater temperature difference between the heating medium and the substance being dried. However, the system does come with a few drawbacks that should not be ignored. To begin, the procedure differs from other drying processes in that it calls for a large quantity of complicated equipment and metals. Additionally, the procedure is expensive and has a high level of energy consumption (LA Bazyma and VA Kutovoy 2005).

Combining technologies to boost efficiency is commonplace in the food industry; for example, microwave systems are frequently used in tandem with vacuum drying to expedite the drying process. González-Cavieres et al (2021) studied the advanced technologies in vacuum microwave drying systems for food products. They explained the fundamental principle underlying vacuum microwave drying technology is that the waves released by the system are absorbed by the water molecules present in the food matrix; this mechanism generates heat in the matrix. The absence of oxygen in a vacuum helps the drying process along, preventing the product from deteriorating any further due to oxidation. This system may reduce processing times by as much as 90% while preserving the quality of heat-sensitive materials for longer and preventing the loss of vital nutrients.

Through the use of microwave vacuum drying, Ishibashi et al (2022) attempted to investigate in-situ measurements of the drying and shrinkage characteristics of potatoes and radish. They came to the conclusion that using microwave vacuum drying at room temperature could help maintain the product’s high quality while also reducing the drying temperature. According to their findings, decreasing the amount of water in food matrices led to an increase in drying rates. According to the findings, they stated that microwave internal heating facilitates the flow of moisture from the inside to the outside, and it also creates some holes inside while reducing the amount of shrinkage that occurs. In addition, they concluded that understanding the glass transition temperature line of the potato’s core helped minimize the shrinkage rate . Samples created by microwave vacuum drying appeared to have a more porous food structure when compared to those created by other drying methods. They also noted that freeze drying samples resulted in very uniform powders, though at a slower rate than other drying methods. The samples dried the fastest in a microwave vacuum dryer. They concluded that compared to spray drying and freeze drying, microwave vacuum drying offers many benefits, it minimizes processing time while maintaining output quality. The structure of the powders produced by grinding was shown by the authors to have a tendency to be more porous and finer, similar to what they obtain from microwave vacuum drying systems.

Elnjikkal Jerome and Dwivedi (2022) demonstrated a microwave vacuum drying system for pomegranate peel. Different microwave powers and vacuum pressures were utilized for their experiments. The effect of these various process parameters on product properties such as color change, total  ydrolysable tannin, and moisture diffusivity has been evaluated. They discovered that a microwave power level of approximately 175 kW produced the least color change in the product. However, applying higher microwave values, such as 485W, caused the product's color to change significantly. In addition, their experimental results indicate that the total amount of  ydrolysable tannin has increased as the microwave power has risen from 175 to 330 W; however, applying 485 W and above caused a substantial decrease in tannin amount, which can be explained by the degradation of tannin at higher temperatures. As a result, it appears that adjusting the process parameters is required to improve the process's efficiency, obtaining products with the desired quality attributes and protecting quality characteristics.

Drying technologies have the potential to alter or even improve the characteristics of the product, in addition to the convenience they provide, and the longer shelf lives they grant to the products. Gomide, Monteiro and Laurindo (2022) conducted research on the oil-free potato chips produced by microwave vacuum drying and analysed the physicochemical properties and the important characteristics of the chips. They came to the conclusion that microwave vacuum drying has the potential to reduce the starch's gelatinization while simultaneously improving the product's structure. They noted, however, that the parameters of the drying process, in particular the microwave power density, can have a major effect on the kinetics of the system as well as the characteristics of the product. The authors reported that the various conditions did not have any substantial effect on the starch structure, but that the product could be preserved more effectively with lower density values. In spite of this, when the processing times were analysed, it was discovered that a higher power density results in a shorter drying time and a crunchier texture, both of which contribute to a greater level of consumer approval and preference for the product.

As it was mentioned earlier that there are many different innovative aspects to implement in drying systems, Liu et al (2022) also conducted a study to understand the improvement of process kinetics and quality characteristics of blueberries by using a different novel innovative technology as far-infrared radiation heating assisted pulsed vacuum drying (FIR-PVD). The purpose of this study was to understand the improvement of process kinetics and quality aspects of blueberries by using FIR-PVD. They stated that it is a new technology, and their findings demonstrated that the ambient pressure and vacuum pressure have a significant impact on the amount of time required for the processing and the ability to maintain the quality for a longer time. The authors concluded that the blueberries that were processed by this new innovative technology showed fewer color differences, better rehydration abilities, and more antioxidant capacities, in addition to another important aspect, which is that these products have been exposed to less oxygen than those that have been exposed by hot air drying.

### 1.5.5. Fluidized Bed Drying

Fluidized bed technology is an advanced technology that has been used for many decades for drying wet solid particles. Their applications include biosynthetic products, several food products including black tea and coconut, fertilizers, tablet form products, maize, and a variety of other applications. The system's most significant benefit in this drying method is the large contact area between the input material and the gas. This results in a shorter processing time, less thermal degradation, and higher drying rates. Additionally, pneumatic conveying makes it possible for the resultant dry particles to be passed on easily out of the dryer in this system, which is an additional convenience that the system provides (Daud 2008)

In their research, Srinivas et al. (2020) mentioned that fluidized bed drying is regarded as one of the most effective drying processes used in the food industry. This technique involves immediately mixing the solid particles with the hot air, which results in a larger contact area. However, the authors also mentioned that this drying technology necessitates a lengthy processing time. Nevertheless, if this technique can be combined with other technologies such as microwave systems, it has the potential to significantly improve its efficacy. Because drying food products in a microwave takes less time than drying them in a fluidized bed, microwave drying is an excellent approach to combine with fluidized bed drying in order to increase performance. The authors employed a microwave-assisted fluidized bed dryer to dry nutmeg mace for essential oil-enriched extracts in their investigation. According to the authors, this technology has helped to reduce energy consumption, provide a faster drying rate, and shorten drying time. When compared to sun drying and convective drying, the loss of myristicin, which is a common aromatic esther found in nutmeg, was negligible in microwave-assisted fluidized bed drying according to their findings. In addition, the authors discovered a linear relationship between the amount of microwave power and the system's drying temperature.

Another microwave-assisted fluidized bed drying study has been conducted by Zahoor and Khan (2021), to understand the drying of red bell pepper kinetics by using this system. The dynamics of the process were studied in terms of variables like ascorbic acid concentration, total carotenoid concentration, and degree of color change. The authors discovered the lowest ascorbic acid content at 180W of microwave power and 40°C of processing temperature. On the other hand, they mentioned that the level of ascorbic acid that was found to be the highest was at 540W when the temperature was 70°C . As a result, it is possible to conclude that lower temperatures and lower microwave power resulted in greater ascorbic acid degradation. The highest total carotenoid content was found at 360W at 55C, and the authors noted that carotenoid degradation is affected by both drying temperature and drying time. They demonstrated that the carotenoid content increased with temperature and microwave power from the start. Regarding the color changes, the product exhibited the greatest color shift when exposed to 540 watts of power at a temperature of 70°C. The authors concluded that the harsh temperature conditions increased the degradation of carotenoids. Based on their findings, they determined that the best microwave power for the system is 468.04 W and the best air temperature is 60.14 °C. These findings support the idea that each product has a unique processing requirement to retain its characteristics.

Another aspect of a fluidized bed is used for agglomeration processes, or to improve milk powder characteristics by size enlargement. For this purpose, the physical properties of agglomerated milk protein isolate, and skim milk powder mixtures were investigated by Seo (2022) through the utilization of fluidized bed agglomeration as a potential means of improving the physicochemical properties of the product. The author has indicated that this method is extensively employed for the purpose of increasing the size of small particles. Additionally, it holds the capability to enhance the physicochemical characteristics of the resultant products, along with their rehydration capacities.  Milk protein isolate is typically generated through ultrafiltration processing followed by spray drying. Despite these products' high functionality and protein content, their rehydration properties and flowability are'poor. Thus, the implementation of agglomeration through fluidized bed technology may potentially enhance their characteristics.  According to the study's results, the implementation of fluidized bed agglomeration led to an increase in particle size and a shift in product flowability from a fair to a good state. Furthermore, the process of agglomeration has resulted in a decrease in cohesiveness, and the wetting time of mixtures has significantly reduced.

As same as other drying technologies, fluidized bed drying can be widely used for encapsulation purposes. A study was conducted by Reineccius, Patil, and Anantharamkrishnan (2022) to investigate the encapsulation of orange oil through the utilization of fluidized bed granulation. According to the authors, spray drying is widely used for conducting encapsulation studies, yet this technique presents certain limitations to the products, such as reduced particle size and insufficient dispersibility. Therefore, the utilization of the agglomeration technique has been employed in their research to comprehend its efficacy in mitigating these limitations.  Fluidized bed granulation has the capacity to generate larger and heavier particles through the incorporation of various processes such as drying and homogenization.  Based on the findings, the authors concluded that the employment of fluidized bed granulation resulted in enhancements in the particle size distribution profiles and density values of the product, as compared to a powder agglomerated through spray drying. The findings indicate that the granulated particles, which went through fluidized bed drying, exhibited a prolonged preservation of their flavor profile with negligible deterioration. Also, this method is seen as more efficient due to its singular step, in contrast to the two-step process of spray drying/ agglomeration.

## 1.6. Dairy Powders – Their Definition, Important Properties and Functionalities

There are vast variety of dairy powders in industry. In this study, the examined dairy powders include Skimmed Milk Powder (SMP), Milk Protein Concentrate 85 and Whey Protein Concentrate 80 (WPC80).

### 1.6.1. Skimmed Milk Powder – SMP

In the dairy industry, one of the types of milk powder that is utilized the most frequently is skim milk powder. Basically, it has been produced by removal of water from pasteurized skim milk, and it has a moisture content that is equal or below 5%, and it has milk fat that is equal or below 1.5%. Lactose is the most abundant component of skim milk powder, and the minimum amount of protein that it should contain is 34%. Products can be categorized by the heat treatment used during manufacturing, which also defines their functionality. The categories are high-, medium, and low-heat skimmed milk powder products (Non-fat Dry Milk & Skim Milk Powder nd).

Table 1. Nutritional Composition of Skimmed Milk Powder

| | |
|---|---|
| Protein | 34-37% |
| Lactose | 49.5-52% |
| Fat | 0.6-1.25% |
| Ash | 8.2-8.6% |
| Moisture | 3-4% (non-instant products)<br>3.5-4.5% (instant products) |

(Source: Non-fat Dry Milk & Skim Milk Powder nd)

There are several drying types that are frequently employed in the industry, including freeze-drying, fluidized bed drying, drum drying, microwave drying, etc., as it was covered in earlier chapters. However, some of these techniques, such as drum drying, can lead to non-reversible reactions like the maillard reaction and caramelization, and some of these techniques are also unsuitable from a cost and convenience perspective. So, one of the most popular drying processes for producing milk powders is spray drying, which may be combined with fluidized bed drying (Schuck 2014).

As Schuck (2014) has mentioned, the production of skim milk powder consisting of some fundamental steps, including milk reception, standardization of the milk, heat treatment, vacuum evaporation, homogenization, drying and packaging (Figure 1.)

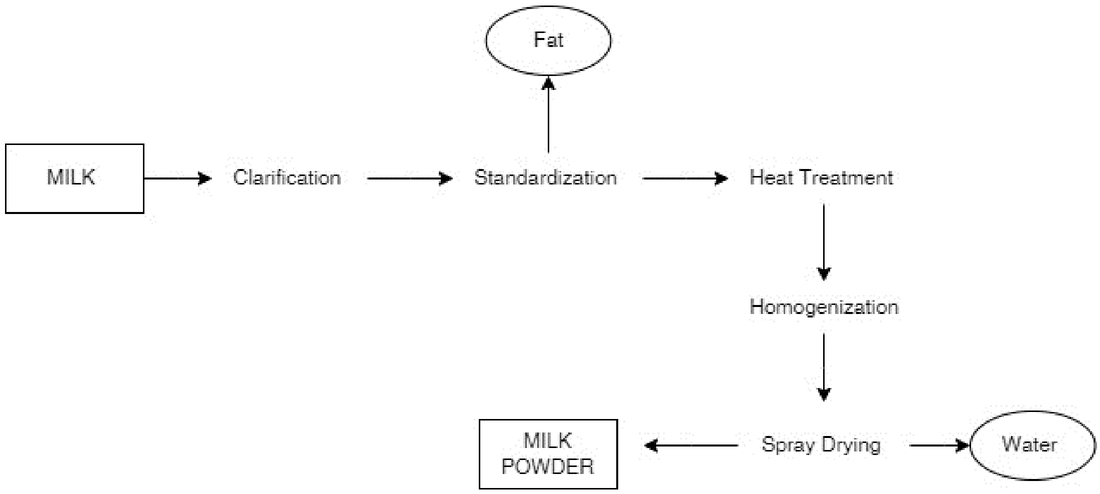



Figure 1. Skim Milk Powder Production Flow Chart (Source: Schuck 2014)

Spray drying procedure is including atomization and desiccation of feed along with hot drying medium to make a rapid drying of the products. During the atomization process, there might be different atomizer types like centrifugal and pressure nozzle. For the skim milk concentrate type products, Padma Ishwarya and Anandharamakrishnan (2017) have reported that there are different studies that have applied these two different atomizer types with varying temperatures of 110-200°C, to produce skim milk concentrate powders. However, the most common applied temperature is between 140 to 150°C.

During the production of skim milk powder, milk type, and composition are important parameters to have a better quality of the product. Er, Sert, and Mercan (2019) investigated the production of skim milk powder by spray-drying milk concentrates treated with transglutaminase enzyme to understand the possible benefits of this enzyme treatment to the physicochemical and structural properties of the products. Their results showed that the powders' particle size had decreased, and enzyme treatment had caused the products' redness (a* value) to increase. According to their findings, enzyme treatment up to a certain concentration improved the flowability of the products, and they concluded that these enzyme-treated skim milk powders can be utilized to make yogurt since the enzyme treatment enhanced the gel formation, texture, and water retention capacity of the products.

Considering raw milk is the primary ingredient in the production of skim milk powder, the handling and transportation of raw milk and the procedures used to reduce impurities are crucial for preserving the quality of the skim milk powder and preventing any inefficiency in its production. Kara and Sert (2022) investigated the impact of milk transport conditions and varying microfiltration treatments on microbial and physicochemical characteristics of skim milk powder products. Their research demonstrated that microfiltration treatments enhanced the microbial quality of raw milk, and they claimed that using a smaller mesh dimension was more effective for microbial inhibitions. When MF-treated skim milk powders have been compared to control samples, the microbial count is found to be lower in the MF-treated powders. They concluded that MF treatment with a smaller mesh size (0.5 micron) can be a successful approach for minimizing microbial load from skim milk powders, and that milk that was properly cooled and then subjected to microfiltration yielded the best results for ensuring the microbial quality of skim milk powders. However, they stated that using a smaller mesh size could make it hard for milk components to pass through the membrane, leading to component losses. Therefore, if microfiltration practice is applied to the products, to prevent any nutritional loss in the skim milk powder products, it should be considered to adjust the membrane size based on the product specifications.

During the processing of dairy powders, spore formation is another microbial concern. Contamination by aerobic endospore-forming bacteria is one of the primary concerns for dairy powders, and it may take place at any stage of processing. Wedel et al. (2022) revealed a review study to comprehend microbial challenges in dairy powder production, and they pointed out that whey and skim milk-based powders are susceptible to microbial spoilage due to the multiple steps that comprise their production. As the separation of raw milk into cream and skim milk generally takes place at temperatures between 50 and 55 degrees Celsius, the authors stated that it is the first crucial step toward discovering the potential growth of thermophilic and thermoresistant spore formers. They discovered that temperatures around 48 °C temperature may prevent the formation of spores, and many different centrifugation techniques, such as two-step centrifugation, are capable of adjusting the nutritional profile of skim milk and eliminating the microbial load. The thermal treatment of milk, which is vital for ensuring microbial quality, is yet another crucial step in milk powder processing. In this step, the heat treatments should be set up according to the whey protein nitrogen index of the product, which implies the quantity of whey protein nitrogen in one gram of powder and the native whey protein quantity in the product. On the basis of these values, powders can be grouped into three groups: high, medium, and low heat. These groups should be exposed to 70°C for 15s, 90-105°C for 30s, and 120°C for 1-2 minutes, respectively. These time and temperature parameters must be adhered to in order to minimize the potential of spore-forming bacteria growth. Overall, the authors concluded that there are a variety of measures that can be taken to reduce the spore count in dairy powders. The use of membrane filtration, applying bactofugation, following the regular sterilization of the equipment, avoiding long processing cycles, and the executing of validated cleaning protocols represent a few of the ways in which contamination can be reduced. In addition, they stated that even though there is a great deal of non-thermal technologies, such as pulsed electric fields, those technologies should be used together with higher temperatures, in order to have better effectiveness in lowering the number of microorganisms.

As was discussed earlier, spray drying is the method of processing that is utilized the most frequently in the production of skim milk powder. The parameters such as atomization pressure, inlet air temperature, and flow rate have an important effect on the special characteristics of skim milk powders. Higher inlet air temperatures, for example, may contribute to the denaturation of proteins in feed, as well as reduce the reconstitution abilities of the products, and higher spray rates may end in larger particle sizes than expected. Research conducted by Felfoul et al. (2022) investigated how the conditions of spray drying affected the characteristic qualities of skim dromedary and cow's milk powders. In their study, they applied 75°C and 85 °C as air outlet temperatures, and according to their findings, using an air outlet temperature of 85 °C resulted in better physicochemical properties for both powders, as well as higher production yields. Powders produced at higher outlet temperatures had lower water activity and a higher total solids content, making them a better fit for handling and storage. The application of a higher temperature did not result in a substantial shift in color values; however, the change in color intensity resulted in a manner that customers perceived as being more appealing. The authors conclude that these procedures have the potential to increase the production efficiency of skim milk powders and, by extension, to improve the overall quality and functionality of these products.

As a result of its particularly full of nutrient composition, skim milk powder finds widespread application in the food industry as a form of fortificant. It is a common practice to use skim milk powders to improve the taste, consistency, texture, and overall nutritional value of the food products. Atwaa, Abou Sayed-Ahmed, and Hassan (2020) conducted a study to understand the physicochemical and sensorial characteristics of fat-free goat milk yogurt that was fortified with skim milk powder and processed with various stabilizers such as carrageenan and pectin. According to their findings, products that had been manufactured with different stabilizers such as pectin and carrageenan exhibited some unfavorable texture characteristics such as graininess, color defects, and poor taste profiles such as bitterness. On the other hand, the product that had skim milk powder added to it revealed an outstanding sensory profile, maintained a consistent viscosity, and received the lowest sensory score for bitterness. Therefore, the authors concluded that skim milk powder is a high-quality source to improve the functionality of yogurt products.

Another study to understand the effect of skim milk fortification on yoghurt type products was conducted by Cândido de Souza, Souza do Amaral, and Lima da Silva Bernardino (2021), who investigated the addition of skim milk powder and dairy cream on the functional characteristics of greek-style yogurt. In the study, they provided a reference sample, a sample with only SMP addition, and a final sample with both SMP and dairy cream addition. According to their research, the researchers discovered that the fermentation process is impacted when SMP is added to the system. This is because SMP contributes to the total solids and lactose in the system, which in turn provides a complete source to the microorganisms and causes the process to be carried out more quickly. According to the authors, out of all of the samples, the one that has been fortified with only SMP has received the most positive feedback from customers. They also came to the conclusion that the fortification of SMP had a significant positive effect on the nutritional value, sensorial profile, taste, and consistency of the yogurt samples. As a result, the authors concluded that SMP is a high-value material that can be used to enhance the functionality of food products.

Garczewska-Murzyn et al.(2021) conducted another valuable study to understand the effect of skim milk fortification on yogurt-type products, in which they attempted to cover the effect of adding skim milk and buttermilk powder to the yogurt products. According to their findings, after being kept in chilled conditions for 21 days, the yogurt samples that had been fortified with buttermilk were found to have higher lactic acid levels than skimmed milk powder fortified samples. They also discovered no differences in the fatty acid profile between yogurts enriched with skimmed milk powder and those enriched with buttermilk powder. They found that adding buttermilk has more benefits than just reducing syneresis; it also increases the water-holding capacity of the mixture. Therefore, it can be stated that even though skim milk powders are excellent sources to increase the functionality of food products, they can be combined with other powders to boost the effectiveness, or in some cases, other powders could be more efficient to improve the physicochemical properties of the products.

Cheese products are yet another type of product scale that can be fortified through the utilization of SMP. Because skim milk powders have a sufficient protein content and a high lactose content, they have the ability to increase the yield of cheese production by adding more solids. Additionally, because of this ability, they have the ability to improve the shelf life of the products by minimizing the amount of moisture content in the products. In addition, the amount of lactose that they contain may be an excellent source that can be converted into lactic acid, thereby enhancing the flavor profile of cheese products. Giménez et al.(2023) investigated a study the effect of using skim milk powder and adjunct cultures on the characteristic properties of cremoso cheese. According to the findings, the addition of SMP not only increased the cheese's yield but also improved the cheese's texture profile by enhancing its chewiness and hardness to a certain degree. They also stated that the addition of SMP at a level of approximately 5% could potentially assist in increasing the cheese plant's production capacity by almost fifty percent, all without adversely affecting the product quality.

Reconstituted skim milk powder can be used as a substitute for whole or part of the fresh milk in cheesemaking. This situation is especially beneficial in areas with limited access to raw milk, as well as during periods of high volatility in raw milk market prices. As a result, it can be an effective strategy for reducing the costs of production. In the study of Tidona et al (2021), there has been a partial replacement of fresh milk with reconstituted low-heat skim milk powder in high-moisture mozzarella cheese production. They stated that adding SMP to fresh cream or milk can help to standardize the product, but it can also result in a different structure of oil-in-water emulsions, which might impact the coagulation process during the production of cheese, since SMP may alter the structure of the emulsions. In their study, however, they determined that mozzarella curds made with a partial replacement of low-heat skim milk had a lower capacity for stretching than the control products. They also concluded that the product's rheological properties had been affected, but the nutritional composition of the cheese products remained consistent. In addition, the mozzarella samples made from reconstituted milk exhibited a superior gel structure and a higher capacity to retain water. Despite this, the amount of fat that was lost during the stretching process was significantly greater in the experimental curd products. Based on these findings, the authors concluded that, even though there are some changes in the structure of the products, the reconstitution process could be used to obtain cheese products with minimal quality changes and lower production costs .

### 1.6.2. Milk Protein Concentrate Powders - MPC 85

Milk protein concentrate powders (MPC) are high-protein products that are typically made using membrane technologies such as ultrafiltration and spray drying. The ratio of casein and whey proteins that make up their nutritional composition is the same as that of milk, and the level of protein differs from 40-85%. In their processing technology, both ultrafiltration and/or diafiltration are used along with evaporation (concentration) (Figure 2.). The process of ultrafiltration facilitates a particular concentration of components with larger molecular sizes, such as milk proteins. This, in turn, allows for the enrichment of the typical protein content in dry matter of skim milk powder (35%), with the assistance of diafiltration, creating a more valuable product as milk protein concentrate with different protein levels. Whey protein is found in its native form in MPC products, which means that it is vulnerable to protein denaturation (O`Kennedy 2019).

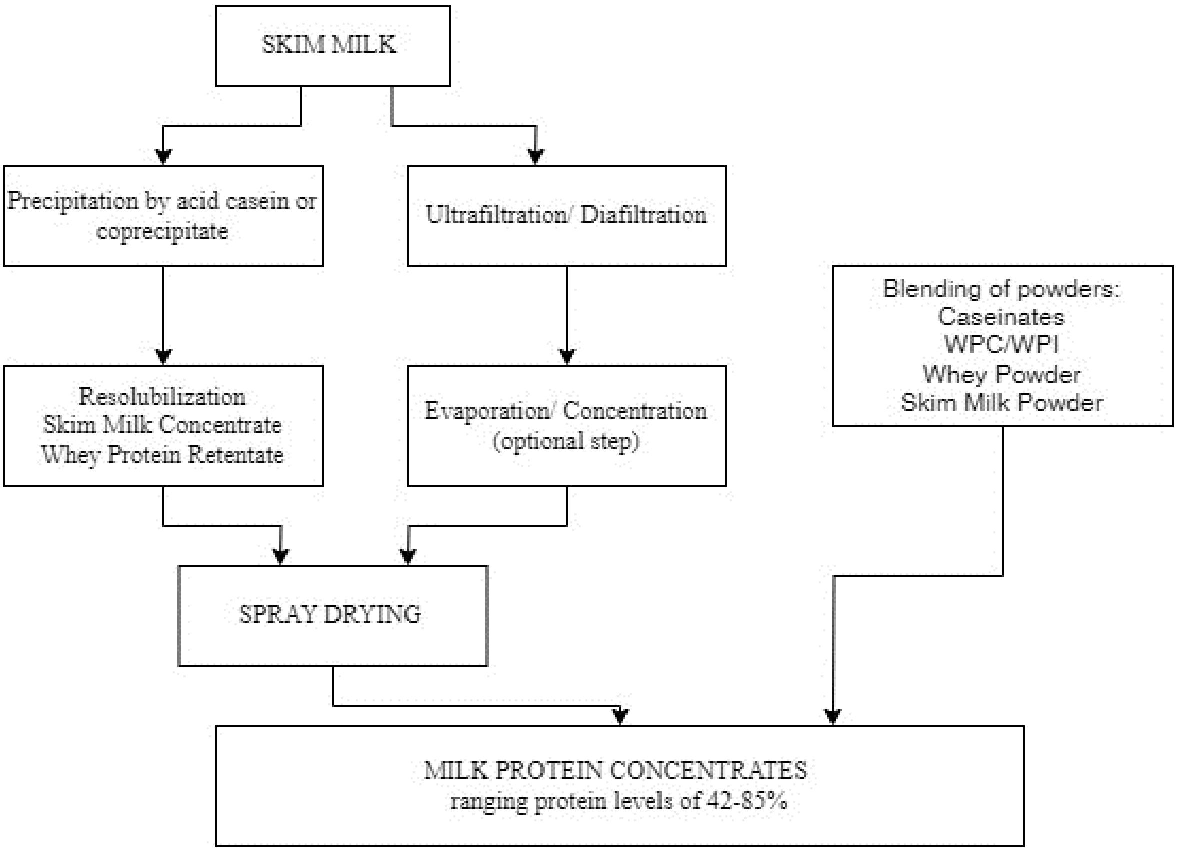



Figure 2. Milk Protein Concentrate Production Scheme (Source: Kelly 2011)

In comparison to skim milk powder, the lactose content of these products is significantly lower. Furthermore, the higher the protein level in the milk protein concentrate, the lower the lactose level. In addition, the double-digit figure in MPC products, denotes the protein content of the products (Table 2.). In addition, milk protein concentrates include a group of products known as milk protein isolates that contain at least 90 percent protein by weight (Kelly 2011, O`Kennedy 2009).

Table 2. Nutritional Composition Values (%) of different Milk Protein Concentrate Powders

| Ingredient | Moisture | Fat | Protein | Lactose | Ash |
|---|---|---|---|---|---|
| MPC-40 | 3.5 | 1.0 | 42.0 | 46.0 | 7.5 |
| MPC-70 | 4.2 | 1.4 | 70.0 | 16.2 | 8.2 |
| MPC-75 | 5.0 | 1.5 | 75.0 | 10.9 | 7.6 |
| MPC-80 | 3.9 | 1.8 | 80.0 | 4.1 | 7.4 |
| MPC-85 | 4.9 | 1.6 | 85.0 | 1.0 | 7.1 |

(Source: Kelly 2011)

The quality of milk protein concentrates can be significantly impacted by various parameters throughout the production process, given the multiple processing steps involved. The thermal output of spray drying equipment can exert an important impact on the moisture content, water activity, and rehydration characteristics of the resulting products. Moreover, significant variations in the inlet temperatures of spray drying systems may result in fluctuations in the particle size distribution parameters of the products. Additionally, the dissociation capabilities of these products may be adversely affected due to unstable inlet temperatures. Also, suddenly elevated inlet temperatures have the potential to induce irregularities in the flowability and viscosity of the products (Kelly 2011).

There are many applications of MPC products that can be applied to the food systems. According to Agarwal et al.(2015), milk protein concentrate products are extremely valuable protein products that impart a unique dairy flavor to food products without contributing extra lactose content. In addition, their nutritional profile is abundant in minerals such as calcium, magnesium, and phosphorus. Consequently, incorporating milk protein concentrate into food formulations will add to the nutritional value of the product. In addition, they have the capacity to enhance the products' water binding, emulsification, and thermal stability. In the review conducted by Agarwal et al. (2015) , the authors noted that their applications are extremely diverse, but including yogurt, processed cheese, nutrition bars, supplements, smoothies, confectionary, ice cream, and infant formula products. Adjusting the protein content of cheese milk is the most crucial stage in the cheese-making process, and it must be executed with precision. The standardization of cheese milk through the addition of MPC products is an industry-wide practice. The amount that should be added can be readily adjusted based on their protein content, allowing for an increase in cheese yield. For instance, a nearly 1% increase in the milk protein content of cheese milk used in the production of cheddar as a result of the use of MPC increased cheese yield and enhanced the milk fat and protein denaturation of the product. Additionally, other studies have demonstrated that the addition of MPC enhances the yield, texture profile, consistency, and flavor profiles of feta cheese and mozzarella (Agarwal et al.2015, Kelly 2011).

Milk protein concentrate 85, also known as MPC85, is a valuable product that contains 85% protein by weight and is frequently utilized in the fortification of various food products like supplements that are high in protein. Additionally, it is utilized extensively in cheese production for various applications including processed cream cheese products (O`Kennedy 2009).

Given that there are various MPC products based on their protein content, it is reasonable to assume that their functionality will also vary. Crowley et al. (2015) conducted a study to determine the rehydration capacities of various milk protein concentrate powders. Based on the protein content of the products, authors divided the powders into three categories: low, medium, and high protein. They placed MPC85 in the category of powders with a high protein content and reported that these powders had more sediments than those with a low protein content. They reported that after hydration at elevated temperatures, the sediment height decreased considerably, especially for high-protein powders. In addition, they highlight an additional claim that ionic strength has an immense effect on the rehydration properties of high-protein products. Based on their findings, they demonstrated that high protein powders, such as MPC85, resulted in inadequate rehydration abilities, and the authors suggested that this may be due to the high Ca-ion kinetics of the products. In addition, they stated that increased temperatures during rehydration (to 50-55C) may aid to improve the products' solubility.

As was shown in the study of Agarwal et al (2015) , using milk protein concentrate powders in ice cream production is a common practice in the industry, as these products have the ability to improve the total solids, viscosity, and textural properties of the products. Alvarez et al. (2005) conducted a study to determine how milk protein concentrates influence the physical properties of ice cream products, and in the study, MPC56 and MPC85 milk protein concentrates were utilized. In comparison to the control samples, the milk protein concentrates mixtures demonstrated improved viscosity, fat globule profile, and shape retention. The viscosity profile of the samples that were fortified with 50% MPC 85 showed promising results in the initial stage and as well as after 24 hours of aging. The particle size distribution values for both powder formulations were found to be very similar. Additionally, they discovered that 20% MPC85 fortification yielded the best results for the overrun. Overall, both fortification levels as 20 and 50% have reached satisfactory sensory results and have added great functional value to the ice cream products .

Warncke and Kulozik (2021) conducted another investigation on the fortification of cheese milk in which they attempted to show the functionality of micellar casein and milk protein concentrate powders on skim milk, as well as the rennet gelation behavior during processing. In the study, skim milk was fortified with micellar casein and milk protein concentrate until it reached 4.5% casein concentration, after which the systems were sheared and homogenized. According to the results, the authors demonstrated that owing to the poor solubility attributes of the powders, the insoluble particles that remains after hydration disrupt the rennet gelation behavior of the products, as all proteins are unable to contribute to gelation. After shearing, the particle size distribution values of MPC85-enriched skim milk reduced with increasing shear rate, as shown by the results. It has been identified that micellar casein is more soluble than MPC85, and the authors explained the situation based on the characteristics of the milk proteins and lactose. They stated that since caseins are often referred to as less soluble proteins, and the whey and lactose dissolve more readily, and the MPC 85 composition is predominately comprised of high protein levels, and its lactose content is minimal, getting poor rehydration abilities for MPC85 is expected. In addition to the protein and lactose content, the casein/whey protein ratio is an important evaluative factor because it implies the protein interaction, aggregation ability, and dissolution activity of the products. Therefore, the authors concluded that the ratio of casein to whey protein may be the driving force behind the rehydration capabilities of these products. Based on their findings, the authors concluded that MPC85 requires higher shear rates than micellar casein powders for full disintegration. In terms of gelation behavior, the structural loss of rennet gel as an indicator of its fragility decreased as shear rate and particle size have increased. Larger particle sizes, according to the authors, disrupt the structure of these gel products.  Since MPC85 has poor rehydration properties and larger particle sizes, MPC85-enriched skim milk has greater structural losses than micellar casein-enriched skim milk.

Due to their poor flowability properties, such as cohesion, high-protein powders such as MPC85 may cause difficulties during handling and storage. In addition, these issues can lead to a loss of functionality in the final products that contain milk protein concentrates. Hazlett et al (2021) studied a review study to understand the traditional and non-traditional methods to improve the flowability of these high-protein products. Particle size enlargement (also called agglomeration) is one of the most common traditional methods of use. This method offers advantages for producing powders in bulk, making them more fluid and resistant to cohesive forces. This method creates products in cluster form, and the structure of these clusters contains a greater volume of interstitial air, which allows them to reduce the bulk density of the powder, making it easier to penetrate via rehydration actions. Utilizing spray drying and/or a fludized bed is a common technique for particle size enlargement. During the initial phase of spray drying, the collapsing of wet particles has occurred. The collisions then led to the formation of agglomerations of both dry and wet particles. In this stage, Fine powder materials may also be recirculated to the spray dryer chamber, allowing them to form agglomerates. Following the spray drying chamber, products are transferred to the fludisied bed unit for final drying and cooling. In fludisied bed systems, the enlargement process may also involve rewetting or the application of some biding solutions to particles. This process ought to be carried out in a few steps, such as the inclusion of the binder, the wetting stage, the dispersion of the binder, and the solidification.

In addition to conventional methods, there are various innovative approaches, such as wet and dry coating. The wet coating method contains fluidized bed processing to enhance powder fluidization by applying a thin coating layer to the powder products. This additional layer enhances particle-particle interactions and prevents quality loss or separation. It provides powders with protection as well as uniformity. This coating material does not induce agglomeration, thereby providing a more effective barrier for modifying the surface properties and composition to enhance flowability. There are numerous coating materials used in the food industry, including lactose, glucose, and starch. The composition and viscosity of these coating solutions play a crucial role in establishing a uniform system for the particles. Dry coating is an emerging technology similar to wet coating; however, since wet coating systems require more energy and are more expensive, dry coating is also the preferred method. There are no organic waste streams, binder additions, or multiple drying stages in dry coating systems. This method involves bringing a material with a sub-micron size into contact with larger powder particles. In this system, the micron-sized particles are referred to as guest particles, while the larger powder particles are referred to as host particles. This system will also reduce the interparticle cohesion of the particles, gives uniformity to the particles (Hazlett et al. 2021).

Depending on temperature and time conditions, the MPC85's functionality may degrade during the storage period. For those kinds of high-protein powders, solubility is one of the most crucial factors. Anema et al. (2006) investigated the effect of storage time on the solubility of MPC 85 powders, and they concluded that the cross-linking of the proteins was the most influential factor in altering the products' solubility. However, they also stated that there are numerous variables that can affect the solubility of the products, especially with higher levels of moisture. This variable includes the extent of maillard reactions, because milk proteins became lactosylated as a result of maillard reactions, which altered their solubility due to change in the ratio of casein to whey proteins. The authors demonstrated one mechanism for the reduction in solubility caused by cross-linked proteins at the powder's surface. This cross-linked structure may prevent optimum hydration of the products by functioning as a barrier to rehydration forces. Based on their findings, they hypothesized that solubility would be disrupted when the surface of the particles was completely cross linked. The solubility results of MPC85 samples stored at 20°C for 60 days did not indicate a significant decrease in solubility. However, once the temperature reached 50°C, the powders were only able to maintain their solubility for a few days before a sudden but continuous decrease in solubility was determined.

### 1.6.3. Whey Protein Concentrate Powders – WPC80

Utilizing by-products to create valuable end products is a crucial step in the development of new ingredients with diverse functionalities. Whey is one of the most nutrient-rich by-products of the cheese industry, and whey protein is a highly valuable product due to its nutritional and functional properties. Whey protein has been ultrafiltered to obtain high-protein products such as whey protein concentrate. Afterward, these concentrates were transformed into powders utilizing diverse techniques, including spray drying and fluidized bed drying. The most popular WPC products are WPC34, WPC60, and WPC80, where the last two digits indicate their protein content (Table 3). Due to its nutritional similarities with skim milk powder, WPC34 is frequently used as an alternative to skim milk powder (Guo 2019).

WPC80 is frequently used in sports nutrition, infant formula, and supplements owing to its high protein content and low fat and carbohydrate content. Furthermore, WPC80 can be readily absorbed by the human body and provides a variety of healthy amino acids (Guo 2019).

Table 3. Nutritional Composition of Whey Protein Concentrate Products (%)

| Products | Protein | Lactose | Fat | Ash | Moisture |
|---|---|---|---|---|---|
| WPC34 | 34-36 | 48-52 | 3-4.5 | 6.5-8 | 3-4.5 |
| WPC60 | 60-62 | 25-30 | 1-7 | 4-6 | 3-5 |
| WPC80 | 80-82 | 4-8 | 4-8 | 3-4 | 3.5-4.5 |
| WPI | 90-92 | 0.5-1 | 0.5-1 | 2-3 | 4.5 |

(Source: Guo 2019)

As previously mentioned by Guo (2019), whey is one of the most abounding coproducts in the cheese industry and is commonly regarded as a waste stream. However, whey's nutritional profile is rich in lactose, proteins, and fats, making it a very valuable ingredient. Bacenetti et al. (2018) conducted a study to examine the environmental impact of the production of whey protein concentrate. Their results implied that waste streams and recovery systems ought to be mandated to be as efficient as possible for these powder productions. According to them, WPC80 has many advantages for use in food production, as it has satisfactory emulsification properties, is highly soluble and quickly absorbed by the human body, which is particularly advantageous in the development of high-protein sports nutrition products, and has a mild, yet highly appealing milky flavor profile. In addition to sports nutrition products, WPC80 is commonly utilized in yogurt and cheese production to enhance the total solids, water-holding capacity, emulsification, and gelation properties, as well as the flavor profile of the products. In the production of WPC80, ultrafiltration is one of the most effective processes for enhancing product functionality. Nevertheless, in terms of energy consumption and sustainability, this method has a couple of drawbacks, including high energy consumption and the use of a substantial quantity of cleaning supplies to ensure hygiene. The production of more effluents, which may be harmful to the environment, is a concern when huge amounts of cleaning products are used. According to their final findings, whey management is the most difficult step in reducing environmental impact, as the high volume of whey produced and its nutritional composition as low total solids make its handling more difficult. The authors state that rather than using whey as a feed, the whey concentration should be used to create products with greater value. In addition to the management of whey, transport and energy consumption during processing were also cited as major contributors to the environmental impact of WPC production (Guo 2019).

It is a common practice to transform valuable end products using whey; however, the physical and chemical properties of the whey can have an effect on the characteristics of the final product. If yellow whey is used in the production of a product that contains whey protein concentrate, for instance, it is possible that the finished product will have an undesirable color profile. Bleaching the whey is a necessary step prior to whey processing to remove any undesirable quality attributes. There are numerous bleaching agents available, including hydrogen peroxide and benzoyl peroxide, both of which are approved by US FDA. However, even though the use of bleaching agents is required, the presence of these chemical materials can lead to lipid oxidation and the production of some unpleasant flavors. Furthermore, some of them may lead to the degradation of important nutrients such as protein in whey (Qui et al. 2015)

Qui et al (2015) used a model in their study to understand the effect of microfiltration bleaching, bleaching with different materials such as lactoperoxidase and hydrogen peroxide on the final characteristics of WPC80, and they also evaluated the effect of unbleached cheddar whey on WPC80 characteristics. When compared to microfiltration and hydrogen peroxide bleaching, they discovered that lactoperoxidase showed the greatest reduction in yellow color intensity in WPC80 products. When compared to unbleached and micro-filtrated WPC80, hydrogen peroxide and lactoperoxidase bleached products had prevailing cardboard flavors and unique cabbage flavors. In terms of functionality, authors concluded that micro-filtrated WPC80 gels had higher firmness and bigger protein particle size compared to other treatments, and based on all perspectives, microfiltration was found to be the most appropriate alternative way to bleach the products.

As it mentioned in other studies (Hazlett et al. 2021; Reineccius, Patil, and Anantharamkrishnan 2022; Seo 2022) agglomeration is the most common technique to improve the physicochemical characteristics of the powders, and as well as their functionality. Wright et al (2009) studied the impact of agglomeration technique and storage on flavor and flavor stability of WPC 80 and WPIs. In the study, they compared the products that is agglomerated by re-wetting and single pass, and non-agglomerated samples during 18 months of storage time. According to the sensory profile results, the changing trend in the flavor profile was distinguished for agglomerated samples versus non-agglomerated samples. It was discovered that agglomerated samples had a more differentiated cardboard flavor, which risen with storage time. There were also many flavor types, such as cucumber and fatty flavors, which generated more prominently in agglomerated samples over time. Because WPC and WPI products contain a small amount of lactose, the color changes were not as dramatic as expected. The results for volatile compounds showed an obvious rise in lipid oxidation flavors and volatiles for all samples, but the change was more noticeable in agglomerated products. Furthermore, panelists began to detect undesirable flavor profiles for all the samples after 4 to 6 months of storage.

The functionality profiles of WPC products are determined by the protein content, as well as other nutrients and drying techniques. For example, the protein, fat, and lactose content of the products differ, giving unique characteristics to the food matrix in which WPC products are involved. Luck et al. (2013) conducted research to compare the functional properties of WPC34, WPC80, and milk serum protein concentrates. Their results in terms of foaming stability demonstrated that freeze-dried WPC34 samples failed to create a stable foam, whereas spray dried WPC34 built a more stable foam. The foam stability of freeze dried WPC34 and spray dried WPC80 was not observed. WPC80 has poor gelation properties, and the formed gels were not sufficiently durable to be tested. As a result, the authors agreed that compositional differences, notably fat content, and protein denaturation level are key variables identifying product functionality. Overall, both spray-dried and freeze-dried WPC80 failed to produce stable gels and foam, but spray-dried samples were carried out better in terms of functionality.

Jervis et al. (2012) conducted another study to comprehend the impact of whey bleaching on the functionality of WPC, where they examined the effect of two separate bleaching chemicals, benzoyl peroxide (BP) and hydrogen peroxide (HP), on the production of WPC80. The results showed that WPC80 samples bleached with benzoyl peroxide (BP) had a lower level of norbixin, a compound that shows the intensity of yellowness, when in comparison with samples bleached with hydrogen peroxide (HP). According to Hunter color values, the bleached WPC80 powders came out as more white and less yellow than the unbleached powders. Regarding product functionality, the HP-bleached WPC80 samples were more soluble than the other samples, and the authors concluded that bleaching with HP led to more heat-stable WPC80 products. Nevertheless, hydrogen peroxide induced the formation of undesirable flavors and rapid lipid oxidation in products.

It has been mentioned in the study of Bacenetti et al (2018) that one of the common applications of WPC is utilization in yogurt manufacturing, owing to rich nutritional composition of the product. Vénica et al (2023) carried out a study to better understand the effect of dairy powders on the physicochemical and functional properties of yogurt. Various ingredients were evaluated in the study, including WPC40, WPC80, and isolated and hydrolyzed whey protein powders. Except for hydrolyzed whey protein, the results showed that introducing whey proteins generally reduced fermentation time, and WPIs and WPC80 enhanced the products' water holding capacity. In the study, two different starter cultures were also evaluated, and it was discovered that whey proteins, including WPC80, give the highest level of protein when compared to other ingredients for both starter usages. The authors explain that the shorter fermentation time is a result of an increase in whey protein:casein ratio by adding WPC 80 as well as other whey proteins (except hydrolyzed whey protein), since lactic acid bacteria can easily digest WPC80, and it can be a readily available nitrogen source for them to break down during fermentation. As a result, increasing the whey protein level implies shorter and faster fermentation. Regarding overall functionality and physical characteristics, the authors concluded that WPC40 and WPC80 exhibited a better profile by providing a higher water-holding capacity, a higher protein concentration, and a shorter fermentation time. They also mentioned that the volatile compounds were not significantly altered by any of the powder additions.

In addition to applications involving yogurt, the industry is currently performing applications involving the addition of WPC to cheese products. Sołowiej, Cheung, and Li-Chan (2014) investigated the effect of using rennet or acid casein with or without the addition of whey proteins on the textural, rheological, and functional properties of processed cheese analogues. According to them, the addition of WPC80 to increase cheese solids significantly decreased the cohesiveness of the cheese products, making them more rigid and adhesive. In terms of viscosity, it was stated that higher protein levels lead to higher viscosity values. Using acid casein alongside WPC80 led to a greater increase in viscosity values than using WPIs. On the other hand, when cheese analogues were produced using rennet casein and WPIs, different results were obtained, that these cheese analogues showed higher viscosity values. This result can be linked to the calcium content of rennet casein, acid casein, and whey proteins, which may create unique protein links and bridges that determine the product's structure. Meltability was found to decrease significantly with higher protein levels. Nonetheless, according to Schreiber test results, all of the products made with acid casein and the products made solely from 11% rennet casein had greater melting properties. Among all of the samples, the analogues derived from acid casein at 10-11% and 1% WPC80 demonstrated the highest meltability. However, meltability results were not satisfactory when WPC80 was used in conjunction with rennet casein. These results were correlated with the interactions between k-casein and b-lactoglobulin, where the structure is formed by casein alone and then joined by whey proteins or their mutual interaction. Additionally, the study mentioned that increasing the temperature leads to an increase in the cross-linking that occurs between whey proteins and caseins, which results in a decrease in the meltability of the final product. The authors concluded that hardness, adhesion, and viscosity values increased with a higher protein concentration, whereas meltability decreased. As a result, cross-linking between proteins, protein structure, and the ratio of whey proteins to casein are all important factors that can affect the texture and rheology of a cheese product. Overall, WPC80 improved various attributes; however, dosages should be chosen carefully to avoid any disruption in the viscosity and/or meltability of the products.

Kusio et al. (2020) conducted a different study to understand the effect of WPC addition to a food matrix on the physicochemical and functional characteristics, and they demonstrated these effects on high protein fat-free dairy desserts. Different WPC80 concentrations were used in their study, along with other ingredients such as skim milk powder and carrageenan. They stated that WPC80 can also be used as a fat replacer in these fat-free products because they have various functional characteristics such as good emulsification, water binding, and gelation, which are similar to beneficial characteristics of lipids. According to the findings of their study, increasing the level of WPC80 in fat-free dairy desserts resulted in increased hardness, adhesiveness, cohesiveness, and springiness. In terms of viscosity, it has been shown that increasing protein concentration increases viscosity levels, as also suggested by . Sołowiej, Cheung, and Li-Chan (2014). The authors found that the highest viscosity is obtained for 13% of WPC80-added fat-free desserts. The water activity results, on the other hand, showed an opposite trend, with values decreasing as WPC80 increased. Regarding sensory evaluation, the 9% WPC80 added samples received the most acceptance from panelists. However, the 13% WPC80 added samples were discovered to be the hardest and yellowest product among the others, as well as having air bubbles and lumps, which panellists' thought were poor quality attributes (Kusio et al. 2020)

## 1.7. General View to the Labneh

Labneh is one of the most common cheese product in especially Middle East area. It Is a soft cheese with a distinct dairy flavor, and it can be produced in a different ways include traditional separation method and reconstitution method.

### 1.7.1. Labneh- Definition, Composition and Processing

Labneh is a fermented dairy product popular in the Middle East. It is also known as concentrated yogurt and has a distinct dairy flavor as well as a creamy and consistent texture. It is a soft cheese with very little syneresis, and it is quite a common product, especially for breakfast applications. However, it can also be used in other applications, such as baking. The nutritional composition of labneh may vary depending on the processing method and country requirements. In general, the total solids content ranges between 23-28%, with fat accounting for 8-12% and protein accounting for 3-

5%. These compositional values can differ depending on the manufacturer, country needs, and processing techniques (Nsabimana, Jiang, and Kossah 2005, Ozer et al. 1998).

There are several different approaches to making labneh products. Traditional methods, membrane processing techniques such as ultrafiltration and reverse osmosis, and direct reconstitution are among them. Despite its drawbacks, the traditional method is widely employed in domestic applications and in some dairy plants. In the traditional method, yogurt is placed in cloth bags and either hung inside a refrigerator or placed under a heavy material to remove the whey and achieve the desired consistency by increasing the amount of the total solid. This method has some limitations in that each product may have different nutritional composition characteristics because it is difficult to see how much whey is removed from the product. As a result, it should be carefully carried out in order to keep the nutritional composition as consistent as possible (Nsabimana, Jiang, and Kossah 2005, Ozer et al. 1998).

As previously stated, traditional methods have drawbacks; as a result, technologies in labneh processing have evolved. One common method is to use mechanical separators. In the processing, nozzles or quark separators can be used to remove whey and increase the total solid content of the product. During that procedure, the system's speed and rotation must be adjusted because these parameters have a direct impact on the product's quality.  There are various steps that involved during labneh production: including pasteurization of the milk, homogenization, standardization etc. (GEA nd, Nsabimana, Jiang, and Kossah 2005) (Figure 3.)

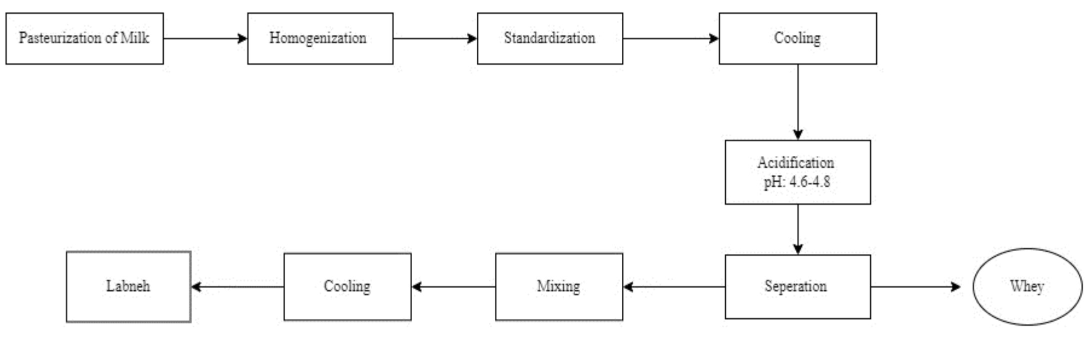



Figure 3. Production flow chart of labneh by using mechanical separator
(Source: GEA nd.)

The ultrafiltration (UF) technique is also commonly used in the industry, however there are some limitations for this method like high cost and energy consumption. The method can be described as utilization of pressure and using membranes to concentrate the retentate milk into the final product. In this method, milk is concentrated, and inoculation also was made to start the fermentation (Nsabimana, Jiang, and Kossah 2005).

Along with UF, there have been numerous studies demonstrating the fortification of UF labneh products with various beneficial compounds. Ebid, Ali and Elewa (2022) conducted one of these studies, in which they attempted to determine the effect of spirulina powder addition on the functional characteristics of labneh. According to them, spirulina powder provides several vitamins, including A, E, and B vitamins, as well as a high number of proteins, amino acids, and essential minerals. They started by inoculating the spirulina powder with *L. acidophilus* and *S. thermophilus*, and then they added the mixture to the milk up to 1%. Their findings indicated that adding spirulina improved the viability of probiotics, increased antioxidant activity, and resulted in higher protein levels than control labneh samples. In addition, the addition of spirulina results in less syneresis in labneh. In terms of vitamin levels, various vitamins such as B12 and B9, as well as very beneficial minerals such as FE, Zn, and Mg, were found to be at higher levels than in the control samples. Based on the sensory evaluation, Panelists stated that there was a color change in the spirulina added samples, to the blue-green, which is unappealing and noted as having a peculiar appearance. There were also some metallic and off flavors discovered, which could be attributed to mineral activities and lipid oxidation. Based on these findings, the authors concluded that, in order to create a functional product, spirulina powder created a superior nutritional profile, but the dosage should not exceed 0.4% in order to avoid developing unattractive quality attributes in the labneh (Ebid, Ali and Elewa 2022)

Khider et al. (2022) published another useful study in which the authors investigated the functional properties of ultrafiltrated labneh products supplemented with oats and probiotic bacteria. In the study, up to 2% oat powders and 2% probiotic bacteria were added to labneh. During the shelf life of all labneh samples, the results showed that the lactose content and pH values of all samples became lower with the addition of oat powders. In terms of nutritional composition, the authors observed that while low-fat labneh samples (without any oat powder addition) can provide 20% DV of protein for humans, those fortified with 2% oats provide the highest protein level among the others. Aside from that, the findings suggested that adding 2% oat powders prolongs shelf life while improving sensory attributes. The low-fat labneh samples were the most favored sample after 7 days of storage, followed by those fortified with 2% oat powders on the 28th day of storage. According to all findings, authors figured out that the addition of oat powders enhanced the the sensory qualities, shelf life, and nutritional profile of the products, and it may serve as an excellent substitute for lactose-intolerant consumers because the lactose content decreased substantially with the addition of oat powders.

As is well known, labneh is a perishable product with a short shelf life. However, shelf life can be extended using various techniques such as heating after fermentation or using biocompounds or preservatives. El-Sayed and El-Sayed (2021) examined the effect of antimicrobial nanoemulsions of thyme essential oil on labneh preservation. Essential oils are aromatic compounds that possess many antimicrobial, antioxidant, and antibacterial properties. For their antimicrobial properties, essential oils have been shown to hinder the growth of numerous microorganisms, including *Listeria monocytogenes* and *E. coli*. In this study, labneh is made through ultrafiltration, and the products' nanoemulsions of thyme oil are added to the labneh samples. The results showed that thyme nanoemulsions inhibited pathogenic bacteria quite effectively. Furthermore, the nanoemulsions expand the shelf life of labneh products to nearly 6 weeks. The products with the lowest microbial stability were those fortified with 0.1% nanoemulsions. Overall, the authors concluded that adding essential thyme oil can inhibit microorganism growth while making no significant difference in chemical properties. As a result, this method can be seen as a potent approach to prolonging the shelf life of labneh.

Fouad et al. (2022) developed a different fortification strategy in which the authors attempted to create bio-labneh samples fortified with microcapsules containing chickpea flour and probiotics. The study's findings revealed that using microcapsules contributed to protecting and maintaining the viability of probiotic bacteria. Probiotics in the bio-labneh also maintained viability with the help of microcapsules during the 21-day storage period. Along with chickpea flour addition, the protein and fat content got increased for the samples that have 5% chickpea flour amount. In addition, the addition of them to the microcapsules increased the antioxidant activity of the bio-labneh samples. Despite the fact that the nutritional levels were found to be higher with the addition of 5% chickpea flour, sensory acceptance was low. As a result, while these approaches are required to create functional products, preserve the products longer, and increase their nutritional values, the dosage of fortifying agents should be carefully chosen to avoid any quality loss from the product.

Labneh quality can be improved in a variety of ways, including increasing the number of total solids, introducing functional ingredients such as stabilizers, and the adjustment of starter cultures during the fermentation stage. In that regard, Elshaghabee, El-Hussein, and Mohamed (2022) conducted a study on the improvement of labneh quality using *Lactocaseibacillus casei* NRRL B-1922. They stated that fermentation is one of the most important steps in the production of labneh, and that bacteria plays a significant role in the fermentation process. Using probiotic bacteria for fermentation can provide numerous benefits to the product, such as improving the consumers' digestion system. In response to this finding, they attempted photobiomodulation with irradiated *Lacticaseibacillus casei* NRRL-B-1922 prior to milk fermentation. This implementation, according to the results, improves the viability and metabolic activities of the bacteria, as well as the overall quality of labneh by providing a better taste profile. The photobiostimulated bacteria were discovered to be a major factor in reducing moisture and, as a result, improving the shelf life stability of the labneh. Diacetyl and acetaldehyde compounds were increased, and sensory acceptance was higher in labneh samples containing photobiostimulated bacteria than in untreated samples. Additionally, the antioxidant activities in the labneh were increased as a result of the treatment, which led to a more functional labneh product. Accordingly, it can be stated that alterations to the microorganisms can lead to an increase in both the quality parameters and the stability of the labneh during the shelf life.

As is well known, the use of stabilizers such as different hydrocolloids is a vital phase in the production of labneh because they have a direct impact on the water-holding capacity, texture, and stability of the products. In the study conducted by Saleh, Al-Baz, and Al-Ismail (2017), the effect of various hydrocolloids as fat substitutes on the physicochemical properties of labneh was examined. Four different hydrocolloids were employed in the study: carboxymethylcellulose, arabic gum, carrageenan, and xanthan gum. Water holding capacity, which is a key feature of labneh, is improved the most when xanthan gum is used in the formulation and the least when carboxymethylcellulose is added. Furthermore, using xanthan gum in conjunction with carboxymethycellulose had the opposite effect on water holding capacity. However, using xanthan gum when combined with arabic gum helped to achieve 98% water holding capacity in labneh products. According to the authors, not every increase in hydrocolloids has significantly improved functionality. For example, increasing carrageenan levels from 17% to 66% increased water holding capacity by only 8%. In terms of flow behavior, the authors mentioned that using a combination of carreganan and arabic gum produced results that were more similar to control samples, but samples containing carboxymethyl cellulose and carreganan, or carboxymethy cellulose, carreganan, and arabic gum, illustrated a high level of shear thickening owing to the large quantity of CMC. As a whole, the authors concluded that xanthan gum and carrageenan substantially raised the water holding capacity of the labneh samples, whereas carboxymethylcellulose significantly lowered water holding capacity. Therefore, understanding the nature of ingredients prior to implementation to the labneh production is a vital approach to be followed, not only for practical but also for industries to keep the production efficiency, cost and the quality of the product as much as in high levels.

Nowadays, there is a growing consumer demand for low-fat products. These demands were made, in particular, after Covid-19, as a result of a rise in number of health-conscious consumers. Regardless of the fact that labneh is a healthy fermented product with numerous health benefits, developing a more functional labneh product with reduced and some additional benefits is essential. In accordance to this viewpoint, Aydinol and Ozcan (2017) published a study on the production of low-fat Labneh cheese using inulin and B-glucan fiber-based fat substitutes. According to the study, fiber has a variety of health benefits, including improved digestion and immune system function, and these benefits can be used to combat diseases such as heart disease and diabetes. It is demonstrated in their study that using fat replacers improves the functional characteristics of low-fat products with regard to the reactions between casein and the fat replacers which make up the product structure. According to the authors, the increase in textural properties such as firmness and stickiness was proportional to the amount of fat in the products. Furthermore, the results revealed that reduced fat labneh samples containing inulin were the firmest among the others. The low fat samples fortified with inulin, on the other hand, had the lowest hardness values. The control samples received the greatest acceptance in terms of sensory profiles. Nevertheless the samples produced with inulin outperformed the samples produced with B-glucan. The taste profiles of the labneh samples differed, with the reduced fat labneh sample with B-glucan having a creamier appearance in addition to some off-taste profiles such as bitterness. In all, inulin and B-glucan, in addition to their health benefits, may lend good functional properties to low-fat labneh samples; however, the improper dosage may possess a negative effect on their characteristics.

# CHAPTER 2

# MATERIALS AND METHOD

## 2.1. Materials- Dairy Powders Supply

The skim milk powder (SMP-A) was supplied from Turkey. The Milk Protein Concentrate 85 (MPC85-B), Whey Protein Concentrate 80 (WPC80-B) and Whey Protein Concentrate 80 S (WPC80S-B) were supplied from Germany. All the powders were produced by spray drying technique. The gross composition of the powders can be found in Table 4, all the chemical and physical composition values were provided by suppliers. Right after the supply of the powders, they were placed into 1 kg double zipper bags, and stored in the incubators under dark conditions.

Table 4. Chemical Composition of Studied Dairy Powders

| Ingredients | Protein | Fat | Lactose | Ash | Moisture |
|---|---|---|---|---|---|
| SMP-A | 34.3% | 1% | 52% | 8% | 3.4% |
| MPC85-B | 85% | 3% | 4.5% | 7% | 5% |
| WPC80-B | 80% | 5.6% | - | 2.6% | 4.5% |
| WPC80S-B | 81.6% | 3.2% | - | 3.5% | 4.4% |

Table 5. Physical Composition of Studied Dairy Powders

| Ingredients | pH | Scorched particles |
|---|---|---|
| SMP-A | 6.6 | Disc A-B |
| MPC85-B | 6.9 | Disc A-B |
| WPC80-B | 6.5 | Disc A-B |
| WPC80S-B | 6.2 | Disc A-B |

## 2.2. Methods

All analysis were examined seperately for dairy powders and labneh products. For both dairy powders and labneh samples, statistical analyses were performed.

### 2.2.1. Dairy Powders Analysis

For all the dairy powders; color, FT-IR, water activity, particle size distribution and turbidity analyses were performed.

#### 2.2.1.1. Color Analysis

The color values of the dairy powders were measured based on the Hunter method. The values were measured using a ColorFlex EZ Spectrophotometer, where the values were defined by CIE Lab. The values are represented as L*,a* and b*. +L* indicates lightness, -L* indicates darkness, +a* indicates redness, -a*indicates greenness, +b* indicates yellowness, and -b* indicates blueness (HunterLab, USA).

### 2.2.1.2. FT-IR Analysis

A FTIR-ATR spectrometer (Spectrum Two, Perkin Elmer, USA) was used for the experiments. A press at a level of 80% gauge has been employed to ensure all the powders were contacted with the crystal part of the measuring area. The spectra were collected using 16 scans with a resolution of 4 cm-1 in the mid-region (400-4,000 cm1) band.

### 2.2.1.3. Water Activity Analysis

Water activity is measured using a Rotronic HygroLab Water Activity Analyser (Rotronic Measurement Solutions, Germany) at room temperature. A thin layer of powder has been created on the measuring plate.

### 2.2.1.4. Particle Size Distribution Analysis

A Malvern Mastersizer 3000 (Malvern Instruments Ltd, Worcestershire, UK) were used to determine particle size distribution of dairy powder samples. Prior to the analysis, milk powders were reconstituted with distilled water (15% w/w), and the solutions were introduced to the wet sample dispersion (Hydro EV, Malvern Instruments Ltd). The obscuration has been set to 6-8%. The refractive index of 1.460 was set (Sert, Mercan, and Kılınç 2022). The analysis provided the values of Dx(10), Dx(50), Dx(90), D[4,3], D[3,2], Specific Surface Area and Span, where span values were calculated based on the formula :

$$Span = \frac{Dx(90) - Dx(50)}{Dx(10)} \qquad (1)$$

### 2.2.1.5. Turbidity Analysis

Turbidity was measured by using Epoch 2 microplate reader (BioTek, Agilent Technologies, USA) at 600 nm, the data is given in unit of OD. The samples presented to the microplate reader in 2.5 ml cuvettes (Thermo Scientific, UK) by reconstituting them in distilled water (15% w/w).

### 2.2.1.6. Statistical Analysis

The standard deviations and averages were calculated by using Excel. The statistical significance of variables and factors were determined by using General Liner Model- ANOVA, and the comparison of the data was performed by Tukey Test using Minitab 17 Statistical Programme ($\alpha$=0.05).

### 2.2.2. Labneh Analysis

For each labneh sample, color, FT-IR, texture, rheological and sensory analyses were performed.

### 2.2.2.1. Labneh Production

In labneh production, direct reconstitution of powders with milk method was used. During the production, Thermomix TM6 (Thermomix, France) was used in mixing applications. All the steps can be seen in Figure 4. As a summary, first raw milk was fortified separately with each dairy powder at 3.5% and butter at 15%, then the mixture was fermented with Premium 5.0 culture (CHN Hansen, Denmark) at 42°C for

4 hours until pH dropped to 4.6 were reached. Once fermentation was completed, the fermented base was put to the refrigerator for cooling until the product temperature reached to 4°C. After cooling was done, the product was heated to 55°C, and the carrageenan-based stabilizer was added to the mixture. After mixing, the product is heated to 75°C, and hot-filled into 1 kg containers. In total, four different labneh products were produced (L-SMP, L-MPC85, L-WPC80, and L-WPC80S). The labneh products were stored at 4°C conditions until the analysis time.

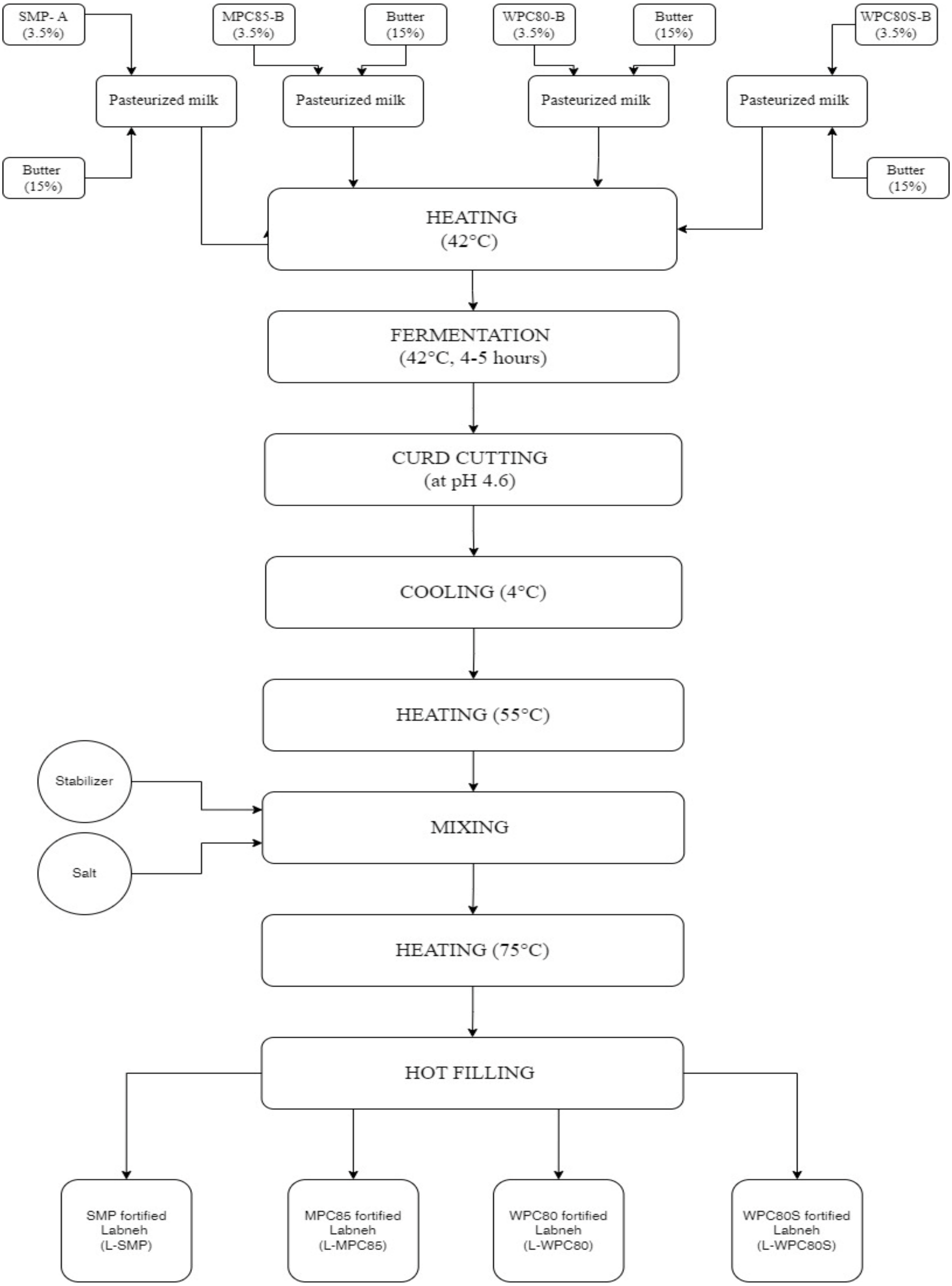



Figure 4. Flow Chart of Labneh Production

#### 2.2.2.2. Color Analysis

The color values of the labneh samples were measured based on the Hunter method. The values were measured using a ColorFlex EZ Spectrophotometer, where the values were defined by CIE Lab. The values are represented as L*,a* and b*. +L* indicates lightness, -L* indicates darkness, +a* indicates redness, -a*indicates greenness, +b* indicates yellowness, and -b* indicates blueness (HunterLab, USA). Also $\Delta E$ of the labneh samples were calculated to understand the color difference between the labneh samples that were prepared with fresh dairy powders and the ones that were prepared with 4-months-old dairy powders from 10°C, 25°C and 37°C conditions.

$$\Delta E = \sqrt{(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2} \qquad (2)$$

#### 2.2.2.3. FT-IR Analysis

A FTIR-ATR spectrometer (Spectrum Two, Perkin Elmer, USA) was used for the experiments. A press at a level of 80% gauge has been employed to ensure all the powders were contacted with the crystal part of the measuring area. The spectra were collected using 16 scans with a resolution of 4 cm-1 in the mid-region (400-4,000 cm1) band (Ye et al. 2017).

#### 2.2.2.4. Texture Analysis

Texture Analyzer (CT3, Brookfield, USA) was used for texture analysis. The compression test was applied for all samples. During the analysis, test speed was selected as 2 mm/s, the probe was selected as TA15/1000. The parameters for the analysis were hardness, adhesiveness and stringiness.

### 2.2.2.5. Rheological Analysis

Rheological properties of the labneh samples were evaluated using a Discovery Series Hybrid Rheometer (DHR) (TA Instruments, USA). Measurements were conducted at 4 C, and the frequency sweep tests were performed under the range of 0.1-30 Hz, and 1% of strain was applied to understand storage modulus (G`), loss modulus (G``), and Tan delta (δ) of the samples (Sözeri Atik et al. 2023).

### 2.2.2.6. Sensory Analysis

Labneh samples were evaluated at the beginning and the end of the 4 month shelf life using a 5-point hedonic scale test (5-very much liked, 4-liked, 3-neither disliked nor liked, 2-disliked, and 1-very much disliked). Hadaf Foods Industries LLC's panelists were presented with 100 grams of labneh for each sample from cold storage (4°C) during the evaluation. 10 trained panelists were used to make the evaluations. Participants were encouraged to drink water and rinse their mouths in between each sample. The samples were graded on their appearance, texture (in two dimensions: thickness and smoothness), color, aroma, and taste (in one dimension: creaminess).

### 2.2.2.7. Statistical Analyses

The significant different of variables and factors were tested by One-Way ANOVA, and comparison of the data was evaluated with Tukey Test by using Minitab 17 Statistical Software ($\alpha=0.05$).

# CHAPTER 3

# RESULTS AND DISCUSSION

## 3.1. Dairy Powders Analysis Results

For 4 different dairy powders, several analyses include color analysis, FT-IR analysis , water activity analysis, particle size distribution and turbidity analysis were conducted on monthly basis during the 4 months of shelf life.

### 3.1.1. Color Analysis Results

The color analysis of dairy powders is conducted every month at different temperature conditions, 10°C, 25°C and 37°C for 4 months. The results were shown according to CIELAB parameters, L*, a* and b*, where L* represents lightness, b* represents yellow to blue (yellow for positive values, blue for negative values), and a* represents red to green (red for positive values, green for negative values (Macdougall 2010). The color results of 10°C storage conditions are shown Table 6.

Table 6. The Color Analysis Results of Dairy Powders at 10°C during 4 months of shelf life

| | *Powder type* | | | | | |
|---|---|---|---|---|---|---|
| | SMP | | | MPC85 | | |
| *Time(m)* | L* | a* | b* | L* | a* | b* |
| *0* | $95.44^{A}$ | $-3.34^{B}$ | $13.10^{A}$ | $92.85^{A}$ | $-1.37^{B}$ | $12.34^{A}$ |
| *1* | $94.72^{B}$ | $-2.88^{AB}$ | $13.09^{A}$ | $92.47^{B}$ | $-1.26^{AB}$ | $12.10^{A}$ |
| *2* | $95.18^{A}$ | $-2.99^{AB}$ | $13.68^{A}$ | $92.54^{A}$ | $-1.29^{AB}$ | $12.39^{A}$ |
| *3* | $93.12^{B}$ | $-2.92^{A}$ | $13.34^{A}$ | $90.57^{B}$ | $-1.25^{A}$ | $12.20^{A}$ |
| *4* | $92.10^{B}$ | $-2.74^{A}$ | $12.96^{A}$ | $90.27^{B}$ | $-1.32^{A}$ | $12.24^{A}$ |
| | *Powder type* | | | | | |
| | WPC80 | | | WPC80S | | |
| *Time(m)* | L* | a* | b* | L* | a* | b* |
| *0* | $89.87^{A}$ | $-0.69^{B}$ | $15.69^{A}$ | $92.35^{A}$ | $-1.64^{B}$ | $13.23^{A}$ |
| *1* | $89.65^{B}$ | $-0.67^{AB}$ | $14.62^{A}$ | $92.10^{B}$ | $-1.48^{AB}$ | $13.25^{A}$ |
| *2* | $90.66^{A}$ | $-0.74^{AB}$ | $15.33^{A}$ | $92.15^{A}$ | $-1.59^{AB}$ | $13.45^{A}$ |
| *3* | $88.40^{B}$ | $-0.67^{A}$ | $14.90^{A}$ | $91.25^{B}$ | $-1.56^{A}$ | $12.87^{A}$ |
| *4* | $88.05^{B}$ | $-0.66^{A}$ | $14.21^{A}$ | $91.04^{B}$ | $-1.55^{A}$ | $13.52^{A}$ |

[a]The same uppercase letters in the same column mean that the samples are not significantly different ($\alpha$=0.05)

During four months of storage at 10 °C, the L* values of the powders decreased. For instance, the L* value of SMP was 95.44 at the start of the study and decreased to 92.10 after four months. Consequently, the L* value of MPC85 was determined to be 90.27, whereas it was 92.85 at the beginning of its shelf life. However, the greatest decrease in L* value was observed in SMP samples, which can be seen in Figure 5. For 2 months, SMP samples keep their brightness more stable, yet after 3 months, L* values started to reduce more dominantly. Throughout all the samples, WPC80S has more stable L* values during the shelf life, which indicates that product brightness was not changed majorly (Figure 5). All samples maintained more stable a* values throughout the shelf life, but SMP and WPC80S a* values decreased more than MPC85 and WPC80.The b* values of the powders were also less variable compared to the L* values; however, the b* value of WPC80 was recorded as 14.21, while it was 15.69 at the beginning of the shelf life.

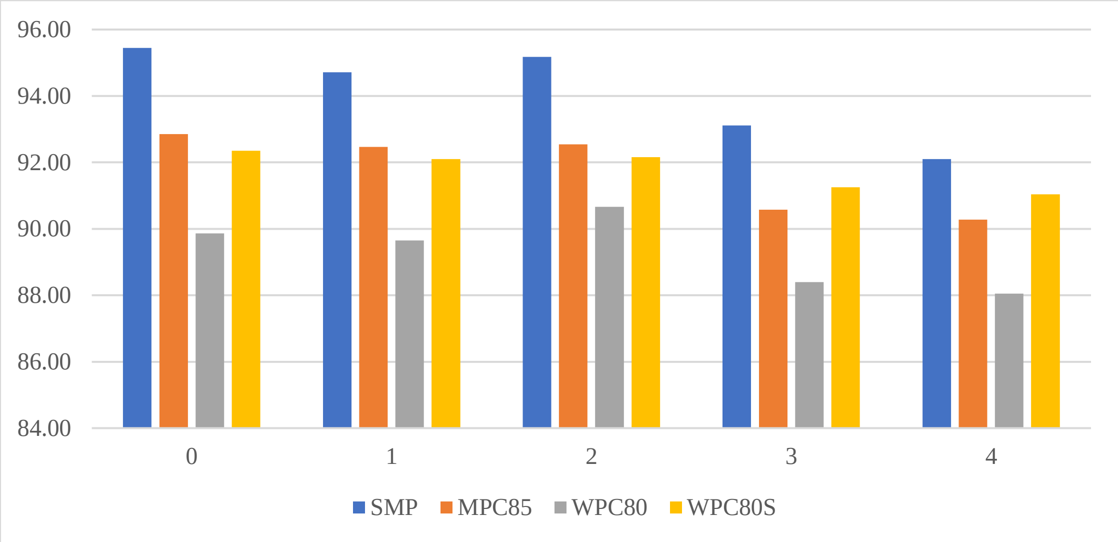



Figure 5. Results of L* values of Dairy Powders during the 4 months of storage in 10°C

Le et al. (2011) conduct a study to comprehend maillard reaction and cross-linking in relation to the solubility of milk powders, and their findings indicate that color change in milk powders could be a result of processing conditions, storage, fat and protein content, and carotenoids. According to their findings, relative humidity is a significant factor that greatly impacts the color change of dairy powders. For instance, they discovered that L* values of samples were more stable than those stored at relative humidity levels exceeding 80%. They stated that an increase in a* and b* indicates the formation of brown color in samples, but their results suggested that the L* and a* values of WPC80 samples kept at 30°C remained more constant over time. In accordance with the findings of Le et al (2011), the a* values of WPC80 remained constant for 4 months, as shown in Table 6.

Table 7. The Color Analysis Results of Dairy Powders at 25°C during 4 months of shelf life

| | *Powder type* | | | | | |
|---|---|---|---|---|---|---|
| | SMP | | | MPC85 | | |
| *Time (m)* | L* | a* | b* | L* | a* | b* |
| *0* | $95.44^{A}$ | $-3.34^{B}$ | $13.10^{A}$ | $92.85^{A}$ | $-1.37^{B}$ | $12.34^{A}$ |
| *1* | $92.56^{B}$ | $-2.93^{AB}$ | $13.35^{A}$ | $92.78^{B}$ | $-1.16^{AB}$ | $16.25^{A}$ |
| *2* | $95.13^{A}$ | $-3.00^{AB}$ | $13.56^{A}$ | $92.19^{A}$ | $-1.32^{AB}$ | $12.44^{A}$ |
| *3* | $92.52^{B}$ | $-2.89^{A}$ | $12.92^{A}$ | $89.29^{B}$ | $-1.21^{A}$ | $12.04^{A}$ |
| *4* | $91.56^{B}$ | $-3.01^{A}$ | $13.68^{A}$ | $90.56^{B}$ | $-1.21^{A}$ | $13.65^{A}$ |
| | Powder type | | | | | |
| | WPC80 | | | WPC80S | | |
| *Time (m)* | L* | a* | b* | L* | a* | b* |
| *0* | $89.87^{A}$ | $-0.69^{B}$ | $15.69^{A}$ | $92.35^{A}$ | $-1.64^{B}$ | $13.23^{A}$ |
| *1* | $88.07^{B}$ | $-0.75^{AB}$ | $13.70^{A}$ | $88.82^{B}$ | $-1.65^{AB}$ | $12.90^{A}$ |
| *2* | $90.64^{A}$ | $-0.70^{AB}$ | $15.60^{A}$ | $92.13^{A}$ | $-1.67^{AB}$ | $13.53^{A}$ |
| *3* | $87.44^{B}$ | $-0.60^{A}$ | $15.37^{A}$ | $91.66^{B}$ | $-1.46^{A}$ | $13.12^{A}$ |
| *4* | $87.82^{B}$ | $-0.57^{A}$ | $14.75^{A}$ | $90.18^{B}$ | $-1.52^{A}$ | $13.80^{A}$ |

aThe same uppercase letters in the same column mean that the samples are not significantly different ($\alpha$=0.05)

The changes in the parameters were more prominent at 25°C conditions than 10°C (Table 7). At the beginning of the shelf life, the L* values of powders varied from 89.37 to 95.44, and the b* values were recorded from 12.34 to 15.69. However, for all the samples, L* values reduced. The highest reduction in L* values from the beginning to 4 months were seen in SMP samples, where it reduces to 91.56 from 95.44 at the beginning of the shelf life, which can be also in from Figure 6. SMP has the highest amount of lactose in all the samples, so this nutritional composition makes it more prone to Maillard reactions, and as well as higher browning rates. Therefore, regardless of temperature values during thorage, SMP samples lose the brightness values faster than other dairy powders. WPC80 had some fluctuations of L* values during the shelf life, yet at the end of the shelf life the L* value dropped compared to first 2 months of the shelf life (Figure 6).

Apart from L* values, the highest increment in b* values which mainly indicates the brown pigment formation in samples were seen in MPC85 samples, where the value increased from 12.34 to 13.65 at the end of 4 months of shelf life (Table 7). The b* values of SMP and WPC80S samples did not increase in a same manner with MPC85 samples, but still there was an increment at the end of the shelf life for these powders. Overall, the a* values remained constant for all the samples, yet the values still increased.

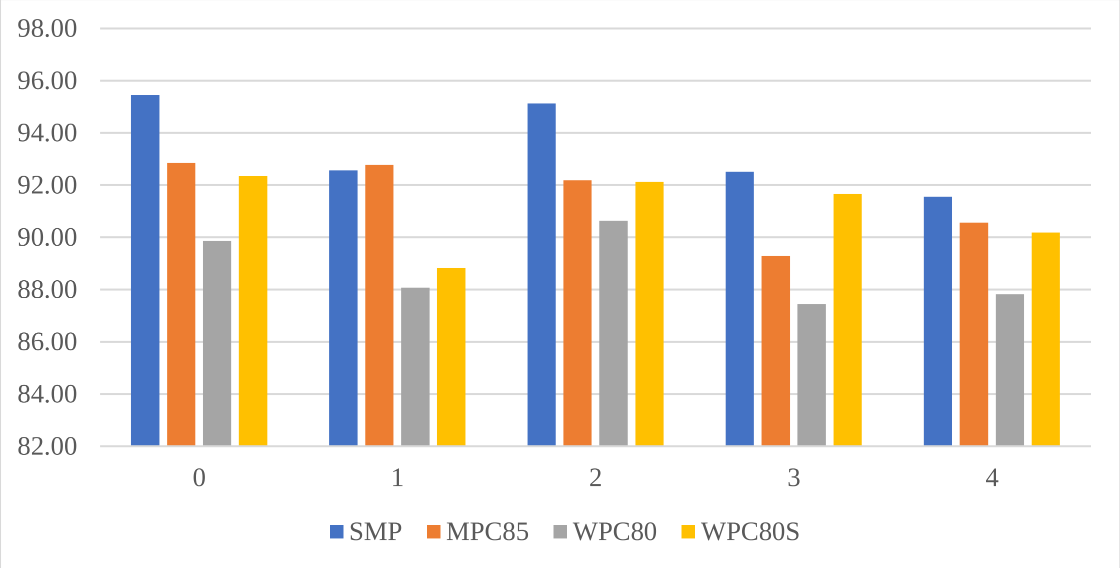



Figure 6. Results of L* values of Dairy Powders during the 4 months of storage in 25°C

Li et al (2019) conducted another study to understand the characteristics and oxidation stability of various commercial milk powders, stating that color change in powders is essential information to understand the extent of the maillard reaction. In their study, they also demonstrated that the b* and L* values are the most indicative parameters for observing the color change of milk powders during storage. In accordance with their findings, the b* values of the samples increased over the course of storage. In accordance to their findings, the b* values of the powder samples stored at 25°C were also increased, with the exception of WPC80 (Table 7). The b* value of MPC85, for instance, was found to be 12.34 at the start of the shelf life and 13.65 after 4 months of storage at 25°C. However, the increase in b* values was only observed for WPC80S in 10°C, where it went from 13.10 to 13.52 over the duration of the storage time. Accordingly, it can be suggested that storage temperature is a vital variable that has an immense impact on the color of products. Also, Li et al. (2019) suggested that color changes can be a useful factor for understanding melanoid formation during the Maillard reaction.

As shown in Tables 6 and 7, the changes in color values are dependent on time, which also reveals the reaction dynamics of the maillard reaction through storage. Wang et al. (2022) carried out a study to look into indicators of the maillard reaction, including their potential formation and alterations in infant formula products produced with various thermal treatments. Throughout the study, the influence of relative humidity at 37 degrees Celsius for 28 days was also investigated. They claimed that 37 °C would result in faster reaction rates than 25 °C because of the increased likelihood of a reaction occurring between the sugar and the amine group at higher temperatures. In this case, it is also possible to conclude that the reaction rates and the change in color values will occur more rapidly at 25°C than at 10°C, which is consistent with the shelf life results at 10°C and 25°C (Table 6 and 7). In agreement with Li et al (2019) , the authors also said that relative humidity is an important factor that affects the rate of reactions and the breakdown of products. For instance, samples stored at 37°C and relative humidity levels of more than 70% brown more quickly than those stored at lower relative humidity levels, such as 43%. They also noted that the water activity of the samples was altered by the relative humidity of storage, which in turn changed the rate of browning. Therefore, it can be concluded that at higher temperatures, browning rates will be higher, and in conjunction with high relative humidities, these rates may be quite high.

Value shifts during the 37°C storage period of samples was more pronounced than those observed at 10°C and 25°C. At the end of the four months, the L* values had dropped for all the samples. In contrast to other samples, however, the decrease was smaller in WPC80, which is shown in Figure 7. In the first 2-3 months of shelf life, the L* values showed some fluctuations, but at 3$^{rd}$ and 4$^{th}$ months, the values become more stable. All samples showed a significant reduction in L* values, also WPC80 showed a reduction but not as much as the other samples (Figure 7).

Table 8. The Color Analysis Results of Dairy Powders at 37°C during 4 months of shelf life

| | *Powder type* | | | | | |
|---|---|---|---|---|---|---|
| | SMP | | | MPC85 | | |
| *Time* | L* | a* | b* | L* | a* | b* |
| *0* | 95.44$^{A}$ | -3.34$^{B}$ | 13.10$^{A}$ | 92.85$^{A}$ | -1.37$^{B}$ | 12.34$^{A}$ |
| *1* | 92.60$^{B}$ | -2.92$^{AB}$ | 13.86$^{A}$ | 88.63$^{B}$ | -1.11$^{AB}$ | 15.33$^{A}$ |
| *2* | 94.74$^{A}$ | -2.86$^{AB}$ | 13.83$^{A}$ | 91.01$^{A}$ | -0.86$^{AB}$ | 17.56$^{A}$ |
| *3* | 91.11$^{B}$ | -2.84$^{A}$ | 13.58$^{A}$ | 88.77$^{B}$ | -0.82$^{A}$ | 16.61$^{A}$ |
| *4* | 90.87$^{B}$ | -2.85$^{A}$ | 14.02$^{A}$ | 88.96$^{B}$ | -0.44$^{A}$ | 18.22$^{A}$ |
| | Powder type | | | | | |
| | WPC80 | | | WPC80S | | |
| *Time* | L* | a* | b* | L* | a* | b* |
| *0* | 89.87$^{A}$ | -0.69$^{B}$ | 15.69$^{A}$ | 92.35$^{A}$ | -1.64$^{B}$ | 13.23$^{A}$ |
| *1* | 85.98$^{B}$ | 0.15$^{AB}$ | 19.54$^{A}$ | 88.80$^{B}$ | -1.42$^{AB}$ | 17.73$^{A}$ |
| *2* | 88.45$^{A}$ | 0.56$^{AB}$ | 22.44$^{A}$ | 90.79$^{A}$ | -1.25$^{AB}$ | 18.96$^{A}$ |
| *3* | 87.97$^{B}$ | 0.75$^{A}$ | 22.19$^{A}$ | 88.96$^{B}$ | -0.97$^{A}$ | 20.18$^{A}$ |
| *4* | 87.42$^{B}$ | 1.42$^{A}$ | 24.82$^{A}$ | 88.77$^{B}$ | -0.69$^{A}$ | 20.77$^{A}$ |

[a]The same uppercase letters in the same column mean that the samples are not significantly different ($\alpha$=0.05)

As the browning rate increased, the a* and b* values also rose for all of the samples. The greatest rise in a* and b* values was observed in WPC80, where an initial a* value of -0.69 was replaced by a value of 1.42 by the end of the 4-month period, and where an initial b* value of 15.69 was taken over by a value of 24.82. The results that are shown in Table 8 was also supported by Wang et al. (2022), who stated that higher temperatures cause more reaction rates along with higher color disruption of the products. Additionally, the water activity results were reduced during the 4 months of shelf life, with a different rate for each product based on their nutritional composition. This situation is yet a significant factor that imparts the color change.

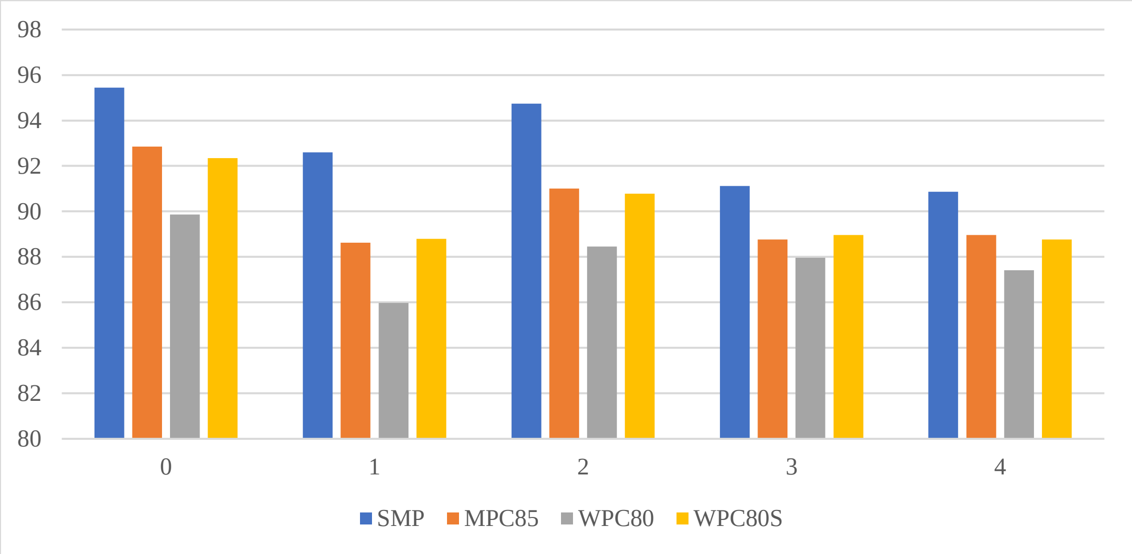



Figure 7. Results of L* values of Dairy Powders during the 4 months of storage in 37°C

As was already said, the color of dairy powders may shift for a number of reasons, including the way they are processed. Dag et al. (2022) investigated the efficacy of radio frequency assisted thermal processing in reducing microbial counts and maintaining quality in whole milk powders immersed in oil. In contrast to traditional heating methods, radio frequency heating warms items quickly and uniformly while keeping damage to minimal. The samples treated with radio frequency and those treated with radio frequency and held in a conventional oven showed the greatest efficacy in minimizing color change, especially in the L* values. However, the heat treatments had more effect on the a* and b* values than they did on the untreated samples. This means that milk powders can be heated for significantly less time using radio frequency-assisted thermal processing without suffering from any noticeable color shifts. To sum up, processing is, along with storage conditions, a crucial factor in comprehending reaction dynamics. Furthermore, with the right processing methods, products are less likely to undergo a change in color because of thermal damage.

To understand the effect of powder type, storage time and temperature on the color values, the ANOVA- General Linear model was applied. According to the results, powder type, storage time and temperature have a significant impact on L*, a* and b* values ($p<0.05$). According to the Tukey Results, L*,a* and b* values were similar in 10C and 25C conditions, however the 37C conditions are separated from those values. (Appendix A).

### 3.1.2. FTIR Analysis Results

The FTIR analysis of powders were performed every month for each temperature conditions, 10°C, 25°C and 37°C for 4 months. The results of spectra at the beginning of shelf-life study can be seen in Figure 8.

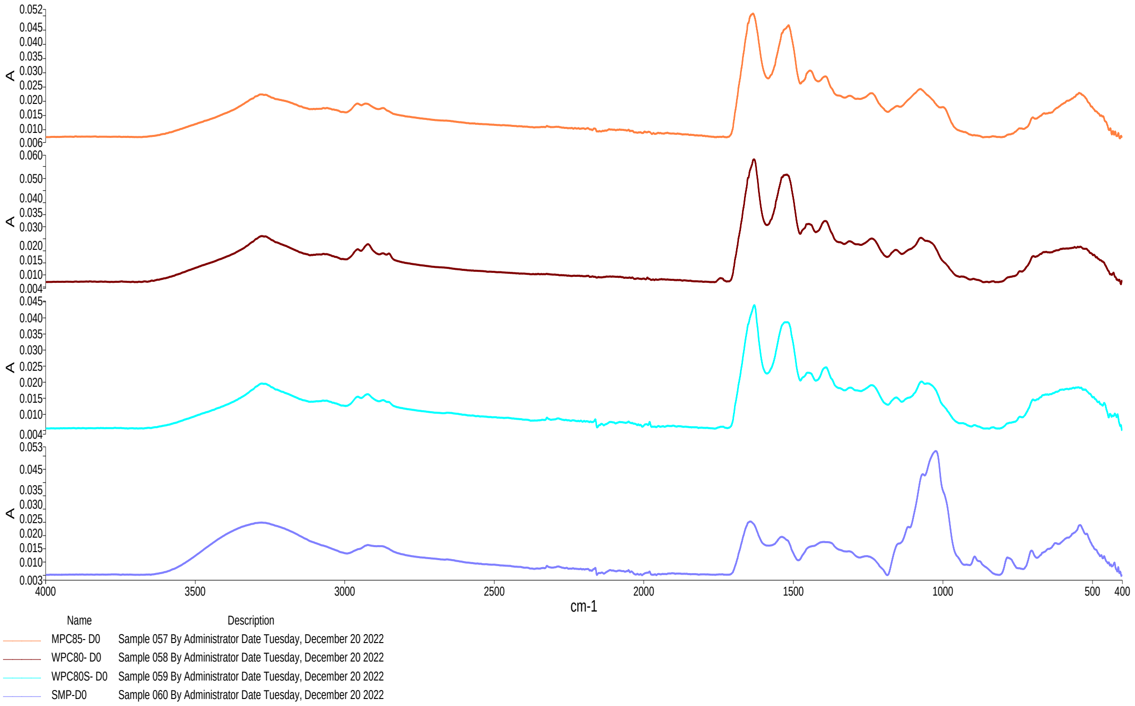



Figure 8. FTIR Results of dairy powders at the beginning of the shelf life (D0- day zero)

Due to their unique nutritional compositions, the powders displayed a wide range of peaks and absorbance values. Similar, though slightly different, peaks were seen in powders with a higher protein content, such as MPC85, WPC80, and WPC80S. Nevertheless, SMP displayed additional, larger peaks around 3000–3500 cm-1 and 1000–1200 cm-1. SMP is distinct from other powders due to its lower protein content and high lactose content, as was previously mentioned.

The critical absorption bands for dairy powders were discussed in the study by Ye et al. (2017) The protein causes the spectral bands at 1630–1680 cm-1 and 1510–

1570 cm-1, which can be attributed to the C=O stretching vibration of amide I and the N–H and C–H bending vibration of amide II. For the fat content of milk powders, other important regions were looked at, such as 2850cm-1, 2920 cm-1, and around 1740 cm-1, where the symmetric and asymmetric CH2 stretching and the C=O double-bond stretching were seen, respectively. Several absorption bands, including those at 3200-3800 cm-1, 1030-1200cm-1, 900-930 cm-1, and 755-785 cm-1, are mentioned by the authors as being relevant to carbohydrate understanding. The amide A band can be found between 3200 and 3800 cm1 and provides insight into the protein dynamics in the final products.

Figure 8 shows that the protein amide I and II bands are best resolved by powders with a higher protein content, such as MPC85, WPC80, and WPC80S, which exhibit stronger peaks in the 1630-1680 cm-1 and 1500 cm-1 ranges, respectively. The sample with the highest fat content was WPC80 (5.6%), while the sample with the lowest fat content was SMP (2%). According to Ye et al. (2017), the characteristic peaks for fat are located at around 2850, 2920, and 1740 cm-1. Figure 8 shows that there are no notable peaks in the frequency range from 2850 to 2920 cm-1. Therefore, it can be concluded that the region around 1740 cm-1 contains more prominent peaks. In this area, WPC80 has the highest absorbance around 0.5, followed by similar values for WPC80S and MPC85 around at 0.4-0.45. However, SMP has the smallest absorbance of the samples and a narrow peak, both of which are consistent with its low-fat content. Also, a study that is conducted by Al Lafi and Al Naser (2022) showed that the fat peaks around 2900-2800 cm-1 and 1200, and 1700 cm-1, and the major protein peaks around 1500-1600 cm-1 are said to become less prominent when the lactose content of milk powder is increased, which supports the results of Figure 8.

Ye et al. (2017) analyzed the spectral features of carbohydrates and identified the following peaks: 3200-3800 cm-1, 1030-1200 cm-1, 900-930 cm-1, and 755-785 cm-1. Figure 8 shows that closer inspection reveals that these areas all have higher SMP peaks than the average. It follows that the lactose in SMP produces relatively sharp and distinctive peaks in these frequency ranges. Following SMP, the highest lactose content is found in MPC85, at 4.5%. There aren't many well-defined peaks in the spectra of MPC85 between 3200 and 3800, 1030 and 1200, and 900 and 930 cm-1. However, there are more peaks in the range of 755-785 cm-1 that are similar to those of SMP, indicating that lactose gives more dominant peaks in that region.

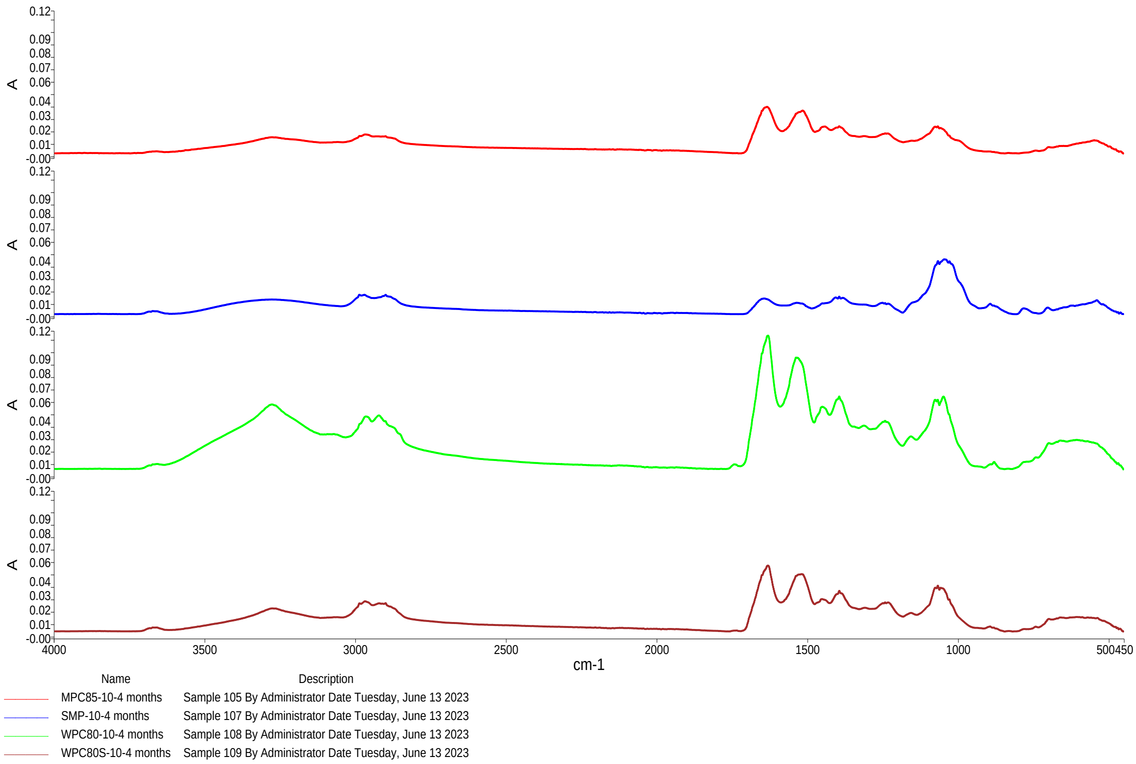



Figure 9. FTIR Results of dairy powders after 4 months of storage at 10°C

At the end of 4 months storage, a notable alteration in the spectra of the samples was observed (Figure 9). As illustrated in Figure 9, the MPC85 and SMP samples exhibited relatively flattened peaks in the 3000-3500 cm-1 range. However, at approximately 1000 cm-1, the SMP sample displayed a greater level of absorbance compared to the MPC85 sample. The peak observed at 1000 cm-1 can be attributed to the elevated lactose content present in SMP relative to the other samples. Moreover, it was observed that WPC80 exhibited a comparable spectral profile to the spectra obtained at the beginning of shelf life. However, the absorbance value at the 3000-3500 cm-1 region was determined to be 0.04, which is higher than the value of 0.02 observed in the spectra at the beginning of the shelf life (as depicted in Figure 8). The MPC85 samples exhibited reduced absorbance values at wavelengths of 3200-3800 cm-1 and 1000 cm-1 after a storage period of four months, in comparison to their absorbance values at the beginning of shelf life (Figure 8 and Figure 9). Specifically, the absorbance at 1000 cm-1 decreased from 0.02 to 0.01, suggesting a degradation of carbohydrates due to the dynamics of the Maillard reaction. Upon thorough investigation of the WPC80S spectra, it is evident that the absorbance value in the 1500-200cm-1 region is approximately 0.04 (Figure 9). However, as a fresh sample without any storage, the absorbance was found as 0.015. This finding is a noteworthy indication that alterations in protein structure occurred following a storage period of four months, and that denaturation has commenced, which is also supported by the findings of Yazdanpanah and Langrish (2013).

Yazdanpanah and Langrish (2013) have reported that the amide I region, spanning from 1600-1700 cm-1, is indicative of the secondary structure of proteins such as alpha-helix, beta-sheet, and random coils. The authors indicated that the spectral maxima observed at 1650 cm-1 and 1658 cm-1 correspond to the a-helix and a large loop of a-helix, respectively, as determined by the fitting algorithm. The observed peaks exhibit varying intensities across the powders, with SMP displaying a relatively insignificant peak in the corresponding region. This outcome can be attributed to the comparatively lower protein content of SMP in comparison to the other samples. The proteins WPC80 and WPC80S exhibit discernible peaks in specific regions, which suggest the occurrence of protein denaturation. Although MPC85 does not exhibit a discernible peak, it does not necessarily indicate the absence of denaturation. Rather, it suggests the presence of alternative structural conformations for the protein samples, as depicted in Figure 9.

Figure 10 represents the spectral changes of the powders after 4 months of storage at 25°*C*. It can be seen that SMP has a high absorbance, with a distinctive peak at 1000cm-1. The absorbance value was recorded around as 0.045 at the beginning of the shelf life, yet it decreased to around 0.035 after 4 months of storage at 25C. According to Yazdanpanah and Langrish (2013) this increase in absorbance may be related with the lactose crystallization over storage, and also a slight shifts in the peaks might be a reason of formation of different shaped lactose crystals. There are some reductions in absorbance values for MPC85, in the region of 3200-3500 cm-1, and 1500-1600cm-1, which represents the carbohydrates. For example, after 4 months of storage at 25C, the absorbance reduced to 0.015 from 0.02 at the region of 3200-3500cm-1 (Figure 8 and Figure 10), which might be related with lactose crystallization and alteration in surface composition.

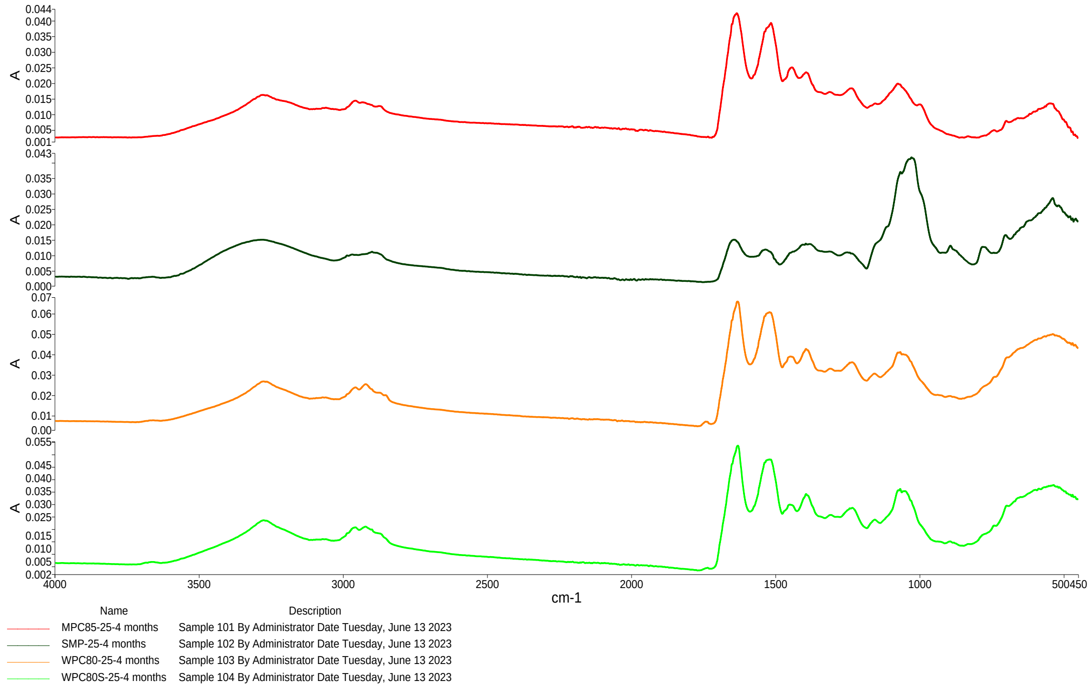



Figure 10. FTIR Results of dairy powders after 4 months of storage at 25°C

Figure 10 represents the spectral changes of the powders after 4 months of storage at 25°*C*. It can be seen that SMP has a high absorbance, with a distinctive peak at 1000cm-1. The absorbance value was recorded around as 0.045 at the beginning of the shelf life, yet it decreased to around 0.035 after 4 months of storage at 25C. According to Yazdanpanah and Langrish (2013) this increase in absorbance may be related with the lactose crystallization over storage, and also a slight shifts in the peaks might be a reason of formation of different shaped lactose crystals. There are some reductions in absorbance values for MPC85, in the region of 3200-3500 cm-1, and 1500-1600cm-1, which represents the carbohydrates. For example, after 4 months of storage at 25C, the absorbance reduced to 0.015 from 0.02 at the region of 3200-3500cm-1 (Figure 8 and Figure 10), which might be related with lactose crystallization and alteration in surface composition.

For WPC80, and WPC80S samples, the intensity of the peaks and absorbance values around 1500-2000 cm-1 has slightly changed. For instance, the absorbance was recorded around 0.03-0.035 for WPC80S at 1500-2000 cm-1 region (Figure 8), and after 4 months of storage it recorded as around 0.04-0.045 (Figure 9). These alterations might be related with protein denaturation as this region is significant for protein understanding. Also, it has been stated from Yazdanpanah and Langrish (2013) the amount of B-sheets, and coils are high in the aged powders, especially for the high-protein powders.

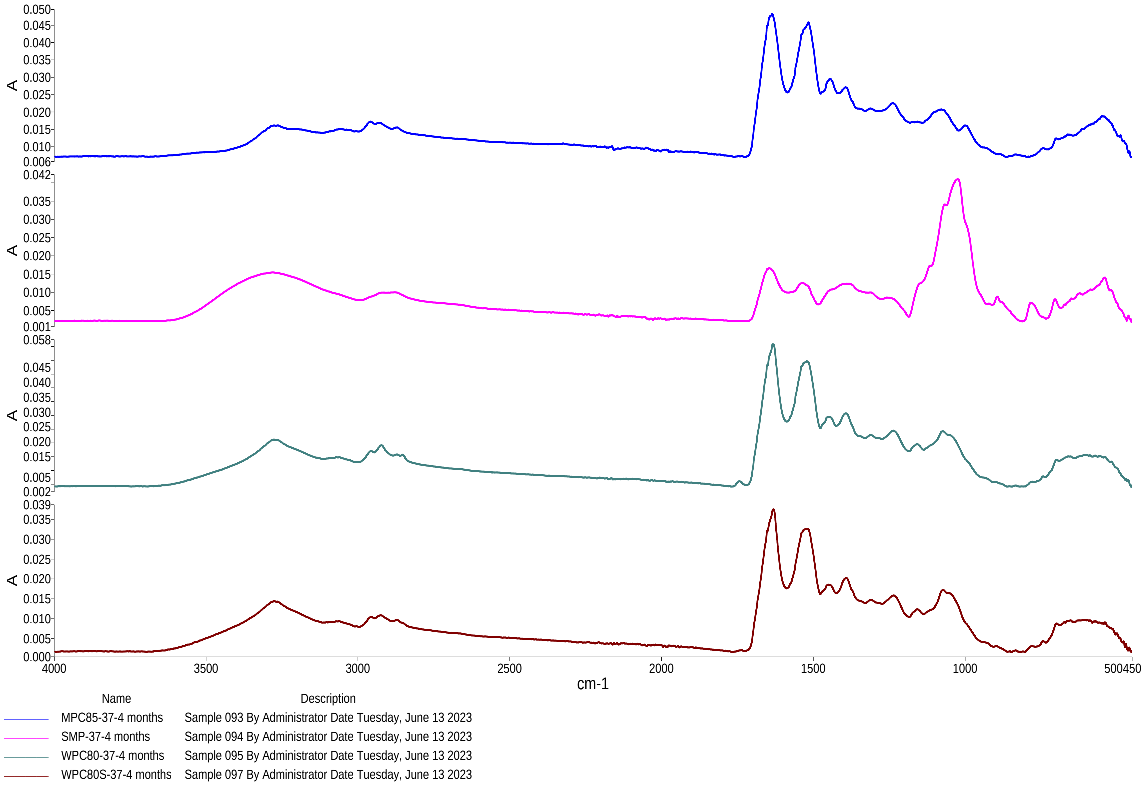



Figure 11.FTIR Results of dairy powders at 37°C after 4 months of shelf life

Figure 11 demonstrates the individual spectra of each powder subsequent to being subjected to storage conditions of 37°C for a duration of 4 months. In general, the outcomes exhibit a similarity to the spectrum outcomes of day zero, as depicted in Figure 8 and Figure 11. Nevertheless, notable alterations include modifications in peak positions and alterations in intensities at specific regions of the spectrum. At the onset of shelf life, the absorbance value for SMP in the 3000-3500 cm-1 region, which is a crucial region for carbohydrates, was documented to be between 0.02-0.025 (as illustrated in Figure 8). The results indicate that the absorbance intensity underwent a reduction to a range of 0.01-0.015 subsequent to a storage period of 4 months at a temperature of 37°C for SMP, as depicted in Figure 11. A minor reduction in intensity is observed in the 3000-3500cm-1 region for the MPC85 samples, as depicted in Figure 11. According to Lei et al (2010) the spectral region of FTIR around 3000-3600 cm-1 and 960-1200 cm-1 is where crystallized lactose is located. Consequently, it can be asserted that the lactose present in SMP and MPC85 has undergone crystallization upon storage, resulting in discernible differences in the peaks.

The absorbance intensity at the wave number range of 1600-1800cm-1 is modified for both the WPC80 and WPC80S specimens. Figure 8 illustrates that the absorbance at 1600-1800 cm-1 is approximately 0.04 and 0.035 for WPC80 and WPC80S, respectively, at the onset of their shelf life. However, it can be observed from Figure 11 that the absorbance values for WPC80 and WPC80S after a storage period of 4 months at 37C are 0.045 and 0.030, respectively. The observed outcomes can be elucidated by the relative abundance of beta-sheet and alpha-helix secondary structures within the protein composition of the specimens. According to Nasser et al (2017) it was found that during storage, there was a potential increase in the intensity of B-sheet and a decrease in alpha-helix. Hence, alterations in the protein structure over a period of time have an effect on the spectrum of the samples. Furthermore, it should be noted that there exists a discrepancy in pH levels between WPC and WPC80S, with the latter exhibiting a comparatively lower pH value than WPC80, as indicated in Table 5.

### 3.1.3. Water Activity Results

The water activity of food products is a crucial parameter for analyzing their microbial growth, stability during storage, resistance to lipid oxidation, and enzymatic and non-enzymatic activities. It has been extensively utilized to understand the quality and safety of food systems. Quantifying these reaction rates is not that easy because of their complex dynamics, but measuring water activity can give insightful information about the thermodynamic equilibrium of the food products and to understand the reaction rates. However, it is possible to state that the browning rate increases in the region of critical water activity values somewhere between 0.2 and 0.3 and that this increase persists until 0.5 to 0.8 aw. After that, the rate settles into equilibrium and drops because the reactants are diminished. In a broad perspective concerning the correlation between water activity and reaction rates, it can be posited that diminished diffusivity capacity resulting from lower water activity levels leads to a deceleration of reaction kinetics (Neutec Group nd.).

The water activity analysis was carried out in triplicate for each month, at each temperature condition (10°C, 25°C, and 37°C), during the shelf-life analysis of the products.

Table 9. Water Activity Results of SMP over 4 months

| | **SMP** | | |
|---|---|---|---|
| ***Time (m)*** | **10°C** | **25°C** | **37°C** |
| ***0*** | 0.334± 0.001[ABc] | 0.334± 0.001[ABd] | 0.334± 0.001[ABe] |
| ***1*** | 0.223 ± 0.001[Bc] | 0.235 ± 0.002[Bd] | 0.141 ± 0.001[Be] |
| ***2*** | 0.306 ± 0.001[Ac] | 0.329 ± 0.001[Ad] | 0.291 ± 0.001[Ae] |
| ***3*** | 0.275 ± 0.001[ABc] | 0.301 ± 0.001[ABd] | 0.224 ± 0.001[ABe] |
| ***4*** | 0.339 ± 0.002[ABc] | 0.368 ± 0.001[ABd] | 0.272 ± 0.001[ABe] |

[a]Results were expressed as mean ± standard deviation from 3 measurements (n = 1).
[b]The same uppercase letters in the same column mean that the samples are not significantly different (α=0.05)
[c]The same lowercase letters in the same column mean that the samples are not significantly different (α=0.05)

The water activity ($a_w$) result for SMP was 0.334 at the start of its shelf life. The value dropped significantly to 0.141 after being stored for a month at 37°C. After being stored for a month at 10°C or 25°C, the water activity decreases to roughly the same levels of 0.223 and 0.235, respectively. As shown in Figure 12, there were some variations in each temperature condition between the second and third months. Nonetheless, water activity values increased to 0.339 and 0.368, respectively, after 4 months of storage in 10°C and 25°C, but not 37°C. At 37°C, the value was found to be

0.272 at the end of the shelf life. Overall, throughout a period of four months, the water activity values remained within the desirable range of 0.3 to 0.4.

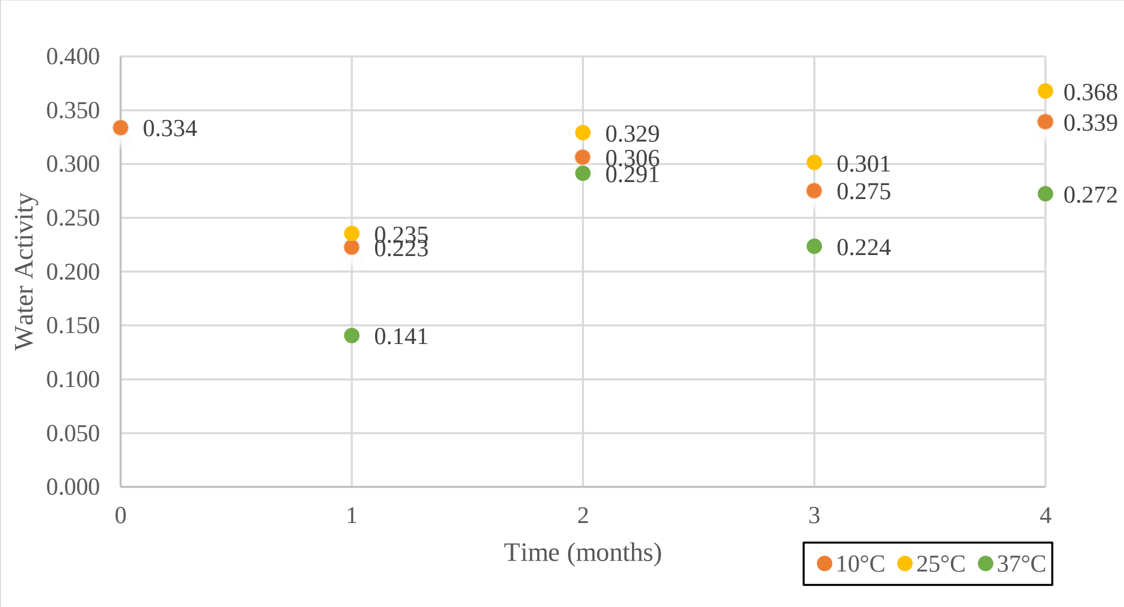



Figure 12. Water Activity (aw) Results of SMP over 4 months

The temperature has a significant effect on the dynamics of water activity. Water activity shifts as a function of temperature owing to alterations to water binding, water dissolution, solute solubility in water, and matrices state. The dynamics of the water activity is critically dependent on the matrix's state. The matrix takes on different forms depending on temperature, such as a glassy or rubbery one; this suggests that temperature has a major effect on water activity. Water activity is temperature dependent in a substance-specific manner. For some of the products, the water activity rises when the temperature rises, but for some of the products gets lower activity at higher temperatures (Neutec Group nd.). For SMP samples, it can be seen from Table 9 and Figure 12, at the end of the shelf life, the water activity decreases when storage temperature rises to 37°C, yet for 25°C the value increased compared to the beginning of the shelf life.

Ryabova, Semipyatny, and Galstyan (2023) did a study in which they looked at the effect of storage time on the properties of milk powder, they looked at the water activity values of different milk powders, including SMP. The results showed that the samples that were kept at 30°C grew after 3 months, but then the values kept going down until the end of their shelf life, which supports the results in Table 9 and Figure 12. Also, the authors found that the water activity values slightly increased at the end of the shelf life at 25°C, which endorses the results in Table 9 and Figure 12.

Table 10. Water Activity Results of MPC85 over 4 months

| | MPC85 | | |
|---|---|---|---|
| ***Time*** | **10°C** | **25°C** | **37°C** |
| ***0*** | 0.388± 0.001$^{ABc}$ | 0.388± 0.001$^{ABd}$ | 0.388± 0.001$^{ABe}$ |
| ***1*** | 0.209 ± 0.003$^{Bc}$ | 0.341 ± 0.001$^{Bd}$ | 0.156 ± 0.001$^{Be}$ |
| ***2*** | 0.451 ± 0.001$^{Ac}$ | 0.431 ± 0.001$^{Ad}$ | 0.324 ± 0.001$^{Ae}$ |
| ***3*** | 0.403 ± 0.001$^{ABc}$ | 0.366 ± 0.001$^{ABd}$ | 0.232 ± 0.001$^{ABe}$ |
| ***4*** | 0.440 ± 0.001$^{ABc}$ | 0.445 ± 0.001$^{ABd}$ | 0.168 ± 0.001$^{ABe}$ |

[a]Results were expressed as mean ± standard deviation from 3 measurements (n = 1).
[b]The same uppercase letters in the same column mean that the samples are not significantly different (α=0.05)
[c]The same lowercase letters in the same column mean that the samples are not significantly different (α=0.05)

The water activity ($a_w$) result of MPC85 was found as 0.388 at the beginning of the shelf life. Over the storage period, a drastic decrease of the value to 0.156 was seen in one month at 37°C. Nonetheless, like the same tendency of SMP, the second and third month resulted with more fluctuations in the values. At 10°C, in the second, third, and the end period of the storage, the values showed more consistency as contrast to 25°C. For 10°C and 25°C conditions, the initial water activity of 0.388 increased to 0.44, and 0.445 at the end of 4 months storage, respectively. This result was similar to SMP samples as well. In conclusion, the highest reduction is seen in 37°C conditions, and 10°C and 25°C conditions resulted with higher and more similar values, as shown in Table 10, where the values were almost overlapped.

Elevating the protein concentration within food matrices is associated with a decrease in water content, a concomitant restriction of hydrolysis, and a rise of water holding capacity. The water activity values can be utilized to estimate the amount of free water in the matrices. However, the water activity of the products may be influenced by a multitude of factors that are intricate to comprehend. The assessment of ion activity and the existence of substrates in food systems are reliable parameters for evaluation (Butré, Wierenga, and Gruppen 2014).

Despite the absence of a direct correlation between protein content and water activity, it is generally observed that a high protein content results in a low water activity. This is attributed to the ability of proteins to bind water molecules, thereby impeding hydrolysis (Butré, Wierenga, and Gruppen 2014).

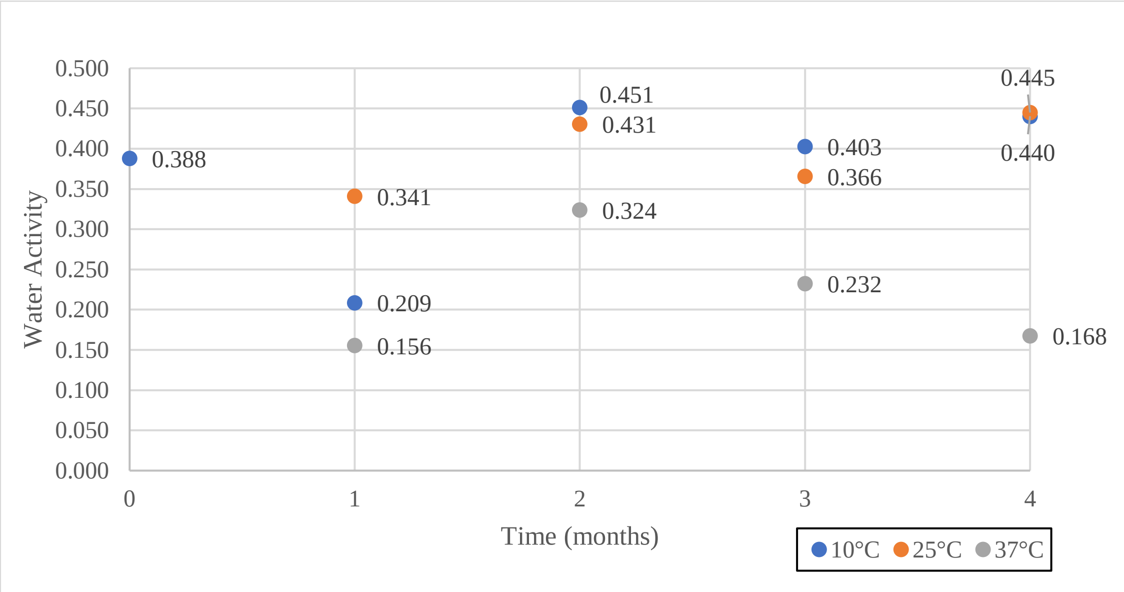



Figure 13. Water Activity (aw) Results of MPC85 over 4 months

Figure 13 shows the overall water activity results of MPC85 over 4 months and it illustrates a significant decrease in water activity at a temperature of 37°C following a storage period of four months. Thus, it can be inferred that the elevated protein content in MPC85 results in the maximum water retention capacity under 37°C conditions, leading to the lowest water activity. However, it is worth noting that over the course of the product's shelf life, the reduction did not follow a linear pattern, but rather exhibited some fluctuations, as depicted in Figure 13.

Table 11. Water Activity Results of WPC80 over 4 months

| | **WPC80** | | |
|---|---|---|---|
| **Time (m)** | **10°C** | **25°C** | **37°C** |
| **0** | 0.202± 0.001$^{ABc}$ | 0.202± 0.001$^{ABd}$ | 0.202± 0.001$^{ABe}$ |
| **1** | 0.232 ± 0.002$^{Bc}$ | 0.234 ± 0.001$^{Bd}$ | 0.182 ± 0.001$^{Be}$ |
| **2** | 0.374 ± 0.001$^{Ac}$ | 0.306 ± 0.001$^{Ad}$ | 0.301 ± 0.001$^{Ae}$ |
| **3** | 0.281 ± 0.001$^{ABc}$ | 0.262 ± 0.001$^{ABd}$ | 0.234 ± 0.001$^{ABe}$ |
| **4** | 0.284 ± 0.001$^{ABc}$ | 0.341 ± 0.001$^{ABd}$ | 0.241 ± 0.001$^{ABe}$ |

[a]Results were expressed as mean ± standard deviation from 3 measurements (n = 1).
[b]The same uppercase letters in the same column mean that the samples are not significantly different (α=0.05)
[c]The same lowercase letters in the same column mean that the samples are not significantly different (α=0.05)

Compared to SMP, and MPC85, WPC80 got lower water activity value as 0.202 at the beginning of its shelf life (Table 11). In the first month of the storage, the value slightly changed at 10°C, and 25°C. At 10°C, it slightly increased to 0.232, and at 25°C it increased to 0.234 from 0.202. As it also observed in SMP and MPC85 results (Table 9 and Table 10), in the second and third month, the variations were seen. Nevertheless, at the end of 4-month storage, the results were found as 0.284, 0.341 and 0.241 for 10°C, 25°C and 37°C conditions, respectively.

Ukuku et al. (2016) conducted a study in which they brought about the water activity and pH variations observed in WPC80 samples during shelf life. The study's findings indicate a marginal rise in water activity levels of WPC80 during a six-month storage period at 25°C. However, there was a corresponding decrease in pH values, which remained relatively stable during the final three months of the product's shelf life. Nevertheless, an increase in the relative humidity from 70% to 90% resulted in a more substantial rise in the water activity values. As similar to SMP, and MPC85, the most increase in water activity at the end of shelf life was seen at 25°C for WPC80 as well.

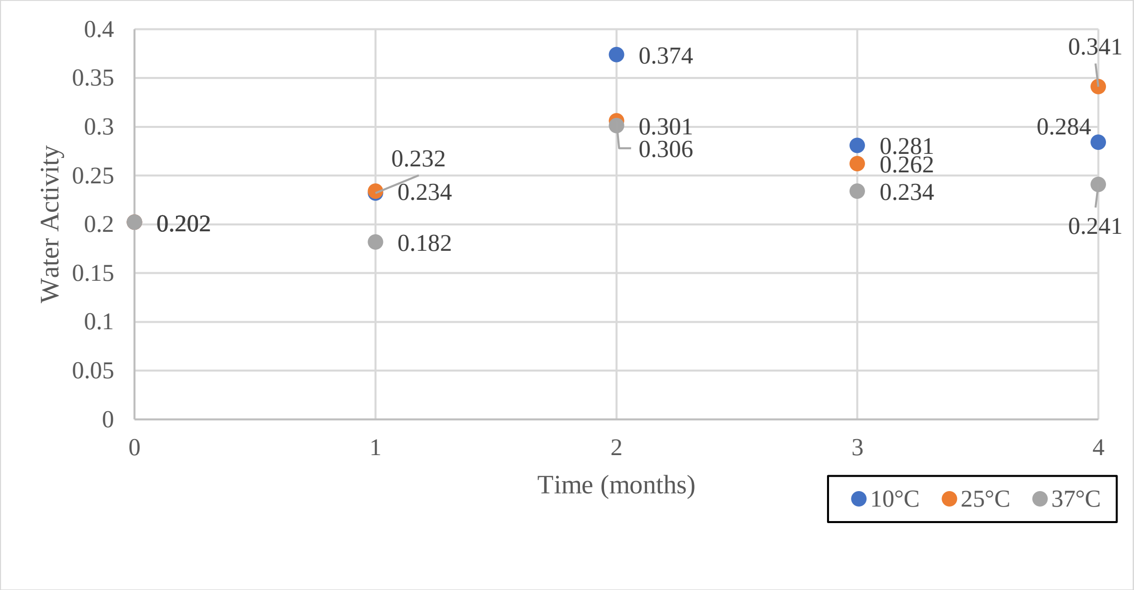



Figure 14. Water Activity (aw) Results of WPC80 over 4 months

As depicted in Figure 14, the values of the samples at 10°C and 25°C were nearly superimposed during the initial month. Furthermore, as a noteworthy outcome, it was observed that all the water activity measurements conducted under 37°C conditions exhibited an increase towards the conclusion of the shelf-life period (as presented in Table 11 and Figure 14). The observed outcome could potentially be ascribed to the higher concentration of whey protein and lower levels of casein proteins present in WPC80. The distinctive composition of WPC80 confers a reduced water holding capacity, which typically yields a higher water activity. Consequently, as the temperature increases, there is a potential increase in the solubility of proteins, resulting in a greater capacity to retain water within the food matrices. Consequently, it can be hypothesized that products containing a greater proportion of whey protein would exhibit a higher amount of water activity.

Table 12. Water Activity Results of WPC80S over 4 months

| | **WPC80S** | | |
|---|---|---|---|
| ***Time (m)*** | **10°C** | **25°C** | **37°C** |
| ***0*** | 0.318± 0.001$^{ABc}$ | 0.318± 0.001$^{ABd}$ | 0.318± 0.001$^{ABe}$ |
| ***1*** | 0.205 ± 0.001$^{Bc}$ | 0.204 ± 0.001$^{Bd}$ | 0.155 ± 0.001$^{Be}$ |
| ***2*** | 0.264 ± 0.001$^{Ac}$ | 0.291 ± 0.001$^{Ad}$ | 0.341 ± 0.001$^{Ae}$ |
| ***3*** | 0.272 ± 0.001$^{ABc}$ | 0.257 ± 0.001$^{ABd}$ | 0.221 ± 0.001$^{ABe}$ |
| ***4*** | 0.256 ± 0.001$^{ABc}$ | 0.287 ± 0.001$^{ABd}$ | 0.212 ± 0.002$^{ABe}$ |

[a]Results were expressed as mean ± standard deviation from 3 measurements (n = 1).
[b]The same uppercase letters in the same column mean that the samples are not significantly different (α=0.05)
[c]The same lowercase letters in the same column mean that the samples are not significantly different (α=0.05)

The water activity of WPC80S was initially measured as 0.318 (Table 12). The stability of water activity reduction during storage at 10°C and 25°C was comparatively higher in the given powder samples as compared to others. At a temperature of 37°C, greater fluctuations were observed in comparison to other conditions. However, after a period of four months, the water activity was determined to be 0.212.

As illustrated in Figure 15, the initial month's storage outcomes at temperatures of 10°C and 25°C exhibit a comparable pattern, while the subsequent months follow a similar trend to that of WPC80, with unique values for each month, though with varying dynamics.

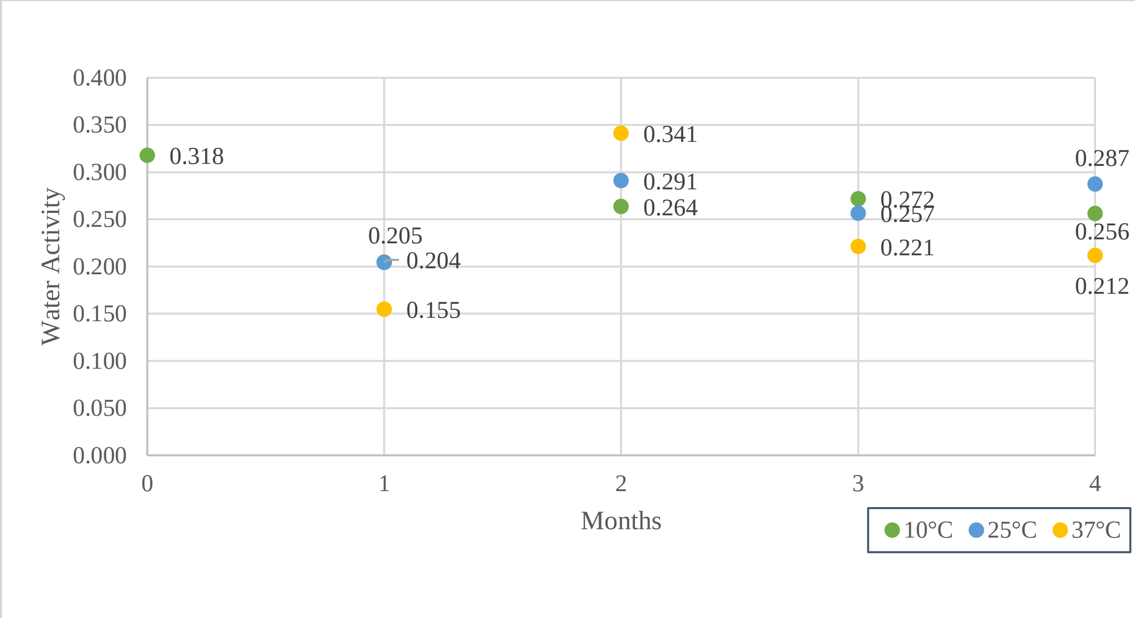



Figure 15. Water Activity (aw) Results of WPC80S over 4 months

WPC80 and WPC80S exhibit a high degree of similarity, albeit with discernible differences in their respective fat content and pH levels. Specifically, WPC80 is characterized by a relatively elevated fat content, while WPC80S is distinguished by a comparatively lower pH level. Despite the absence of substantial dissimilarities among the products, alterations in their nutritional composition and pH levels result in distinct functionalities. In contrast to WPC80, it was observed that WPC80S exhibited lower initial water activity values as illustrated in Table 11 and Table 12. However, at the end of the shelf life, all temperature conditions led to a decrease in water activity values, which was contrary to the trend observed in WPC80. The impact of various parameters on water activity has been extensively discussed in literature. Among these parameters, pH is a significant factor that affects water activity in food matrices. It has been observed that lower pH values generally result in lower water activity levels. This indication pertains to the ion activity within the system and its impact on the accessibility of unbound water molecules. As the ions diffuse further into the system, the availability of free water will become limited. However, it should be noted that these assumptions may not hold true for all food systems, as there exist numerous factors such as solute concentration that can alter the water activity (Bell and Labuza 1994, Butré, Wierenga, and Gruppen 2014).

To understand the effect of powder type, storage time and temperature, the General Linear Model- ANOVA was applied to the overall results. The results showed that all of the variances have a significant effect to determine water activity ($p<0.05$). However, the powder type was found to be most significant factor, following by storage temperature and storage time ($p<0.05$). According to the Tukey results, the powders are grouped into same category. The storage temperatures of 10C, 25C and 37C conditions are grouped into each different categories. Lastly, for the storage time, the results indicated that there is no significant difference for the values of day zero, 3$^{rd}$ month and 4$^{th}$ month ($p<0.05$). (Appendix B).

### 3.1.4. Particle Size Distribution Analysis Results

The results of the particle size distribution of dairy powders in Dx(10), Dx(50), Dx(90), D[4,3], Span, Specific Surface Area, and D[3,2] are represented each month for each powder at every temperature condition. The solution samples, with a concentration of 15% w/w, were introduced to the wet dispersion unit of the system and subjected to proper mixing to ensure complete solubility.

The Dx(10) parameter denotes the particle size at which 10% of the particles exhibit smaller dimensions, thereby indicating the lower end tail of the particle size distribution graphs. The Dx(10) parameter is utilized to comprehend the minimum dimensions of particles present within the matrices. The term Dx(50) denotes the median diameter, which represents the particle size at which 50% of the particles are smaller. The parameter Dx(50) holds significant importance as it denotes the mean particle size of the product. The Dx(90) parameter is utilized to comprehend the higher particle size fraction of the products. It indicates the proportion of the particle size below which 90% of the particles in a given sample are present (Method of Particle-Size Evaluation of Ground Material nd.)

The notation D[3,2] denotes the surface area moment mean, which provides significant insights into the specific surface area, particularly with regards to bioavailability and reactivity. This parameter is highly susceptible to the presence of fine particles in the sample matrices. The notation D[4,3] denotes the volume moment mean, a crucial parameter for comprehending the bulk characteristics of a given sample volume. The presence of larger particles within the distribution may result in variations in the value. If the bulk volume of the product needs to be understood, it is an important parameter to consider (Malvern Instruments 2015)

The span values are determined utilizing the formula below, which denotes the width range of the particle size distribution.

$$Span = \frac{Dx(90) - Dx(50)}{Dx(10)} \quad (1)$$

### 3.1.4.1. First Month Analysis Results for Each Temperature Conditions

Table 13. The Initial Particle Size Distribution Results of Dairy Powders

| Sample | Dx (10) | Dx (50) | Dx (90) | D[4,3] | Span | Specific Surface Area | D [3,2] |
|---|---|---|---|---|---|---|---|
| **SMP- D0** | 0.148 | 0.319 | 0.703 | 2.24 | 1.739 | 21910 | 0.274 |
| **MPC85- D0** | 22.8 | 98 | 209 | 109 | 1.905 | 116.7 | 51.4 |
| **WPC80- D0** | 0.758 | 15.4 | 76.4 | 29.1 | 4.9 | 1927 | 3.11 |
| **WPC80S- D0** | 0.549 | 24.2 | 76.2 | 32.3 | 3.125 | 3116 | 1.93 |

Table 13 illustrates the initial particle size distribution results of dairy powders. The Dx(10) values of the samples exhibit a range of 0.148 to 22.8 µm. The MPC85 exhibited the highest Dx(10) value, suggesting that its particle size is comparatively larger than that of the other powders. Conversely, the SMP samples exhibited the lowest

Dx(10) value, suggesting a greater concentration of fine particles within the sample. It can be asserted that 10% of the particles present in the SMP sample exhibit a size smaller than or equivalent to 0.148 µm. Both the WPC80 and WPC80S exhibited comparable Dx(10) outcomes, measuring at 0.758 and 0.549 µm, respectively.  WPC80 exhibited a larger particle size in comparison to WPC80S, while the findings indicate that WPC80S contains a greater proportion of smaller particles than WPC80.

The Dx(50) values of the samples vary from 0.319 to 98 µm. As the same trend, the lowest Dx(50) value was found as 0.319 for SMP, while the highest value was found as 98 µm for MPC85 samples. WPC80 and WPC80S did not get very similar results 15.4 was recorded for WPC80, and WPC80S got 24.2 Dx(50) value. Dx(50) values show the centralization of the particle size of the samples. Therefore, it can be concluded that the particle size of the SMP was centered around 0.319 µm, while the distribution of MPC85 was centered around 98 µm.. For WPC80, and WPC80S the center values are 15.4 and 24.2 µm, respectively. Additionally, it can be said that these values support the higher particle size of MPC85 than other samples, as the Dx(50) of 98 µm reveals that the 50% of the MPC85 particles have a size of 98 µm or smaller than that (Table 13).The dairy powders exhibit span values ranging from 1.739 to 4.9. Despite the larger particle sizes observed in MPC85 in comparison to SMP, the span values of these two powders were found to be similar, with respective values of 1.905 and 1.739. The WPC80 exhibited the highest span value, measuring at 4.9.

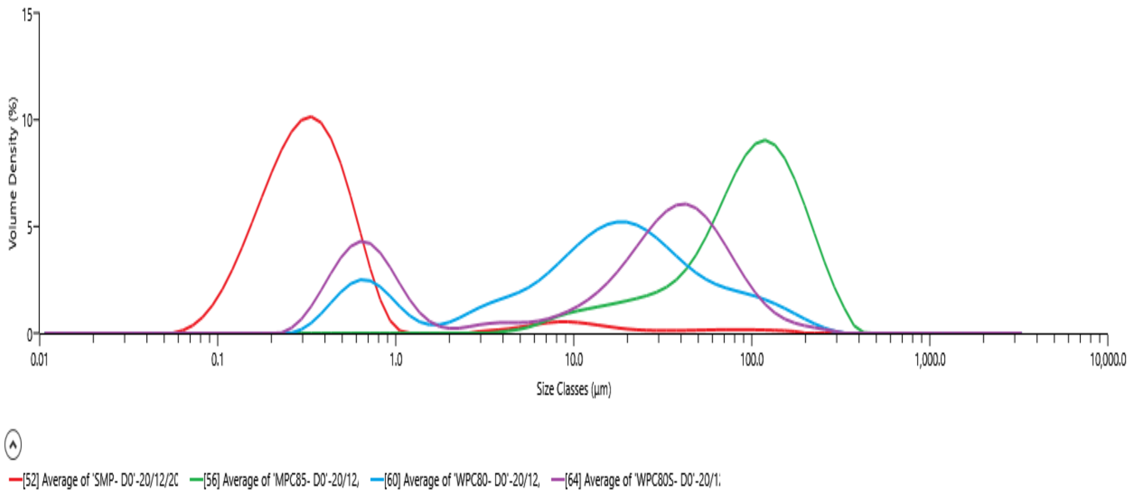



Figure 16. Initial Particle Size Distribution Results of Dairy Powders

The findings indicate that WPC80 exhibits a wider distribution in comparison to other samples, possibly due to its inconsistent structure and broad spectrum of particle size, which can be seen in Figure 16.

The distribution of particle sizes of the samples is illustrated in Figure 16. The data presented in the graph indicates that MPC85 exhibits a single, narrow peak on the right-hand side, suggesting a larger particle size in comparison to other powders. Conversely, the graph depicts that SMP is positioned on the left-hand side with comparatively smaller particle size measurements. Nevertheless, it is worth noting that SMP exhibits a more restricted peak similar to that of MPC85, thereby providing evidence for their uniform dispersion. Moreover, it is noteworthy that WPC80 and WPC80S exhibit two discernible peaks that are situated at the midpoint of the chart. The presence of two distinct wide peaks in Figure 16 indicates the likelihood of the samples containing particles with irregular shapes. Furthermore, the findings confirm the data presented in Table 13, indicating that WPC80 and WPC80S exhibited higher span values, specifically 4.9 and 3.125, respectively. As depicted in Figure 16, it is evident that while both WPC80 and WPC80S exhibit a broad distribution, the particle size distribution of WPC80S is relatively narrower than that of WPC80. This observation is further supported by the lower span value of WPC80S as compared to WPC80 (Table 13).

In a study conducted by Fournaise et al. (2021), an investigation was carried out to determine the effects of the whey/casein ratio of dairy powders on their reconstitution and flowability properties. The findings of the study indicate that the protein level and composition of the products have a significant impact on their particle size and shape. The authors posit that an increase in casein content leads to larger particle sizes, a conclusion that is supported by the data presented in Table 13. Pugliese and colleagues (2017) have reported that various SMP powders available in the market exhibit a span value range of 1.7 to 2.3, which is consistent with the findings presented in Table 13. The authors claim that the particle size is significantly influenced by the processing method, with spray-dried particles exhibiting smaller sizes compared to roller-dried samples.

In summary, it can be inferred that SMP exhibits the most diminutive particle dimensions, though with a more restricted range of particle sizes and a uniform distribution. The MPC85 exhibits higher particle dimensions, yet with a uniform dispersion that is relatively narrow. WPC80 and WPC80-S exhibit broader distributions in comparison to SMP and MPC85.

Table 14. The Particle Size Distribution Results of Dairy Powders after 1 month of storage at 10°C

| Sample | Dx (10) | Dx (50) | Dx (90) | D [4,3] | Span | Specific Surface Area | D [3,2] |
|---|---|---|---|---|---|---|---|
| **SMP-10-1st month** | 0.16 | 0.311 | 0.605 | 0.783 | 1.431 | 21570 | 0.278 |
| **MPC85-10-1st month** | 26.3 | 103 | 241 | 123 | 2.093 | 112.3 | 53.4 |
| **WPC80-10-1st month** | 5.19 | 64.3 | 189 | 82.8 | 2.868 | 804.2 | 7.46 |
| **WPC80S-10-1st month** | 0.574 | 28.2 | 84.4 | 36.1 | 2.971 | 2810 | 2.14 |

As it can be seen from Table 14, upon storage at a temperature of 10°C for a duration of one month, alterations in the particle size kinetics of the products were observed. The Dx(10) value of the SMP exhibited an increase from 0.148 µm to 0.16 µm. The Dx(50) and Dx(90) values exhibited a decrease in the same sample, however, the decrease was not significantly different. The initial span values for SMP and MPC85 were determined to be 1.739 and 1.905, respectively. Following a storage period of one month at a temperature of 10°C, the span values exhibited no significant deviation, and the values obtained for SMP and MPC85 were 1.431 and 2.093, respectively (Table 14). The findings indicate that the particle size distribution remained narrow and homogeneous for the SMP and MPC85. However, it was observed that the span values for WPC80 and WPC80S were 2.093 and 2.868, respectively, in contrast to the previous values of 4.9 and 3.125. The conclusion that can be drawn from this finding is that the distribution dynamics of the product are not very stable which may be due to the presence of agglomerated or undissolved particles.

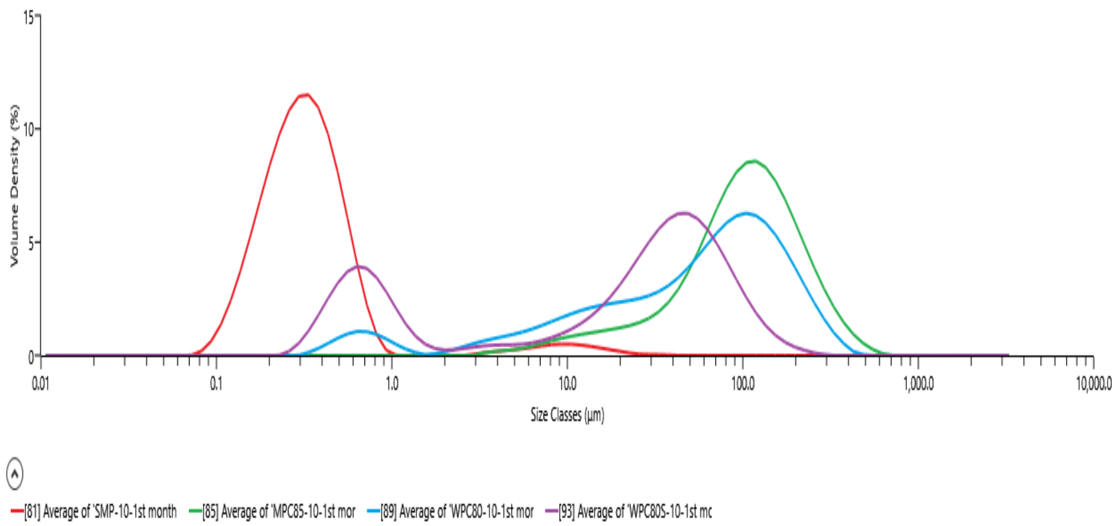



Figure 17. Particle Size Distribution Results of Dairy Powders after 1 month of storage at 10°C

Figure 17 shows the particle size distribution resulys of the powders after being stored for one month at 10°C. Especially for the WPC80, the peaks were changed, and the sample peak was relocated around the right side of the graph (Figure 17). This observation is further supported by the specific surface area measurements of the samples. Specifically, the specific surface area of WPC80 was determined to be 1927, while that of WPC80S was found to be 3116 at the beginning of the shelf life. Upon completion of the 1-month storage period at 10°C, the specific surface area of WPC80 was measured to be 804.2, whereas that of WPC80S was determined to be 2810 (Table 14). The observed reduction in specific surface area of the samples is attributed to an increase in particle size. Thus, this escalation could potentially impact their dispersion, and distribution of particle size.

Table 15. The Particle Size Distribution Results of Dairy Powders after 1 month of storage at 25°C

| Sample | Dx (10) | Dx (50) | Dx (90) | D [4,3] | Span | Specific Surface Area | D [3,2] |
|---|---|---|---|---|---|---|---|
| **SMP-25-1st month** | 0.171 | 0.354 | 0.777 | 2.15 | 1.711 | 19250 | 0.312 |
| **MPC85-25-1st month** | 26.2 | 100 | 235 | 120 | 2.086 | 110.4 | 54.4 |
| **WPC80-25-1st month** | 3.79 | 54.2 | 171 | 72.7 | 3.091 | 967.6 | 6.2 |
| **WPC80S-25-1st month** | 0.745 | 34.2 | 92.2 | 43.1 | 2.673 | 1751 | 3.43 |

After 1 month of storage at 25°C, Table 15 showed that the Dx(10) value of SMP was increased to 0.171 µm, and Dx(50) value increased to 0.354 from 0.319 µm, compared to initial values. The particle size values of MPC85 kept more stable, and only showed some small changes like an increase of Dx(50) to 100 µm from 98 µm, compared to the beginning of the shelf life. All the particle size values of WPC80 were increased drastically as a result of 1-month storage at 25°C, like an increase of Dx(50) to 54.2 µm from 15.4 µm.

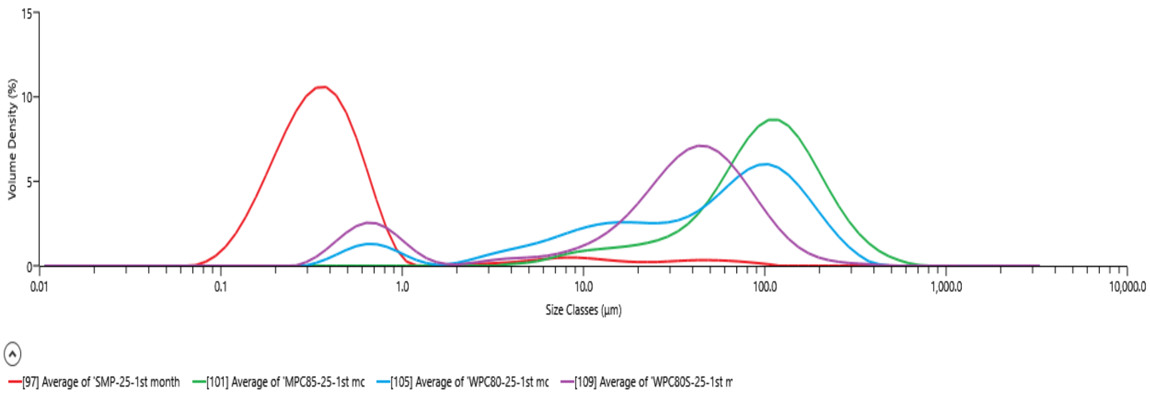



Figure 18. Particle Size Distribution Results of Dairy Powders after 1 month of storage at 25°C

The particle size distribution of the samples after being stored for a duration of one month at a temperature of 25°C is shown in Figure 18. Evidently, the SMP and MPC85 exhibit discernible and more constrained peaks relative to the remaining specimens, similar to the outcome observed under 10°C circumstances and at the onset of the shelf life. In general, it can be observed that MPC85 did not result in a significant increase in particle size. This assertion is further corroborated by the specific surface values, which did not exhibit a marked deviation from the initial measurements (Figure 18). Specifically, the specific surface value was recorded as 116.7 initially, and 110.4 after a storage period of one month at a temperature of 25°C. Regarding alterations, WPC80 exhibited a comparable pattern to that observed after one month at a temperature of 10°C. The utilization of WPC80S resulted in a notable increase in particle size, characterized by the presence of a small peak and a distinct peak located at higher particle sizes.

The most prominent alterations were observed subsequent to a storage period of one month at a temperature of 37°C, as expected (Table 16). The span value of the SMP exhibited an increase from 1.739 to 4.172. Furthermore, the Dx(50) measurement of SMP exhibits an increase to 23.9 µm, as compared to its initial value of 0.319 µm. The MPC85 sample exhibited greater stability in comparison to the other samples under consideration, though with an increase in the span value from 1.905 to 2.144. After being stored at 37°C for a month, the particle size measurements of WPC80 have exhibited an increase. For example, the Dx(50) value has risen from 15.4 µm to 53 µm, as indicated in Table 13 and Table 16. The stability of WPC80S values was

comparatively higher than that of WPC80. However, there was a marginal increase in certain values such as Dx(50), which exhibited a rise from its initial value of 24.2 μm to 32 μm.

Table 16. The Particle Size Distribution Results of Dairy Powders after 1 month of storage at 37°C

| Sample | Dx (10) | Dx (50) | Dx (90) | D [4,3] | Span | Specific Surface Area | D [3,2] |
|---|---|---|---|---|---|---|---|
| **SMP-37-1st month** | 0.315 | 23.9 | 99.9 | 37.9 | 4.172 | 5390 | 1.11 |
| **MPC85-37-1st month** | 28.3 | 106 | 255 | 129 | 2.144 | 107.8 | 55.7 |
| **WPC80-37-1st month** | 3.83 | 53 | 164 | 71 | 3.025 | 910.2 | 6.59 |
| **WPC80S-37-1st month** | 0.602 | 32 | 89.9 | 39 | 2.787 | 2531 | 2.37 |

The most prominent alterations were observed subsequent to a storage period of one month at a temperature of 37°C, as expected (Table 16). The span value of the SMP exhibited an increase from 1.739 to 4.172. Furthermore, the Dx(50) measurement of SMP exhibits an increase to 23.9 μm, as compared to its initial value of 0.319 μm. The MPC85 sample exhibited greater stability in comparison to the other samples under consideration, though with an increase in the span value from 1.905 to 2.144. After being stored at 37°C for a month, the particle size measurements of WPC80 have exhibited an increase. For example, the Dx(50) value has risen from 15.4 μm to 53 μm, as indicated in Table 13 and Table 16. The stability of WPC80S values was comparatively higher than that of WPC80. However, there was a marginal increase in certain values such as Dx(50), which exhibited a rise from its initial value of 24.2 μm to 32 μm.

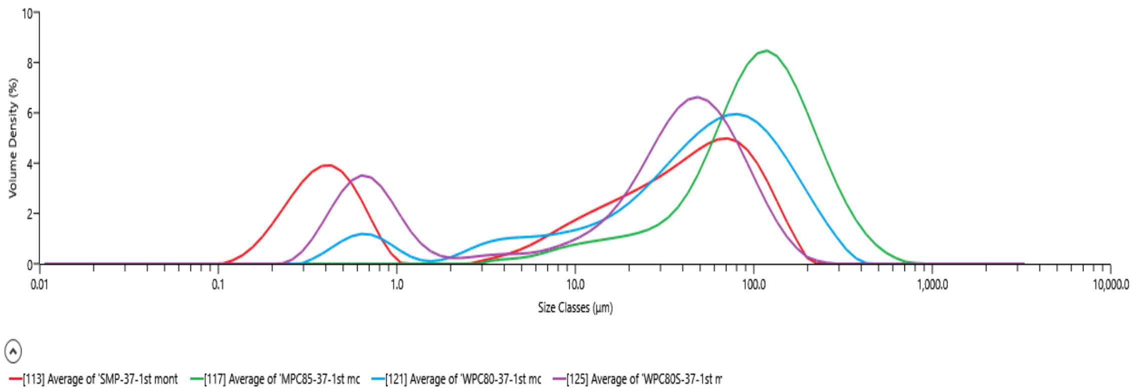



Figure 19. Particle Size Distribution Results of Dairy Powders after 1 month of storage at 37°C

Figure 19 illustrates the distribution of particle size values after 1-month storage at 37 °C. The distinctive peak of MPC85 did not change significantly from the initial state (Figure 16 and Figure 19). However, instead of one symmetric narrow peak of SMP, this figure shows two asymmetric peaks of SMP, which indicates that the volume density of particles changed. Also, the homogenous structure of the particles was disrupted after 1 month of storage at 37°C. In addition, it can be concluded that all the samples increased their particle size with wider several peaks. These results showed that 37°C conditions are harsh enough to disrupt the homogenous structure of the particles, and it might result in poor rehydration properties of the powders.

Ryabova, Semipyatny, and Galstyan (2023) reported that after 2 months of storage at 30°C, the median value of the particles started to change. They also stated that the distribution curves generally shifted right side, as an indication of an increase in particle size, as the storage time increases, which supports the trends of Figures 17,18 and 19.

### 3.1.4.2. The Fourth Month Analysis Results for Each Temperature Conditions

After the 4 months of storage at each temperature condition, the particle sizes values and distribution changed.

Table 17. The Particle Size Distribution Results of Dairy Powders after 4 months of storage at 10°C

| Sample | Dx (10) | Dx (50) | Dx (90) | D [4,3] | Span | Specific Surface Area | D [3,2] |
|---|---|---|---|---|---|---|---|
| **SMP-10-4th month** | 0.144 | 0.292 | 0.588 | 0.971 | 1.525 | 23450 | 0.256 |
| **MPC85-10-4th month** | 25.2 | 97.6 | 229 | 116 | 2.085 | 114.4 | 52.5 |
| **WPC80-10-4th month** | 3.47 | 58.9 | 159 | 71.3 | 2.636 | 969.4 | 6.19 |
| **WPC80S-10-4th month** | 0.651 | 44.2 | 99.1 | 46.7 | 2.227 | 2180 | 2.75 |

Table 17 illustrates the particle size distribution results of dairy powders after 4 months of storage at 10°C. At the end of the 4 months at 10°C, a marginal decrease in particle size values was found for SMP samples compared to 1st-month results at 10°C. For instance, the Dx(50) value of SMP decreased from 0.311 m to 0.292 µm. In addition, after being stored for 4 months at 10°C, the span value was found to increase from 1.431 to 1.525. The particle size values of the MPC85 remained more stable than those of other powders after being stored for an additional 3 months at 10°C, resulting in only some marginal decreases. WPC80 samples followed the same pattern as SMP samples, but the decline was more pronounced in the WPC80 samples. After 1 month of storage at 10°C, Dx(50) was measured to be 64.3 µm, but after another 3 months, the value dropped to 58.9 µm. WPC80S, however, displayed a distinct trend in which the particle size increased after being stored at 10°C for an additional three months. For instance, after 1 month of storage at 10°C, the sample's Dx(50) value was 28.2 µm, while after 4 months of storage at the same temperature, it was found to be 44.2 m. Additionally, the span value was found to decrease from 2.971 to 2.227 (Tables 14 and 17).

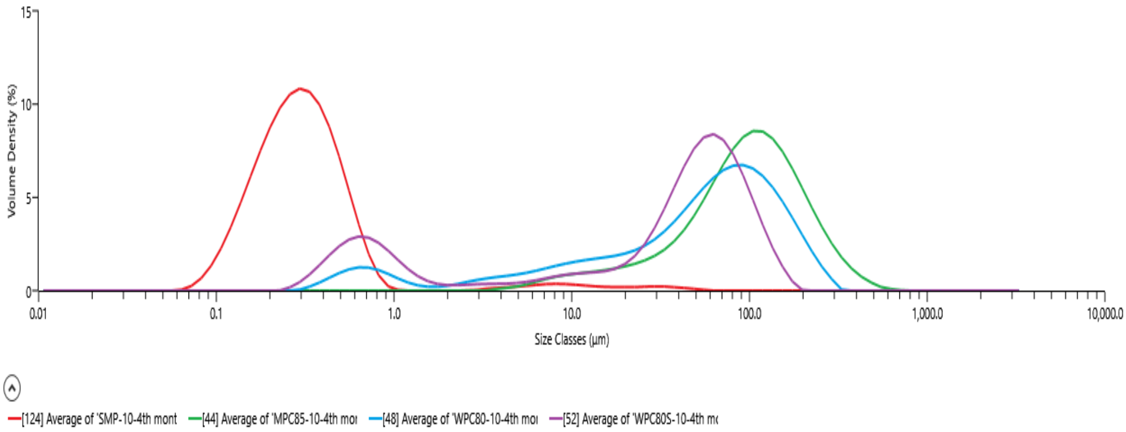



Figure 20. Particle Size Distribution Results of Dairy Powders after 4 months of storage at 10°C

Figure 20 shows the particle size distribution of the powders after 4 months of storage at 10°C. The distribution of SMP consists of one big and narrow peak, with a negligible peak around 10 µm, which looks alike the SMP peaks of Figure 16 and Figure 18, which represents the results of the beginning of shelf life, and results of storage at 25°C for 1 month. Compared to Figure 17, which represents the result of storage at 10°C for 1 month, it can be concluded that the distribution of WPC80 becomes narrower, which indicates a more homogenous structure of the particles. Furthermore, the same trend is also seen for WPC80S, with a narrower distribution of particles. Also, compared to Figure 17, it can be concluded that the particle size of WPC80 increased. MPC85 kept remained more stable in terms of distribution, and as well as the particle sizes.

Table 18. The Particle Size Distribution Results of Dairy Powders after 4 months of storage at 25°C

| Sample | Dx (10) | Dx (50) | Dx (90) | D [4,3] | Span | Specific Surface Area | D [3,2] |
|---|---|---|---|---|---|---|---|
| **SMP-25-4th month** | 0.155 | 0.322 | 0.709 | 1.33 | 1.721 | 21210 | 0.283 |
| **MPC85-25-4th month** | 24.6 | 97.5 | 232 | 118 | 2.129 | 116.8 | 51.4 |
| **WPC80-25-4th month** | 2.38 | 32.6 | 147 | 57.1 | 4.445 | 1168 | 5.14 |
| **WPC80S-25-4th month** | 0.447 | 31.6 | 82.4 | 33.4 | 2.595 | 4824 | 1.24 |

When comparing the results of fourth months of storage at 25°C with those of one month of storage at the same temperature (Table 15), it is clear that the particle size of SMP decreases during this time (Table 18). The findings indicate a reduction in particle size measurements, specifically a decline in Dx(50) from 0.354 µm to 0.322 µm. The span values remained relatively consistent, with a recorded value of 1.711 after 1 month of storage and 1.721 after 4 months of storage at a temperature of 25°C. The MPC85 exhibited consistent trends across various temperature conditions, demonstrating greater stability in particle size and span values. The temperature conditions did not significantly disrupt the distribution of particle size and homogeneity of the particles over time. After an additional 3 months of storage at 25°C, it was observed that the particle size values of the powders decreased, however, not all the span values exhibited a decrease. As demonstrated in Table 15 and Table 18, the span value of WPC80 stored at 25°C increased from 3.091 after one month to 4.445 after four months. Consequently, it can be posited that the dispersion of the particles is expanded, and the potential for agglomeration may impact the uniformity of the particles throughout their duration on the shelf.

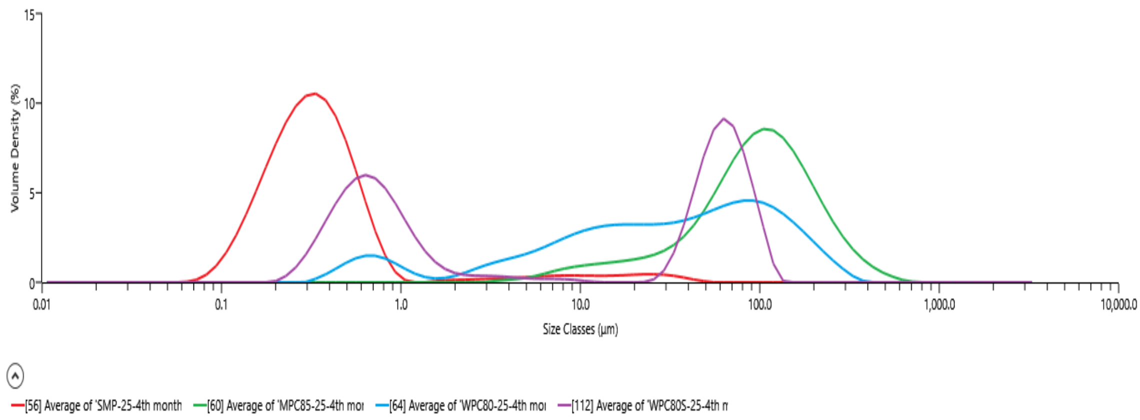



Figure 21. Particle Size Distribution Results of Dairy Powders after 4 months of storage at 25°C

The particle size distribution of the dairy powders subsequent to a storage period of 4 months at a temperature of 25°C is shown in Figure 21. The graph depicts that SMP is maintaining its singular and prominent peak in the graphical representation. In contrast to Figure 18, which illustrates the outcomes of storing for a month at 25°C, the distribution of WPC80 was observed to be broader with more asymmetrical peaks, as evidenced by its increased span value. Another observation indicates that particle size of WPC80S increase, and peaks showed more prominently. However, it can be observed that the distribution of WPC80S tends to become more homogeneous after a storage period of 4 months at 25°C, as depicted in Figure 21.

The alteration of particle size is a significant factor that has a direct impact on the rehydration characteristics of powders. According to Zhang et al.'s research (2020), it was observed that particles of smaller size exhibit superior rehydration properties, particularly in terms of wettability and solubility. Additionally, it has been asserted that the diffusion of diminutive molecules, such as water, may occur at a greater velocity in particles of smaller dimensions as opposed to those of larger dimensions. The above findings hold significant implications for the food industry, particularly in the context of utilizing powders as fortifying agents, texturizing agents, and the like. It is crucial to comprehend the dynamics of hydration over time and make necessary adjustments to maintain the quality of the final product within acceptable limits and avert any potential quality defects.

Table 19. The Particle Size Distribution Results of Dairy Powders after 4 months of storage at 37°C

| Sample | Dx (10) | Dx (50) | Dx (90) | D [4,3] | Span | Specific Surface Area | D [3,2] |
|---|---|---|---|---|---|---|---|
| **SMP-37-4th month** | 0.155 | 0.322 | 0.726 | 1.29 | 1.775 | 21210 | 0.283 |
| **MPC85-37-4th month** | 27 | 96.9 | 238 | 119 | 2.18 | 116.8 | 51.4 |
| **WPC80-37-4th month** | 2.26 | 57.7 | 159 | 71 | 2.723 | 1168 | 5.14 |
| **WPC80S-37-4th month** | 0.463 | 29.7 | 86.3 | 34.3 | 2.892 | 4824 | 1.24 |

In comparison to the storage outcomes of the initial month at a temperature of 37°C, as demonstrated in Table 16, it was observed that all the particle size measurements of SMP exhibited a decrease, as it shown in Table 19. Additionally, a reduction from 4.172 to 1.775 was observed in the span values. The data presented in Figure 19 indicates that SMP exhibited two asymmetrical peaks, and its particle size distribution was heterogeneous. However, as depicted in Figure 22, it can be asserted that a solitary narrow peak is present, indicating the homogeneous structure of the particles. Conversely, the MPC85 particle size measurements remained relatively consistent with the findings presented in both Table 16 and Table 19. A reduction in particle size measurements was observed for both WPC80 and WPC80S. The span values of WPC80 and WPC80S were measured at the end of a 4-month period at a temperature of 37°C. The recorded values were 2.723 and 2.892, respectively. Additionally, after 1 month of storage at the same temperature, the span values for WPC80 and WPC80S were found to be 3.025 and 2.787, respectively. Table 13 presents the span values of 4.9 and 3.125 for WPC80 and WPC80S, respectively, at the onset of their shelf life. Hence, it can be posited that the particle size and distribution underwent modifications over time.

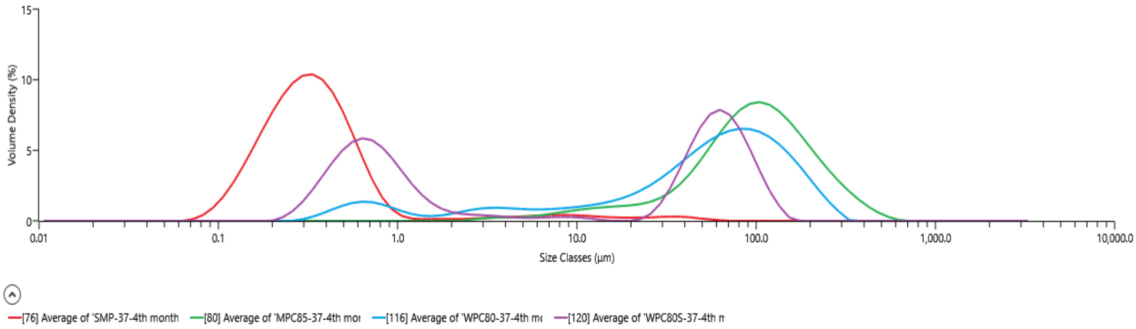



Figure 22. Particle Size Distribution Results of Dairy Powders after 4 months of storage at 37°C

The findings of the particle size distribution analysis of the powders following a storage period of 4 months at a temperature of 37°C are shown in Figure 22. Despite the fact that the span values of MPC85 did not undergo significant changes over time, there is observable evidence indicating a tendency for MPC85 particles to exhibit a wider distribution as time progresses. In addition, it was observed that the WPC80 samples exhibited the most asymmetric peaks characterized by the possible presence of particles with irregular shapes.

In the study of Kang et al (2022), different infant milk formulas were studied. Their results indicated that different brand product exhibit various functionalities over the storage time. However, a similar trend of the results of our study was seen there that every particle showed some fluctuations in terms of particle sizes, then most of them increased or remain stable.

### 3.1.5. Turbidity Results

Turbidity refers to the extent of clarity of a liquid, given by the presence of suspended particles that scatter or absorb light. The phenomenon in question pertains to the optical properties of water and involves quantifying the extent to which light is diffused by substances present in each water sample when illuminated by a light source. Turbidity is directly proportional to the intensity of scattered light. Turbidity is a phenomenon that results in the cloudiness or opacity of water (Turbidity and Water | U.S. Geological Survey 2019).

Table 20. Overall Turbidity Results of Dairy Powders during 4 months of storage

| | **Powder type** | | | | | |
|---|---|---|---|---|---|---|
| | **SMP** | | | **MPC85** | | |
| **Time** | **10°C** | **25°C** | **37°C** | **10°C** | **25°C** | **37°C** |
| **0** | $3.425^{Ac}$ | $3.425^{Ad}$ | $3.425^{Ae}$ | $3.112^{Ac}$ | $3.112^{Ad}$ | $3.112^{Ae}$ |
| **1** | $3.357^{Ac}$ | $3.189^{Ad}$ | $3.000^{Ae}$ | $3.097^{Ac}$ | $3.370^{Ad}$ | $3.102^{Ae}$ |
| **2** | $3.379^{Ac}$ | $3.359^{Ad}$ | $3.438^{Ae}$ | $3.134^{Ac}$ | $2.959^{Ad}$ | $2.699^{Ae}$ |
| **3** | $2.667^{Bc}$ | $2.655^{Bd}$ | $2.652^{Be}$ | $2.521^{Bc}$ | $2.523^{Bd}$ | $2.415^{Be}$ |
| **4** | $3.516^{Bc}$ | $2.525^{Bd}$ | $2.557^{Be}$ | $2.394^{Bc}$ | $2.496^{Bd}$ | $2.348^{Be}$ |
| | **Powder type** | | | | | |
| | **WPC80** | | | **WPC80S** | | |
| **Time** | **10°C** | **25°C** | **37°C** | **10°C** | **25°C** | **37°C** |
| **0** | $3.067^{Ac}$ | $3.067^{Ad}$ | $3.067^{Ae}$ | $1.915^{Ac}$ | $1.915^{Ad}$ | $1.915^{Ae}$ |
| **1** | $3.042^{Ac}$ | $2.874^{Ad}$ | $3.268^{Ae}$ | $1.857^{Ac}$ | $2.278^{Ad}$ | $2.308^{Ae}$ |
| **2** | $3.079^{Ac}$ | $3.003^{Ad}$ | $2.070^{Ae}$ | $1.570^{Ac}$ | $1.943^{Ad}$ | $1.749^{Ae}$ |
| **3** | $2.465^{Bc}$ | $2.502^{Bd}$ | $2.474^{Be}$ | $1.567^{Bc}$ | $1.555^{Bd}$ | $1.602^{Be}$ |
| **4** | $2.466^{Bc}$ | $2.458^{Bd}$ | $2.511^{Be}$ | $1.552^{Bc}$ | $1.535^{Bd}$ | $1.579^{Be}$ |

[a]The same uppercase letters in the same column mean that the samples are not significantly different (α=0.05)
[b]The same lowercase letters in the same column mean that the samples are not significantly different (α=0.05)

The turbidity results were found to be unique for each powder, as it is shown in Table 20. At the beginning of shelf life, the turbidity values are found as 3.425, 3.112, 3.067 and 1.915 for SMP, MPC85, WPC80 and WPC80S, respectively. The WPC80S sample had a very low intense color as visual compared to other powders. This might be a result of its processing technique, and the low pH composition.

After 4 months of storage, the turbidity of SMP samples that kept at 25°C and 37°C did not show significant changes, as it is found as 2.525 and 2.557, respectively. However, after 4 months storage at 10°C, the turbidity is increased to 3.516 from 3.425 (Table 20). For all the MPC85 samples, 4 months of storage led to a reduction of turbidity values. Nonetheless, the highest reduction was seen for 37°C as it is reduced to

2.348 from 3.112. For the WPC80 and WPC80S samples, same trend with MPC85 was seen that all the turbidity values reduced upon the 4 months of storage. For both of them, highest reduction is recorded for the samples of 25°C conditions. For WPC80, the value decreased to 2.458 from 3.067, and to 1.535 from 1.915 for WPC80S.

Gaiani et al. (2009) studied the using a turbidity sensor to understand the rehydration properties of dairy powders. Their results revealed that turbidity is important to understand the rehydration properties of the powders. For instance, their turbidity results indicate that when the particle size is increased, the turbidity values are decreased. This indication is supported by the results of Table 13, Table 17, Table 18 and Table 19. Over the storage of these powders, at 10°C conditions, SMP was the only powder that has reduced particle size. However, the particle size of other samples were increased after 4 months of storage at 10°C (Table 13 and Table 17). Therefore, the increase in turbidity of SMP is expected after 4 months of storage at 10°C (Table 20). For the other powders, the particle size increased for all over the temperature conditions, and parallely the turbidity values decreased (Table 13, 17,18, 19 and 20).

Low turbidity is preferable from the industry as the translucent appearance of the powders indicate more uniform distribution, and better rehydration properties. Orlien et al (2010) investigated the casein micelles dissociation in skim milk powder during high-pressure treatment. The authors showed that innovative techniques like high pressure treatment helped to reduce turbidity of milk. They suggested that for any sort of variation like temperature and pH of the products, high pressure help to ensure micelle dissociation. Therefore, it can be said that these types of novel techniques can be widely used to improve turbidity profiles of the powders.

To understand the effect of all variations (powder type, storage time and temperature), the General Linear Model-ANOVA is applied. The results revealed that powder type and storage time has a significant impact on turbidity, yet storage temperature does not have a significant impact on turbidity values. The Tukey Results showed that the significant difference of the values recorded for 3$^{rd}$ and 4$^{th}$ month results. For the storage temperature conditions, no significant difference is found ($p<0.05$) (Appendix C).

## 3.2. Labneh Analysis Results

For the labneh samples, different analyses include color analysis, FT-IR analysis, texture analysis, rheology analysis and sensory analysis were conducted.

### 3.2.1. Color Analysis Results

At the beginning and end of the powders' shelf life, powders were used to produce labneh. Color analysis was applied to understand how powders' storage conditions have an impact on the quality of the final product as labneh. Color values of each respective powder's labneh sample can be seen in Table 21.

Table 21. The Color Values of Labneh Samples that were prepared with dairy powders from 10°C conditions

| | **L-SMP** | | | **L-MPC85** | | |
|---|---|---|---|---|---|---|
| **Sample** | L* | a* | b* | L* | a* | b* |
| **1** | 95.34 | -3.00 | 13.25 | 93.85 | -1.23 | 12.89 |
| **2** | 92.85 | -2.34 | 13.36 | 91.34 | -1.38 | 12.46 |
| | **L-WPC80** | | | | **L-WPC80S** | |
| **Sample** | L* | a* | b* | L* | a* | b* |
| **1** | 90.01 | -0.89 | 14.87 | 92.68 | -1.62 | 13.95 |
| **2** | 88.23 | -1.10 | 15.3 | 90.69 | -1.47 | 14.20 |

(1: the sample prepared with fresh powder samples at the beginning of the shelf life, 2: the sample that is prepared with the same powders after 4 months of storage at 10°C)

Table 21 shows the results of color values for labneh samples that were prepared with all respective powders at the beginning and at the end of their shelf life. The results showed storage effect on all the powders impacted the final product as well in terms of lightness, which is shown by L*. The biggest reduction after 4 months of storage of the powder was seen for the labneh samples that are fortified with SMP, which is an indication that is supported by Table 6. The increase in a* and b* values of the labneh samples indicates a browning reaction. However, because the storage temperature is not high, can be almost classified as chilled conditions, the change in the values, and consequently rate of the reaction is slower.

In the study of Tarakci, Temiz and Ugur (2010), incorporation of different herbs into labneh was studied. Their control sample results revealed that the processing technique and the ingredients are main factors that affect the color scale of labneh. For example, their control samples have L* values are around 87.9-88.3, a* values are around -3, and b* values are around 11-12. Although some of the values are close to what it is shown in Table 1, there are some differences. For example, L-WPC80 and L-WPC80S showed higher b* values around 14-15, because the products resulted in yellower color due to high levels of whey protein concentrate.

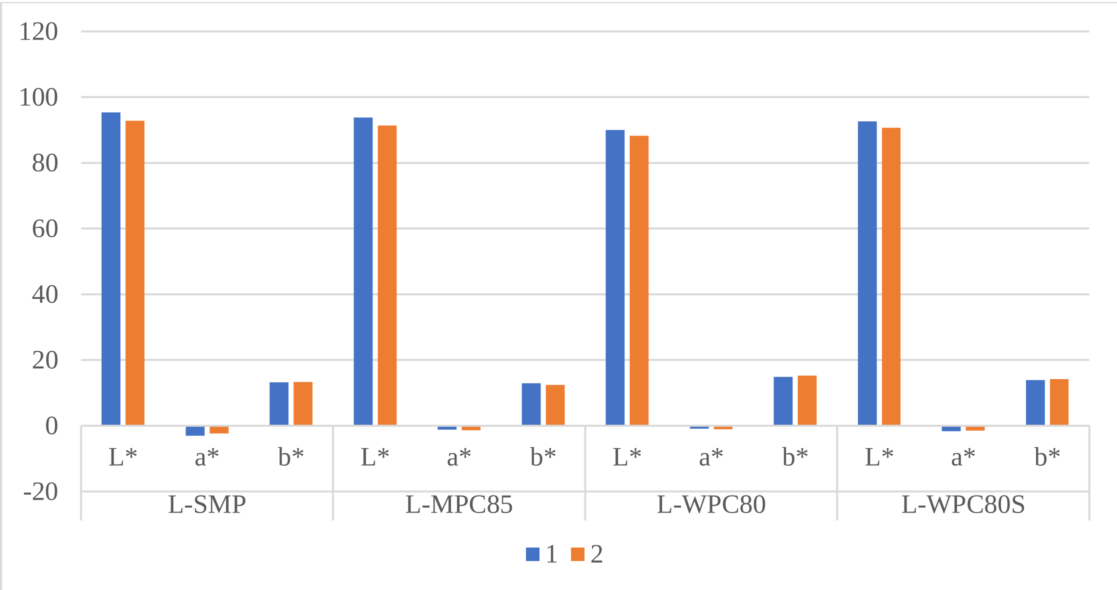



Figure 23. The Color Values of Labneh Samples that were prepared with dairy powders from 10°C conditions at the beginning and end of their shelf life

*((1: the sample prepared with fresh powder samples at the beginning of the shelf life, 2: the sample that is prepared with the same powders after 4 months of storage at 10C)*

Figure 23 represents the color values of the labneh samples, and their tendency to change with the fortification of fresh powders and 4-month-old powders. It can be understood from Figure 1 that even though there are some observed changes in b* values from Table 21, these changes are not predominantly seen from figure 1 as a significant increase or decrease. Nonetheless, the change in a* values look more distinctive.

To understand the exact color change over time, the delta E values of the samples over 4 months of storage of powders were calculated as well. The formula is:

$$\Delta E = \sqrt{(\Delta L *)^2 + (\Delta a *)^2 + (\Delta b *)^2} \qquad (2)$$

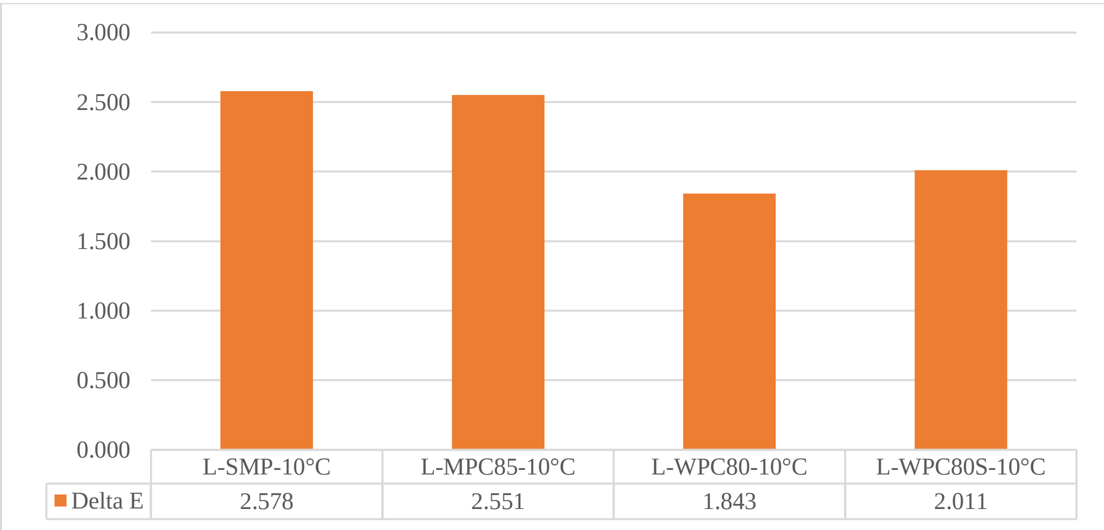



Figure 24. Delta E values of Labneh Samples that were prepared with dairy powders from 10°C conditions

The Delta E values denote the alteration observed between the labneh samples that were produced using newly acquired powders and those that were prepared by utilizing powders that had been stored for a duration of four months. The values obtained were 2.578 for L-SMP, 2.551 for L-MPC85, 1.843 for L-WPC80, and 2.011 for L-WPC80S (Figure 24). Schuessler provides an explanation for the Delta E values. The human eye is unable to perceive values that are less than or equal to 1. Values falling within the range of 1-2 can be perceived through close observation, while those within 2-10 can be perceived at a glance. When values fall within the range of 11-49, the colors are more similar than they are opposite. A value of 100 indicates that the colors are precisely opposite to each other (Daniel 2021).

Based on the given description, it can be inferred that alterations in the color properties of labneh samples are readily apparent. However, the most significant alteration was observed in L-SMP samples, potentially attributable to the higher lactose content relative to other powders, resulting in a heightened incidence of browning. However, the L-MPC85 exhibited a comparable delta E value to that of the SMP. The L-WPC80 and L-WPC80S exhibited a higher degree of similarity in their delta E values, which can be attributed to their closely matched nutritional composition and comparatively lower sugar content in comparison to the other samples.

Table 22. The color values of labneh samples that were prepared with dairy powders from 25°C conditions

| | **L-SMP** | | | **L-MPC85** | | |
|---|---|---|---|---|---|---|
| **Sample** | L* | a* | b* | L* | a* | b* |
| **1** | 95.34 | -3 | 13.25 | 93.85 | -1.23 | 12.89 |
| **2** | 91.02 | -1.99 | 14.43 | 90.85 | -1.07 | 13.55 |
| | **L-WPC80** | | | **L-WPC80S** | | |
| **Sample** | L* | a* | b* | L* | a* | b* |
| **1** | 90.01 | -0.89 | 14.87 | 92.68 | -1.62 | 13.95 |
| **2** | 87.56 | 1.20 | 16.35 | 88.15 | 0.98 | 15.78 |

(1: the sample prepared with fresh powder samples at the beginning of the shelf life, 2: the sample that is prepared with the same powders after 4 months of storage at 25°C)

The L* values of labneh samples prepared using 25°C powders exhibited a greater reduction in comparison to those prepared using 10°C powders across all samples. For example, Sample 2 of labneh, which was prepared using SMP at a temperature of 10°C, exhibited a L* value of 92.85 (Table 22). Sample 2 of the L-SMP, as presented in Table 2, exhibited a decrease in L* value to 91.02. Similarly, there has been an observed rise in the b* values across all samples, surpassing the findings presented in Table 22. Upon examination of the color value alterations in said powders (Table 7), it becomes evident that the degree of change is directly proportional to the resultant product.

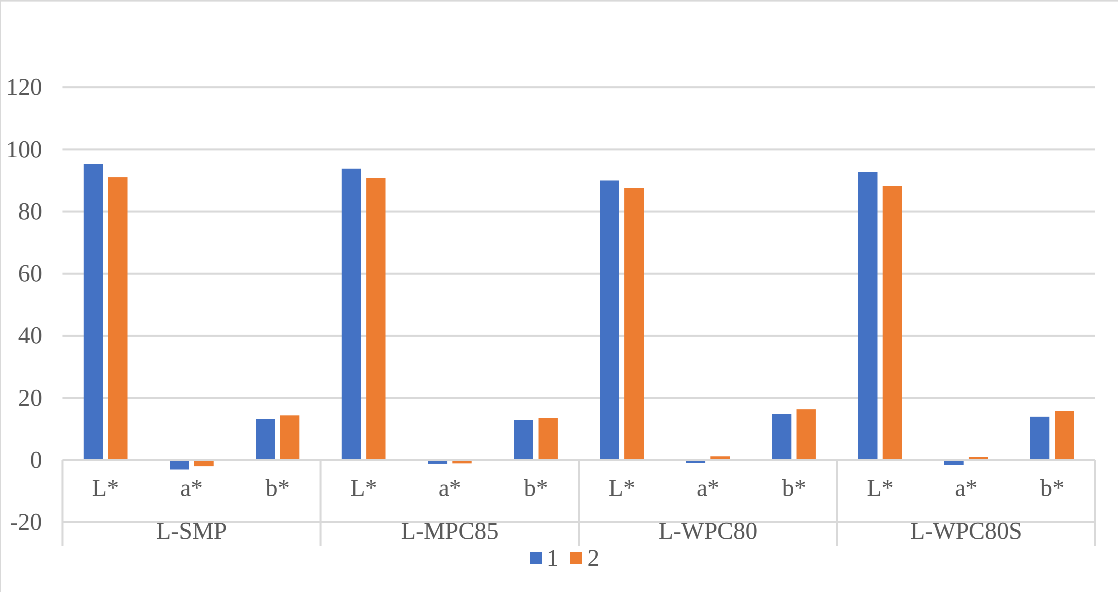



Figure 25. The Color Values of Labneh Samples that were prepared with dairy powders from 25°C conditions at the beginning and end of their shelf life

*((1: the sample prepared with fresh powder samples at the beginning of the shelf life, 2: the sample that is prepared with the same powders after 4 months of storage at 25°C)*

The results depicted in Figure 25 indicate that the incorporation of SMP and MPC85 into the labneh samples led to the attainment of the highest L* values. The utilization of 4-month-old powders in the formulation resulted in an increase in the b* values for all of the labneh samples. However, as indicated in Table 22, the utilization of WPC80 in the formulations results in the highest b* value for both sample 1 and sample 2.

The utilization of dairy powders is a widely recognized practice due to their texturizing and emulsifying properties, as well as their significant nutritional compositions. The impact of the addition of skim milk powder to fat-free goat milk on the sensorial and functional properties of the final product was investigated by Bruzantin et al (2016). The study findings indicated that the inclusion of skim milk powder had a positive impact on both the total solids-non-fat (SNF) and total protein levels of the product. Additionally, it was suggested that the incorporation of skimmed milk powder at an amount of 4.65% resulted in an enhancement of the product's viscosity. Furthermore, during the sensory evaluation, it was reported that the incorporation of skim milk powder in goat milk yogurt resulted in noteworthy ratings for both texture and flavor attributes, while obtaining the least score for bitterness in comparison to the remaining samples.

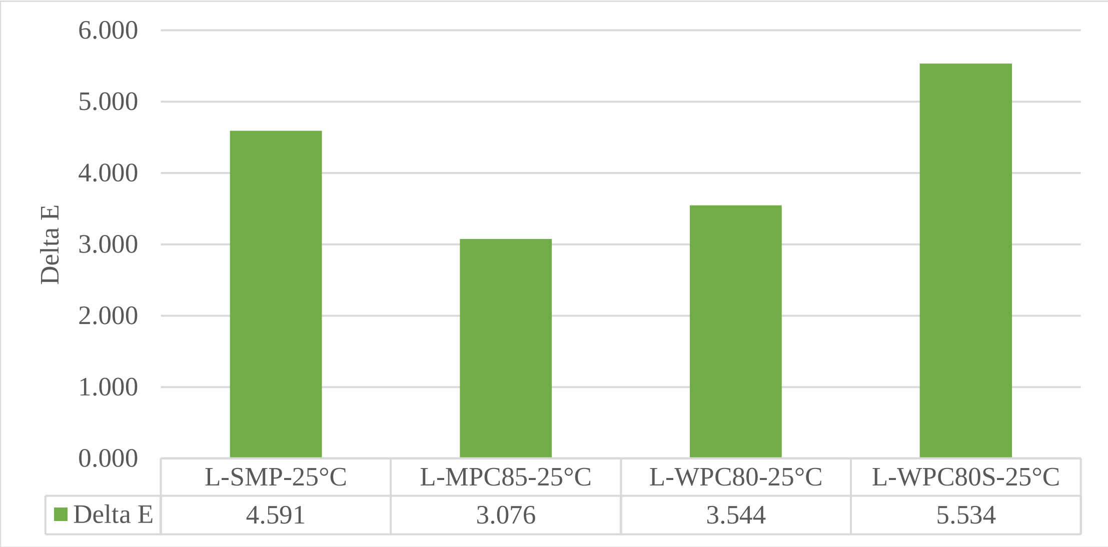



Figure 26. Delta E values of Labneh Samples that were prepared with dairy powders from 25°C conditions

To see the color change effect of each individual powders on the final product, the Delta E values are calculated based on above formula, the results can be seen in Figure 26. All the Delta E values are found to be in the range of 3 to 5.5. According to Schuessler (Daniel 2021) the delta E values between 2-10 can be perceived easily from human eye. Therefore, it can be said that all the samples showed a difference in color, once they prepared with fresh powders, and once the preparation has been done with 4-month-old powders. The biggest change is recorded for L-WPC80S samples, then secondly for L-SMP samples. However, among the others, L-MPC85 showed a better consistency and minor changes. These results can be attributed to several reactions that was seen in powders, like browning reactions, and also processing and the source of milk that was used to produce these powders.

Kusio et al. (2020) conducted a study on the impact of whey protein concentrate on the functional properties of high protein fat-free dessert. The findings of the study indicated that minor variations in the quantity of whey protein concentrate significantly influenced the acceptability of the products. The authors proposed that the desserts formulated with 9% of WPC80 were deemed more favorable among the panelists, as evidenced by high scores in sensory attributes. The utilization of 13% WPC80 in conjunction with k-carrageenan resulted in the highest number of issues, particularly with regards to phase separation. Additionally, it has been suggested that the utilization of a high quantity of proteins in formulations has an immediate influence on the sensory attributes of the product, including taste, aroma, and color. Thus, it can be inferred that the color of the end product can be directly influenced by proteins, and the degree of alteration is contingent upon factors such as protein composition, solubility, and dispersibility.

Table 23. The Color Values of Labneh Samples that were prepared with dairy powders from 37°C conditions

| | **L-SMP** | | | **L-MPC85** | | |
|---|---|---|---|---|---|---|
| **Sample** | L* | a* | b* | L* | a* | b* |
| **1** | 95.34 | -3 | 13.25 | 93.85 | -1.23 | 12.89 |
| **2** | 90.01 | -0.89 | 15.62 | 89.98 | -0.87 | 16.67 |
| | **L-WPC80** | | | **L-WPC80S** | | |
| **Sample** | L* | a* | b* | L* | a* | b* |
| **1** | 90.01 | -0.89 | 14.87 | 92.68 | -1.62 | 13.95 |
| **2** | 86.35 | 1.6 | 22.68 | 87.15 | 1.2 | 19.77 |

(1: the sample prepared with fresh powder samples at the beginning of the shelf life, 2: the sample that is prepared with the same powders after 4 months of storage at 37°C)

As anticipated, significant alterations in the chromatic properties of the end product were observed in the samples that were formulated using powders under 37°C conditions (Table 23). At elevated temperatures, the rate of all reactions is observed to increase. The L* value of L-SMP sample 2 is shown as 91.02 in Table 2. However, Table 3 indicates that the L* value for sample 2 L-SMP was observed to be 90.01. Moreover, the decline in L* values was more pronounced for the samples fortified with 37°C powders (Table 23)

Table 21 and Table 22 demonstrate that the samples fortified with WPC80 and WPC80S exhibited higher a* and b* values, indicating a greater presence of yellowish hues, compared to the L-SMP and L-MPC85 samples. However, it is noteworthy that the rise in b* values observed in L-SMP and L-MPC85 was not negligible, thereby providing further evidence that the Maillard reaction has an impact on the ultimate product.

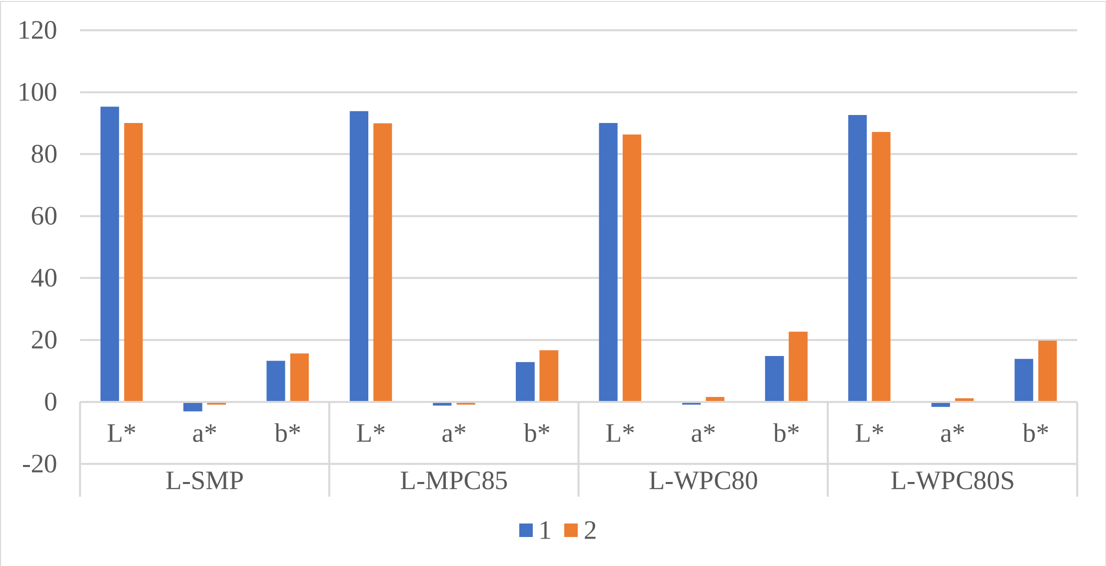



Figure 27. The Color Values of Labneh Samples that were prepared with dairy powders from 37°C conditions at the beginning and end of their shelf life

*((1: the sample prepared with fresh powder samples at the beginning of the shelf life, 2: the sample that is prepared with the same powders after 4 months of storage at 37°C)*

As evidenced by the data presented in Figures 23, 25 and 27, the sample denoted as L-MPC85 exhibited a higher degree of color consistency relative to the other samples. The innovative applications of Milk Protein Concentrates (MPC) in novel food product development were investigated by Agarwal et al. (2015). The authors asserted that there exist numerous applications for diverse milk protein concentrates, such as processed cheese, ice cream, and high-performance sports nutrition, among others. The findings of their study indicate that the integration of MPCs into the product enhances its functionality with respect to viscosity, gelling, and heat stability. Nonetheless, the authors asserted that the consumption of MPC products may result in a creamy flavor and a degree of opaqueness in hue, albeit with negligible variations. Hence, it can be asserted that the superior heat stability of MPC products endows them with greater resilience to physical alterations, thereby imparting a desirable color profile to the end products in which they are incorporated.

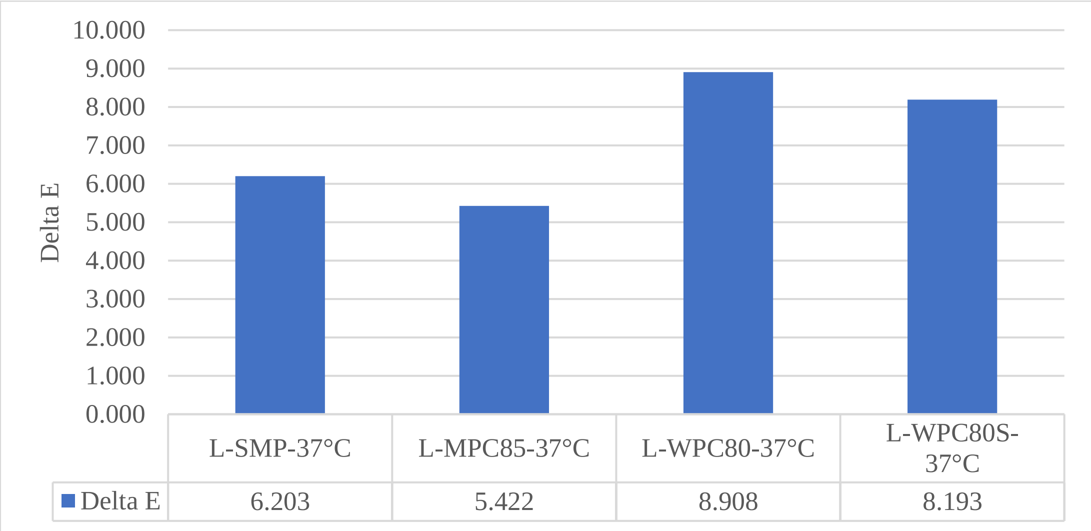



Figure 28. Delta E values of Labneh Samples that were prepared with dairy powders from 37°C conditions

Figure 28 displays the Delta E values of the samples that were prepared using 37powders. The values obtained for L-SMP, L-MPC85, L-WPC80, and L-WPC80S are 6.203, 5.422, 8.908, and 8.193, respectively. The findings suggest that the employment of WPC80 powders that are 4 months old in labneh formulations elicits the most significant degree of alteration. The aforementioned outcome exhibits a potential correlation between the rate of Maillard reaction and protein oxidation throughout the duration of storage of WPC80 powders. The color formation of whey protein isolates during fibrillization was investigated by Ouyang et al. (2023). Their findings established a correlation between color alteration and the maillard reaction, as well as protein oxidation in the resulting products. According to the authors, an increase in pH, temperature, and protein concentration resulted in a higher rate of oxidation of tryptophan in the samples. Furthermore, it was determined that the rate of the Maillard reaction is contingent upon temperature, resulting in significant discoloration of the final products. Nonetheless, it was asserted that the Maillard reaction byproducts were observed to be diminished in alkaline conditions. Hence, it can be posited that the Maillard reaction of WPC80 exhibited an increase at 37°C, akin to other powder samples, thereby resulting in greater discoloration in the end products. Despite the fact that the Maillard reaction was observed to increase in other samples as a result of higher temperatures, it is important to note that whey protein concentrate 80 (WPC80) inherently possesses a yellowish hue. Consequently, the occurrence of browning reactions had a more pronounced impact on the final product's color in comparison to the other samples.

A One-Way ANOVA test was applied to understand how these all labneh samples are significantly different from each other, and the results showed that all the samples are completely different from each other in terms of L*,a* and b* values ($p<0.05$) (Appendix D).

### 3.2.2. FT-IR Analysis of Labneh Samples

The FTIR analysis for the labneh samples that were prepared with fresh powders, and with the 4 months aged powder from different temperature conditions were performed.

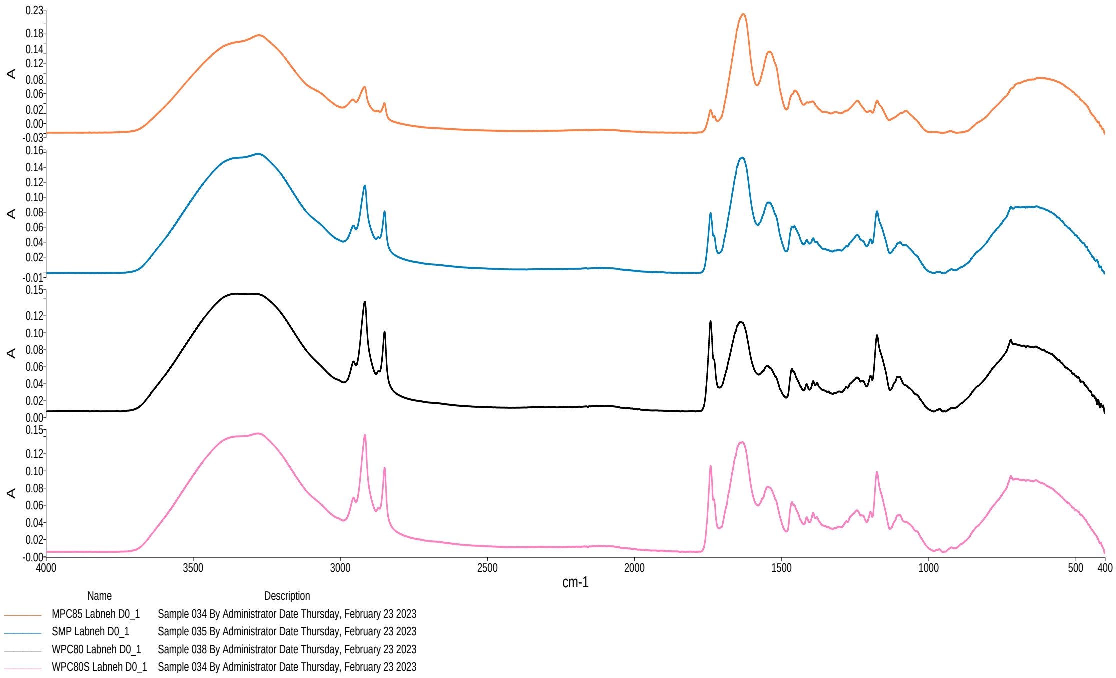



Figure 29. The FTIR Results of Labneh Samples that were prepared with the fresh dairy powders at the beginning of their shelf life

Figure 29 represents the spectra of the labneh samples that were prepared with the dairy powders at the beginning of their shelf life. The spectra have lots of similarities, however, their absorbance intensities at certain wavenumbers are different. For example, the region of 1600-1800cm-1 which is specific for proteins has the highest absorbance around 0.18-0.2 for the labneh sample that contains MPC85, which is an expected result owing to highest protein content of MPC85 (Figure 29). However, because all the powders have same milk content, there is a contribution in protein structure for all of the products. In the spectra, it can be seen that still all the other powders than MPC85 have quiet extend absorbance values around 0.12-0.14 in the 1600-1800cm-1 region.

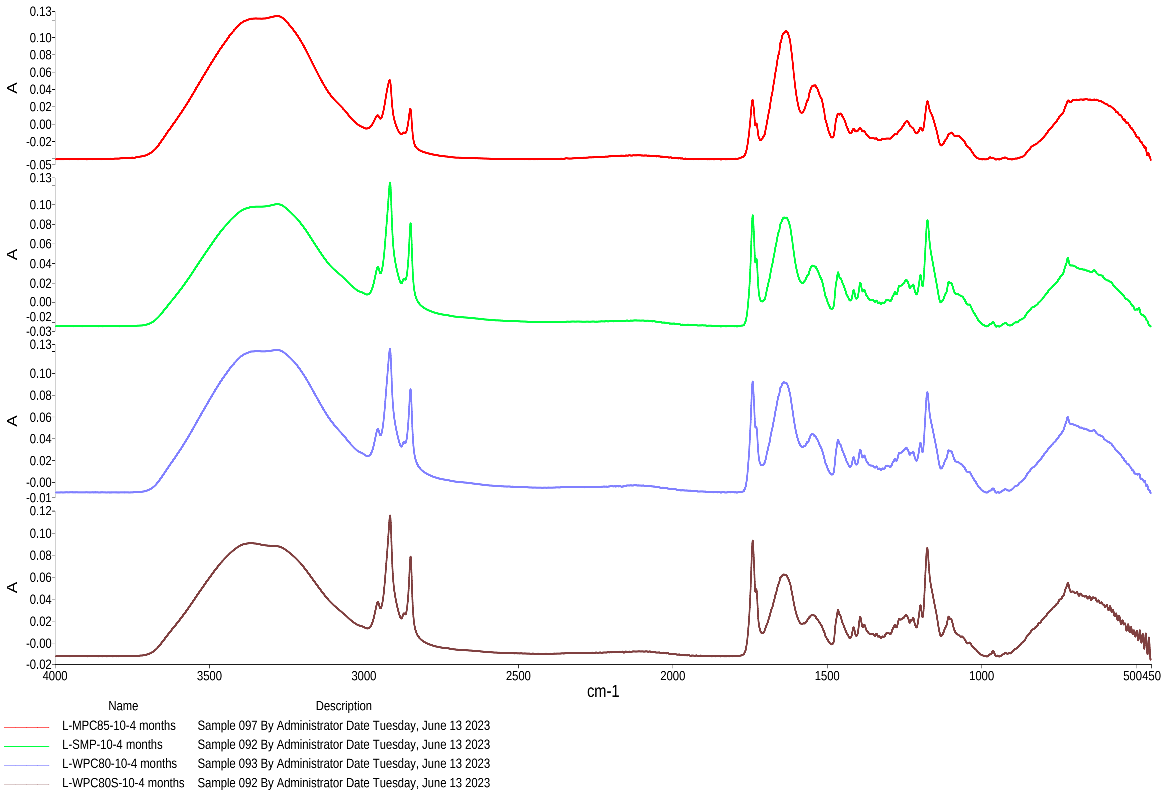



Figure 30. The FTIR Results of Labneh Samples that were prepared with the 4-month old dairy powders from 10°C conditions

Figure 30 illustrates that the labneh samples exhibit consistent characteristics even when prepared using 4 month-old powders from 10°C conditions. The alterations in the spectral properties can be primarily attributed to the protein composition and the occurrence of browning reactions in the powders. According to Yazdanpanah and Langrish (2013), powders with elevated lactose content exhibit changes in lactose crystallization that can result in peak shifts. The data presented in Figure 30 indicates that the L-WPC80 sample exhibited the most prominent peaks in the 2800-3000 cm-1 region, which is indicative of the presence of fat. This observation is consistent with the higher fat content of WPC80 as compared to other dairy powders, as reported in Table 4. Protein modifications were observed within the spectral range of 1500-1600 cm-1. Figure 30 illustrates that L-MPC85 exhibited greater absorbance in this region, while L-WPC80S samples displayed the lowest absorbance values. This suggests that protein bonds may have undergone a weakening effect in this particular region. A noteworthy observation pertains to the 1000cm-1 region, which is indicative of carbohydrates. Specifically, L-MPC85 exhibited the lowest absorbance, followed by L-SMP, L-

WPC80S, and L-WPC80. The present study suggests that the rapid decrease in absorbance values observed in MPC85 and SMP may be attributed to their comparatively higher lactose content than other powders. Additionally, the findings indicate that lactose is significantly affected by the ageing process, potentially leading to degradation and alterations in surface composition that can result in shifts in the observed peaks (Figure 30).

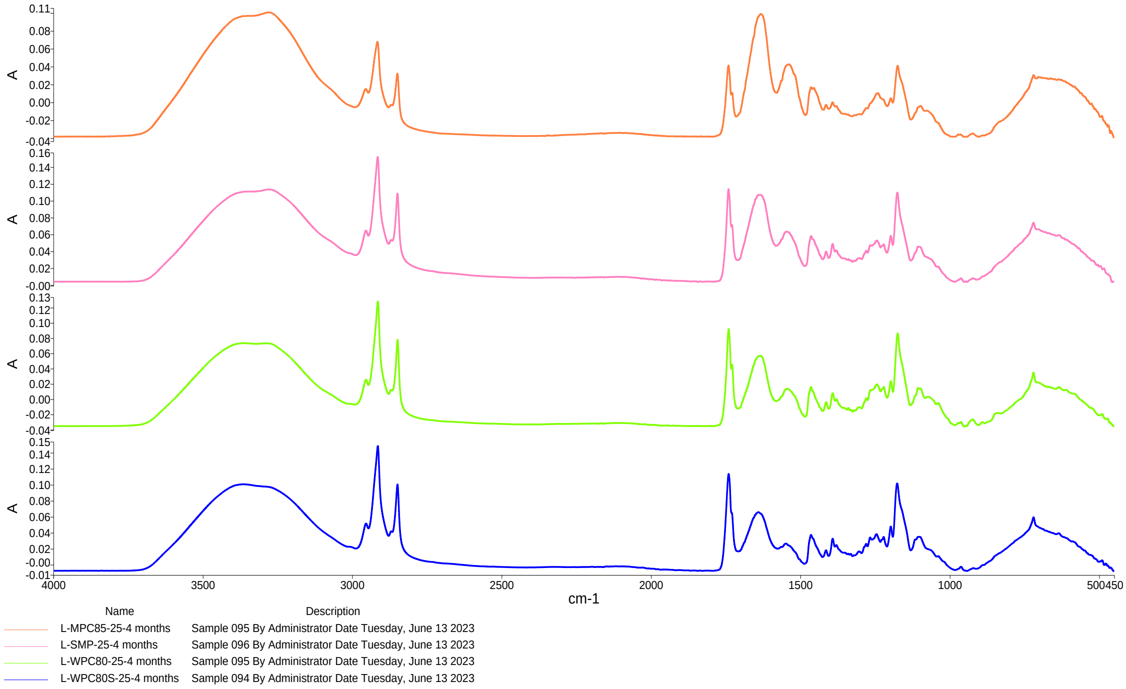



Figure 31. The FTIR Results of Labneh Samples that were prepared with the 4-month-old dairy powders from 25°C conditions

The spectral changes of labneh samples, which were prepared with the powders, after a storage period of 4 months at a temperature of 25°C are depicted in Figure 31. In the spectral region of 1000 cm-1, where the carbohydrate groups were observed, the recorded results were consistent with those presented in Figure 30, indicating that the L-MPC85 samples exhibited the lowest absorbance values. In contrast to the findings illustrated in Figure 30, the L-SMP samples exhibited the highest values of absorbance. The reason for this discovery can be elucidated by the potential occurrence of lactose crystallization during storage, which may result in inconsistent outcomes across varying temperature conditions. Divergent trends were observed in the labneh samples at the spectral region ranging from 1600-1800 cm-1, as compared to the outcomes shown in Figure 30. The L-SMP samples exhibited the highest absorbance values, followed by the L-MPC85 samples. The finding that SMP exhibits the lowest protein content may suggest that its protein composition remained comparatively more stable than that of other powders. This observation could potentially suggest that the stability of protein structures is not uniform and that the bonds between proteins in that particular region exhibit greater stability under conditions of 25°C.

Yuan et al. (2018) discovered that the amide I protein region contains significant regions of secondary protein structure. The α-helix conformation was predominantly observed within the spectral range of 1646-1664 cm-1, whereas the β-sheet structure was identified at 1682-1700 cm-1. The random coil formations were primarily manifested within the spectral range of 1637-1645 cm-1. According to Figure 31, the a-helix region exhibits the greatest absorbance for L-SMP and L-WPC80S, with L-MPC85 and L-WPC80 following closely behind. Furthermore, it was observed that the absorbance in the β-sheet region exhibited the greatest magnitude for L-SMP, followed by L-MPC85, L-WPC80S, and L-WPC80. The absorbance values of the random coil region were observed to be in the same order as those of the β-sheet region. The findings revealed the secondary structural composition of the dairy powders. Yuan et al. (2018) have also determined that modifications in the secondary structures of proteins result in variations in the antioxidant potential of the yogurt specimens. The alteration in the degradation degree of dairy powders was observed to be dependent on the secondary structure of their proteins, as depicted in Figure 31. Hence, it can be posited that comprehending the secondary configuration of proteins can aid in maintaining the durability and stability of end products.

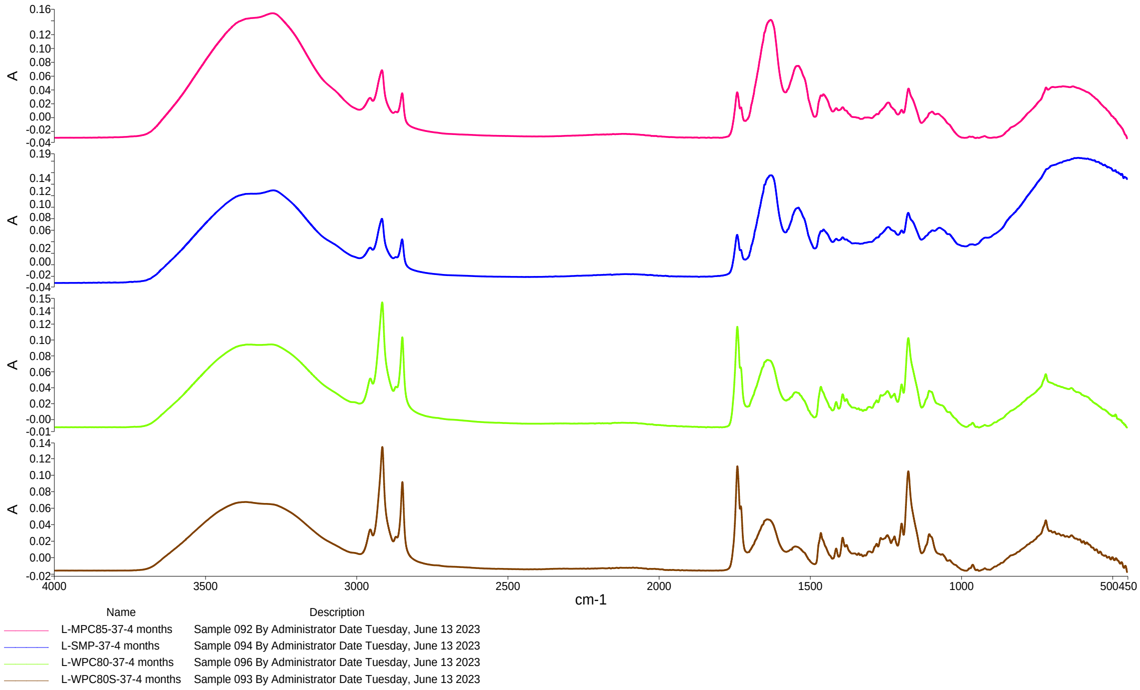
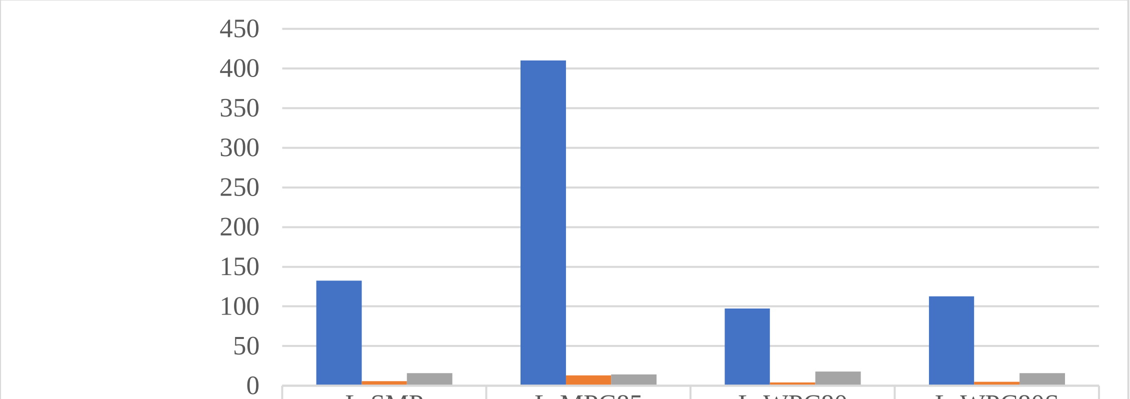



Figure 32. The FTIR Results of Labneh Samples that were prepared with the 4-month old dairy powders from 37°C conditions

Figure 32 represents the FTIR results of labneh samples that were prepared with the dairy powders after 4 months of storage at 37°C. The most obvious peak in those spectrums were seen for L-SMP sample, at the region of 700-800 cm-1 region. Ye et al. (2017) stated that the region of 755 to 785 cm-1 can be mainly assessed for carbohydrates. Stronger bond formations, and also a possible degradation along with various crystallization reactions might be the reasons of this high and intensive peak of L-SMP around the region. Higher absorbance values at the region of 1600-1700cm-1 was recorded for L-SMP samples, than L-MPC85, followed by L-WPC80 and L-WPC80S. The alpha-helix region of 1646-1664 cm-1, was recorded as the highest absorbance for L-SMP, then L-MPC85, followed by L-WPC80 and L-WPC80S. For β-sheet structure and random coil regions around 1630-1700cm-1, also the same order was followed for the intensities of the peaks. Therefore, it is clear that over temperature and aging of the powders, their secondary structures are changed, which causes shifts and various alterations in the peaks of the labneh samples that they were used.

### 3.2.3. Texture Analysis Results

The texture analysis for the labneh samples that were prepared with fresh powders, and with the 4 months aged powder from different temperature conditions were performed.




| | L-SMP | L-MPC85 | L-WPC80 | L-WPC80S |
|---|---|---|---|---|
| Hardness (g) | 132.5 | 410 | 97.5 | 112.5 |
| Adhesiveness (mJ) | 5.76 | 13.19 | 4.08 | 5.07 |
| Stringiness (mm) | 15.65 | 14.15 | 17.78 | 15.98 |

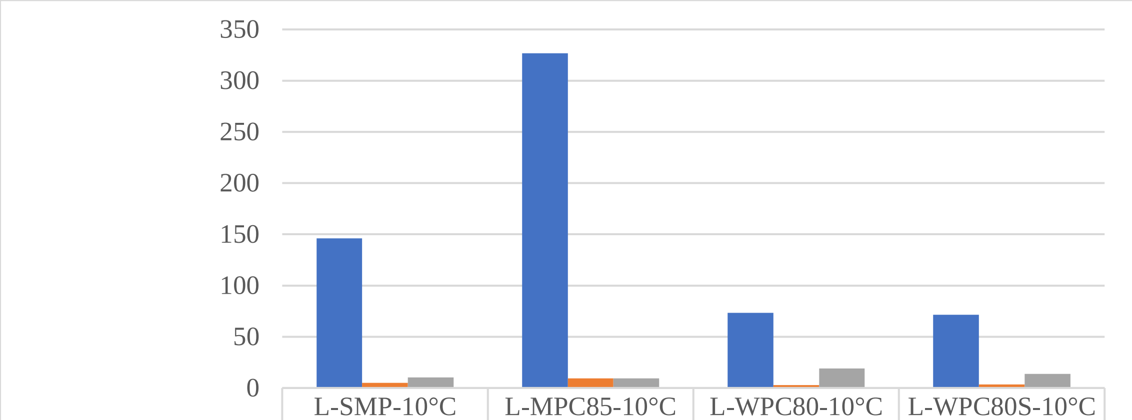
Figure 33. The Texture Results of Labneh Samples that were prepared with fresh dairy powders

Figure 33 represents the texture analysis results of labneh samples that were prepared with fresh dairy powders. Hardness values are given in units of grams, the adhesiveness values are given in millijoules (mJ), and stringiness is given by millimeters. The hardness values are found as 132.5 g, 410 g, 97.5 g and 112.5 g for L-SMP, L-MPC85, L-WPC80 and L-WPC80S, respectively. The adhesiveness values are found as 5.76 mJ, 13.19 mJ, 4.08 mJ, 5.07 mJ for L-SMP, L-MPC85, L-WPC80, and L-WPC80S, respectively. Lastly, the stringiness values are recorded as 15.65 mm, 14.15 mm, 17.78 mm, and 15.98 mm for L-SMP, L-MPC85, L-WPC80, and L-WPC80S (Figure 33).

The term "hardness" is technically defined as the maximum force generated by the compression of a sample within a specified time, distance, or deformation. The consistency of food products is a crucial factor, particularly for dairy items such as yogurt and labneh. It refers to the degree of firmness or softness exhibited by these products. Conversely, adhesiveness is a measure of the degree to which a food sticks to the mouth's lining during mastication. Finally, despite the infrequent usage of the term "stringiness," it pertains to the filamentous morphology of samples. The parameter of stringiness primarily denotes the length of the string-like structure of the products and the fibrous structure of the sample (Glossary: Terminology of Food Texture | Mecmesin | Texture Analysis).

Kaaki et al. (2012) conducted a study on the preference mapping of commercial labneh samples in Lebanon. The findings of the study indicate that labneh samples containing no fat exhibited greater levels of hardness and lower ratings of meltness in comparison to labneh samples containing full fat and reduced fat. The results represented in Figure 11 indicate that the L-MPC85 exhibited the highest recorded hardness value, while the lowest value was observed for L-WPC80. The above results can be primarily attributed to the protein content and composition of the products. The protein composition of WPC80 is predominantly comprised of whey proteins, which exhibit greater solubility in comparison to caseins. However, it is noteworthy that MPC85 primarily comprises caseins (80%) and whey proteins to a lesser extent (20%). Thus, it can be inferred that casein proteins possess a greater capacity to generate robust structures in comparison to whey proteins, primarily owing to variations in their solubility. The adhesiveness measurements of the labneh samples, with the exception of L-MPC85, were observed to fall within the range of 4-5.7 mJ. Conversely, L-MPC85 exhibited a significantly higher adhesiveness value of 13.19 mJ. This finding provides insight into the impact of casein on oral stickiness, suggesting that it elicits a greater degree of stickiness compared to whey proteins. Hence, it is imperative to recognize that the incorporation of MPC85 in formulations may result in distinct sensory attributes such as altered after-taste and mouthfeel in the end products (Figure 33). According to the findings of the sensory analysis (Figure 50a and Figure 50b), the panellists reported that the L-MPC85 samples were comparatively less attractive in terms of their appearance and smoothness. This was observed particularly in the case of labneh samples that were formulated using MPC85 powders under 25C and 37C conditions over a certain period. In addition, it is noteworthy that the elevated level of adhesiveness exhibited by MPC85 provides a distinct sensory attribute to the products.

The length of the stringiness of samples provides valuable information regarding their melting stability and fibrous structure. As illustrated in Figure 33, the L-MPC85 exhibits the minimum stringiness value of 14.15 mm, whereas the L-WPC80 samples demonstrate the highest value. The findings of this study indicate that the incorporation of MPC85 in the formulations resulted in the development of robust and compact structures, whereas the utilization of WPC80 enhanced the tenderness of the products, along with an increased ability to melt. The results obtained do not exhibit any adverse indications for the powders under investigation. Rather, they demonstrate their broadened functional properties, thereby rendering them more suitable for use in various formulations.

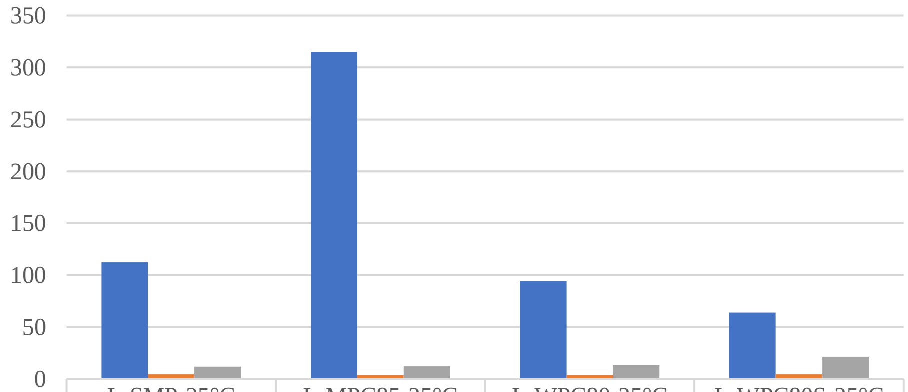



| | L-SMP-10°C | L-MPC85-10°C | L-WPC80-10°C | L-WPC80S-10°C |
|---|---|---|---|---|
| Hardness (g) | 146 | 326.8 | 73.5 | 71.4 |
| Adhesiveness (mJ) | 5.18 | 9.36 | 2.78 | 3.41 |
| Stringiness (mm) | 10.3 | 9.39 | 19.1 | 13.65 |

Figure 34. The Texture Results of Labneh Samples that were prepared with 4-month-old dairy powders from 10°C conditions

The texture results of the labneh samples formulated with the 4-month-old powders of 10C storage conditions are shown in Figure 34. The results revealed that there is a reduction of hardness values for all samples, expect L-SMP-10°C. This might be reason of lactose content in SMP, which may undergo crystallization, and cause some firmness in the product. Even though it is not clear that lactose crystallization can cause firmness, the formation of different shaped and sized lactose crystals may cause a increase in hardness. As a same trend in Figure 33 , the highest adhesiveness value was recorded for L-MPC85-10°C samples, yet the value decreased compared to the L-MPC85 (Figures 33 and 34).

The highest stringiness values are found as 19.1 mm and 13.65 mm for L-WPC80-10°C, and L-WPC80S-10°C, respectively (Figure 34). According to sensory analysis results (Figure 50.a), the appearance and smoothness of L-WPC80 were higher than L-WPC80-10C. This result can be attributed to the variation in texture values, where hardness and adhesiveness decreased, and stringiness increased. The increase in stringiness can be considered as a defect, especially for the melting stability of the products.




| | L-SMP-25°C | L-MPC85-25°C | L-WPC80-25°C | L-WPC80S-25°C |
|---|---|---|---|---|
| Hardness (g) | 112.6 | 315 | 94.5 | 64.1 |
| Adhesiveness (mJ) | 4.63 | 4.09 | 4.02 | 4.73 |
| Stringiness (mm) | 11.93 | 12.43 | 13.65 | 21.51 |

Figure 35. The Texture Results of Labneh Samples that were prepared with 4-month-old dairy powders from 25°C conditions

Figure 35 represents the texture results of the labneh samples that were prepared with the dairy powders of 25°C conditions. The results revealed that still L-MPC85-25C has the highest hardness value as 315g. However, the L-MPC85-10°C sample, and as well as L-MPC85 samples had higher hardness values as 326.8 g and 410g, respectively (Figures 34 and 35). Therefore, it should be noted that effect of temperature conditions of powders have a significant impact on hardness of the labneh samples. The hardness values of L-SMP-25°C was recorded as 112.6, and L-WPC80S-25°C had a hardness of 64.1 g. These values was higher for L-SMP-10°C and L-WPC80S-10°C as 146 and

71.4g. The only increase in hardness is shown for L-WPC80-25°C compared to L-WPC80-10°C (Figures 34 and 35). Overall, the conclusion that storage temperature has an impact on powder functionality, which alter the hardness of the final product which the powders were utilized.

The increase of hardness in L-SMP-10°C was not confirmed by the results of sensory analysis, yet the decrease of hardness in L-SMP-25°C when compared to L-SMP sample, the preference of thickness is increased to 3.429 from 3 scoring (Figure 50.a).

The adhesiveness values of labneh samples that contains 25°C powders were very similar to each other, in the range of 4-4.73 mJ (Figure 35). The decrease in adhesiveness has led to an improvement of aroma acceptance of L-SMP-25°C than L-SMP-10°C. Even though, it can not directly say that adhesiveness totally affects the aroma acceptance, it should be definitely noted that the taste is directly affected from aroma, and adhesiveness can directly alter the mouth perceptions. Therefore, it might affect each other. This indication is also supported by L-WPC80-25°C and L-WPC80S-25°C samples, the aroma acceptance got lower when adhesiveness got increased for those samples than L-WPC80-10°C, and L-WPC80S-10°C (Figures 34 and 35, Figure 50.b)

The stringiness values are found as 11.93 mm, 12.43 mm, 13.65 mm and 21.51 mm for L-SMP, L-MPC85,L-WPC80 and L-WPC80S, respectively. Compared to the results of labneh samples that were prepared with 10C powders, stringiness is increased for all labneh samples, expect L-WPC80-25. The increase in stringiness values affect the appearance preference of panelists in a positive way for L-SMP-25°C,L-MPC85-25°C and L-WPC80S-25°C compared to labneh samples that were prepared with 10C powders. However, the decrease in stringiness of L-WPC80-25°C compared to L-WPC80-10°C also improved the appearance scores (Figures 34 and 35, Figure 50.a)

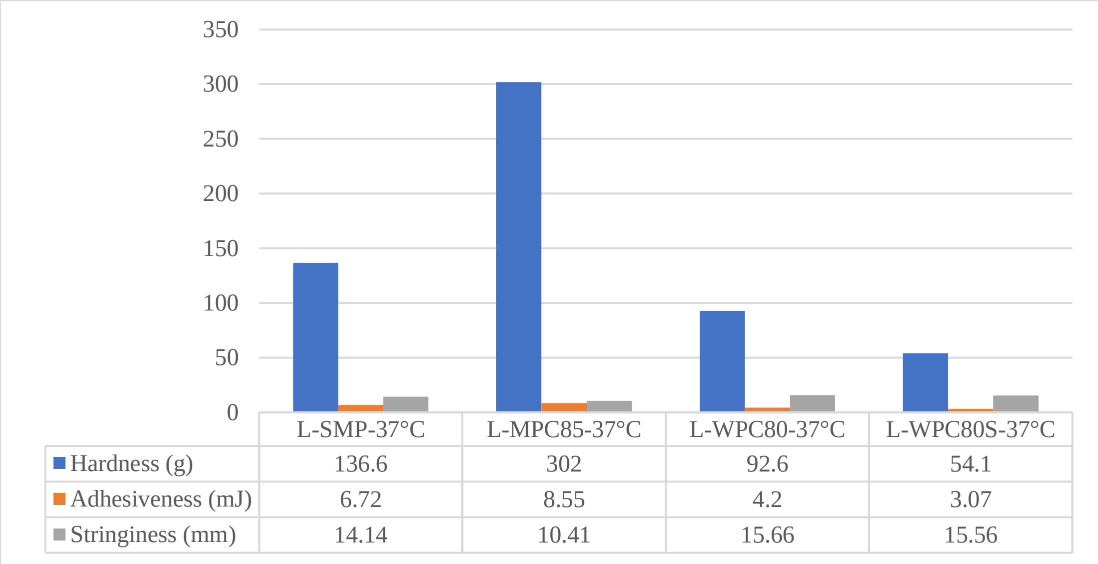



Figure 36. The Texture Results of Labneh Samples that were prepared with 4-month-old dairy powders from 37°C conditions

The results of labneh samples that were prepared with 37°C powders are shown in Figure 36. The hardness values are found as 136.6 g, 302 g, 92.6g and 54.1 g for L-SMP-37°C, L-MPC85-37°C, L-WPC80-37°C and L-WPC80S-37°C, respectively. Compared to the labneh samples that has powders of 10°C and 25°C conditions (Figures 34 and 35), the hardness values of all the labneh samples that were formulated with 37°C got their lowest values. There was only one variation in the L-WPC80-25C sample; the hardness value was lower than L-WPC80-37°C. Nonetheless, the hardness of L-WPC80-37°C was found as 92.6 g, and L-WPC80-25°C was 94.5, which is not a significant reduction (Figures 34 and 35).

The acceptance of thickness by panellists did not change for L-SMP-25°C and L-SMP-37°C samples. However, the acceptance was reduced for other labneh samples that contain 37°C powders compared to samples that has 25°C powders (Figure 50.a, Figure 50.b) The adhesiveness values of the labneh samples that contains 37°C powders was higher compared to the samples that formulated with 25°C powders, expect the L-WPC80S-37°C sample (Figure 36).

The stringiness values for the samples of L-SMP-37°C, L-MPC85-37°C, L-WPC80-37°C, and L-WPC80S-37°C were found as 14.14 mm, 10.41 mm, 15.66 mm, and 15.56 mm. When these results are compared with the results of labneh samples that contain 25°C powders, there are variations, which the samples that contain MPC85 and

WPC80S got lower stringiness values, while the addition SMP and WPC80 from 37°C conditions caused an increase in stringiness of labneh samples (Figures 35 and 36).

### 3.2.4. Rheology Analysis Results

The rheology analysis was performed for the labneh samples. The first rheology analysis was made for the labneh samples that were formulated with fresh dairy powders. Afterwards, the last rheology analysis was performed with the labneh samples that were formulated with 4-months old dairy powders from each different temperature conditions, 10°C,25°C and 37°C, respectively.

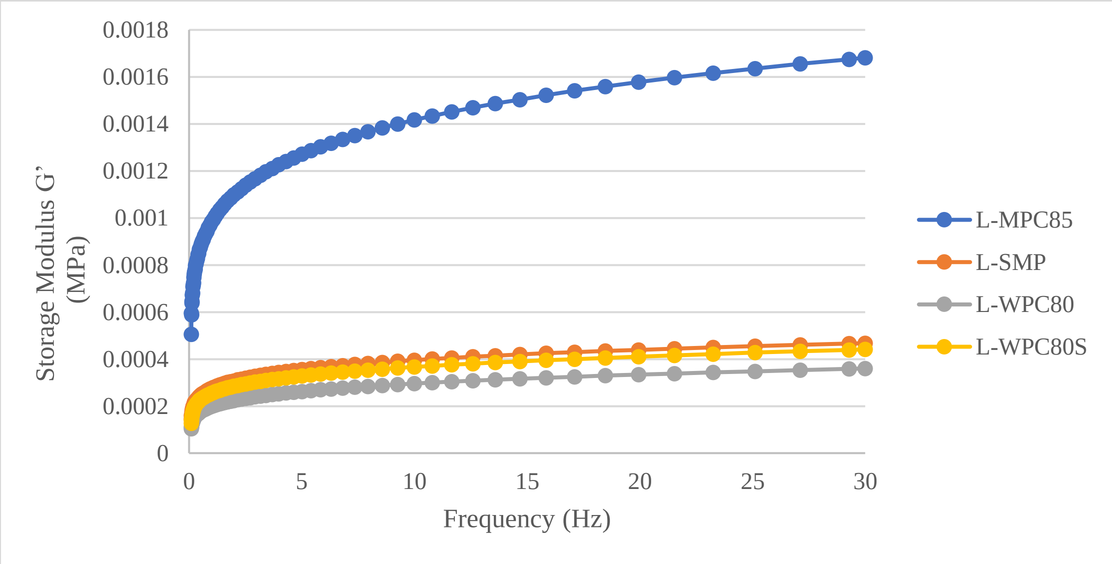



Figure 37. The Storage Modulus G' (elastic modulus) Results of Labneh Samples that were prepared with fresh dairy powders.

Figure 37 represents the results of the storage modulus which is also known as elastic modulus of the labneh samples. As figure illustrates, the rheology analysis was performed under 0-30 Hz of frequency, and each freuqency showed a different storage modulus value. The first very indicative result of the graph is L-MPC85 samples are highly elastic than other samples, and also represents more stiffer sample than other samples. The increase of storage modulus in L-MPC85 was more predominant than the others, and the L-SMP and L-WPC80S had a similar path through until the end of the graph. L-WPC80 can be considered less elastic than other samples, since it started with lower storage modulus values and it did not show any significant rise in the graph.

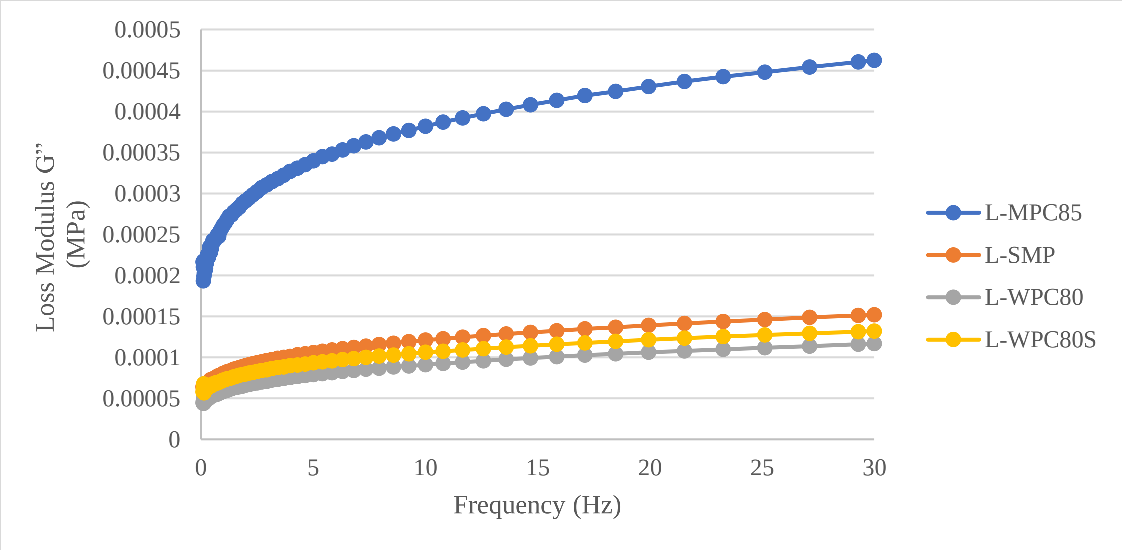



Figure 38. The Loss Modulus G'' (viscous modulus) Results of Labneh Samples that were prepared with fresh dairy powders

The Figure 38 represents the results of storage modulus which is also known as viscous modulus of labneh samples. The results show that apart from being more stiff and elastic sample, L-MPC85 can be also considered as more viscous product compared to other samples. Also, it definitely shows that the resistance of MPC85 to the flow is much more higher than other labneh samples. In contrast the tendency that was shown in Figure 1, L-SMP and L-WPC80S did not show any overlay in the Figure 38, yet their growth of storage modulus is very similar, but still L-SMP has more viscous structure than L-WPC80S. As a same result of Figure 37, L-WPC80 sample was found to be least viscous sample, and has the lowest resistance to the flow.

In the study of Sozeri Atik et al. (2023), the texture profile of yogurts produced with different cultures were investigated. Even though labneh is not totally a same product like yogurt, but in most of the countries it is known as concentrated yogurt. Therefore, the yogurt results can be good estimation to understand rheology of the labneh. The researchers showed that the storage modulus values were higher than loss modulus values of yogurt products. In Figures 37 and 38, the results indicate that these labneh samples have higher storage modulus values, and less loss modulus values. Therefore, it can be concluded that these labneh systems have a solid structure. Nonetheless, it is clear that using MPC85 in a labneh formulation will result in a different structure than the labneh samples formulated with SMP, WPC80 or WPC80S. MPC85 will create a solid and elastic structure, and it will give higher resistance to the product against flow. On the other hand, the L-SMP, L-WPC80 and L-WPC80S showed more similar profiles, yet L-SMP can be considered more elastic and viscous than others. Lastly, it can be seen from the results of Figure 37 and Figure 38, using WPC80 in the formulations will create less elastic and less viscous products.

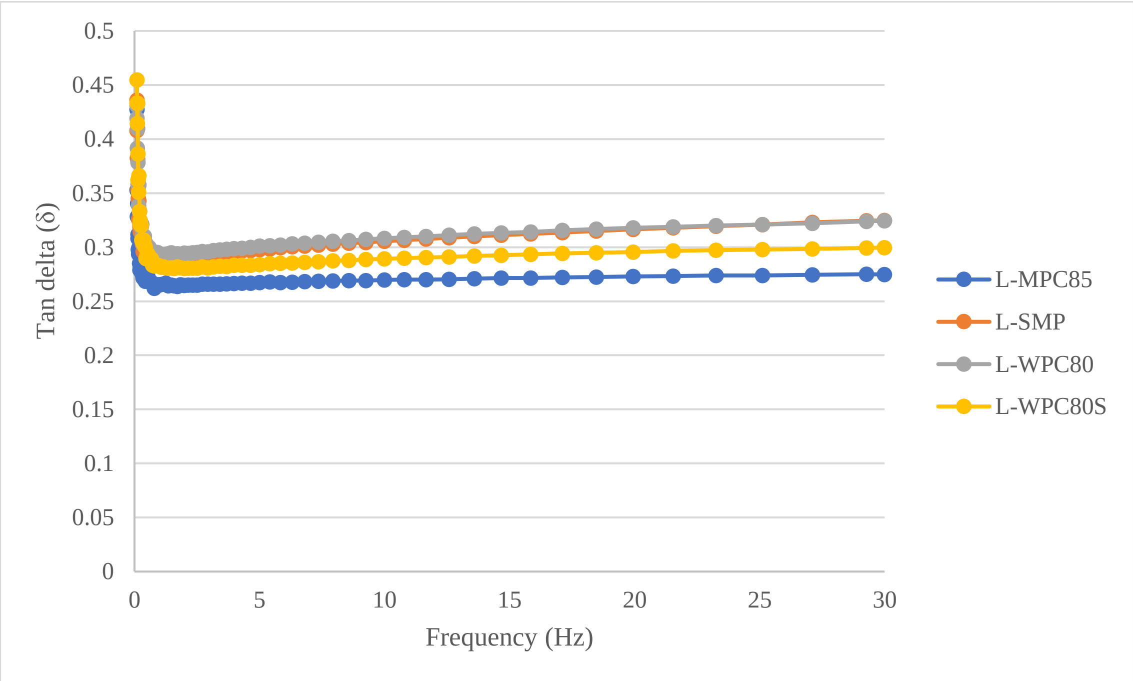



Figure 39. Tan Delta (δ) Results of Labneh Samples that were prepared with fresh dairy powders

The tan delta (δ) values of labneh samples are illustrated in Figure 39. The tan delta is the ratio of the loss modulus (viscous modulus) to the storage modulus (elastic modulus), and it can get a range of 0 to 1. If a tan delta value is greater than 1, it represents a viscous material, while if the value is less than 1, it means that the material is elastic (NETZSCH nd.) All the labneh samples have almost same initial results of tan delta around 0.4-0.45, than a reduction is seen. The delta tan results of labneh samples support the findings of Figure 1 and Figure 2, since all the values are less than 1, which means the samples have predominantly an elastic structure than a viscous structure.

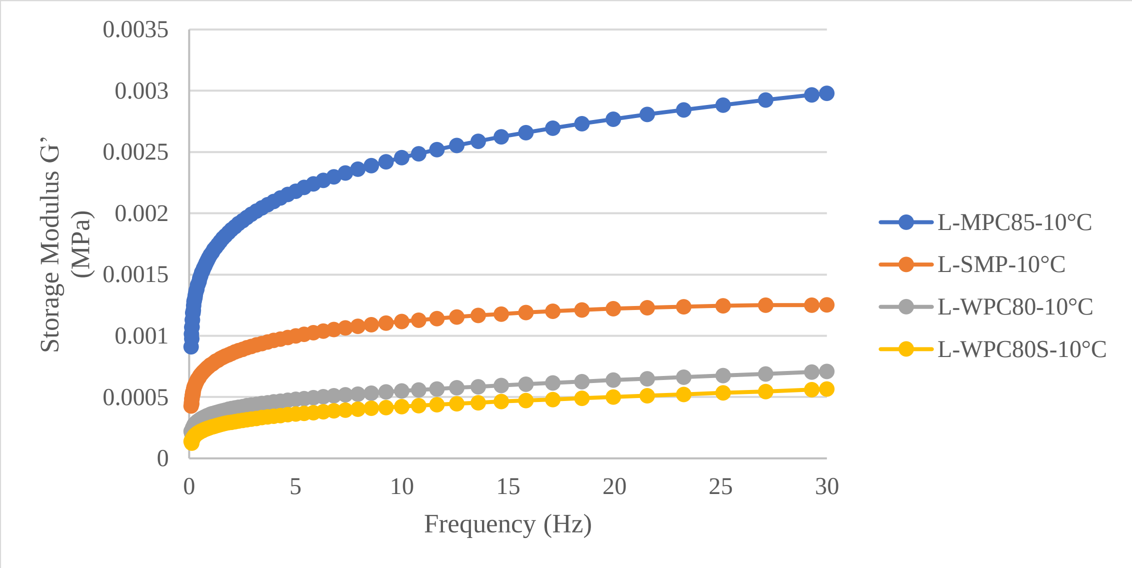



Figure 40. The Storage Modulus G' (elastic modulus) Results of Labneh Samples that were prepared with 4-month-old dairy powders from 10°C conditions

The storage modulus results are given for the labneh samples that was formulated with 4-months old 10C powders in Figure 40. The results revealed that for all of the samples the elastic modulus values increased as compared to Figure 37. Therefore, it should be noted that using a powder that is kept in 10C conditions for 4 months have an impact of rheological profile of the product which this powder was utilized. According to the Figure 40, as a same trend in Figure 37, the highest elastic modulus is found for L-MPC85-10°C samples. Following to that, the highest values are found for L-SMP-10°C, then L-WPC80-10°C and lastly L-WPC80S-10°C. In comparison to Figure 37, it should be noted that storage modulus of L-SMP-10°C is higher than L-SMP sample. This result indicates that storage of SMP powders in 10°C conditions had some alterations on the protein interactions, and as well as the lactose crystallization reactions of the product. L-SMP-10°C was found to be more elastic than L-SMP sample (Figures 37 and 40). As it discussed several times, SMP has less protein content than other samples, yet it has the highest lactose content among other samples.

In light of this nutritional composition, it should be understood that apart from protein reactions, lactose crystallization dynamics may create different alterations for the product as well. A slight increase of storage modulus was seen for L-WPC80-10°C samples as compared to L-WPC80 (Figure 40).However, for both samples of L-WPC80 and L-WPC80S, there is not a significant change of storage modulus, as a result of using 4-months old powder that was kept in 10C conditions as compared to fresh powder samples.

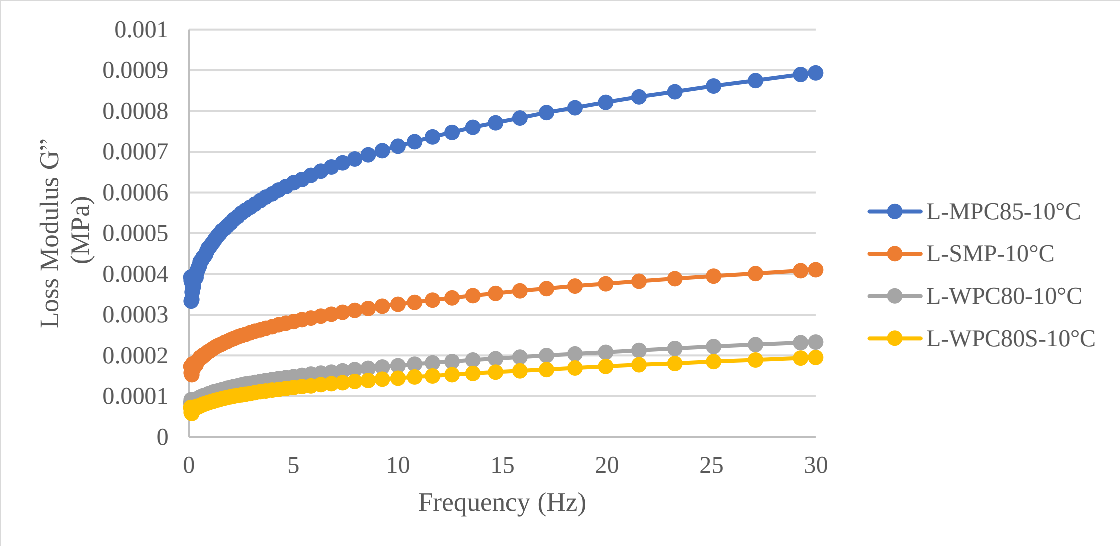



Figure 41. The Loss modulus G'' (viscous modulus) Results of Labneh Samples that were prepared with 4-month-old dairy powders from 10°C conditions

The viscous elasticity of the labneh samples that were formulated with 4-month-old 10C powders is shown in Figure 41. When Figures of 40 and 41 are compared to each other, it can be seen that the values of loss modulus are lesser than storage modulus values. This result shows that these labneh samples can be considered predominantly elastic samples, not viscous samples. However, when Figure 41 is compared to Figure 38, an increase in loss modulus values is seen for all of the labneh samples that contain 4-month-old 10C powders. As a result, even for both of the conditions (using fresh powders vs using 4-months old 10C powders) the labneh samples are found to be elastic, the dynamics of the samples are different from each other. Both of the profiles elastic and viscous, are increased and their dynamics changed as a result of using 4- months old powders that were kept in 10C conditions. Apart from these results, the most significant increase in loss modulus values is seen for L-MPC85-10°C and L-SMP-10°C samples (Figures 38 and 41).

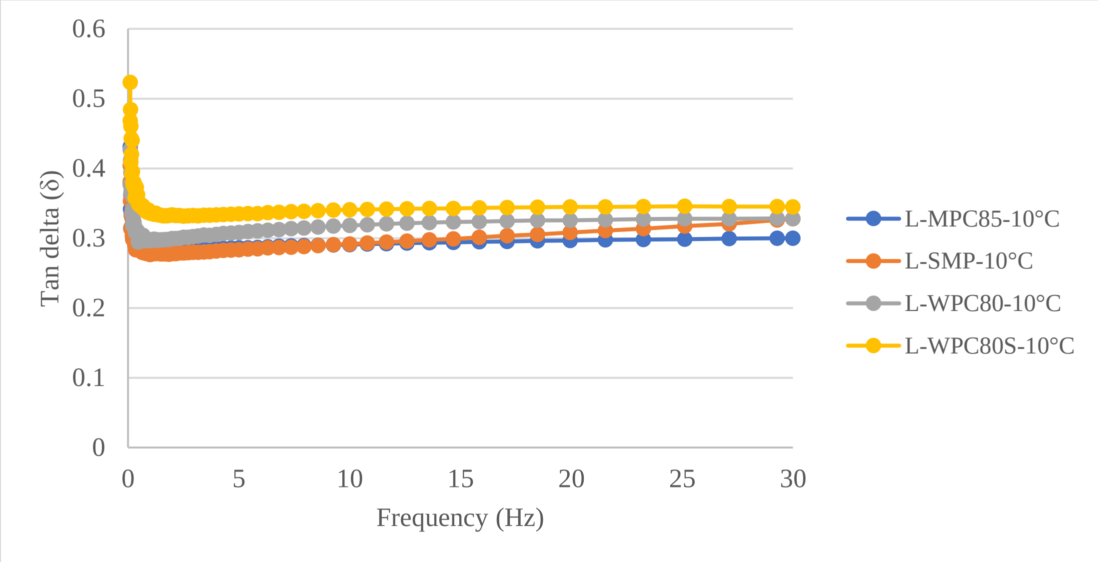



Figure 42. Tan Delta (δ) Results of Labneh Samples were prepared with 4-month-old dairy powders from 10°C conditions

Figure 42 represents the tan delta (δ) results of labneh samples that was formulated with 4-months old 10°C powders. Compared to Figure 39, as same trend, all the delta tan values are found less than 1, which means all the samples are predominantly elastic, which is also supported by the results of Figures 40 and 41. L-SMP-10°C and L-WPC80-10°C samples have almost the same delta tan values at the end of the graph, yet the tendency of increase is more sharp in L-SMP-10C than L-WPC80-10 samples. When Figure 6 is compared to Figure 3, even though there are some slight shifts, the delta tan values are similar to the values of Figure 39.

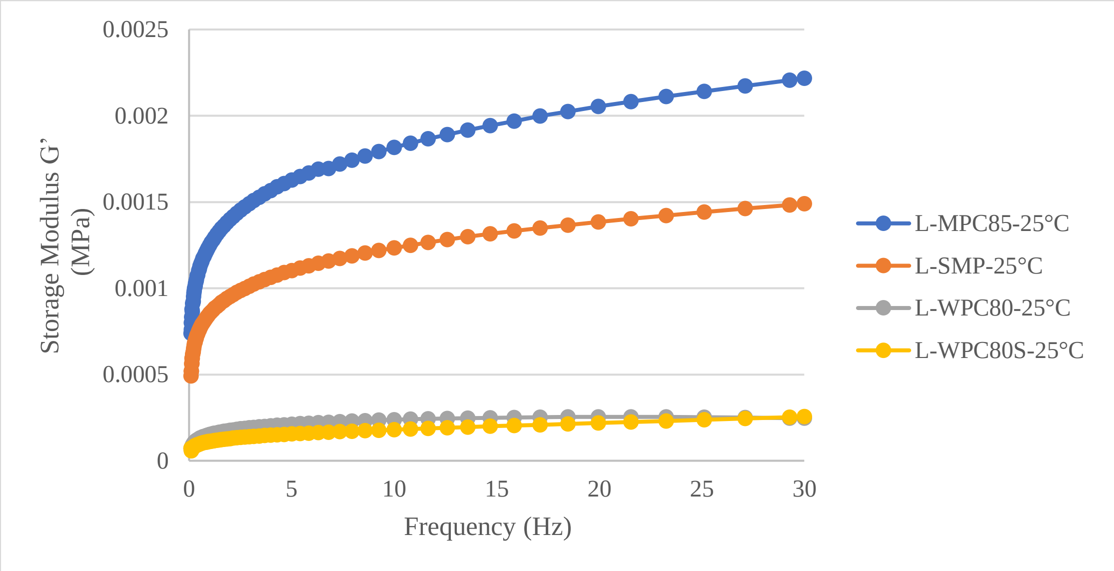



Figure 43. The Storage Modulus G' (elastic modulus) Results of Labneh Samples that were prepared with 4-month-old dairy powders from 25°C conditions

The Figure 43 represents the results of storage modulus values of labneh samples that were formulated with 4-month-old 25°C powders. The results have the same trend of Figures 37 and 40 , as the highest storage modulus was found for the L-MPC85-25°C sample. Then L-SMP-25°C had the highest storage modulus, followed by L-WPC80S-25°C and L-WPC80-25°C with almost same results. When the results of Figure 43 is compared to Figure 40, it can be seen that the storage modulus is lower for the L-MPC85-25°C sample than L-MPC85-10C. The reverse result is found for L-SMP-25°C sample, in which the storage modulus is higher than L-SMP-10°C sample. Therefore, it can be interpreted that the protein interactions, as well as lactose dynamics over the aging of the dairy powders, have a significant impact on the final rheology profile of the samples in which the powders were utilized. Moreover, the reduction of storage modulus is also seen for L-WPC80-25°C and L-WPC80S-25°C compared to the results of L-WPC80-10°C and L-WPC80S-10°C (Figures 40 and 43).

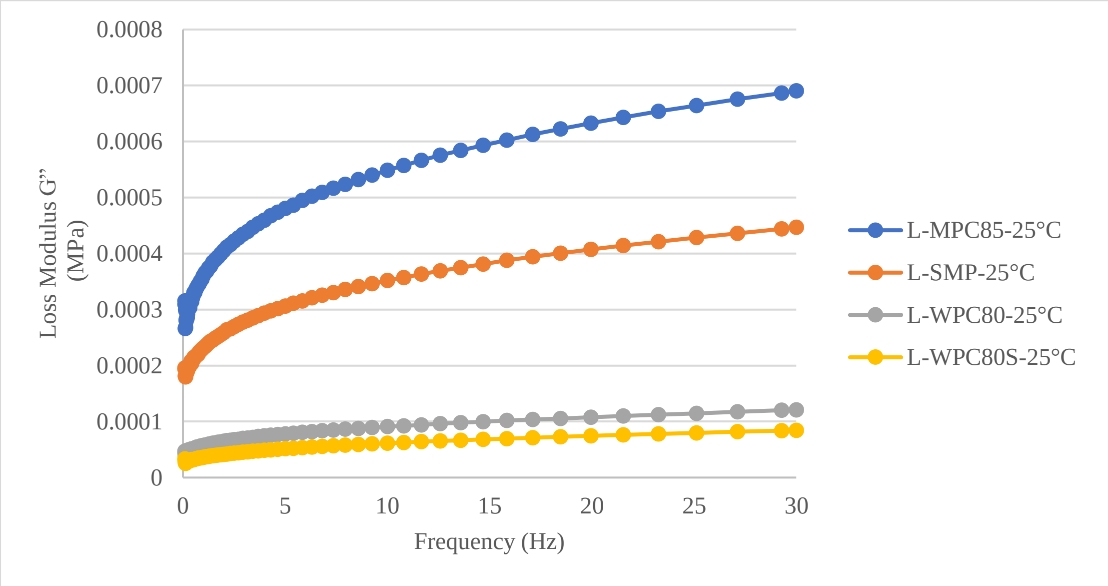



Figure 44. The Loss Modulus G'' (viscous modulus) Results of Labneh Samples that were prepared with 4-month-old dairy powders from 25°C conditions

The loss modulus results of labneh samples that were prepared with 4-months old 25°C powders were shown in Figure 44. The results indicate that still the loss modulus results are lower than storage modulus, and it means these labneh samples are also elastic like the ones that were prepared with fresh powders, and 4-months old 10°C powders. However, at higher frequencies, every labneh sample got higher values of loss modulus, and as well as storage modulus. Khubber et al (2021) stated that this increase indicates the strenght in protein network of the system, which can be directly impacted with protein structures of the powders. Also, as it stated in materials and method part, these labneh samples have prepared with a stabilizer that contains carreganan. The authors stated that protein can be trapped inside of the stabilizer network in the system, and cause a firm texture. Aging effect of the powders impact their rehydration properties, which can cause different reaction dynamics in the formulation systems, and led to firmer or looser structures. Therefore, it can be said that especially the powders that have higher casein fractions like MPC85 will create more elastic and firm structures, yet over aging their rehydration and dynamics might cause reverse results as well. The powders that have higher whey protein fractions will still create elastic structures, however their effect will not be the high like MPC powders.

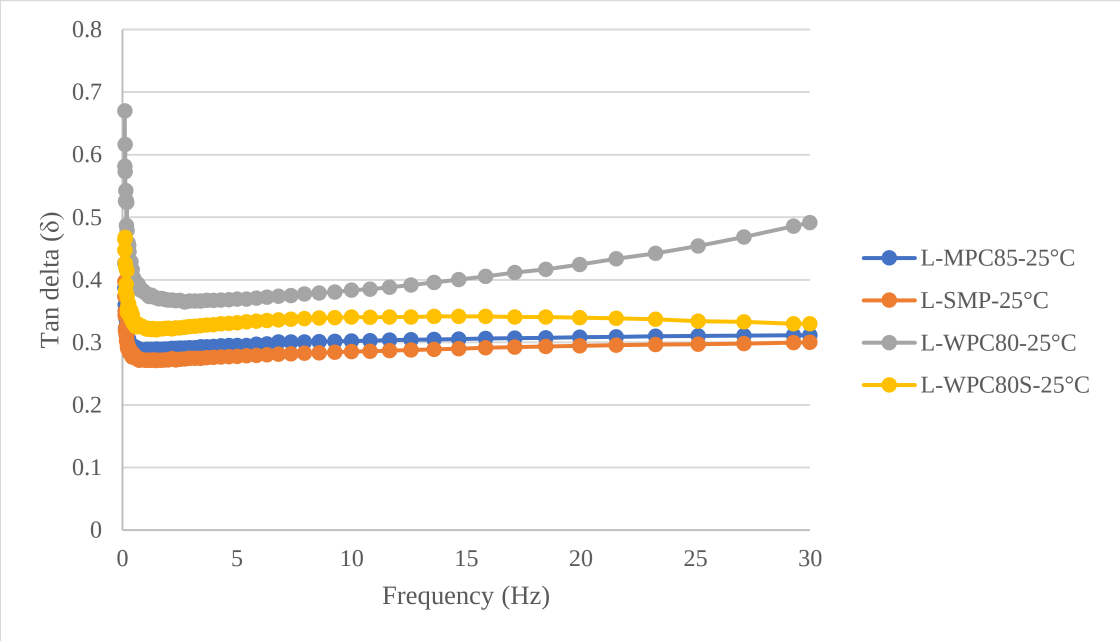



Figure 45. Tan Delta (δ) Results of Labneh Samples that were prepared with 4-month-old dairy powders from 25°C conditions

The results of tan delta for labneh samples that were prepared by 4-months old 25°C powders is shown in Figure 45. The final results are located between 0.3 to 0.5, which supports the findings of Figure 43 and 44 that these labneh samples have elastic profiles. Nonetheless, the variations of tan delta values are observed in Figure 45, compared to Figure 39 and 42. For example, the tan delta value of L-WPC80-25C was found as almost 0.5, yet this value was between 0.3-0.35 for L-WPC80 and L-WPC80-10 samples. This change indicates that the storage effect of 25C on powders have also impacted the elasticity of the formulation that they were used. As it is shown by Khubber et al (2021), and Sozeri Atik et al (2023), these yogurt type systems are very dynamic, so their rheological profile is dependent on several variables like stabilizer type, protein composition etc. Nonetheless, it can be definetely concluded that using aged powders in product formulations have ability to alter their rheological dynamics.

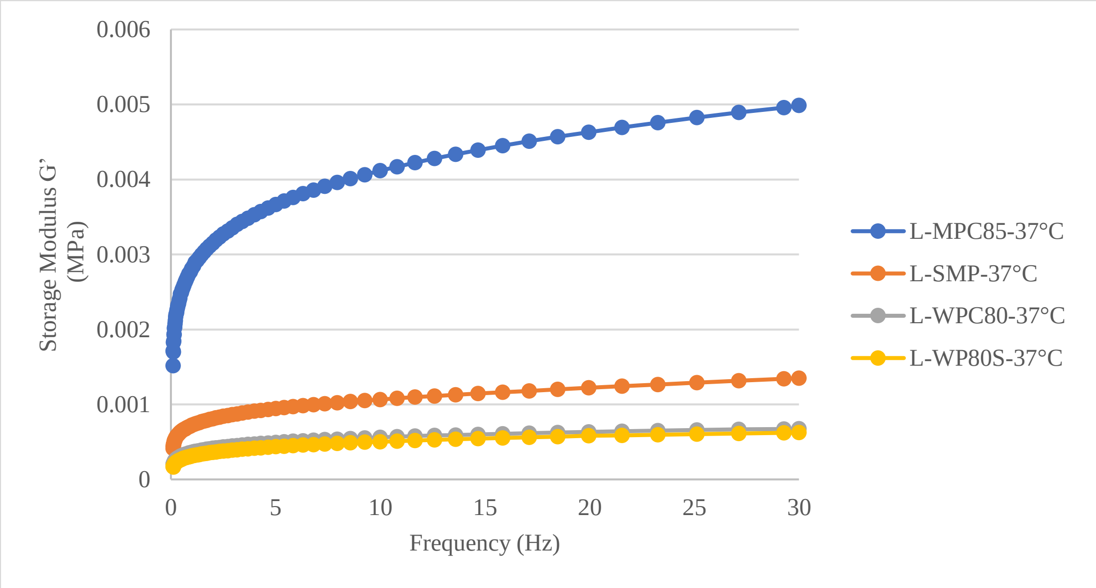



Figure 46. The Storage Modulus G' (elastic modulus) Results of Labneh Samples that were prepared with 4-month-old dairy powders from 37°C conditions

Figure 46 illustrates the storage modulus results of labneh samples that were prepared with 4-months old powders that kept in 37°C conditions. The results showed that as similar to Figures 37,40 and 43, the highest storage modulus is owned by L-MPC85-37°C samples. However, it is also the highest storage modulus of the labneh samples that were formulated with MPC85. Therefore, it should be noted that aging of MPC85 along with temperature conditions had an impact on rheological profile of labneh sample. This effect was the most for the powders of 37°C conditions. Also, this result is an insight of excellent capability of MPC85 to create rigid structure among all samples, owing to its protein structure, and also most probably water holding capacity. Compared to Figure 43, L-SMP-37°C got almost the same result as L-SMP-25°C. For L-WPC80-37°C and L-WPC80S-37°C samples, the storage modulus found to be higher than L-WPC80-25°C and L-WPC80S-25°C. This result may be attributed to lowering of water holding capacity of the powders over the age, and also with the effect of storage temperature.

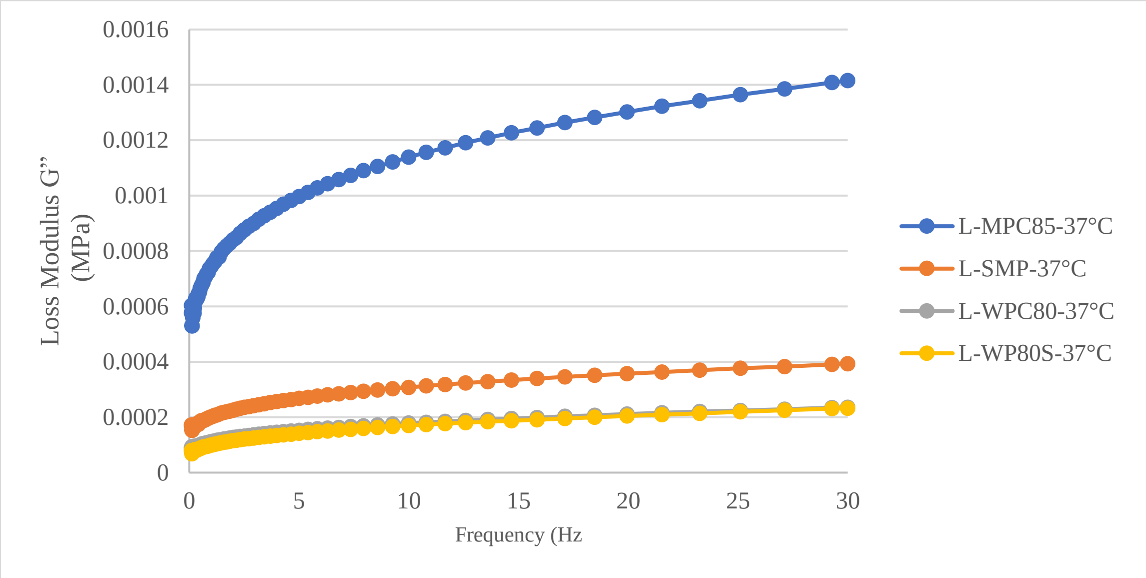



Figure 47. The Loss Modulus G'' (viscous modulus) Results of Labneh Samples that were prepared with 4-month-old dairy powders from 37°C conditions

The Figure 47 represents the results of the loss modulus for the labneh samples that were formulated with 4-month-old 37°C powders. When Figure 47 is compared to Figure 38, 41 and Figure 44, the results show that the highest loss modulus values for the labneh samples formulated with 37°C powders are achieved. L-MPC85-37°C got the highest loss modulus value compared to other labneh samples that contain MPC85 (Figure 47). For the labneh samples that were formulated with SMP powders, SMP caused a fluctuation in loss modulus with regard to storage conditions. L-SMP-37°C got a lower loss modulus than L-SMP-25°C, yet its value was higher than L-SMP (Figures 38,44 and 47). L-WPC80-37°C and L-WPC80S-37°C samples got higher loss modulus values than L-WPC80-25°C and L-WPC80S-25°C, which might be an indication of the change in water holding capacity of whey proteins over storage time and conditions. Also, as these loss modulus values are also lower than the storage modulus values, the elasticity of labneh samples that contain 37°C powders is also confirmed, like other temperature conditions (Figures 38, 44 and 47).

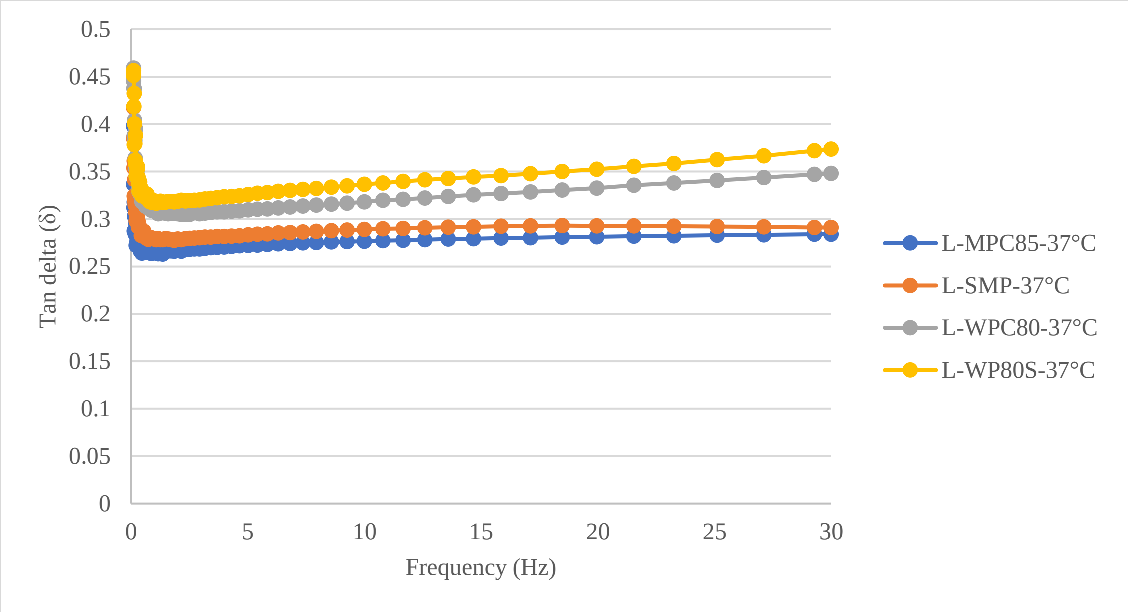



Figure 48. Tan Delta (δ) Results of Labneh Samples that were prepared with 4-month-old dairy powders from 37°C conditions

The Figure 48 illustrates the tan delta results of labneh samples that contains 4-month-old 37°C powders. As it can be seen from the Figure 48, the delta tan values are between 0.3-0.4, and the highest delta tan was found for L-WPC80S-37°C among all samples. Even though all the samples are elastic, the higher tan delta indicates that the L-WPC80S-37°C sample is more viscous than other samples. In accordance with the results of Figure 46 and 47, L-MPC85-37°C got the lowest delta tan value, which shows the highest elasticity among all samples. The delta tan value was found around 0.5 for L-WPC80-25°C, while it is around 0.35 for L-WPC80-37°C (Figure 45 and 48). This finding also showed that WPC80 powders that kept in 37°C conditions led an increase of firmness of labneh samples, which might be attributed to the altered water holding capacity of WPC80 powders.

### 3.2.5. Sensory Analysis Results

The labneh samples were first made with fresh powders which was at the beginning of their shelf life. Following this, the powders were collected from their respective temperature conditions, specifically 10°C, 25°C, and 37°C, subsequent to a storage duration of 4 months. Subsequently, the mentioned powders were integrated into labneh compositions.

The product’s quality attributes were evaluated through sensory analysis conducted on both sample sets. The other goal was to analyze the impact of powder storage and aging on labneh's final quality characteristics. The powders were uniformly integrated into the formulations at a concentration of 4.5%, while maintaining consistency in all other ingredients and raw materials, including stabilizer, milk, culture, and so on, across all labneh samples. The sensory analysis was carried out with the assistance of ten trained panelists from Hadaf Foods Industries, which is the first processed cheese factory in the United Arab Emirates. It is a subsidiary of Pinar Dairy Products, one of Turkey's largest and most established dairy companies. As part of their daily work, panelists evaluate labneh and processed cream cheese on a consistent basis. Hence, a group of 10 expert panelists were chosen to participate in the sensory evaluation of the labneh samples. The samples were presented in small sample cups labeled with three-digit numbers. Furthermore, the panelists were directed to utilize water for the purpose of rinsing their palates between each instance of sample tasting. The evaluators assessed the characteristics using a 5-point hedonic scale.

Table 24 represents the sensory analysis results for all labneh samples. The highest acceptability of appearance is found for L-WPC80 as 3.714. Two same results of acceptability was found for L-SMP and L-WPC80S. However, L-MPC85 obtained the lowest acceptability in terms of appearance. Nonetheless, the highest acceptability in terms of thickness was noted for L-MPC85 and L-WPC80S. Almost all of the samples are found to have same preference of smoothness as 3.714, yet L-MPC85 got the lowest value as 2.857. The color values of the samples were found to be similar to each other, yet L-SMP and L-WPC80S got lower values as 3.714. The aroma profiles of the product found to be different from each other, which is also noted in the comments sections of sensory sheets by panelists. The highest acceptability was found for L-MPC85 samples, and also panelists noted that it has a pleasant dairy flavor compared to other samples. Aroma scores of L-WPC80 and L-WPC80S was found as 3.571, yet the panelists noted that these labneh samples have more sour notes than other samples (Table 24).

Table 24. The Sensory Analysis Results of Labneh Samples that were prepared with fresh dairy powders

| Sample | Appearance | Thickness | Smoothness | Color | Aroma | Creaminess |
|---|---|---|---|---|---|---|
| **L-SMP** | 3.571 | 3.000 | 3.714 | 3.714 | 3.143 | 3.000 |
| **L-MPC85** | 3.429 | 3.429 | 2.857 | 3.857 | 3.714 | 3.286 |
| **L-WPC80** | 3.714 | 2.714 | 3.714 | 3.857 | 3.571 | 3.714 |
| **L-WPC80S** | 3.571 | 3.429 | 3.714 | 3.714 | 3.571 | 4.000 |

Creaminess is considered as an important quality attribute for labneh especially in Middle East, and the lowest score of creaminess was found for L-SMP samples as 3, while the highest score was obtained for L-WPC80S. The panelists noted that L-WPC80S had some sour notes, however, the creaminess felt from that sample more, with also a pleasant smoothness (Table 24).

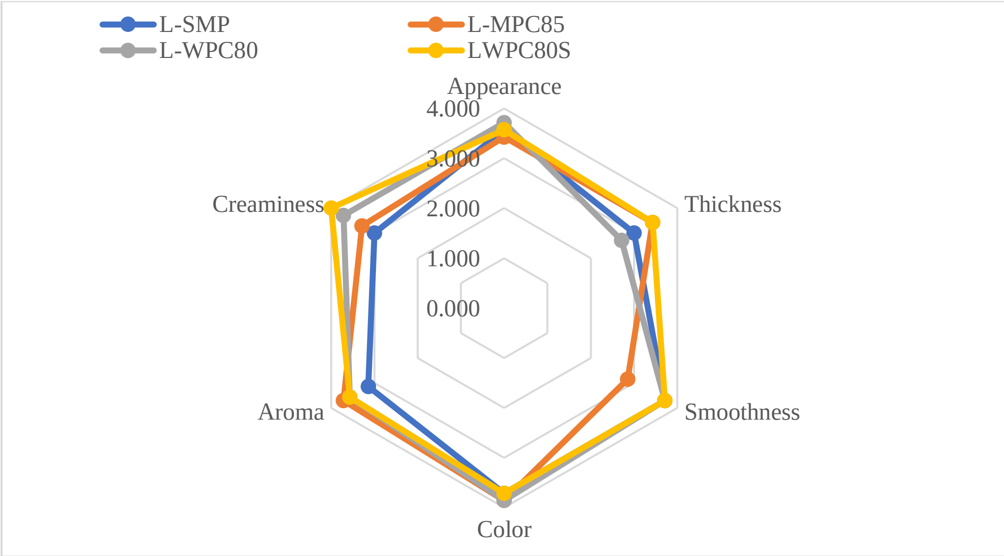
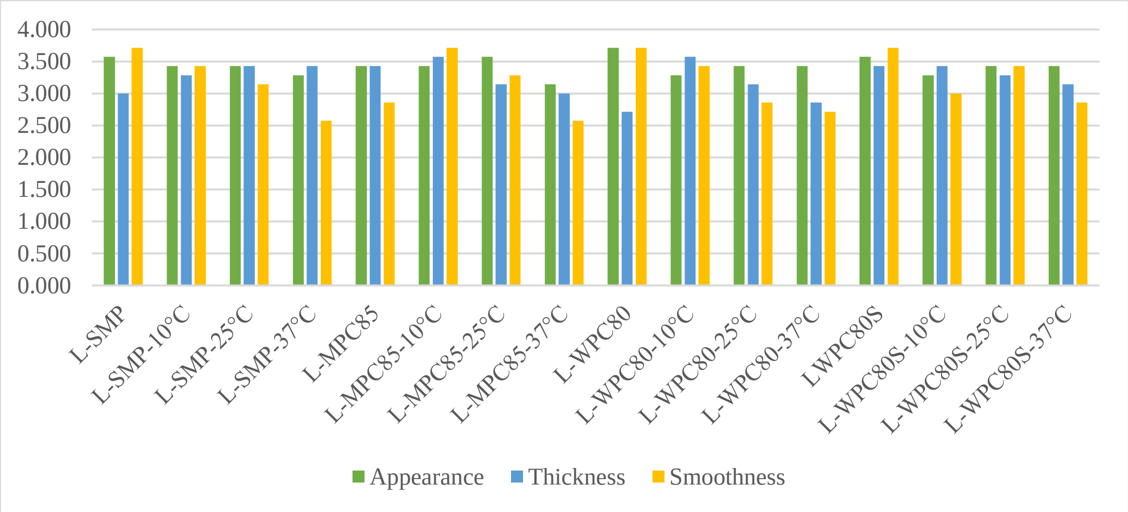



Figure 49. Radar Diagram of Sensory Analysis Results for Labneh Samples that were prepared with fresh powders

Labneh samples prepared with fresh powders are shown on a radar diagram of sensory analysis results in Figure 49. Figure 49 shows that there was a lot of variation in the degree to of creaminess and thickness of labneh samples. Since each of these powders has a unique nutritional profile, they each impact the product's final texture and flavor differently. The panel agreed that L-MPC85 has a pleasant dairy flavor, but that the smoothness was not ideal because product was very thick, for the preparation of formulationin the food industry, on the basis of these results, it is possible to conclude that the formulations could be improved in a more favorable manner if each powder were utilized in the formulations at different ratios.



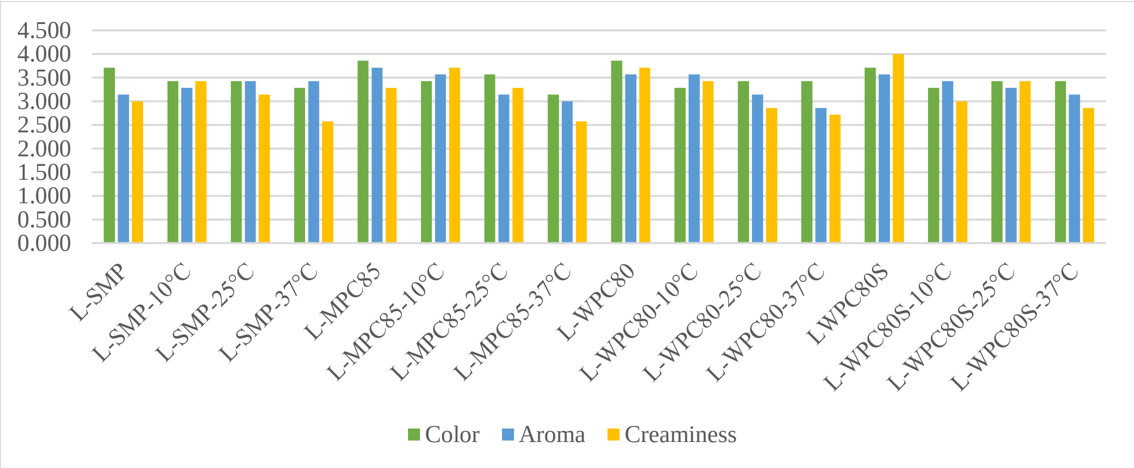




Figure 50. Overall Sensory Analysis Results of Labneh Samples a) Appearance, Thickness and Smoothness Results of Labneh Samples, b) Color, Aroma and Creaminess Results of Labneh Samples

[a]*The second part of sample name represents the respective powder, and the last part represents the respective storage temperature*

Figure 50.a represents the sensory analysis results of labneh samples in terms of appearance, thickness, and smoothness. The results of the graph illustrate that appearance of the labneh samples is highly affected by the storage conditions of the powders that they were formulated with. For example, the appearance values of L-SMP, L-MPC85 and L-WPC80S got higher scores. However, over time, alterations were seen. For instance, the L-MPC85-37°C sample got a lower appearance score when compared to the labneh sample that was prepared with fresh MPC85 powder. The scores of appearances were higher for 10°C for L-SMP samples, yet it decreased when the product was formulated with the SMP of 37C conditions. The same effect was seen for

L-MPC85 and L-WPC80S samples, but the results were contrasting for L-WPC80 samples where the appearance got higher acceptance when WPC80 from 37C was used in the formulation. Thickness values were also changed over the storage conditions of the powders. For instance, L-SMP-25°C and L-SMP-37°C samples got higher thickness preferences over the L-SMP-10°C and L-SMP. A similar result was also seen for L-WPC80 samples, yet only an increase in thickness scores was seen for L-WPC80-10 samples, while a reduction of acceptance of thickness was found for L-WPC80-25°C and L-WPC80-37°C samples. For almost all samples, smoothness were altered when 37°C powders were used in the formulations. The lowest acceptance values for smoothness were recorded for all the labneh samples that formulated with powders of 37°C conditions (Figure 50.a). For the samples that contain powders of 37°C conditions, the panellists noted that products are grainy, and do not have a smooth structure. This indication is a result of alteration in particle size, and as well as rehydration properties of powders. However, the labneh samples that contain MPC85 were found to have most grainy texture for all labneh samples.

The Figure 50.b reveals the overall results for color, aroma and creaminess of the labneh samples. The lowest acceptance values of color was recorded for the labneh samples that formulated with powders of 37°C conditions, except L-WPC80-37°C sample. This result can be correlated with the color values of the powders in Table 8, where the most significant alterations were seen. Especially the decrease in L* value and increase in b* value was seen for all the powders. These results indicate the extent of browning reactions in the powders. It can be seen that panelists prefer more whiteish color profiles for labneh, they do not prefer to have yellowish labneh samples. The aroma profile acceptance was reduced for the labneh samples that formulated with the powders of 37°C conditions. This reduction can be seen for the samples of L-MPC85-37°C, L-WPC80-37°C and L-WPC80S-37°C. However, the aroma profile acceptance was more stable for L-SMP samples with the formulation of different powder storage conditions.

Smith et al (2016) studied the flavor and stability of the milk proteins, and their findings revealed that the milk protein concentrates which stored at lower temperatures showed more milky flavors, and also a sweet taste as it is noted by our panelists as well. However, the authors showed that with the ageing of powders, some of the undesirable aroma profiles like cardboard, animal and corn chip/tortilla are increased. They also stated that these increase in undesirable aroma intensities were more seen at higher temperature conditions. Therefore, the reduction in aroma acceptance of labneh samples when they formulated with powders of 37°C conditions is supported with this finding. The scores of creaminess is also reduced for labneh samples with 37°C powders, yet it didn’t show a significant and stable reduction like aroma acceptance. The lowest acceptance of creaminess was recorded for L-SMP-37°C and L-MPC85-37°C samples. Moreover, L-WPC80-37°C and L-WPC80S-37°C samples showed a significant reduction of acceptance in creaminess when they compared to L-WPC80 and L-WPC80S samples (Figure 50.a and Figure 50.b)

# CHAPTER 4

# CONCLUSION

Four different dairy powders, namely SMP, MPC85, WPC80, and WPC80S were kept in 3 different storage conditions of 10°C, 25°C, and 37°C for 4 months. Beginning of the shelf life, the day zero (D0) analysis was done for the powders, also they were utilized in labneh formulations at 3.5%, and several analyses for these respective labneh samples were made. The dairy powders were evaluated in terms of color, FT-IR, particle size distribution, water activity, and turbidity. The color analysis results showed that powder type, storage time, and temperature have a significant impact on the L*, a*, and b* values. For all temperature conditions, the highest reduction of the L* value was seen for SMP samples. For L* values, MPC85 and WPC80S were found to be similar to each other. The predominant impact on L* values was seen especially for 3rd and 4th month time periods. For a* values, the significant differences start after 1 month, and MPC85 and WPC80S were found to be similar for a* values, as well. As a contrast result, even though there were alterations in the b* values, the change was not found to be significant throughout the storage time. The water activity values were not affected from powder types, all powders are grouped into the same categories. However, still, the powder type as a variance affected the water activity most. The 37°C conditions are found to be significantly different from the 10°C and 25°C conditions. Nonetheless, values of 25°C conditions are grouped between 10°C and 37°C conditions. Except for WPC80, with higher temperature storage conditions, the water activity values are found to be lowest as compared to their D0 values.

FT-IR spectrums are found to be different for each powder, and with each temperature condition, alterations were predominantly seen in the spectra. Due to several reasons like Maillard reaction, protein denaturation, component degradations, and lactose crystallization, several shifts and peaks were seen in the spectrums. Most significant alterations as compared to D0 results were seen for the 4-month-old powders for every temperature condition. Nonetheless, different secondary structures of proteins were especially seen for 4-month-old powders from 37°C conditions. The particle size distribution profiles of the powders were significantly changed by different storage temperatures over time. However, MPC85 was the most stable powder, and its particle size did not change significantly due to storage time and temperature. Overall, WPC80 and WPC80S samples showed a wider distribution compared to other powders, and with respect to storage temperature and time conditions, they showed major variations. Also, the most significant variations in particle sizes were seen in 37°C conditions. It should be also noted that over the aging and higher storage conditions, particle size of the majority of the powders were increased. The turbidity values were found to be decreased with the aging of the powders, except the SMP that was kept in 10°C conditions. Also, it is found that when particle size increases, turbidity is more willing to decrease. Moreover, it is found that storage temperature does not impact turbidity significantly, yet the storage time affects.

For each powder` respective labneh samples, the color values are found to be significantly different from each other. The highest change in color values (Delta E) is found for 37°C conditions, specifically for L-WPC80-37°C. The color changes were more predominant and significant at higher storage temperature conditions. For the FT-IR results of labneh samples, the most alterations in the peaks were seen in the samples that were prepared with 4-month-old powders, especially from higher storage temperature conditions, mainly due to browning reactions and protein denaturation of powders. The texture analysis of labneh samples showed that the samples which formulated with MPC85 showed the highest hardness profile among others. Over the aging of powders, the stringiness of labneh samples were increased. Adhesiveness were also increased with the aging of powders, but not as stable as stringiness. The rheology analysis of labneh samples showed that all the samples had an elastic profile, not viscous profile. However, the intensity of elasticity and viscous structure were changed over the aging of powders with the influence of storage temperature. The sensory analysis results showed that the acceptance of the products were changed according to their texture, appearance, mouthfeel etc. The labneh samples that were prepared with MPC85 were found to be very thick, yet with a pleasant dairy flavor. The labneh samples that were prepared with SMP were found to have burnt taste, while the samples that contain WPC80S found to be smooth.

As a conclusion, the functionality and stability of dairy powders are prone to change over the storage conditions. Moreover, these changes have significant impacts on final food product quality, which these dairy powders were utilized in. Therefore, to maximize production effiency, and prevent any quality defects, the functionality of the ingredients should be understood well.

# REFERENCES


Aalaei, Kataneh, Ingegerd Sjöholm, Marilyn Rayner, and Eden Tareke. 2017. "The Impact of Different Drying Techniques and Controlled Storage on the Development of Advanced Glycation End Products in Skim Milk Powders Using Isotope Dilution ESI-LC-MS/MS." *Food and Bioprocess Technology* 10, no. 9 : 1704–14. https://doi.org/10.1007/s11947-017-1936-x.

Aalaei, Kataneh, Marilyn Rayner, and Ingegerd Sjöholm. 2016. "Storage Stability of Freeze-Dried, Spray-Dried and Drum-Dried Skim Milk Powders Evaluated by Available Lysine." *LWT* 73 : 675–82. https://doi.org/10.1016/j.lwt.2016.07.011.

Agarwal, Shantanu, Robert L. W. Beausire, Sonia Patel, and Hasmukh Patel. 2015. "Innovative Uses of Milk Protein Concentrates in Product Development." Journal of Food Science 80, no. S1 : A23–29. https://doi.org/10.1111/1750-3841.12807.

Al-Lafi, Abdul Ghaffar, and Isam AL-Naser. 2022. "Application of 2D-COS-FTIR Spectroscopic Analysis to Milk Powder Adulteration: Detection of Melamine." *Journal of Food Composition and Analysis* 113 :104720. https://doi.org/10.1016/j.jfca.2022.104720.

Almena, A., K.R. Goode, S. Bakalis, P.J. Fryer, and E. Lopez-Quiroga.2019. "Optimising Food Dehydration Processes: Energy-Efficient Drum-Dryer Operation." *Energy Procedia* 161 : 174–81. https://doi.org/10.1016/j.egypro.2019.02.078.

Altay, Özgül, Özgün Köprüalan, Işıl İlter, Mehmet Koç, Figen Kaymak Ertekin, and Seid Mahdi Jafari. "Spray Drying Encapsulation of Essential Oils; Process Efficiency, Formulation Strategies, and Applications." *Critical Reviews in Food Science and Nutrition*, August 25, 2022, 1–19. https://doi.org/10.1080/10408398.2022.2113364.

Alvarez, V.B., C.L. Wolters, Y. Vodovotz, and T. Ji. 2005. "Physical Properties of Ice Cream Containing Milk Protein Concentrates." Journal of Dairy Science 88, no. 3 : 862–71. https://doi.org/10.3168/jds.s0022-0302(05)72752-1.

Anema, S.G., D.N. Pinder, R.J. Hunter, and Y. Hemar. 2006. "Effects of Storage Temperature on the Solubility of Milk Protein Concentrate (MPC85)." *Food Hydrocolloids* 20, no. 2–3 : 386–93. https://doi.org/10.1016/j.foodhyd.2005.03.015.

Atwaa, E., Eman Abou Sayed-Ahmed, and M. A. A. Hassan. 2020. "Physicochemical, Microbiological and Sensory Properties of Low Fat Probiotic Yoghurt Fortified with Mango Pulp Fiber Waste as Source of Dietary Fiber." *Journal of Food and Dairy Sciences* 11, no. 9 : 271–76. https://doi.org/10.21608/jfds.2020.118368.

Aydinol, Pinar, and Tulay Ozcan.2017 "Production of Reduced-Fat Labneh Cheese with Inulin and β-Glucan Fibre-Based Fat Replacer." International Journal of Dairy Technology 71, no. 2 : 362–71. https://doi.org/10.1111/1471-0307.12456.

Bacenetti, Jacopo, Luciana Bava, Andrea Schievano, and Maddalena Zucali. 2018. "Whey Protein Concentrate (WPC) Production: Environmental Impact Assessment." Journal of Food Engineering 224: 139–47. https://doi.org/10.1016/j.jfoodeng.2017.12.018.

Baldelli, Alberto, Hale Oguzlu, Diana Yumeng Liang, Alison Subiantoro, Meng Wai Woo, and Anubhav Pratap-Singh. 2022. "Spray Freeze Drying of Dairy Products: Effect of Formulation on Dispersibility." *Journal of Food Engineering* 335 : 111191. https://doi.org/10.1016/j.jfoodeng.2022.111191.

Bell, Leonard N., and Theodore P. Labuza. 1994. "Influence of the Low-Moisture State on pH and Its Implication for Reaction Kinetics." Journal of Food

Engineering 22, no. 1–4 : 291–312. https://doi.org/10.1016/0260-8774(94)90036-1.

Bruzantin, F.P., J.L.P. Daniel, P.P.M. da Silva, and M.H.F. Spoto. 2016. "Physicochemical and Sensory Characteristics of Fat-Free Goat Milk Yogurt with Added Stabilizers and Skim Milk Powder Fortification." *Journal of Dairy Science* 99, no. 5 : 3316–24. https://doi.org/10.3168/jds.2015-10327.

Butré, Claire I., Peter A. Wierenga, and Harry Gruppen. 2014. "Influence of Water Availability on the Enzymatic Hydrolysis of Proteins." Process Biochemistry 49, no. 11 : 1903–12. https://doi.org/10.1016/j.procbio.2014.08.009.

Cândido de Souza, Weysser Felipe, Carlos Roberto Souza do Amaral, and Priscilla Diniz Lima da Silva Bernardino. "The Addition of Skim Milk Powder and Dairy Cream Influences the Physicochemical Properties and the Sensory Acceptance of Concentrated Greek-Style Yogurt." *International Journal of Gastronomy and Food Science* 24 (July 2021): 100349. https://doi.org/10.1016/j.ijgfs.2021.100349.

Córdova, Constanza, Juan P. Vivanco, Julián Quintero, and Andrea Mahn. 2020. "Effect of Drum-Drying Conditions on the Content of Bioactive Compounds of Broccoli Pulp." *Foods* 9, no. 9 : 1224. https://doi.org/10.3390/foods9091224.

Crowley, Shane V., Benjamin Desautel, Inge Gazi, Alan L. Kelly, Thom Huppertz, and James A. O'Mahony. 2015. "Rehydration Characteristics of Milk Protein Concentrate Powders." *Journal of Food Engineering* 149 : 105–13. https://doi.org/10.1016/j.jfoodeng.2014.09.033.

Dag, Damla, Rakesh K. Singh, Jinru Chen, Abhinav Mishra, and Fanbin Kong. 2022. "Radio Frequency Assisted Thermal Processing for Pasteurization of Packaged Whole Milk Powder Surrounded by Oil." Food Control 135 : 108762. https://doi.org/10.1016/j.foodcont.2021.108762.

Daniel. 2021. “What Is Delta E? And Why Is It Important for Color Accuracy? - ViewSonic Library.” ViewSonic Library, . https://www.viewsonic.com/library/creative-work/what-is-delta-e-and-why-is-it-important-for-color-accuracy/.

Daud, Wan Ramli Wan. 2008. “Fluidized Bed Dryers — Recent Advances.” *Advanced Powder Technology* 19, no. 5 : 403–18. https://doi.org/10.1016/s0921-8831(08)60909-7.

Deshwal, Gaurav Kr, Ashish Kumar Singh, Devendra Kumar, and Heena Sharma. 2020. “Effect of Spray and Freeze Drying on Physico-Chemical, Functional, Moisture Sorption and Morphological Characteristics of Camel Milk Powder.” *LWT* 134 : 110117. https://doi.org/10.1016/j.lwt.2020.110117.

DESOBRY, STEPHANE A., FLAVIA M. NETTO, and THEODORE P. LABUZA. 1997. “Comparison of Spray-Drying, Drum-Drying and Freeze-Drying for β-Carotene Encapsulation and Preservation.” *Journal of Food Science* 62, no. 6 : 1158–62. https://doi.org/10.1111/j.1365-2621.1997.tb12235.x.

Du, Yuwei, Min Zhang, Arun S. Mujumdar, Wenchao Liu, and Chaohui Yang. 2021. “Innovative Applications of Freeze-Drying to Produce Compound Formula Instant Foods: A Review.” *Drying Technology* 40, no. 13: 2583–97. https://doi.org/10.1080/07373937.2021.1966795

.

Ebid, Warda M. A., Gehad S. Ali, and Neimat A. H. Elewa.2022. “Impact of Spirulina Platensis on Physicochemical, Antioxidant, Microbiological and Sensory Properties of Functional Labneh.” Discover Food 2, no. 1 . https://doi.org/10.1007/s44187-022-00031-7.

Elnjikkal Jerome, Rifna, and Madhuresh Dwivedi. 2022. “Microwave Vacuum Drying of Pomegranate Peel: Evaluation of Specific Energy Consumption and Quality Attributes by Response Surface Methodology and Artificial

Neural Network." *Journal of Food Processing and Preservation* 46, no. 3 . https://doi.org/10.1111/jfpp.16325.

El-Sayed, Samah M., and Hoda S. El-Sayed. 2021. "Antimicrobial Nanoemulsion Formulation Based on Thyme (Thymus Vulgaris) Essential Oil for UF Labneh Preservation." *Journal of Materials Research and Technology* 10 : 1029–41. https://doi.org/10.1016/j.jmrt.2020.12.073.

Elshaghabee, Fouad M. F., Ahmed El-Hussein, and Mahmoud S. M. Mohamed. 2022. "Enhancement of Labneh Quality by Laser-Induced Modulation of Lactocaseibacillus Casei NRRL B-1922." Fermentation 8, no. 3 (March 18, 2022): 132. https://doi.org/10.3390/fermentation8030132.

Er, Betül, Durmuş Sert, and Emin Mercan. 2019. "Production of Skim Milk Powder by Spray-Drying from Transglutaminase Treated Milk Concentrates: Effects on Physicochemical, Powder Flow, Thermal and Microstructural Characteristics." *International Dairy Journal* 99 : 104544. https://doi.org/10.1016/j.idairyj.2019.104544.

Felfoul, Imène, Jennifer Burgain, Carole Perroud, Claire Gaiani, Joël Scher, Hamadi Attia, and Jérémy Petit. 2022. "Impact of Spray-Drying Conditions on Physicochemical Properties and Rehydration Ability of Skim Dromedary and Cow's Milk Powders." Drying Technology 40, no. 3 : 665–77. https://doi.org/10.1080/07373937.2020.1828448.

Forecast ltd, Market Data. "Market Data Forecast | Industry Reports & Business Intelligence." Market Data Forecast, n.d. http://www.marketdataforecast.com/.

Fouad, Mohamed T., Asmaa G. Abu-El Khair, Samah M. El-Sayed, Ahmed B. Shazly, and Hoda S. El-Sayed. 2022. "Bio-Labneh Fortified with Functional Microcapsules Filled with Chickpea Flour and Probiotics." Biocatalysis and Agricultural Biotechnology 42 : 102345. https://doi.org/10.1016/j.bcab.2022.102345.

Fournaise, Tristan, Jennifer Burgain, Carole Perroud-Thomassin, and Jérémy Petit. 2021. “Impact of the Whey Protein/Casein Ratio on the Reconstitution and Flow Properties of Spray-Dried Dairy Protein Powders.” Powder Technology 391 : 275–81. https://doi.org/10.1016/j.powtec.2021.06.026.

Gaiani, C., J. Scher, P. Schuck, S. Desobry, and S. Banon. 2009. “Use of a Turbidity Sensor to Determine Dairy Powder Rehydration Properties.” Powder Technology 190, no. 1–2 : 2–5. https://doi.org/10.1016/j.powtec.2008.04.042.

Galaz, P., M. Valdenegro, C. Ramírez, H. Nuñez, S. Almonacid, and R. Simpson. 2017. “Effect of Drum Drying Temperature on Drying Kinetic and Polyphenol Contents in Pomegranate Peel.” *Journal of Food Engineering* 208 : 19–27. https://doi.org/10.1016/j.jfoodeng.2017.04.002.

Garczewska-Murzyn, Anna, Michał Smoczyński, Natalia Kotowska, and Katarzyna Kiełczewska. 2021. “Effect of Buttermilk and Skimmed Milk Powder on the Properties of Low-Fat Yoghurt.” *Journal of Food Science and Technology* 59, no. 6: 2160–67. https://doi.org/10.1007/s13197-021-05227-w.

GEA. nd. “Processing Concentrated and Fermented Dairy Products .” https://www.gea.com/en/binaries/centrifuges-process-lines-concentrated-fermented-dairy-product-yoghurt-soft-cheese_tcm11-92896.pdf.

Giménez, Paula, Guillermo H. Peralta, Mara E. Batistela, Guillermo A. George, Elisa C. Ale, Juan Pablo Quintero, Erica R. Hynes, and Carina V. Bergamini. 2023. “Impact of the Use of Skim Milk Powder and Adjunct Cultures on the Composition, Yield, Proteolysis, Texture and Melting Properties of Cremoso Cheese.” *International Dairy Journal* 140 : 105595. https://doi.org/10.1016/j.idairyj.2023.105595.

Glossary: Terminology of food texture | Mecmesin | Texture Analysis. “Glossary: Terminology of Food Texture | Mecmesin | Texture Analysis,” n.d. https://www.textureanalyzers.com/glossary.

Gomide, Aline Iamin, Ricardo Lemos Monteiro, and João Borges Laurindo. 2022. “Impact of the Power Density on the Physical Properties, Starch Structure, and Acceptability of Oil-Free Potato Chips Dehydrated by Microwave Vacuum Drying.” LWT 155 : 112917. https://doi.org/10.1016/j.lwt.2021.112917.

González-Cavieres, Luis, Mario Pérez-Won, Gipsy Tabilo-Munizaga, Erick Jara-Quijada, Rodrigo Díaz-Álvarez, and Roberto Lemus-Mondaca. 2021. “Advances in Vacuum Microwave Drying (VMD) Systems for Food Products.” Trends in Food Science & Technology 116 : 626–38. https://doi.org/10.1016/j.tifs.2021.08.005.

Guo, Mingruo, ed.2019. “Whey Protein Production, Chemistry, Functionality, and Applications,” https://doi.org/10.1002/9781119256052.

Guowei, Shu, Xin Yang, Chen Li, Dan Huang, Zhangteng Lei, and Chen He. 2019. “Comprehensive Optimization of Composite Cryoprotectant for Saccharomyces Boulardii during Freeze-Drying and Evaluation of Its Storage Stability.” *Preparative Biochemistry & Biotechnology* 49, no. 9 : 846–57. https://doi.org/10.1080/10826068.2019.1630649.

Han, Jie, John Fitzpatrick, Kevin Cronin, Valentyn Maidannyk, and Song Miao. 2022. “Breakage Behaviour and Functionality of Spray-Dried Agglomerated Model Infant Milk Formula: Effect of Proteins and Carbohydrates Content.” *Food Chemistry* 391 : 133179. https://doi.org/10.1016/j.foodchem.2022.133179.

Hazlett, R., C. Schmidmeier, and J.A. O'Mahony. 2021. "Approaches for Improving the Flowability of High-Protein Dairy Powders Post Spray Drying – A Review." Powder Technology 388 : 26–40. https://doi.org/10.1016/j.powtec.2021.03.021.

Ishibashi, Ryota, Takuya Numata, Hirofumi Tanigawa, and Takaharu Tsuruta. 2022."In-Situ Measurements of Drying and Shrinkage Characteristics during Microwave Vacuum Drying of Radish and Potato." *Journal of Food Engineering* 323 : 110988. https://doi.org/10.1016/j.jfoodeng.2022.110988.

Jervis, S., R. Campbell, K.L. Wojciechowski, E.A. Foegeding, M.A. Drake, and D.M. Barbano. 2012. "Effect of Bleaching Whey on Sensory and Functional Properties of 80% Whey Protein Concentrate." *Journal of Dairy Science* 95, no. 6 : 2848–62. https://doi.org/10.3168/jds.2011-4967.

Kaaki, D., O. Kebbe Baghdadi, N.E. Najm, and A. Olabi. 2012. "Preference Mapping of Commercial Labneh (Strained Yogurt) Products in the Lebanese Market." Journal of Dairy Science 95, no. 2: 521–32. https://doi.org/10.3168/jds.2011-4409.

Kandasamy, Sengodan, and Rajshri Naveen. 2022. "A Review on the Encapsulation of Bioactive Components Using Spray-drying and Freeze-drying Techniques." *Journal of Food Process Engineering* 45, no. 8 . https://doi.org/10.1111/jfpe.14059.

Kang, Renxi, Xiao Wang, Ming Zhao, Lisa E. Henihan, and Colm P. O'Donnell. 2022 "A Comparison of Benchtop and Micro NIR Spectrometers for Infant Milk Formula Powder Storage Time Discrimination and Particle Size Prediction Using Chemometrics and Denoising Methods." Journal of Food Engineering 329 : 111087. https://doi.org/10.1016/j.jfoodeng.2022.111087.

Kara, Ümmügülsüm, and Durmuş Sert. 2022. "The Use of Microfiltration Technique in the Production of Skim Milk Powder: The Effect of Milk Transport Conditions on the Microbiological and Physicochemical

Properties of Milk and Milk Powders." International Journal of Dairy Technology 75, no. 2: 438–47. https://doi.org/10.1111/1471-0307.12855.

Karthik, P, N Chhanwal, and C Anandharamakrishnan. 2017. "Chapter 4 - Drum Drying." In *Drum Drying. Handbook of Drying for Dairy Products*, 43–56. https://doi.org/doi:10.1002/9781118930526.ch4.

Kelly, P. 2011. "MILK PROTEIN PRODUCTS | Milk Protein Concentrate." *Encyclopedia of Dairy Sciences*, 2011, 848–54. https://doi.org/10.1016/b978-0-12-374407-4.00346-0.

Khider, Manal, Nesreen M. Nasr, K. M. Atallah, and Wedad A. Metry.2022. "Functional UF-Low and Full-Fat Labneh Supplemented with Oats (Avena Sativa L.) Powder and Probiotic Bacteria." *Journal of Umm Al-Qura University for Applied Sciences* 8, no. 1–2 : 21–32. https://doi.org/10.1007/s43994-022-00003-8.

Khubber, Sucheta, Kartikey Chaturvedi, Nirja Thakur, Nitya Sharma, and Sudesh Kumar Yadav.2021. "Low-Methoxyl Pectin Stabilizes Low-Fat Set Yoghurt and Improves Their Physicochemical Properties, Rheology, Microstructure and Sensory Liking." *Food Hydrocolloids* 111 : 106240. https://doi.org/10.1016/j.foodhyd.2020.106240.

Kusio, Katarzyna, Jagoda O. Szafrańska, Wojciech Radzki, and Bartosz G. Sołowiej. 2020. "Effect of Whey Protein Concentrate on Physicochemical, Sensory and Antioxidative Properties of High-Protein Fat-Free Dairy Desserts." Applied Sciences 10, no. 20 : 7064. https://doi.org/10.3390/app10207064.

LA Bazyma and VA Kutovoy. 2005. "Vacuum Drying and Hybrid Technologies." *Stewart Postharvest Review* 1, no. 4 : 1–4. https://doi.org/10.2212/spr.2005.4.7.

Le, Thao T., Bhesh Bhandari, John W. Holland, and Hilton C. Deeth. 2011. "Maillard Reaction and Protein Cross-Linking in Relation to the Solubility of Milk Powders." *Journal of Agricultural and Food Chemistry* 59, no. 23 : 12473–79. https://doi.org/10.1021/jf203460z.

Lei, Yu, Qun Zhou, Yan-ling Zhang, Jian-bo Chen, Su-qin Sun, and Isao Noda.2010. "Analysis of Crystallized Lactose in Milk Powder by Fourier-Transform Infrared Spectroscopy Combined with Two-Dimensional Correlation Infrared Spectroscopy." Journal of Molecular Structure 974, no. 1–3 : 88–93. https://doi.org/10.1016/j.molstruc.2009.12.030.

Li, Y.H., W.J. Wang, L. Guo, Z.P. Shao, and X.J. Xu. 2019. "Comparative Study on the Characteristics and Oxidation Stability of Commercial Milk Powder during Storage." *Journal of Dairy Science* 102, no. 10 : 8785–97. https://doi.org/10.3168/jds.2018-16089.

Liu, Zi-Liang, Long Xie, Magdalena Zielinska, Zhongli Pan, Li-Zhen Deng, Jing-Shou Zhang, Lei Gao, Shan-Yu Wang, Zhi-An Zheng, and Hong-Wei Xiao. 2022. "Improvement of Drying Efficiency and Quality Attributes of Blueberries Using Innovative Far-Infrared Radiation Heating Assisted Pulsed Vacuum Drying (FIR-PVD)." *Innovative Food Science & Emerging Technologies* 77 : 102948. https://doi.org/10.1016/j.ifset.2022.102948.

Luck, P.J., B. Vardhanabhuti, Y.H. Yong, T. Laundon, D.M. Barbano, and E.A. Foegeding. 2013. "Comparison of Functional Properties of 34% and 80% Whey Protein and Milk Serum Protein Concentrates." Journal of Dairy Science 96, no. 9 : 5522–31. https://doi.org/10.3168/jds.2013-6617.

Macdougall, D.B. 2010."Colour Measurement of Food: Principles and Practice." In Colour Measurement , 312–342. Woodhead Publishing Limited. https://doi.org/doi:10.1533/9780857090195.2.312.

Malvern Instruments. 2015. A basic guide to particle characterization - iowa state university. Accessed June 19, 2023. https://www.cif.iastate.edu/sites/default/files/uploads/Other_Inst/Particle%20Size/Particle%20Characterization%20Guide.pdf.

McCarthy, Noel A., Jonathan B. Magan, Clodagh M. Kelleher, Alan L. Kelly, James A. O'Mahony, and Eoin G. Murphy. 2022. "Heat Treatment of Milk: Effect on Concentrate Viscosity, Powder Manufacture and End-Product Functionality." International Dairy Journal 128 : 105289. https://doi.org/10.1016/j.idairyj.2021.105289.

McSweeney, David J., Valentyn Maidannyk, James A. O'Mahony, and Noel A. McCarthy.2021. "Rehydration Properties of Regular and Agglomerated Milk Protein Concentrate Powders Produced Using Nitrogen Gas Injection Prior to Spray Drying." *Journal of Food Engineering* 305 : 110597. https://doi.org/10.1016/j.jfoodeng.2021.110597.

Milk Powder Market Size & Share Analysis - Industry Research Report - Growth Trends. "Milk Powder Market Size & Share Analysis - Industry Research Report - Growth Trends," n.d. https://www.mordorintelligence.com/industry-reports/milk-powder-market..

Milk Powder Market Size, Industry Share & Trends – 2032. 2022. "Milk Powder Market," https://www.futuremarketinsights.com/reports/milk-powder-market.

Nasser, Sarah, Alain Hédoux, Alexandre Giuliani, Cécile Le Floch-Fouéré, Véronique Santé-Lhoutellier, Isabelle de Waele, and Guillaume Delaplace. 2017. "Investigation of Secondary Structure Evolution of Micellar Casein Powder upon Aging by FTIR and SRCD: Consequences on Solubility." Journal of the Science of Food and Agriculture 98, no. 6 : 2243–50. https://doi.org/10.1002/jsfa.8711.

NETZSCH. (n.d.). Tan Delta. https://analyzing-testing.netzsch.com/en/training-know-how/glossary/tan-delta

Neutec Group. nd. What is Water Activity? “What Is Water Activity?,” https://www.neutecgroup.com/resource-library/water-activity/white-papers/75-what-is-water-activity#:~:text=Water%20activity%20is%20very%20temperature,the%20state%20of%20the%20matrix.

Nevara, Gita Addelia, Chay Shyan Yea, Roselina Karim, Kharidah Muhammad, and Hasanah Mohd Ghazali. 2018. “Effects of Moist-Heat Treatments on Color Improvement, Physicochemical, Antioxidant, and Resistant Starch Properties of Drum-Dried Purple Sweet Potato Powder.” *Journal of Food Process Engineering* 42, no. 1: e12951. https://doi.org/10.1111/jfpe.12951.

Non-fat Dry Milk & Skim Milk Powder | ThinkUSAdairy by the U.S. Dairy Export Council. “Non-Fat Dry Milk & Skim Milk Powder | ThinkUSAdairy by the U.S. Dairy Export Council,” n.d. https://www.thinkusadairy.org/products/milk-powders/milk-powder-categories/non-fat-dry-milk-and-skim-milk-powder.

NSABIMANA, CONSOLATE, BO JIANG, and RIMA KOSSAH. 2005. “Manufacturing, Properties and Shelf Life of Labneh: A Review.” *International Journal of Dairy Technology* 58, no. 3 : 129–37. https://doi.org/10.1111/j.1471-0307.2005.00205.x.

O’Kennedy, B.T. 2009.“Dairy Ingredients in Non-Dairy Food Systems.” *Dairy-Derived Ingredients*, 2009, 482–506. https://doi.org/10.1533/9781845697198.3.482.

Obradović, Nataša, Mina Volić, Viktor Nedović, Marica Rakin, and Branko Bugarski. 2022. “Microencapsulation of Probiotic Starter Culture in Protein–Carbohydrate Carriers Using Spray and Freeze-Drying Processes:

Implementation in Whey-Based Beverages." *Journal of Food Engineering* 321 : 110948. https://doi.org/10.1016/j.jfoodeng.2022.110948.

Ogolla, Jackline Akinyi, Boris Kulig, Liliana Bădulescu, Michael Wandayi Okoth, Günter Esper, Jutta Breitenbach, Oliver Hensel, and Barbara Sturm. 2019. "Influence of Inlet Drying Air Temperature and Milk Flow Rate on the Physical, Optical and Thermal Properties of Spray-Dried Camel Milk Powders." *Food and Bioprocess Technology* 12, no. 5 : 751–68. https://doi.org/10.1007/s11947-019-2243-5.

Orlien, V., L. Boserup, and K. Olsen. 2010. "Casein Micelle Dissociation in Skim Milk during High-Pressure Treatment: Effects of Pressure, pH, and Temperature." *Journal of Dairy Science* 93, no. 1 : 12–18. https://doi.org/10.3168/jds.2009-2244.

Ouyang, Kefan, Hexiang Xie, Yufeng Wang, Fangjian Ning, Hua Xiong, and Qiang Zhao. 2023. "Color Formation during the Fibrillization of Whey Protein Isolate: Maillard Reaction and Protein Oxidation." Food Hydrocolloids 142 : 108819. https://doi.org/10.1016/j.foodhyd.2023.108819.

Oyinloye, Timilehin Martins, and Won Byong Yoon. 2020. "Effect of Freeze-Drying on Quality and Grinding Process of Food Produce: A Review." Processes 8, no. 3 (March 20, 2020): 354. https://doi.org/10.3390/pr8030354.

OZER, B.H., A.E. BELL, A.S. GRANDISON, and R.K. ROBINSON. 1998. "RHEOLOGICAL PROPERTIES OF CONCENTRATED YOGHURT (LABNEH)." *Journal of Texture Studies* 29, no. 1 : 67–79. https://doi.org/10.1111/j.1745-4603.1998.tb00154.x.

Padma Ishwarya, S., and C. Anandharamakrishnan. 2017. "Spray Drying." Handbook of Drying for Dairy Products, February 157–94. https://doi.org/10.1002/9781118930526.ch5.

Pugliese, Alessandro, Giovanni Cabassi, Emma Chiavaro, Maria Paciulli, Eleonora Carini, and Germano Mucchetti. 2017. "Physical Characterization of Whole and Skim Dried Milk Powders." *Journal of Food Science and Technology* 54, no. 11: 3433–42. https://doi.org/10.1007/s13197-017-2795-1.

Qiu, Jun, Koen Kloosterboer, Yang Guo, Remko M. Boom, and Maarten A.I. Schutyser. 2019. "Conductive Thin Film Drying Kinetics Relevant to Drum Drying." *Journal of Food Engineering* 242 : 68–75. https://doi.org/10.1016/j.jfoodeng.2018.08.021.

Qiu, Y., T.J. Smith, E.A. Foegeding, and M.A. Drake.2015. "The Effect of Microfiltration on Color, Flavor, and Functionality of 80% Whey Protein Concentrate." *Journal of Dairy Science* 98, no. 9 : 5862–73. https://doi.org/10.3168/jds.2014-9174.

R, Heema, Murugan B, Rita Narayanan, and Pugazhenthi Pugazhenthi.2022. "Development of Herbal Bio-Yoghurt Powder Using Freeze Drying Technology." Madras Agricultural Journal 109, no. https://doi.org/10.29321/maj.10.000581.

Reineccius, Gary, Shardul Patil, and Vaidhyanathan Anantharamkrishnan. 2022. "Encapsulation of Orange Oil Using Fluidized Bed Granulation." *Molecules* 27, no. 6 : 1854. https://doi.org/10.3390/molecules27061854.

Ren, Jinbo, Minjie Liao, Lingjun Ma, Fang Chen, Xiaojun Liao, Xiaosong Hu, Song Miao, John Fitzpatrick, and Junfu Ji. 2022. "Effect of Spray Freeze Drying on the Structural Modification and Rehydration Characteristics of Micellar Casein Powders." *Innovative Food Science & Emerging Technologies* 80: 103093. https://doi.org/10.1016/j.ifset.2022.103093.

Roman, Laura, Mitchell R. Walker, Nicole Detlor, Janice Best, and Mario M. Martinez. 2022. "Pregelatinized Drum-Dried Wheat Starch of Different

Swelling Behavior as Clean Label Oil Replacer in Oil-in-Water Emulsions." *Foods* 11, no. 14 : 2044. https://doi.org/10.3390/foods11142044.

Ryabova, A.E., V.K. Semipyatny, and A.G. Galstyan. 2023. "EFFECTS OF STORAGE CONDITIONS ON MILK POWDER PROPERTIES." *Journal of Dairy Science*. https://doi.org/10.3168/jds.2022-23094.

Saleh, Mohammed, Fahed Al-Baz, and Khalid Al-Ismail. 2017. "Effects of Hydrocolloids as Fat Replacers on the Physicochemical Properties of Produced Labneh." *Journal of Texture Studies* 49, no. 1 : 113–20. https://doi.org/10.1111/jtxs.12296.

Samborska, Katarzyna, Sadegh Poozesh, Alicja Barańska, Mariia Sobulska, Aleksandra Jedlińska, Cordin Arpagaus, Narjes Malekjani, and Seid Mahdi Jafari. 2022. "Innovations in Spray Drying Process for Food and Pharma Industries." *Journal of Food Engineering* 321 : 110960. https://doi.org/10.1016/j.jfoodeng.2022.110960.

Schuck, P. 2014. "MILK AND MILK PRODUCTS | Microbiology of Dried Milk Products." *Encyclopedia of Food Microbiology*, 738–43. https://doi.org/10.1016/b978-0-12-384730-0.00220-2.

Sefidan, Ali M., Mathieu Sellier, James N. Hewett, Ayoub Abdollahi, Geoff R. Willmott, and Sid M. Becker. 2022. "Numerical Model to Study the Statistics of Whole Milk Spray Drying." *Powder Technology* 411: 117923. https://doi.org/10.1016/j.powtec.2022.117923.

Seo, Chan Won. 2022. "Effect of Fluidized Bed Agglomeration on Rheological and Physical Properties of Soy Protein-Enriched Milk Powder for Dietary Supplementation in Sarcopenia." *Preventive Nutrition and Food Science* 27, no. 4 (December 31, 2022): 483–89. https://doi.org/10.3746/pnf.2022.27.4.483.

Sert, Durmuş, Emin Mercan, and Mehmet Kılınç. 2022. “Powder Flow Behaviour, Functional Characteristics and Microstructure of Whole Milk Powder Produced from Cow and Buffalo Milk Mixtures.” International Dairy Journal 135: 105474. https://doi.org/10.1016/j.idairyj.2022.105474.

Setiawan, Budi, Jeallyza Muthia Azra, Zuraidah Nasution, Ahmad Sulaeman, and Sri Estuningsih. 2022. “Development of Freeze-Dried Coconut Drink and Its Nutrient Content, Sensory Profile, and Shelf Life.” *Journal of Culinary Science & Technology*, 1–17. https://doi.org/10.1080/15428052.2022.2079578.

Sharma, Anup, Atanu H. Jana, and Rupesh Shrikant Chavan. 2012. “Functionality of Milk Powders and Milk-Based Powders for End Use Applications-A Review.” *Comprehensive Reviews in Food Science and Food Safety* 11, no. 5: 518–28. https://doi.org/10.1111/j.1541-4337.2012.00199.x.

Smith, T.J., R.E. Campbell, Y. Jo, and M.A. Drake. 2016. “Flavor and Stability of Milk Proteins.” Journal of Dairy Science 99, no. 6 : 4325–46. https://doi.org/10.3168/jds.2016-10847.

Sołowiej, Bartosz, Imelda W.Y. Cheung, and Eunice C.Y. Li-Chan. 2014. “Texture, Rheology and Meltability of Processed Cheese Analogues Prepared Using Rennet or Acid Casein with or without Added Whey Proteins.” International Dairy Journal 37, no. 2 : 87–94. https://doi.org/10.1016/j.idairyj.2014.03.003.

Sözeri Atik, Didem, Hale İnci Öztürk, Nihat Akın, and Barbaros Özer. “Textural and Rheological Characterisation of Yoghurts Produced with Cultures Isolated from Traditional Back-Slopped Yoghurts.” *International Dairy Journal* 138 (March 2023): 105557. https://doi.org/10.1016/j.idairyj.2022.105557.

Srinivas, Yarrakula, Santhi Mary Mathew, Anjineyulu Kothakota, Nukasani Sagarika, and R. Pandiselvam. 2020. "Microwave Assisted Fluidized Bed Drying of Nutmeg Mace for Essential Oil Enriched Extracts: An Assessment of Drying Kinetics, Process Optimization and Quality." *Innovative Food Science & Emerging Technologies* 66 : 102541. https://doi.org/10.1016/j.ifset.2020.102541.

Statista. "Topic: Dairy Industry in New Zealand," n.d. https://www.statista.com/topics/6069/dairy-industry-in-new-zealand/

TARAKCI, ZEKAI, HASAN TEMIZ, and ATNAN UGUR. 2010. "The Effect of Adding Herbs to Labneh on Physicochemical and Organoleptic Quality during Storage." International Journal of Dairy Technology 64, no. 1 : 108–16. https://doi.org/10.1111/j.1471-0307.2010.00636.x.

The global standard for mixing, defoaming, dispersing, and pulverizing THINKY CORPORATION. nd."Method of Particle-Size Evaluation of Ground Material ｜ The Global Standard for Mixing, Defoaming, Dispersing, and Pulverizing THINKY CORPORATION," https://www.thinkymixer.com/en-gl/library/report/method-of-particle-seze-evaluation-of-ground-material/.

Tidona, Flavio, Marcello Alinovi, Salvatore Francolino, Gianluca Brusa, Roberta Ghiglietti, Francesco Locci, Germano Mucchetti, and Giorgio Giraffa. 2021. "Partial Substitution of 40 g/100 g Fresh Milk with Reconstituted Low Heat Skim Milk Powder in High-Moisture Mozzarella Cheese Production: Rheological and Water-Related Properties." LWT 137 : 110391. https://doi.org/10.1016/j.lwt.2020.110391.

Toniazzo, Taíse, Alexandre Minami Fioroto, Elias da Silva Araújo, and Carmen Cecília Tadini.2023. "Honey Powder Produced by Spray Drying as an Ingredient: A New Perspective Using a Plant-Based Protein as a Carrier." *Drying Technology*, February 3, 2023, 1–12. https://doi.org/10.1080/07373937.2023.2172028.

Turbidity and Water | U.S. Geological Survey. 2019. "Turbidity and Water | U.S. Geological Survey," https://www.usgs.gov/special-topics/water-science-school/science/turbidity-and-water#:~:text=Turbidity%20is%20the%20measure%20of,light%2C%20the%20higher%20the%20turbidity.

Ukuku, Dike O., Charles Onwulata, Sudarsan Mukhopadhyay, Lee Chau, Audrey Thomas-Gahring, and Michael H. Tunick. 2016 "Changes in Microbial Populations of WPC34 and WPC80 Whey Protein During Long-Term Storage." *Journal of Food Processing and Preservation* 41, no. 1 : e12743. https://doi.org/10.1111/jfpp.12743.

Vénica, Claudia Inés, Irma Verónica Wolf, María Julia Spotti, María Luján Capra, Diego Javier Mercanti, and María Cristina Perotti.2023. "Impact of Protein-Providing Milk Ingredients on Volatile Compounds, Microstructure, Microbiology and Physicochemical Characteristics of Yogurts." Food Bioscience 53 : 102588. https://doi.org/10.1016/j.fbio.2023.102588.

Voronin, Grace Lewis, Charith A. Hettiarachchi, and Federico M. Harte. 2021. "High Pressure Jet Spray Drying of Condensed Skim Milk Results in Powders with Enhanced Interfacial Properties." *Journal of Food Engineering* 292 : 110249. https://doi.org/10.1016/j.jfoodeng.2020.110249.

Wang, Mengqi, Xianwei Yuan, Yao Zheng, Zhengyan Wu, Hongbo Li, Hongjuan Li, and Jinghua Yu. 2022. "Maillard Reaction Indicators Formation, Changes and Possible Intake in Infant Formula Produced by Different Thermal Treatments during Domestic Use." Food Chemistry 395: 133576. https://doi.org/10.1016/j.foodchem.2022.133576.

Warncke, Malou, and Ulrich Kulozik. 2021. "Functionality of MC88- and MPC85-Enriched Skim Milk: Impact of Shear Conditions in Rotor/Stator Systems and High-Pressure Homogenizers on Powder Solubility and Rennet Gelation Behavior." Foods 10, no. 6 : 1361. https://doi.org/10.3390/foods10061361.

Wedel, Carolin, Zeynep Atamer, Anna Dettling, Mareike Wenning, Siegfried Scherer, and Jörg Hinrichs. 2022. "Towards Low-Spore Milk Powders: A Review on Microbiological Challenges of Dairy Powder Production with Focus on Aerobic Mesophilic and Thermophilic Spores." *International Dairy Journal* 126 : 105252. https://doi.org/10.1016/j.idairyj.2021.105252.

Wright, B.J., S.E. Zevchak, J.M. Wright, and M.A. Drake. 2009. "The Impact of Agglomeration and Storage on Flavor and Flavor Stability of Whey Protein Concentrate 80% and Whey Protein Isolate." Journal of Food Science 74, no. 1 : S17–29. https://doi.org/10.1111/j.1750-3841.2008.00975.x.

Yazdanpanah, Nima, and Tim A.G. Langrish. 2013."Comparative Study of Deteriorative Changes in the Ageing of Milk Powder." Journal of Food Engineering 114, no. 1 : 14–21. https://doi.org/10.1016/j.jfoodeng.2012.07.026.

Ye, M.P., R. Zhou, Y.R. Shi, H.C. Chen, and Y. Du. 2017. "Effects of Heating on the Secondary Structure of Proteins in Milk Powders Using Mid-Infrared Spectroscopy." Journal of Dairy Science 100, no. 1 : 89–95. https://doi.org/10.3168/jds.2016-11443.

Yuan, HaiNa, JianMin Lv, JinYan Gong, GongNian Xiao, RuiYu Zhu, Ling Li, and JiangNan Qiu. 2018. "Secondary Structures and Their Effects on Antioxidant Capacity of Antioxidant Peptides in Yogurt." *International Journal of Food Properties* 21, no. 1: 2167–80. https://doi.org/10.1080/10942912.2018.1501700.

Zahoor, Insha, and Mohammad Ali Khan. 2021. "Microwave Assisted Fluidized Bed Drying of Red Bell Pepper: Drying Kinetics and Optimization of Process Conditions Using Statistical Models and Response Surface Methodology." *Scientia Horticulturae* 286 : 110209. https://doi.org/10.1016/j.scienta.2021.110209.

Zhang, Jie, Dasong Liu, Yaowei Liu, Yun Yu, Yacine Hemar, Joe M. Regenstein, and Peng Zhou. 2020. “Effects of Particle Size and Aging of Milk Protein Concentrate on the Biophysical Properties of an Intermediate-Moisture Model Food System.” *Food Bioscience* 37 : 100698. https://doi.org/10.1016/j.fbio.2020.100698.

Zhang, Yan, Zhaojun Zheng, Chunhuan Liu, Chin-ping Tan, Kui Xie, and Yuanfa Liu. 2022b. “A Comparative Study between Freeze-Dried and Spray-Dried Goat Milk on Lipid Profiling and Digestibility.” *Food Chemistry* 387 : 132844. https://doi.org/10.1016/j.foodchem.2022.132844.

Zhang, Zunhao, Junxia Zhang, Wei Tian, Yang Li, Yahui Song, and Peng Zhang. 2022a. “Multi-Objective Optimization of Milk Powder Spray Drying System Considering Environmental Impact, Economy and Product Quality.” *Journal of Cleaner Production* 369 : 133353. https://doi.org/10.1016/j.jclepro.2022.133353.

# APPENDICES

# APPENDIX A

## STATISTICAL ANALYSES RESULTS FOR COLOR VALUES OF DAIRY POWDERS

Table A.1. General Linear Model- Anova Results of L* value

**Analysis of Variance**

| **Source** | **DF** | **Adj SS** | **Adj MS** | **F-Value** | **P-Value** |
|---|---|---|---|---|---|
| Powder Type | 3 | 175.02 | 58.3406 | 87.56 | 0.000 |
| Storage Temperature | 2 | 23.78 | 11.8911 | 17.85 | 0.000 |
| Storage time | 4 | 76.23 | 19.0564 | 28.60 | 0.000 |
| Error | 50 | 33.31 | 0.6663 | | |
| Total | 59 | 308.34 | | | |

Table A.2. Tukey Test Results of L* Value

**Grouping Information Using the Tukey Method and 95% Confidence**

| **Storage Temperature** | **N** | **Mean** | **Grouping** | |
|---|---|---|---|---|
| 10 | 20 | 91.7388 | A | |
| 25 | 20 | 91.1930 | A | |
| 37 | 20 | 90.2168 | | B |

*Means that do not share a letter are significantly different.*

**Grouping Information Using the Tukey Method and 95% Confidence**

| **Storage time** | **N** | **Mean** | **Grouping** | |
|---|---|---|---|---|
| 0 | 12 | 92.6275 | A | |
| 2 | 12 | 92.1333 | A | |
| 1 | 12 | 90.5981 | | B |
| 3 | 12 | 90.0881 | | B |
| 4 | 12 | 89.8008 | | B |

*Means that do not share a letter are significantly different.*

Table A.3. General Linear Model- Anova Results of a* values

**Analysis of Variance**

| **Source** | **DF** | **Adj SS** | **Adj MS** | **F-Value** | **P-Value** |
|---|---|---|---|---|---|
| Powder Type | 3 | 56.599 | 18.8662 | 208.73 | 0.000 |
| Storage Temperature | 2 | 2.977 | 1.4884 | 16.47 | 0.000 |
| Storage time | 4 | 1.641 | 0.4103 | 4.54 | 0.003 |
| Error | 50 | 4.519 | 0.0904 | | |
| Total | 59 | 65.736 | | | |

Table A.4. Tukey Test Results of a* values

**Grouping Information Using the Tukey Method and 95% Confidence**

| **Storage Temperature** | **N** | **Mean** | **Grouping** | |
|---|---|---|---|---|
| 37 | 20 | -1.15950 | A | |
| 10 | 20 | -1.63033 | | B |
| 25 | 20 | -1.63367 | | B |

*Means that do not share a letter are significantly different.*

**Grouping Information Using the Tukey Method and 95% Confidence**

| Storage time | N | Mean | Grouping | |
|---|---|---|---|---|
| 4 | 12 | -1.26250 | A | |
| 3 | 12 | -1.37083 | A | |
| 2 | 12 | -1.47556 | A | B |
| 1 | 12 | -1.50611 | A | B |
| 0 | 12 | -1.75750 | | B |

*Means that do not share a letter are significantly different.*

Table A.5. General Linear Model- Anova Results of b* values

**Analysis of Variance**

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Powder Type | 3 | 112.72 | 37.573 | 11.91 | 0.000 |
| Storage Temperature | 2 | 175.06 | 87.531 | 27.75 | 0.000 |
| Storage time | 4 | 27.12 | 6.780 | 2.15 | 0.088 |
| Error | 50 | 157.70 | 3.154 | | |
| Total | 59 | 472.60 | | | |

Table A.6. Tukey Test Results of b* values

**Grouping Information Using the Tukey Method and 95% Confidence**

| Storage Temperature | N | Mean | Grouping | |
|---|---|---|---|---|
| 37 | 20 | 17.1998 | A | |
| 25 | 20 | 13.7502 | | B |
| 10 | 20 | 13.4245 | | B |

*Means that do not share a letter are significantly different.*

**Grouping Information Using the Tukey Method and 95% Confidence**

| Storage time | N | Mean | Grouping |
|---|---|---|---|
| 4 | 12 | 15.5522 | A |
| 2 | 12 | 15.2306 | A |
| 3 | 12 | 14.9422 | A |
| 1 | 12 | 14.6425 | A |
| 0 | 12 | 13.5900 | A |

*Means that do not share a letter are significantly different*

# APPENDIX B

## STATISTICAL ANALYSES RESULTS FOR WATER ACTIVITY VALUES OF DAIRY POWDERS

Table B.1.General Linear Model- Anova Results of water activity values

**Analysis of Variance**

| **Source** | **DF** | **Adj SS** | **Adj MS** | **F-Value** | **P-Value** |
|---|---|---|---|---|---|
| Powder Type | 3 | 0.09892 | 0.032974 | 3.73 | 0.017 |
| Storage Temperature | 2 | 0.07320 | 0.036599 | 4.14 | 0.022 |
| Storage time | 4 | 0.09468 | 0.023670 | 2.68 | 0.042 |
| Error | 50 | 0.44222 | 0.008844 | | |
| Total | 59 | 0.70902 | | | |
| | | | | | |
| | | | | | |

Table B.2. The Tukey Test Results of Water Activity Values

**Grouping Information Using the Tukey Method and 95% Confidence**

| **Powder Type** | **N** | **Mean** | **Grouping** |
|---|---|---|---|
| 2 | 15 | 0.341933 | A |
| 1 | 15 | 0.340267 | A |
| 4 | 15 | 0.261267 | A |
| 3 | 15 | 0.258578 | A |

*Means that do not share a letter are significantly different.*

**Grouping Information Using the Tukey Method and 95% Confidence**

| **Storage Temperature** | **N** | **Mean** | **Grouping** | |
|---|---|---|---|---|
| 10 | 20 | 0.336383 | A | |
| 25 | 20 | 0.311983 | A | B |
| 37 | 20 | 0.253167 | | B |

*Means that do not share a letter are significantly different.*

**Grouping Information Using the Tukey Method and 95% Confidence**

| **Storage time** | **N** | **Mean** | **Grouping** | |
|---|---|---|---|---|
| 2 | 12 | 0.334167 | A | |
| 3 | 12 | 0.330972 | A | B |
| 0 | 12 | 0.310500 | A | B |
| 4 | 12 | 0.302083 | A | B |
| 1 | 12 | 0.224833 | | B |

*Means that do not share a letter are significantly different.*

# APPENDIX C

## STATISTICAL ANALYSES RESULTS FOR TURBIDITY VALUES OF DAIRY POWDERS

Table C.1.General Linear Model- Anova Results of Turbidity values

**Analysis of Variance**

| **Source** | **DF** | **Adj SS** | **Adj MS** | **F-Value** | **P-Value** |
|---|---|---|---|---|---|
| Powder Type | 3 | 15.0777 | 5.02589 | 115.95 | 0.000 |
| Storage Temperature | 2 | 0.0699 | 0.03496 | 0.81 | 0.452 |
| Storage time | 4 | 4.2005 | 1.05012 | 24.23 | 0.000 |
| Error | 50 | 2.1672 | 0.04334 | | |
| Total | 59 | 21.5153 | | | |

Table C.2. Tukey Results of Turbidity values

**Grouping Information Using the Tukey Method and 95% Confidence**

| **Powder Type** | **N** | **Mean** | **Grouping** | | |
|---|---|---|---|---|---|
| 1 | 15 | 3.12287 | A | | |
| 2 | 15 | 2.82627 | | B | |
| 3 | 15 | 2.76087 | | B | |
| 4 | 15 | 1.78933 | | | C |

*Means that do not share a letter are significantly different.*

**Grouping Information Using the Tukey Method and 95% Confidence**

| **Storage Temperature** | **N** | **Mean** | **Grouping** |
|---|---|---|---|
| 10 | 20 | 2.65910 | A |
| 25 | 20 | 2.63715 | A |
| 37 | 20 | 2.57825 | A |

*Means that do not share a letter are significantly different.*

**Grouping Information Using the Tukey Method and 95% Confidence**

| Storage time | N | Mean | Grouping | |
|---|---|---|---|---|
| 1 | 12 | 2.91800 | A | |
| 0 | 12 | 2.87975 | A | |
| 2 | 12 | 2.69850 | A | |
| 4 | 12 | 2.32808 | | B |
| 3 | 12 | 2.29983 | | B |

*Means that do not share a letter are significantly different.*

# APPENDIX D.

## STATISTICAL ANALYSES RESULTS FOR COLOR VALUES OF LABNEH SAMPLES

Table D.1. The One-Way ANOVA Results of L* Values of Labneh Samples

**Analysis of Variance**

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Labneh Samples | 15 | 94.34 | 6.289 | * | * |
| Error | 0 | * | * | | |
| Total | 15 | 94.34 | | | |

Table D.2. The One-Way ANOVA Results of a* values of Labneh Samples

**Analysis of Variance**

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Labneh Samples | 15 | 27.38 | 1.825 | * | * |
| Error | 0 | * | * | | |
| Total | 15 | 27.38 | | | |
| | | | | | |

Table D.3. The One-Way ANOVA Results of b* values of Labneh samples

**Analysis of Variance**

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Labneh Samples | 15 | 106.6 | 7.108 | * | * |
| Error | 0 | * | * | | |
| Total | 15 | 106.6 | | | |

# APPENDIX E

## STATISTICAL ANALYSES RESULTS FOR TEXTURE VALUES OF LABNEH SAMPLES

Table E.1. The One-Way Anova Results of Hardness of Labneh Samples

**Analysis of Variance**

| **Source** | **DF** | **Adj SS** | **Adj MS** | **F-Value** | **P-Value** |
|---|---|---|---|---|---|
| Labneh Samples | 15 | 188976 | 12598 | * | * |
| Error | 0 | * | * | | |
| Total | 15 | 188976 | | | |

Table E.2. The One-Way Anova Results of Adhesiveness of Labneh Samples

**Analysis of Variance**

| **Source** | **DF** | **Adj SS** | **Adj MS** | **F-Value** | **P-Value** |
|---|---|---|---|---|---|
| Labneh Samples | 15 | 112.0 | 7.470 | * | * |
| Error | 0 | * | * | | |
| Total | 15 | 112.0 | | | |

Table E.3. The One-Way Anova Results of Stringiness of Labneh Samples

**Analysis of Variance**

| **Source** | **DF** | **Adj SS** | **Adj MS** | **F-Value** | **P-Value** |
|---|---|---|---|---|---|
| Labneh Samples | 15 | 160.1 | 10.67 | * | * |
| Error | 0 | * | * | | |
| Total | 15 | 160.1 | | | |