Reviewing The Potential Application of Bovine Dairy Powders in Supporting Healthy Aging of Humans

A Thesis Presented as part fulfilment for the Award of

Master of Science in Food Business Management and Technology

By

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Declaration

I, Tom Hayes, hereby declare that the material included in this thesis submitted for assessment for the programme of MSc Food Business Management and Technology is entirely my own work, under the guidance of my supervisor, Mary O'Connor. This work has not been submitted for any academic award at this University, or any other University or Higher Education Institute. Any use of the work of others has been fully acknowledged by reference in both text and bibliography.

Signed: Tom Hayes **Date:** 11/12/23

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Abstract

By 2050, twenty-two percent of the world's population will be over the age of 60. Of this cohort, 80% will reside in developing regions. The focus of this thesis is to review the potential application of bovine dairy powders in supporting healthy aging of humans. Due to the economic status of this cohort require an affordable product with a prolonged shelf life is required.

The evaluation of dairy and its role supporting a healthy aging population was assessed through evaluation of peer reviewed scientific papers and studies. Healthy aging allows enables the wellbeing in an individual both physically and mentally to carry out daily functions free from disease and disability.

Osteoporosis, sarcopenia and cognitive decline were the three most prevalent diseases associated with aging and are considered global health concerns. With the aging demographic increasing, these 3 diseases were the focus of this study.

Bovine milk powders are the most affordable source of dairy nutrients and also have the longest shelf life. Through investigation it was found that a lack of bone density was the cause of osteoporosis, muscle weakness was the cause of sarcopenia and oxidative stress was a key factor in cognitive decline. Calcium and vitamin D combined in fermented dairy was shown to increase bone density. Whey protein was shown to increase muscle mass. Whey peptides and amino acids were found to reduce oxidative stress.

The key nutrients required to mitigate all 3 disease was found in a whey protein isolate powder and fortified in line with the recommended daily intake of an elderly person and a manufacturing cost was calculated in order to assess affordability for developing regions which may require a government subsidy.

Future work would include manufacturing the fortified whey protein isolate powder and conducting subclinical trials to examine its effectiveness.

Abbreviations

AD	Alzheimer disease
ADRD	Alzheimer's Disease and Related Dementias
AE	Adverse Event
aMD	adjusted mean difference
AMM	Apendicular Muscle mass
ANCOVA	1-way analysis of covariance
ASM	appendicular skeletal muscle mass
BCAA	Branched Chain Amino Acids
BMD	Bone Mineral Density
BMI	Body Mass Index
BMP	butter milk powder
CHS	Cardiovascular Health Study
CI	confidence intervals
CLSA	Canadian Longitudinal Study on Aging
COWAT	Controlled Oral Word Association Test
CVD	Cardiovascular Disease
DALY	disability-adjusted life years
DNA	Dairy Nourishes Africa
DWP	demineralized whey powder
DXA	dual-energy X-ray absorptiometry
EEX	European Energy Exchange
EU	European Union
FAO	Food and Agriculture Organization
Fig	Figure
FOB	Free On Board
g	grams
GDT	Global Dairy Trade
GTWY	glycine-threonine-tryptophan-tyrosine
HAALSI	Health and Aging in Africa Longitudinal Study of an In-depth
HCAP	Harmonized Cognitive Assessment Protocol
HTST	High Temperature Short Time
IDF	International Dairy Federation
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
kgs	kilograms
L. helveticus	*Lactobacillus helveticus*
LAB	lactic acid bacteria
LTLT	Low Temperature Long Time
MANCOVA	multivariate analysis of covariance
MCC	micellar casein concentrates
MCI	micellar casein isolates
MENA	Middle East and North Africa

MFGM	milk fat globule membrane
mg	milligrams
ml	millimetre
mm	millimetre
MNA	mini nutrient assessment
MPC	milk protein concentrates
MPI	milk protein isolates
MRI	magnetic resonance imaging
MS	Muscle Strength
n	sample size
NA	Not Available
NIRS	near-infrared spectroscopy
NMR	nuclear magnetic resonance
NZX	New Zealand Exchange
OR	odds ratio
OR	osteoporosis risk
OSTA	The Osteoporosis Self-Assessment Tool for Asians
PHE	Plate Heat Exchanger
RBANS	repeatable battery tests of neuropsychological status
RDA	Recommended Daily Allocation
RR	relative risk
RT	Resistance Training
SD	Standard deviation
SE	Standard Error
SMI	skeletal muscle mass index
SMP	Skim Milk Powder
SPPB	Short Physical Performance Battery
TS	Total Solids
UHT	Ultra Heat Treatment
USA	United States of America
UV	Ultra Violet
WHO	World Health Organisation
WMP	Whole Milk Powder
WPC	whey protein concentrates
WPI	whey protein isolates
WPNI	Whey Protein Nitrogen Index
WY	tryptophan-tyrosine
μm	micrometre

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phosphorus as adapted from Hwang, et al., 2023, Polzonetti, et al., 2020, Ha, et al., 2020 and Hejazi, et al., 2020

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Chapter 1

Introduction

The focus of this thesis is to review the nutritional content bovine dairy and the application of milk powders in mitigating morbidities associated with aging. This will be achieved through examining the regions where there is a high consumption of dairy or lack of dairy consumption and identifying the age-related disease in these regions. The nutrient deficiencies of the diseases will be identified and a suitable dairy product will be chosen or fortified to provide the necessary dairy nutrients to mitigate these diseases. The introductory chapter will define bovine dairy and give background of the bovine dairy industry. This chapter will also review the process in manufacturing dairy powders and associated costs. Healthy aging will be examined. Aging as well as population and demographics in terms of disease and hidden hunger will be investigated. Diet will be reviewed in terms of dairy, non-dairy, challenges faced by dairy and current trends. Mortality and morbidity will be defined as well as the associated diseases. Affordability of dairy will be investigated and thesis outline will be presented.

1.1 The Definition of Bovine Dairy

Milk has been the primary source of nutrition for mammals since time began and due to its rich nutritional content and is why bovine dairy has been integrated into the human diet (Kleinjan, et al., 2021). Bovine dairy products are “product obtained by any processing of milk, which may contain food additives, and other ingredients functionally necessary for the processing” as per Codex Alimentarius definition (Gonçalves, et al., 2022).

These products are derived from bovine milk itself and consists of proteins, fat, minerals, vitamins and lactose. The typical composition of milk is 87% water, 4.6 % lactose, 4.2 % fat, 3.4% protein, 0.8% minerals and 0.1% minerals. Additionally, it contains immunoglobulins, hormones, growth factors, cytokines, nucleotides, peptides, polyamines, enzymes, and other bioactive peptides that promote cognitive function, regulate human microbiota, and stimulate the immune system. (Aaradhana, et al., 2023).

Due to the nutritional's mentioned, bovine dairy is used and commonly associated as an alternative to breast milk. Its ability to be fortified allows bovine dairy to provide the necessary nutrients for infants and is seen as a whole food in infant nutrition (Cheng & Yeung, 2021).

Milk proteins have both hydrophilic and hydrophobic groups in their structure, they make excellent surfactants. Surfactants are surface active agents which reduce interfacial energy of both proteins and allow them to interact with one another under certain conditions (Dandigunta, et al., 2021). Caseins (80%) and whey proteins (20%) make up the two main types of milk proteins. The caseins (S1-, S2-, -, and -casein) are a heterogeneous of phosphoproteins. Whey proteins, which are hydrophobic and are smaller globular proteins (Xiong, et al., 2020).

The availability of these proteins allows them to interact with bioactive compounds which can be used for advanced nutrition which is the fortification of milk products with vitamins and minerals to improve quality of life. The bonding takes place through hydrophilic and hydrophobic complexes. Van der Waals forces of attraction and hydrophobic bonds are responsible for the non-covalent interactions. The covalent bonds formed between the bioactive and milk proteins can be irreversible thus permanently altering the structure of the protein. Protein interactions also have an impact on the bioactives that regulate dairy products' antioxidant functions. Therefore, while it is a complex process, the addition of bioactives to dairy products can be used to improve the human diet. (Adinepour, et al., 2022)

While milk proteins have an extremely important role in dairy products, fat content and structure must be taken into consideration. The milk fat globule membrane (MFGM) is a complex, three-layer membrane structure that develops from the apical plasma membrane and endoplasmic reticulum.

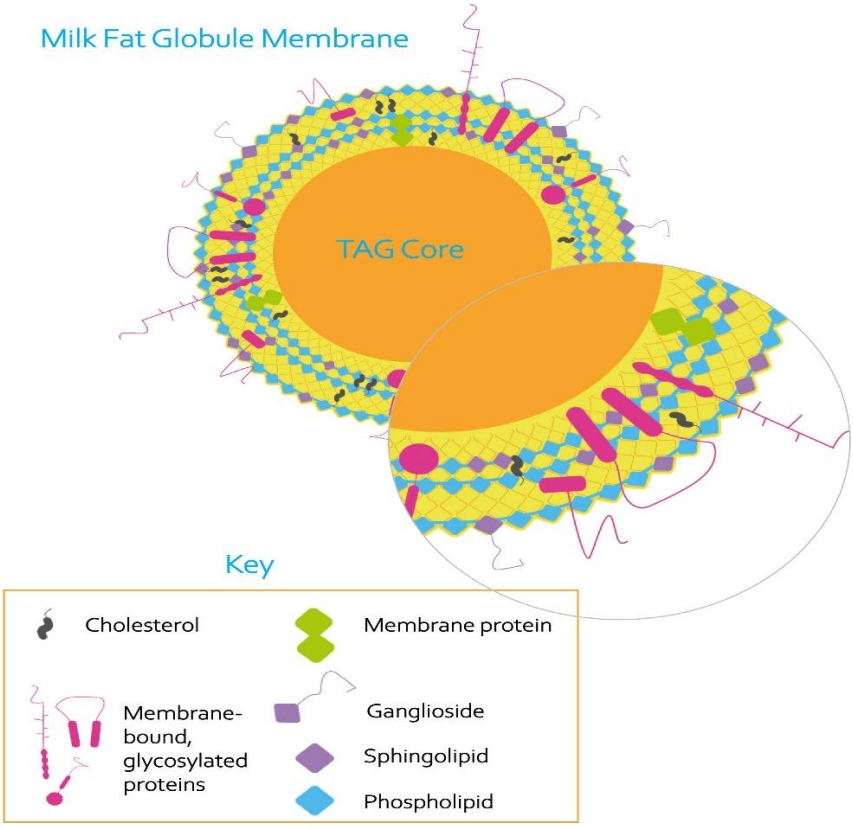


Figure 1.1: Representation of the Milk Fat Globule Membrane displaying its three-layer structure taken from The Journal of Nutritional Biochemistry 2020.

An emulsion's stability is maintained by MFGM because of the elevated levels of surface-active polar lipids that are amphiphilic, which keep the milk fat globules stable. This is relevant in relation to enriched milk-based powders, in particular infant grade milk powders (Li, et al., 2023). It is made up of a variety of substances, primarily membrane-specific proteins, glycoproteins, enzymes, polar lipids, and neutral lipids as seen in Fig 1.1. MFGM proteins, which make up just 1–4% of all milk proteins, are essential for preserving the physical integrity of milk's fat globules (Zhao, et al., 2023).

A study was carried out by (Li, et al., 2023) to investigate if the MFGM improved stability of infant grade powder and also its effect on the physiochemical properties of the finished product. The outcomes demonstrated that MFGM improved the microstructure of the MFGM, increased the viscosity, and decreased the emulsion's particle size.

Moreover, MFGM raised the glass transition temperature, decreased the amount of surface fat, and decreased the moisture content of the powder. In conclusion, by strengthening the emulsion stability created during IF production, the inclusion of MFGM improves the end powder stability. Thus the MFGM is a key component in the fortification of powders.

1.2 Bovine Dairy Consumption

Milk and other dairy products are used as an energetic food source consumed by over 6 billion people across the globe, most of which are located in developing countries. A sizable portion of a child's nutritional and physiological demands are met by milk because it contains prebiotics, beneficial bacteria that support gut health (Anusha Siddiqui, et al., 2024).

The majority of the global population consume cow's milk because it is regarded as a nutritious, complete food that contains fat, proteins, and carbohydrates. (Aleena Paul, et al., 2019). The consumption of milk and milk products is rising quickly all across the world, and it is predicted that this trend will continue moving in the same manner going forward. From 2020 to 2029 fresh and processed bovine dairy consumption is expected to increase by 1% per annum which is in correlation with higher per capita income growth (OECD, 2023).

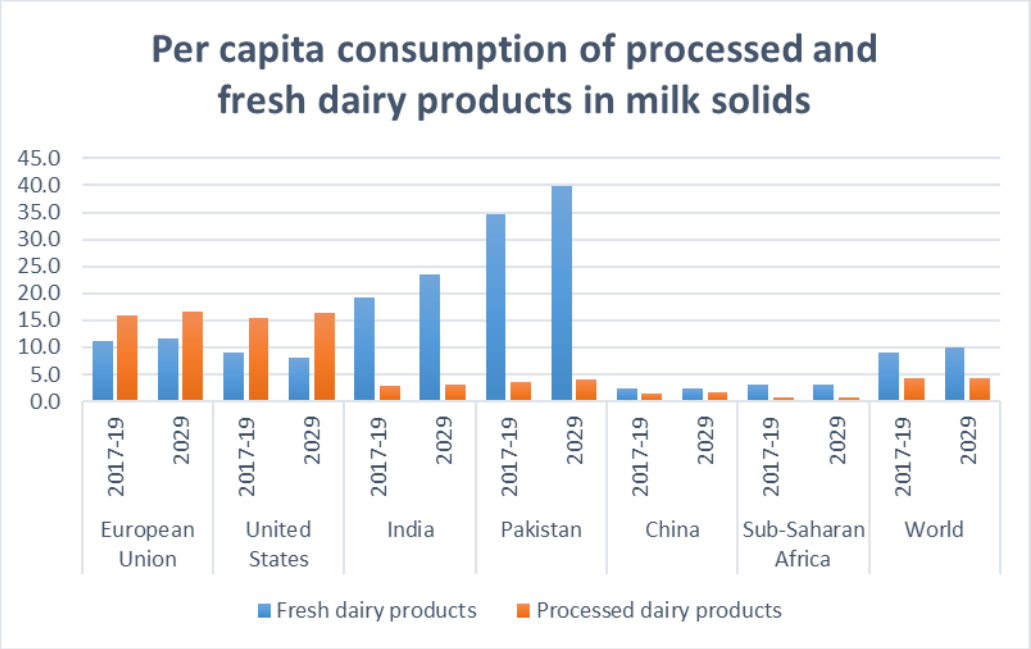


Figure 1.2: Graphical representation of processed dairy product and fresh dairy product consumption per kg milk solid/year with a comparison from 2017-2019 to projected figures in 2029 based on a 1% rise per annum, taken from OECD-FAO Agricultural Outlook 2020-2029.

Fig 1.2 illustrates global consumption of dairy and dairy products per capita in specific regions and globally. Per capita consumption is the yearly use of goods and services by each individual, calculated by dividing the whole population's usage of goods and services (Asheim, et al., 2023) which in this case is fresh and processed dairy. The amount of milk solids is calculated by combining the amounts of fat and non-fat solids for each product. Butter cheese, skim milk powder, and whole milk powder are examples of processed dairy products (OECD, 2023).

In accordance with Fig 1.2, Pakistan has the highest consumption of dairy per capita of fresh dairy products at 35 kilograms (kgs) of milk solids consumed per capita and is projected to grow to 40 kgs of milk solids however they have lower consumption levels of processed dairy in comparison to other regions. The United States and the European Union have the largest consumption of processed dairy just above 15 kgs of milk solid

per capita. While both regions have a high consumption of fresh dairy products, the US shows the only negative projection of dairy consumption on the graph. India has the second largest consumption of fresh dairy consumption behind Pakistan with over 15 kgs of milk solids and projected to grow above 20 and have a low consumption of fermented dairy on a global scale which is less than 5 kgs of milk solids per capita including projections (OECD, 2023)

China and Sub-Saharan Africa have a low consumption of both categories and both showing a higher consumption of fresh dairy rather than fermented products. Globally fresh dairy product consumption is calculated to grow to 10 kgs of milk solids. There is less consumption of fermented dairy products at less than 5 kgs and showing little growth in according with Fig 1.2 (OECD, 2023)

Vietnam is an example of a developing country that has a dependence on dairy. With a dairy production of around one million tonnes in 2018 and an average growth rate of 14.4 % from 2010 to 2018, Vietnam is the sixth-largest producer of milk in all of Asia. Vietnam is home to large dairy enterprises such as Vina Milk, TH True milk and Nutimilk. Some farmers in Vietnam cannot produce milk to meet their high-quality standards or provide the required volume resulting in much dairy produce such as milk powders are bought in to meet the demand of these factories from locations such as New Zealand, Singapore and the USA (Hoang, et al., 2023).

1.2.1 Bovine Dairy Consumption and Economic Growth

In 2019, almost 76.7 million metric tons of milk were traded internationally. The world population is predicted to increase by 0.9% annually during the next ten years, with the majority of this growth occurring in developing regions. The demand for dairy products is anticipated to rise as a result of this population growth and economic growth. The global milk production is anticipated to expand by 1.75 percent annually (Herron, et al., 2022).

The demand for dairy products has increased as a result of the economy of Vietnam's quick development. Over €4 billion in dairy sales was generated in 2018, representing an average growth rate of 13.6% from 2013 to 2018. About €2 billion in liquid milk sales were made in 2018. The increase in consumption meant that demand did not match supply. Only 40% of the country's domestic dairy demand was met in 2018 by domestic production; the remaining 60% was filled by imports. Additionally, Vietnam exports dairy goods to 43 nations, primarily infant formula. From over €77 million in 2016 to over €110 million in 2018, its dairy export value climbed. Iraq, China, Hong Kong, the Philippines, Laos, Myanmar, the USA, Afghanistan, the UAE, the EU, and Japan are its top export destinations (Hoang, et al., 2023).

Similar to Vietnam, Ireland is heavily dependent on the dairy industry. In 2015 the Irish dairy sector generated €3.2 billion in exports accounting 30% of the total food and drink exports. These dairy exports are to developing countries like Vietnam and South East Asia. The Irish dairy industry has begun to expand as a result of the abolition of the European Union (EU) milk production quotas in April 2015 and the global demand for dairy products in developing countries, which is expected to increase by up to 1.7% year by 2025. Processors consumed 13.2% more whole milk overall in 2015 than in 2014, 5.9% more during the peak month of May 2016 than in May 2015, and 7.9% more during May 2017 than in May 2016 (Yan & Nicholas M., 2018).

Ireland is one of the top producers of milk and dairy products per capita. According to the Bord Bia (Irish Food Board) annual report on Export Performance and Prospects in 2018, exports of dairy products and ingredients were valued more than €4 billion and made up one-third of all export categories (Li, et al., 2019).

Milk is one of the most widely used and lucrative agricultural products, with 852 million metric tons of milk produced worldwide in 2019 and a market value of 340 billion dollars. Dairy products, including milk, are produced and eaten almost everywhere in the world. Importantly, production is expected to rise 1.6% per year over the next decade, reaching

997 million tonnes in 2029 and continuing to rise until 2050. Demand in Asia is particularly driving these gains, with Pakistan experiencing compound annual growth rates of 14% and Vietnam experiencing compound annual growth rates of 12% (Pope, et al., 2021).

1.2.2 Current Dairy Economics

On a global scale Bovine milk accounts for the majority of dairy product production volume worldwide. More over 540 million metric tonnes of bovine milk were generated in 2021, which was then used to make 22 million metric tonnes of cheese, 11 million metric tonnes of butter, and 9 million metric tonnes of powder milk.

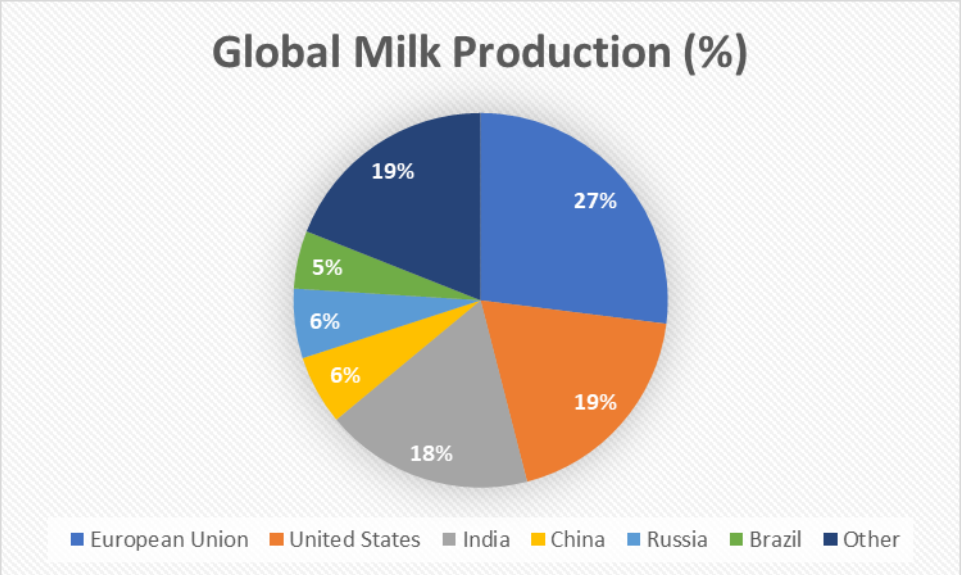


Figure 1.3: Pie chart displaying the volume of milk produced across the world expressed as a percentage taken from the Journal of Food Composition and Analysis (Gliszczyńska-Świgło & Rybicka, 2023).

In Fig 1.3 it is clear that the largest volume of milk produced comes from the European Union at 27% of the Global share. The major milk producing countries involved within this region are Germany, France, Italy, the Netherlands, Poland and Ireland. The United

States (US) and India are the second and third largest producers respectively producing 19% and 18 % of the world's milk. China, Russia and Brazil all fall within the 5-6% range (Gliszczyńska-Świgło & Rybicka, 2023).

With this in mind, this milk is consumed as an essential source of energy and nutrients in certain regions. Asia, Africa, Europe and Oceania rely on milk to make up 2%,4%,8% and 9% of their total energy supply respectively. In terms of protein Africa and Asia are 5-8% dependant. Dairy proteins make up 19% of the total protein intake in both Europe and Oceana (Gliszczyńska-Świgło & Rybicka, 2023).

Following on from production global production percentages, it is important to identify that dairy primary production methods differ over the world depending on a variety of elements like land availability, climate and infrastructure. In recent years there has been an increased demand for dairy products with a "grass fed" label which often carries a premium from regions such as Ireland for example. This term gives consumers the perception that the raw milk has been produced by cows in a healthy outdoor setting with a lower environmental setting in line with current trends (Moscovici Joubran, et al., 2021).

In developing countries, there is a rising demand for milk and dairy products as a result of population increase, urbanization, rising incomes, and dietary changes. This trend is mostly prominent in East and Southeast Asia, especially in nations with dense populations like China, Indonesia, and Vietnam. Consumption is anticipated to develop faster than local production in these regions, as well as in Africa and the Middle East, leading to a significant increase in dairy trade across international borders from countries such as Ireland (Moscovici Joubran, et al., 2021).

Among the many items that fall under the category of "dairy products" are whole milk, yogurt, cheese, butter, kefir, ricotta, casein, dairy drinks, and ice cream, to name a few. These items are widely used to supplement diets with minerals, vitamins, probiotic

bacteria, prebiotics, flavourings, fruit and vegetable extracts, omega-3 fatty acids, and other nutrients (Gonçalves, et al., 2022).

1.2.3 Market Availability

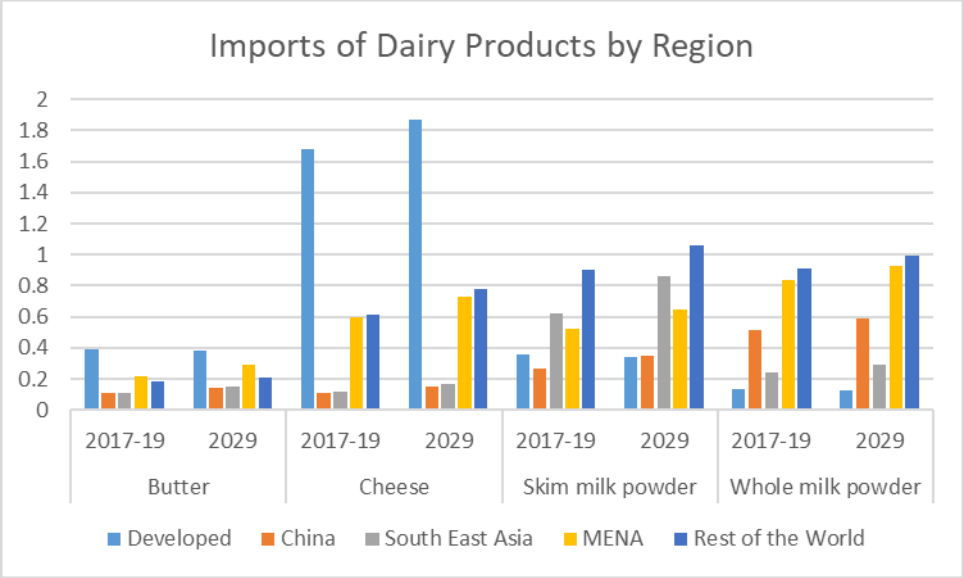


Figure 1.4: Graphical representation of imported Dairy product per region per metric tonne comparison from 2017-2019 to projected figures in 2029 taken from OECD-FAO Agricultural Outlook 2020-2029.

The market for dairy products is dominated by particular regions which can be seen by the product per metric tonne imported in Fig 1.4 which are developed countries, China, South East Asia, MENA (Middle East and North Africa) and the rest of the world. The majority of these imports are coming from the European Union and from Oceana also. China is the largest importer of whole milk powder (WMP) and has also been importing skim milk powder (SMP) and butter in recent years. MENA as a whole import its powders from the European Union however South East Asia sources its milk powders from Oceania and the United States. This report shows that dairy is widely available (OECD, 2023). The developing regions such as Mena and South East Asia require mainly import milk powders and looking at the prices from the GDT results from Fig 1.8 it would appear that the cheaper commodities are imported by developing regions.

Taking into consideration the majority of the aging population will reside in developing, low-income regions such as Africa, Asia and Latin America (Mavrodaris, et al., 2018) and that the majority of dairy imported by these regions comes from the EU (OECD, 2023) the fortified dairy product to combat the associated morbidities must be in powder format as the distance requires a prolonged shelf life and ambient storage conditions which dairy powders have. Affordability is also a major parameter for low-income countries as they simply do not have the money to spend. Spray dried dairy powders are the cheapest source of dairy nutrition most suited to these regions (D'Incecco, et al., 2021).

1.3 Bovine Dairy History

1.3.1 Bovine Dairy History of Ireland

In Ireland and across Europe, the Mesolithic (8000-4300 BC) to Neolithic (4300-2000 BC) transition highlights a distinct change in human diet, which is often defined as the move from hunting and gathering to farming. However, meat from domesticated animals and the eating of grown plants were not the only significant changes in diet at the beginning of farming. The entrance of dairy products and new methods of producing, preparing, and storing food also unfolded (Bickle, 2018).

This extreme dietary change led to a change in the relationships with the surrounding environment and society as animals were now kept rather than being slaughtered. The domestication of animals also led to the production, processing and consumption of milk leading to lifestyle and economic improvements. Milk brought a new source of nutrients in the form of energy, carbohydrates, lipids, proteins, electrolytes and vitamin D. Fresh milk was used as an alternative, uncontaminated source to water and products such as cheese that had a yearlong shelf life were also discovered. The discovery of milk and milk consumption led to the increase in population during this period and the digestion of lactose (Tacail, et al., 2021). Dairy constantly evolved from this period onwards with the discovery of bog butter in the iron age (Mattiangeli, et al., 2020).

In medieval (c.700 – c.1600) times cattle were important as they were seen as a sign of wealth. A lord's status would be based on the quantity and quality of the herd in his possession. Milk was the main source of protein for the lower class mainly sourced from cows but also from goats and sheep. Other products include cream, cheese, butter, buttermilk, whey, and sour curds. Fresh milk products were mostly consumed in the summer months because fresh milk production peaked between April and September, whereas processed dairy goods, including hard cheeses, would have been stored for the winter (McKenzie, *et al*., 2020).

The advances in technology and farming knowledge grew to the point where farms and herd sizes were producing too much milk to meet demand and causing a decline in value of milk which resulted in the milk quota being put in place (Klopčič, et al., 2019). Moreover, Dairy Co-operatives were formed during this period in order to help farmers add value to their product and access foreign markets, provide information, research and sustainable farming methods (Cele, 2022).

The milk quota system, which has been in place in the EU since 1984, has controlled the milk supply for more than three decades. Production was restricted in this market environment, and farmers were required to modify the size of their herds in order to stay inside their quota. The AGMEMOD model, a well-known "modelling tool," accurately captured this "quota" context when producing market outlooks for agricultural commodities at the European level (Jongeneel & Gonzalez-Martinez, 2022).

Since the EU milk quota limits were lifted in 2015, the dairy industry in Ireland, one of the country's most major agricultural sectors, has experienced tremendous growth. The dairy industry is still largely dependent on cooperatives. There are ten milk processors and 17 milk purchasing cooperatives. Farmers operating family farms or businesses own and control the majority of the Irish dairy industry. Dairy cooperatives are essential for helping farmers increase their incomes, manage risks, and respond to global markets in a way that is effective while also ensuring coordinated action or farmers' meaningful involvement in the dairy market (Cele, 2022).

1.4 Milk Powders

By definition milk powder is “milk products which can be obtained by the partial removal of water from milk or cream” (FAO/WHO, 2018).The addition and/or removal of milk constituents in such a way as to avoid changing the whey protein to casein ratio of the milk being adjusted is the only way to modify the fat and/or protein content of the milk in order to meet the compositional requirements in Section 3 of Codex Alimentarius milk powder standards (FAO/WHO, 2018).

Spray drying is the term given to the process of milk powder production. This method is commonly used because of the extended shelf life while minimizing nutrient loss as well as storage and logistical costs (Fialho, et al., 2019). There is a wide variety of commercial dairy powders available, including whole, skimmed, and fat-filled milk powders, in addition to a variety of high-protein additives. One thing they all have in common is that they are all heated during preparation to minimize the microbial load. In the dairy sector, the main objective of heat treatment is to render all vegetative microorganisms, including bacteria, moulds, and yeasts, inactive rendering safe and extending shelf life (McCarthy, et al., 2022).

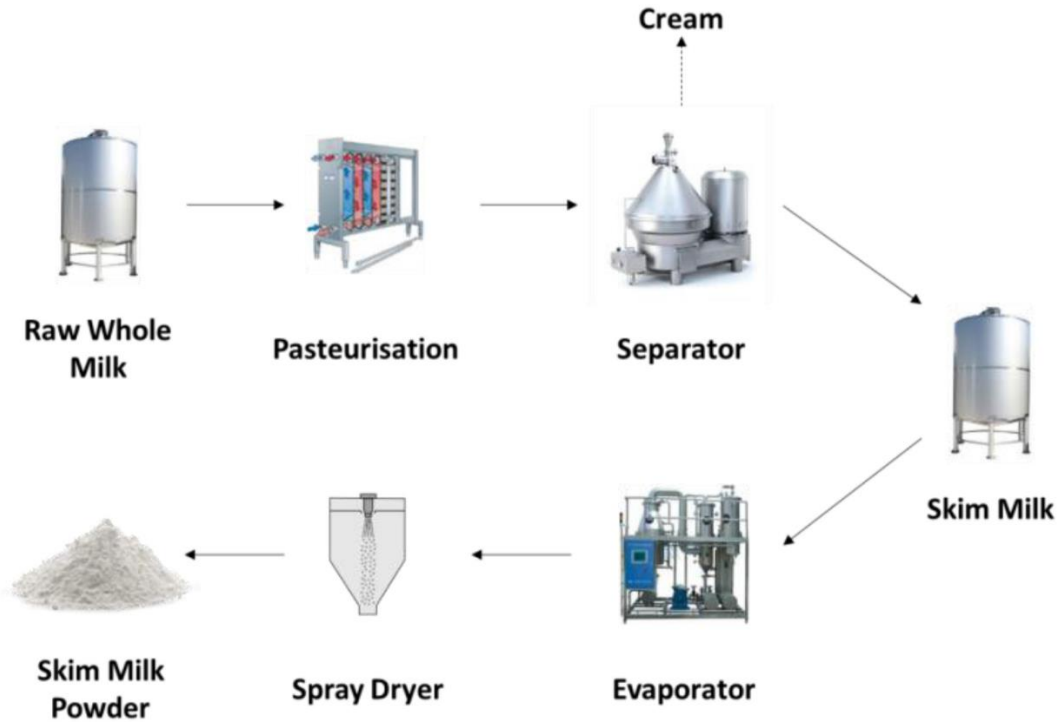


Figure 1.5: Representation of the spray drying process from raw milk intake through to powder including the equipment, extracted from the International Dairy Journal (McCarthy, et al., 2023)

Milk powders are frequently used as components in the production and stabilization of prepared meals and drinks, where they offer nutritional and technologically functional features such as water binding, viscosity, surface activity, gelation, structuring, and heat stability. Applications include foods and drinks like cream liqueurs, infant formula, and high-protein supplements for healthy nutrition and in athletic performance almost used as a meal replacement. Additionally, they are used to create products like cheese and yoghurt by combining milk, protein-fortified milk, or reconstituted milk (Lin, et al., 2016).

Dairy protein powders are used as base formulations or as complete nutritional sources in a wide range of dietary supplements. Low protein powders are widely utilized in fat filled products like yogurt, coffee whiteners, and other products. These products are exported all over the world. High protein dairy powders are used to standardize the protein content such as skim milk powder due to its low-fat content. Other high value products

that require a high protein content are infant formula and protein powders used for muscle growth and sports recovery (Maidannyk, et al., 2020)

Take chocolate for example. Chocolate contains sugar, cocoa solids, and, in some varieties, milk powders as solid ingredients. All chocolates employ WMP, SMP, and demineralized whey powder (DWP) as milk powders due to industrial usage and consumer preferences. All the mentioned powders are produced using a process called spray drying (Konar, et al., 2023).

Since milk and dairy products are taken on a regular basis and serve as a valuable source of numerous macro- and micronutrients, they constitute an essential component of the Western diet. Fortification of milk and dairy products with calcium or vitamin D, as well as a particular need for lactose-free milk, have become large industries as a result of an increase in consumer demand for "healthy foods." However, customers' expectations for a longer stability and shelf life of milk and dairy products have also expanded quickly. This is in addition to the growing interest in products with a certain health aspect (van den Oever & Mayer, 2021).

The phases of production for all varieties of milk powders include heat treatment, evaporating it to between 45 and 50 percent of total solids (TS), and spray drying to a final content of approximately 97% TS. The degree of whey protein denaturation, the interaction of the denatured whey protein with casein micelle, and the partitioning of components such as casein, whey protein, and salts between the serum and colloidal phases of milk are all affected by heat treatment, depending on the intensity of temperature, time, and milk pH (Lin, et al., 2018).

1.4.1 Evaporation and Spray Drying

The process of evaporation requires the intake of standardised milk with a TS content typically of 13 % and remove the water content to achieve a TS of 45-50%. TS refers to

the constituents of milk other than water expressed as a percentage. This step in the powder production process takes place after the initial heat treatment (Lincoln, et al., 2022). The process of evaporation takes place under vacuum to mitigate negative effects of heat on thermally sensitive milk components like lipids and to prevent the thermal deterioration of essential elements like vitamins. The dairy sector uses a variety of evaporators, including falling-film, plate, and horizontal-tube evaporators. For the manufacturing of milk powder, falling-film evaporators are most frequently used (Zhang, et al., 2018)

The shell-and-tube design of falling-film evaporators is depicted in Fig. 1.6 As steam directly heats the evaporator shell to cause evaporation, milk is circulated inside vertical tubes. Because of their simple design, large heat-transfer surface, and quick residence time, falling-film evaporators are popular (Zhang, et al., 2018).

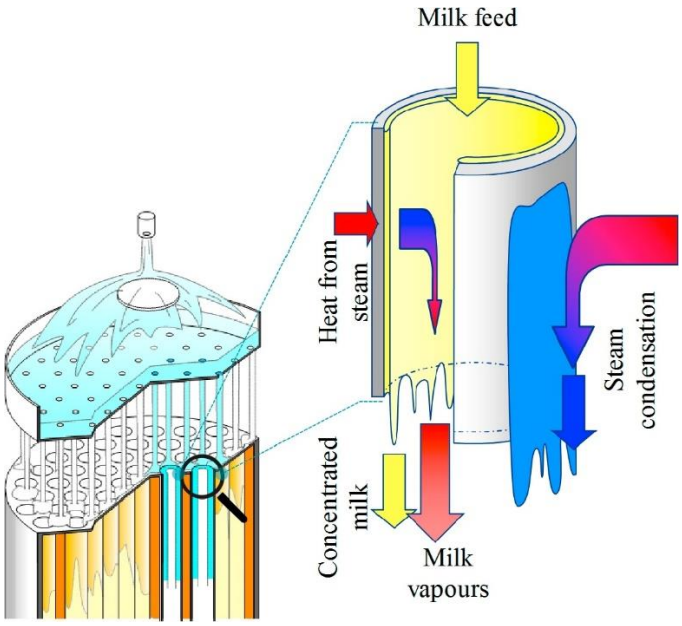


Figure 1.6: Diagram of the inside of a falling film evaporator demonstrating how steam is used to remove moisture from the liquid taken from the Journal of Food Engineering 2018.

After drying, evaporation is the process that consumes the greatest energy in the manufacturing of milk powder. Therefore, energy use during evaporation has a significant impact on the cost of producing milk powder (Zhang, et al., 2018). Other than this paper there has been little to no studies on milk analysis in the evaporator in the last 5 years.
The production of powdered milk, dried spices, coffee, tea, medications, paint pigments, and other products uses spray drying extensively. The process of turning liquid slurry into powder is a common unit operation. Small droplets are created when a solution is atomized. This is done to enhance the surface area available for mass and heat transfer, which promotes rapid drying. The nozzle's design and operational circumstances affect the droplets' size distribution. The size distribution of the droplets created during atomization is typically not uniform and ranges widely. As a result, the surface area is not uniform, which leads to different rates of mass and heat transfer. (Hussain, et al., 2022).

In this instance, a standardised milk formula is pumped in a high pressure through the atomiser. Good flowability, solubility, and a minimal number of fines, or a low number of microscopic particles, are desired properties of manufactured powders. The degree of particle agglomeration caused by collisions between initial particles made of droplets or viscous droplets and recycled fines, or small dry particles, has a significant impact on particle size (Hussain, et al., 2022). For these reasons a fluid bed is placed at the bottom of the drying tower to produce a more uniform particle size and a more consistent product. The fluidized bed is a reactor that allows gas-solid reactions or liquid-solid reactions to occur by passing gas or liquid through a granular solid bed to cause the solid particles to rise in suspension. Thus reducing the amount of sifter produced and increasing output (Gao, et al., 2022).

1.4.2 Heat Treatment Before Drying and Evaporation

Since there are still harmful bacteria, toxins from bacterial growth, and other biochemical contaminants in bovine milk, industrial processing and raw milk quality control are essential in the dairy sector. Before spray drying or even homogenisation, milk would undergo a heat treatment which is product dependent (Aaradhana, et al., 2023).

The heat treatment process or thermal pasteurization, which it is commonly known as, is popular in the dairy sector. This process removes and inactivates microbial flora by heat treatment, prolonging shelf life and stability. Depending on the severity of the heat applied, heat treatment can influence milk in different ways, but they are all associated with unfavorable alterations in colour, consistency, and nutritional value (Liu, et al., 2020).

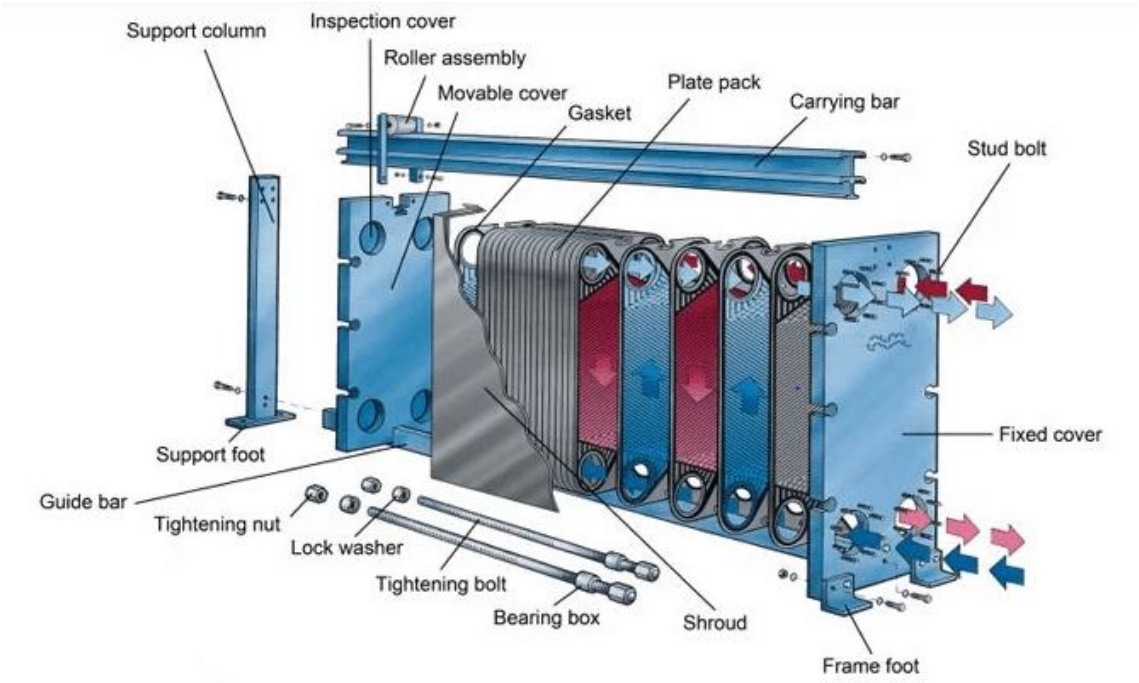


Figure 1.7: Graphical representation of the inner workings of a Plate Heat Exchanger used in the Pasteurization process demonstrating the heat transfer between the hot and cold liquids taken from the Alfa Laval Website (Alfa Laval, 2015).

Fig 1.7 is a typical example of a Plate Heat Exchanger (PHE) manufactured by Alafa Laval. Based in Sweeden, they are one of the largest dairy parts manufacturers in the world. The concept behind a PHE is that a temperature equilibrium is reached when a hot and cold fluid is run through the unit simultaneously. Therefore, not only can this piece of equipment be used to heat milk, but also to cool milk.

Temperature and time are the two parameters to which pasteurization is based on. Thus, the two main types of pasteurization are Low Temperature Long Time (LTLT) pasteurization and High Temperature Short Time (HTST) pasteurization. Heat treatment differs between various dairy products. For example, it is common practice in cheese for the milk to receive a LTLT heat treatment where bye pasteurization takes place at 62.8^0C for 30 minutes and then cooled to 40^0C. Similarly in butter manufacture, heat treatment is 63^0C for 30 minutes. Both receive low heat treatments so as not to over dissociate the fat globule membrane. The Typical shelf life for this milk is 2.5 days (Kumar Dash, et al., 2022).

HTST processing is used in the production of powders such as infant formula and Ultra Heat Treatment (UHT) products such as sweet and condensed milks. Temperatures can range from 135-150^0C for 1 to 10 seconds depending on these products. The higher heat treatment is required to kill endo spores as well as bacteria (Taher, et al., 2020).

Spore formers are the main organisms of interest when it comes to powdered milk products, particularly those that their optimum growth temperature is 55–60 °C. It is not known that thermophilic spore formers, as opposed to the mesophilic representative Bacillus cereus, are harmful to humans. Though reports of it in powdered milk products are extremely rare, it is the only aerobic spore formation that can result in a foodborne illness. Multiple government agencies monitor the number of aerobic spore-forming bacteria on a given plate. High bacillus counts that produce spores are not wanted due to the possibility of spoiling following reconstitution. The environment becomes more favourable for spores when the powder is reconstituted with water, and they begin to show signs of outgrowth. Protease and lipase are enzymes that are products of these spores which cause the breakdown of milk products (Wedel, et al., 2022).

The classification of powders depends critically on the temperature and heating duration. The Whey Protein Nitrogen Index (WPNI) is typically applied. The values are given in

grams of powder (milligrams of whey protein nitrogen). With the use of this parameter, the powders can be categorized as high, medium, or low heat powders. The corresponding heat treatments are 120 °C for 1-2 min, 90–105 °C for 30 s and 70 °C for 15 s. As a result of each heat treatment, the respective WPNI's are less than 1.5, 1.5–5.9 and 6 or greater (Wedel, et al., 2022).

1.4.3 Shelf Life

When kept in cold storage, HTST extends the shelf life by 10°C because the greater heat treatment lowers the level of pathogenic organisms that pose a risk to consumer health. Consumer demand and current trend indicate that there is a further requirement for dairy products with an extended shelf life and increased stability, specifically dairy products fortified with Vitamin D (van den Oever & Mayer, 2021). Typically, the shelf life for standard liquid milk bought in store is 5-10 days when pasteurized at 72 °C for 15-20s and stored in a refrigerator.

Product	Heat Treatment	Storage	Shelf Life
Pasteurised Milk	72°C,15-20s	Refrigerated	5-10 days
Extended Shelf-Life Milk	72°C,15-20s & Microfiltration	Refrigerated	14-28 days
UHT Milk	135-141°C, 3-6s	Ambient	3-12 months
Sterilised Milk	121°C, 20 min	Ambient	12-24 months

Table 1.1: Product, Heat treatment, storage conditions and shelf life of liquid milk types adapted from the International Dairy Journal,2022.

In Table 1.1 the effect of temperature and holding time are shown in relation to shelf life where bye the greater the heat treatment results in a longer shelf life of liquid milk. Also, there is a differentiation between storage conditions once milk receives a higher heat treatment from refrigerated to ambient. Commercially sterile products with a longer shelf life at room temperature are produced via UHT and sterilizing procedures. These procedures may lead to important chemical alterations that affect the nutritional value and organoleptic properties, including the loss of vitamins and vital amino acids. The limiting factor is organoleptic changes and loss of physical stability brought on by

physical-chemical reactions or residual enzymatic activity during the resultant shelf life. The product's packaging and storage conditions have a significant impact on the rate of these reactions. (Rauh & Xiao, 2022).

When it comes to storage and transportation, milk powder is more practical than liquid milk. For the consumer, milk powder is a ready-to-eat food item that, in an emergency, can completely substitute liquid milk. Considering the established structure and history of nutrition, milk powder helps to ensure food security, particularly in terms of the availability of food goods regardless of a citizen's location of residency (Ryabova, et al., 2023). The high consumption of dairy per capita of developing countries and low internal supply, countries trading with these regions have had to adopt these processes to extend the shelf life of dairy products allowing for shipping and storage time (D'Incecco, et al., 2021).

Due to the high associated capital and operational investment necessary to create these ingredients, dairy protein powders become more expensive as the protein level increases. Powders are packaged under atmospheric conditions after drying, sent around the world, and frequently stored at low temperatures. As a result, these powders' functional characteristics such as flowability, wettability, solubility, etc., may be considerably impacted (Maidannyk, et al., 2020).

1.4.4 Milk powder Quality

The reputation of food and the protection of users and consumers depend heavily on the safety of dairy products. The threat of bacterial spores in dairy powders has long been a source of worry in terms of microbiological risks (Li, et al., 2019).

Bacterial spores can withstand heating procedures, including the most popular pasteurization used in the manufacturing of milk powder. Some can withstand even ultra-UHT processing, which may result in food spoiling and possible food poisoning. Two of the spore-forming bacteria most frequently associated with food spoilage and found in dairy products are Bacillus spp. and Clostridium spp. These bacteria are commonly associated with their environment and can easily enter the food chain in raw bulk tank milk at farm level, making its way into the finished product if the correct procedures are not put in place. By increasing the holding time during the heat treatment process by giving milk a high heat treatment (120ºC) helps to reduce the thermophilic and mesophilic spore count of milk powder. With this in mind it is imperative to produce milk and dairy products to an acceptable standard both on farm and in a factory setting (Li, et al., 2019).

1.4.5 Nutrition and Fortification

Fermented milk products, also known as cultured dairy products, are widely consumed due to their numerous health advantages. But customer needs have been changing all the time. Innovative shelf-stable functional foods are now the main focus. Probiotics and prebiotics work together to improve therapeutic value and promote health in the creation of functional food products. Recently, a number of novel food processing techniques have been used to guarantee the highest possible probiotic survival in dairy products that have undergone fermentation. Making fermented dairy products like buttermilk into a powder extends their shelf life and makes them easier to store and carry (Ahlawat, et al., 2023)

Due to the spray drying causes severe thermal stress on bacteria, the greater drying temperature lowers bacterial viability. As previously established, the probiotic bacteria in fermented dairy products are of customers' interest because of their health advantages. Therefore, it is necessary to construct fermented food products so that the population of viable bacteria in the spray-dried product is sustained for a significant period of time during storage. Utilizing protectants, such as glucose, whey protein concentrate, sucrose, maltodextrin, and skim milk powder, to act as a shield and shield the bacteria during spray drying, is one such technique (Ahlawat, et al., 2023).

1.4.6 Reconstitution

Spray-drying milk powder produces a variety of morphologies and sizes, including agglomerates and spherical fines. Oversized particles and agglomerates can be as small as 1 mm (millimetre), but their mean diameter is usually between 200 and 500 μm (micrometre). Particles smaller than 125 μm are referred to as fines or tiny particles. It's noteworthy that agglomerates have been shown to enhance milk powders' ability to reconstitute in water. Conversely, fines are difficult to handle and cause poor rehydration because they are stick (Wahyu N. Nugroho, et al., 2021).

An ideal milk powder should reconstitute rapidly, settle into water, disperse completely in a short amount of time. It should also exhibit no signs of lumps or remaining insoluble elements. Since milk powders can be used and delivered after reconstitution, the factors influencing dispersal are defined as the ability of wet particles to scatter uniformly in contact with water (Wahyu N. Nugroho, et al., 2021).

Particle density and composition are two other variables that affect milk powder dispersibility in addition to structural porosity and particle size distribution. A single particle's density is referred to as particle density. Yet, a group of particles can also be referred to as having "density." An immiscible solvent is added to a container to measure the particle densities of large and fine particles. The fine fractions exhibit stronger adhesion between the larger particles due to their higher free-fat content. Presuming the large and tiny particles had the same mass, this means that the smaller the size, the more solvent is required to disperse the particles due to an rise in the surface area-to-volume ratio. Consequently, the low particle density found in fines slow precipitation resulting in a poor-quality milk powder from a reconstitution point of view (Wahyu N. Nugroho, et al., 2021).

1.4.7 Instantization

Instantiation refers to the rehydration of milk powder with water and its ability to break up individual particles forming a consistent solution. The rehydration of milk can divide in to three different categories which are solubility, wettability and dispersibility. Furthermore, these properties are dependent on both physical and chemical composition. Due to the many variables, it can be hard to measure and the International Dairy Federation (IDF) have their own complex method of testing which is a timely and laborious method (Ding, et al., 2020).

One test method known as kinetic pulse nuclear magnetic resonance (NMR) that can characterize milk powder rehydration. Another method involves the use of specially designed equipment to assess the dispersibility and wettability of skim milk powders by detecting the electrical resistance difference between air and water. These two approaches are faster than the IDF standard, but they are not suited for real-time online or at-line measurement due to the expensive testing equipment and complex analytical tools required. Furthermore, while much research is focused on the rehydration behaviour of different types of milk powder, the key concern in industry is controlling the rehydration behaviour within the same type of powder (Ding, et al., 2020).

1.4.8 Whey Protein Isolates/Concentrates

Because of their significant nutritional and functional qualities, high-protein dairy powders are used in high-value commercial applications such as newborn and sports nutrition products. By 2022, the global dairy protein component industry is anticipated to be worth 58 billion US dollars. The increasing consumer demand for high-protein label declarations on a wide range of food and beverage goods (e.g., breakfast bars, yoghurts, and coffee drinks) has propelled the significant expansion of the protein-enriched dairy ingredient industry. Between 2010 and 2015, the appearance of "high-protein" claims surged by 500% in the UK market alone (Hazlett, et al., 2021).

Advances in technology have allowed for selective protein enrichment of dairy proteins whey and casein. These proteins can be isolated through centrifugal separation and membrane filtration in the liquid phase before the drying process. Dairy protein concentration, followed by depletion of milk serum phase (water, lactose, and minerals) and fat constituents, can give an extensive range of dairy protein ingredients. Protein concentrates (35-89% protein), such as milk protein concentrates (MPC), whey protein concentrates (WPC), and micellar casein concentrates (MCC), or protein isolates (90%), such as milk protein isolates (MPI), whey protein isolates (WPI), and micellar casein isolates (MCI) (Hazlett, et al., 2021).

1.4.9 Cost of Production

With population growth and increasing wealth, market demand for milk powder continues to rise, which not only encourages the improvement of production capacity, but also raises the energy consumption and emissions of milk powder and related equipment during their entire life cycle (Zhang, et al., 2022).

Spray drying is the most energy-intensive phase in the manufacture of milk powder. As a result, optimizing the environmental performance of the spray drying system under the premise of providing high quality and reasonable cost of milk powder is critical for the dairy industry's long-term development (Zhang, et al., 2022). Market demand is the key driver of milk price which is the raw material in this case which will be discussed in detail. It costs €600 per tonne to cover energy costs and labour to spray dry commodity powders in Ireland such as butter milk powder (BMP) and SMP to less than 4% moisture. For the likes of whey powders the energy required would be far greater due to the higher moisture content in the liquid phase and can be up to €1000/tonne. There is additional cost on top of this for co-operatives products WPC and WPI due to the membrane filtration and ion exchange (Tipperary Co-Operative Creamery, 2023).

The cost of milk and dairy products in this case milk powders are driven mainly by demand which is often calculated by trading platforms such as the Global Dairy Trade (GDT). Fonterra Cooperative Group Ltd., New Zealand's largest dairy corporation, established the GDT platform in 2008 as a dairy trading platform. It is now owned and administered by a strategic alliance of the European Energy Exchange (EEX), Fonterra, and the New Zealand Exchange (NZX) (Global Dairy Trade, 2023). The structure is an ascending-price clock auction in which the trading manager declares an offer volume and starting price for a certain commodity established by the seller, and participating bidders then enter the quantities they are willing to buy at that price.

In basic terms, if the quantity required exceeds or falls short of the amount supplied, the trading manager will alter the price in subsequent bidding rounds, and buyers will adjust their bid volumes in accordance with the new price. This procedure is repeated until supply and demand at the auction are balanced. The price at which the market clears is published as the official auction (spot) price for that commodity, and it is the amount paid by all winning purchasers (Fernandez-Perez, et al., 2023).

Figure 1.8: Graphical representation of the Global Dairy Trade results published on the 7th of November 2023 showing the increase or decline in price of dairy commodities such as Anhydrous Milk Fat, Butter, BMP, Lactose, SMP and WMP extracted from the official Global Dairy Trade website (Global Dairy Trade, 2023).

GDT results are published every 2 weeks at 12 pm (Irish Time) on a Tuesday. The percentages expressed in Fig 1.8 reflect the rise or fall of the previous auction.
In 2018, more than 500 registered buyers from Africa, Europe, the Middle East, North America, China, South and Central America, and South East Asia may bid for dairy commodities every two weeks at auction events on the auction platform. The results are widely used as a gauge for spot price references on worldwide scale with an annual trade volume of more than 860,000 metric tons and a corresponding yearly trade value averaging three billion US dollars between 2014 and 2018 (Global Dairy Trade, 2023).

1.5 Healthy Aging

1.5.1 Healthy Aging Definition

Health Aging is defined by the World Health Organisation (WHO) is "the process of developing and maintaining the functional ability that enables wellbeing in older age". Functional ability refers to the abilities that allow all people to be and do what they value. This is based in the inner capability of the individual in question and their environment. The intrinsic ability is based on two main factor which are physical and mental capacity to carry out actions like walking, seeing, hearing, thinking and remembering. The ability to carry out these functions not only gives a higher quality of life but also increases lifespan (World Health Organisation, 2023).

1.5.2 Aging

To understand Healthy Aging, aging itself must first be analysed. To define aging on a biological level, it is the accumulation of "molecular and cellular damage over time". This leads to the deterioration of both mental and physical capacity ultimately leaving you susceptible to disease and death. Maintaining good habits throughout life and healthy balanced diet, engaging in regular physical activity, and not smoking, all contribute to lowering the chance of contracting nontransmissible diseases. This in turn, enhancing

physical and mental capacity, and postponing care needed (World Health Organisation, 2023).

As a result, humans can undergo ineffective aging, which is characterized by age-related disorders and a reduction in physical and cognitive performance. Instead, successful aging entails avoiding or delaying the onset of age-related diseases, impairment, and maintaining cognitive and physical function as well as social activities throughout the lifespan. (Alì, et al., 2021).

In accordance with Kim, 2023 an aging population is dependant of the number of people over the age of 64. Therefore, a person is considered elderly from their 65th birthday onwards. In a report carried out by the United Nations in 2019, it stated that a society where 7-14% of the population is over 65, it is an “aging society”. An “aged society” requires 15-20% of the population to be over 65 and a “super aged society” has a population of 21% or higher over the age of 65 (United Nations, 2019).

While an aged population is determined by the ratio of people over 64 to the working-age population between 15 and 64, it is important to recognise that the quality of life varies from region-to-region weather, they are developing countries or not which will be examined in detail in relation to diet (Machado, et al., 2023).

Malnutrition, obesity, diet-related noncommunicable diseases, and environmental degradation are among the most pressing societal concerns of the twenty-first century as a primary driver, these interlocking global crises share unhealthy and unsustainable food systems. Current food systems are failing to satisfy the demands of current and future generations because they operate outside multiple planetary boundaries while providing inequitable and insufficient amounts, quality, and diversity of safe, affordable, and nutritious foods (Machado, et al., 2023).

1.5.3 Population and Demographics

Globally, human life expectancy is rising. Nowadays, most people can live into their sixties and beyond. The number of individuals aged 60 and above is predicted to reach 2 billion by 2050, up from 900 million in 2015. Similarly, the world population of those aged 80 and up is expected to treble from 2020 to 2050, reaching 434 million (Alì, et al., 2021). While aging is inevitable, the World Health Organisation regards healthy aging as a critical goal and the key to transforming population aging from a challenge to an opportunity. Individual elderly people, their families, and societies all benefit from healthy aging. It improves the quality of life of older people, strengthens family bonds, and reduces societal resource demand (Kit Ying Chan, et al., 2023).

Take Ireland for example, Ireland's population was expected to reach 5.01 million in April 2021, the first time it has surpassed five million since the 1851 census, when the equivalent population was 5.11 million. In 1851, the island of Ireland had a total population of 6.6 million people. There were 742,300 residents 65 years of age and older. This age group were the only cohort to increase in population since 2016, rising from 13.3% to 14.8% representing 112,500 people. The 15 to 64 cohort, representing the working population has increased by 170,000 since 2016 however their share of the population has decreased from 65.5% to 65.3%. The final Cohort aged 0-14 has reduced by 1.3% since 2016. Moreover, this means one in every seven people was 65 or older (Central Statistics Office, 2023). By United Nation standards, Ireland having a population of 14.8% is considered to be an aging population (United Nations, 2019).

Japan is another region that has an aging population however within the last 10 years. The old age decency ratio has increased rapidly in the last century alone. Future projections show a decline in the working age population and the population as a whole. This will lead to a further increase in the percentage of people over 65 years of age (Okamoto, 2021). Studies have shown that the Mediterranean diet that the Japanese have adopted has led to a lower mortality rate and helped them in the later years with regard to healthy

aging thus causing an increase in the aging population of Japanese society (Shu, et al., 2019).

Diet is major factor in healthy aging, there are regions where poor diets have led to adverse effects in adulthood. The United States of America (USA) is a prime example. The incidence of prediabetes among adults in the United States is 38%, with this figure expected to rise slightly to 40% by 2030. Obesity has been discovered to be even more common than prediabetes, with an estimated 42% of US people already obese, and this number expected to climb to 49% by 2030. Obesity and prediabetes have both been linked to cardiovascular and renal issues. Due to the increased incidence of ailments such as hypertension and metabolic syndrome, obesity has been identified as a risk factor for cardiovascular disease. Obesity, on the other hand, is recognized as an independent risk factor for the development of cardiovascular disease (Ford, et al., 2023).

Of the 2 billion people over 60 by 2050 (22% of the world's population), 80% of these people will be living in developing regions countries such as Latin America, Asia and Africa. It is important to recognise the proportion of this cohort. This is a worry statistic because there is a prevalence of age-related health concerns of the elderly in this region currently. Cognitive impairment and dementia are on the rise worldwide, and are expected to rise even more rapidly in developing countries. It is projected that 35.6 million people globally currently suffer with dementia, with the figure roughly doubled every 20 years, reaching 115.4 million in 2050, with the majority residing in developing regions. (Mavrodaris, et al., 2018). Most Sub-Saharan African countries' populations are rapidly aging. Alzheimer's disease and related dementias are expected to affect 72 million individuals in Sub-Saharan Africa by 2050, representing a 257% rise since 2015 (Kobayashi, et al., 2019).

While the image obesity is associated with over eating among Americans, the USA has also experienced food insecurity which is a lack of access to nutrient dense foods due low of expenditure and resources which represent a type of hidden hunger. By purchasing these foods of low quality, nutrient deficient foods, it has led to the early decline of physical and cognitive function thus leading to early mortality which was extremely

prevalent during COVID-19 (Neff, 2020). The link between poverty and hidden hunger is not only prevalent among Americans and obesity, but also associated with malnutrition in Africa and Western Asia where there is also poor food security (Lenaerts & Demont, 2021).

1.5.4 Hidden Hunger

A study was carried out by Sulser, et al., 2021 where they used the International Food Policy Research Institute's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) and calculated the disability-adjusted life years (DALYs) due to both chronic and hidden hunger which is the sum of years of life lost as a result of early passing and the years lived with disability. DALYs associated with chronic and hidden hunger are defined as those caused by protein-energy malnutrition or those caused by micronutrient deficiencies such as iron, vitamin A, iodine, zinc, and others. This is as a result of consuming nutrient dense products. Growth stunting and wasting, anaemia, immune system deficits, osteoporosis, cardiovascular diseases or decreased cognitive development are all possible outcomes of these deficiencies. Chronic and hidden hunger are caused mostly by a lack of major grains, which dominate global diets.

The level of global food security is mostly a reflection of the state of global economic development. Indeed, global economic development and food security are varied. Twenty years after the start of the first Industrial Revolution, economic development is still unevenly distributed, with huge differences in average income between Western Europe, its subsidiaries and the rest of the world. While the global frequency of malnutrition has been progressively falling, the overall number of undernourished individuals in Africa, Western Asia, and Oceania is now higher than it was a decade ago. This is significant since food security is a result of economic growth (Lenaerts & Demont, 2021).

Many of the competencies that young people need to succeed in school and later in life depend on executive function. However, a variety of factors, including weight, eating habits, physical activity, muscle strength, and cardiorespiratory endurance, have an impact on executive function. Among them, diet and dietary practices have a significant impact on neurodevelopmental processes. Dairy products have long been regarded as a source of good nutrition because they contain high levels of biologically valuable nutrients like protein, calcium, phosphorus, magnesium, potassium, zinc, selenium, vitamin A, riboflavin, and vitamin B-12 (Shi, et al., 2023).

Dairy products added to the diet on a regular basis during adolescence considerably boost bone mineral content. The majority of dietary recommendations worldwide encourage the intake of dairy products due to their high nutritional value. A high intake of dairy during adolescence will help decrease problems associated with aging later in life (Shi, et al., 2023)

1.6 Diet

In October 2019, the United Nation’s Food and Agriculture Organization (FAO) and the WHO released a report on guiding principles for defining "Sustainable Healthy Diets" as dietary patterns that promote all dimensions of health and wellbeing, have low environmental pressure and impact, are accessible, affordable, safe, and equitable, and are culturally acceptable. Sustainable healthy diets aim to achieve optimal growth and development of all individuals, as well as to support functioning and physical, mental, and social wellbeing at all stages of life for current and future generations. Also, to contribute to the prevention of all forms of malnutrition and to lower the risk of diet-related noncommunicable diseases as well as and to promote biodiversity and planetary health (Machado, et al., 2023).

Poor eating habits may contribute to disability and death. According to the Global Burden of Disease Study 2017, dietary risks accounted for 21.1% of DALYs lost (e.g., 5.4% for a diet low in fruit, 2.8% for a diet low in vegetables, 2.7% for a diet poor in omega-3 fatty

acids in fish, and 0.7% for a diet high in red and processed meats). Dietary patterns differ depending on the quantities and variety of foods, dietary groups, and nutrients consumed, allowing for potential interaction effects. Furthermore, when individual foods or nutrients have a minor impact on health outcomes, it is easier to identify a dietary pattern with integrated benefits (Shu, et al., 2019).

Dairy products are considered nutritious foods because of their high protein and vitamin content. Their consumption has been linked to bone health in children and adolescents. Dairy products are recommended in several dietary standards all around the world. Dairy products have been regarded as a significant carrier for the transfer of bioactive substances with health benefits and functional qualities due to their nutritional content and widespread consumption (Velázquez, et al., 2022).

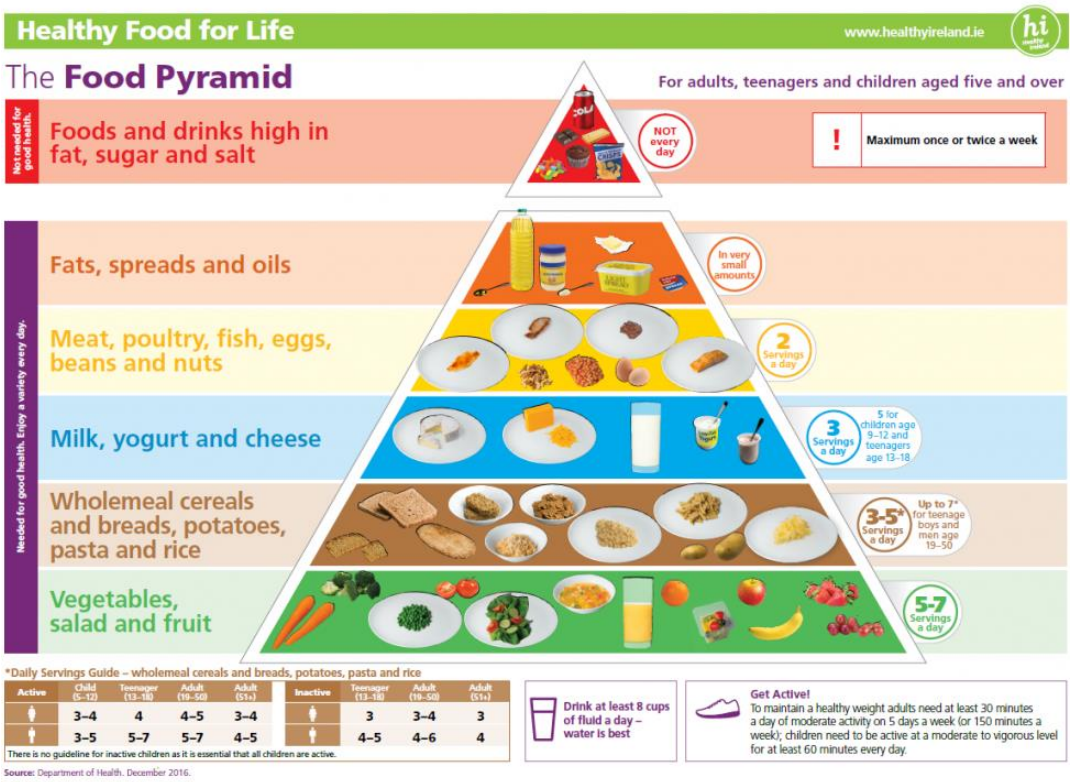


Figure 1.9: Represents a food pyramid resembling daily recommended servings in a healthy diet in accordance with the Irish Department of Health where bye the food consumption increases as you move down the pyramid taken from the National Dairy Council, 2022.

In accordance with Fig 1.9, the recommended daily intake is 3 servings daily as part of a healthy balanced diet for adults 18 years or older (National Dairy Council, 2022). The forms of dairy include milk, yoghurt and cheese. This recommended intake of milk and milk derived products relates to the concept of healthy aging as there is evidence to show that milk and milk derivatives can mitigate common morbidities associated with aging such as sarcopenia, cognitive decline, osteoporosis and cardiovascular disease which will be discussed in detail in this chapter (Cuesta-Triana, et al., 2019) (Matía-Martín, et al., 2019) (Mishali, et al., 2019).

On the other hand, Japan has a healthy aging population however their diet does not consist of any dairy consumption. Their diet is known as a Mediterranean diet which consists of a high consumption of green and yellow vegetables, fish, shell fish, Japanese pickles, beans and green tea. This diet also includes low intakes of coffee and red meat. This diet is proven to minimize the chance of disability in old age and death (Shu, et al., 2019). The food sources mentioned in this diet are also in correlation with the food pyramid in Fig 1.9 where the recommended intake is 2-7 times daily however the protein sources are less desirable than the dairy sources of protein (National Dairy Council, 2022).

1.6.1 Dairy Consumption Challenges

Conscious consumption is an increasing trend in all industries, including the dairy industry. Consumer demand for ethical products is reflected in the rise of plant-based dairy substitutes, many of which promise to be more sustainable, healthier, natural, or animal-friendly. Dairy products are facing increased competition from plant-based alternatives. In 2018, although cow milk sales fell by 6%, plant-based milk sales climbed by 9%. The average dairy product consumer believes that plant-based alternatives are more environmentally friendly than dairy alternatives, putting dairy at a disadvantage when vying for socially conscious consumers (Schiano, et al., 2021).

There are numerous plant-based milk replacements available, including those made from soybeans, nuts, seeds, and cereals. Despite their growing popularity, bovine milks remain the standard in many Western countries, and the overall image of cow's milk remains more positive than that of plant-based milk alternatives especially when it comes to taste (Collier, et al., 2023).

While milk is quite nutrient dense, lactose is a naturally occurring constituent in milk. A portion of the world's population is lactose intolerance preventing them from absorbing milk creating more of a demand for dairy alternatives or lactose free dairy products (Li, et al., 2023).

1.6.2 Lactose Intolerance

Lactose intolerance occurs when the small intestine lacks β-galactosidase, resulting in unpleasant symptoms such as nausea, bloating, and stomach pain. Lactose content in 240 ml of fluid milk is around 12 g. A lactose intolerant person can handle roughly 12 g of lactose per day. Lactose is a problem for lactose intolerant people, yet it also delivers carbohydrate calories. A lactose-free diet is the primary treatment for persons affected by lactose intolerance. Many dairy manufactures have ventured down the lactose free milk route. In 2021 the lactose free milk market has estimated sales of $1.7 billion, with 201 million gallons sold in the United States showing there is consumer demand for lactose free milk rather than not including dairy in the diet (Hernandez, et al., 2023).

1.6.3 Current Trends

Consumer factors important for dairy product sustainability included healthiness, a low carbon footprint and greenhouse gas emissions, few or no preservatives, animal contentment and care, and simple or minimal ingredients (Schiano, et al., 2021). In a study carried out by (Schiano, et al., 2020) the majority of dairy product consumers (>50%) thought protein powders were nutritious however, only 30% and 20% thought they were sustainable or natural respectively.

Consumer trends are also leaning towards living healthier lives, achieving this through the consumption of fermented dairy products. Clean labelling is of high priority reducing the level of preservatives and artificial flavouring. Dairy processors are investigating ways to increase safety and quality of products using natural flavourings in dairy and dairy based products. Previous research has found that optimizing the use of *Lactobacillus helveticus* (L. helveticus) strains can result in a variety of functionally improved dairy products, emphasizing the impact on product quality and public health (Chelladhurai, et al., 2023).

Due to L. helveticus's high functional, probiotic, and proteolytic capabilities, as well as its ability to create bioactive peptides with antioxidant function, it is advisable to assess the benefits of L. helveticus-fermented products in the dairy industry. Recently, there has been an increase in scientific interest in the potential of several bacterial strains in food fermentation. As recently reviewed, several strains of L. helveticus are known to have numerous health benefits, including enhanced gut health, immunological function, and mental wellness. It is mainly found in current yoghurt products and cheeses to aid the fermentation process also (Verma, et al., 2023).

Figure 1.10: Graphical representation of global yoghurt revenue from 2018-2022 and predicted sales from 2023-2028 in United States Dollars extracted from the Global Statistics Website (Statista, 2023).

There is a large demand for yoghurt as seen in Fig 1.10 due to its high nutrient status including bioactives, low-fat or fat free, high protein, and flavour however shelf life is a limiting factor. The addition of whey protein has shown to extend shelf life however it would not have the shelf life of spray dried powders (Gantumur, et al., 2024).

Flavoured milks have gained popularity in recent years especially in the US. Similarly, to yoghurt, they are fortified with the necessary nutrients such as vitamin D, calcium, potassium, and fibre to support healthy aging and avoid risk of osteoporosis and cardiovascular disease. By adding flavourings, it is more enticing from an organoleptic point of view (Ricklefs-Johnson & Pikosky, 2023).

1.7 Morbidity Vs Mortality

In accordance with Liu, 2018, morbidity is defined as a measure "of disease frequency characterize the number of persons in a population who become ill (incidence, i.e., new cases) or are ill at a given time (prevalence, i.e., currently existed cases at the study point in time), or mortality in a given period" which in this case there is a focus on the elderly and the associated morbidities are osteoporosis, sarcopenia, cognitive decline and cardiovascular disease. These 3 morbidities have been identified as global health concerns associated with aging by the WHO (World Health Organisation, 2023).

As defined by the WHO, mortality is "the estimated total number of deaths in a population of a given sex and/or age, divided by the total number of this population, expressed per 100,000 population, for a given year, in a given country, territory, or geographic area" (World Health Organisation, 2023). In this study there is a focus on the elderly, 65 years and older and the geographical regions have been examined.

1.7.1 Osteoporosis

Osteoporosis is a disease that developed in your bones causing bone mineral density and mass to decrease causing the strength and structure of the bone to change. This can result in a loss in bone strength, increasing the risk of fractures (National Institute of Arthritis and Musculosketal and Skin Disease, 2022).

In biological terms bones undergo two processes which are continuous cycles of modelling and remodelling. During modelling, either bone development or bone resorption occurs at specific points independently. Thus, changes in bone size and structure throughout growth, as well as bone adaptation to changing mechanical demands, are enhanced. Alternatively, remodelling is a highly coordinated process of both resorption and production at a specific region that maintains skeletal integrity by rebuilding old and injured bone (Föger-Samwald, et al., 2020).

Additionally, remodelling mechanisms maintain calcium and phosphate homeostasis by releasing and incorporating calcium and phosphate from and into the bone matrix. The fact that defective remodelling favours bone resorption over bone production is a major pathophysiological process leading to bone diseases such as osteoporosis which emphasizes the how crucial the remodelling process is in overall bone homeostasis (Föger-Samwald, et al., 2020).

Within the bone there are 3 types of bone cells which are bone resorbing osteoclasts, bone forming osteoblasts, and osteocytes, previous osteoblasts that have become caught in the bone matrix. Remodelling, in particular, is dependent on fine-tuned interaction between these protagonists to guarantee that the amount of bone resorbed by osteoclasts equals the amount of bone generated by osteoblasts, and so that bone mass is maintained (Föger-Samwald, et al., 2020).

Aging leads to bone loss, fragility, and an increased risk of osteoporotic fractures or breaks. The prevalence of osteoporosis in industrialized countries has been estimated to be 9-38% for females and 1-8% for males over the age of 50. Several nutritional components have been linked to bone mass density and the risk of osteoporosis. Calcium, inorganic phosphate, vitamin D, and proteins are examples of nutrients. Milk and dairy products, as well as, more recently, dietary trends such as the Mediterranean diet (Matía-Martín, et al., 2019). Low fat dairy products such as cheese and yoghurt have been proven to support bone density and osteoporosis supplying the required nutrients while not causing cholesterol problems in adults (Bian, et al., 2018).

With this in mind, prevention via dairy may be a cheaper option that the associated medical costs of osteoporosis. Osteoporosis and osteoporotic fractures have a significant impact on the global economy, both directly and indirectly. The annual cost of osteoporosis to the US health-care system is estimated to be between $5 and $10 billion among the elderly. Fractures are more likely in elderly people who have osteoporosis and can result in a lower quality of life, hospitalization, disability, and an increase in mortality rates (Salari, et al., 2021).

This economic burden is not only faced by the USA but globally. Over 8.9 million osteoporotic fractures occur worldwide. In other words, every three seconds, an osteoporotic fracture occurs. Because the average age of the population is rapidly increasing, a growth in the number of people with osteoporosis and, as a result, an increase in the number of fractures owing to osteoporosis can be projected (Cui, et al., 2020). Therefore, a cheaper alternative need to be found which possibly could be through dairy products.

1.7.2 Sarcopenia

Sarcopenia is an age-related reduction in skeletal muscle mass, with lower muscular strength or physical performance, leading in an increased risk of adverse outcomes such

as falls, limited mobility, and frailty, resulting in morbidity and death. (Catalán, et al., 2018). Sarcopenia is common is later years of life, particularly the over 65 age brackets. This idea is related to physical weakness. The current thinking is that sarcopenia is a major cause of frailty, however not all sarcopenic people are weak. Physical frailty is associated with cognitive decline and incident mild cognitive impairment. It is defined as weariness, a low level of physical activity, slowness, weight loss, and diminished grip strength. The term "frailty" has a far broader meaning and encompasses other aspects, such as cognitive performance. This morbidity can be caused by a lack of nutrients such as vitamins amino acids and proteins which can be provided by dairy products (Cuesta-Triana, et al., 2019).

Sarcopenia, in addition to muscle loss and contractile failure, includes metabolic and endocrine changes, as well as low-grade age-related systemic inflammation, commonly known as inflamm-aging amoung the elderly. Muscle loss is characterized by a considerable decrease in protein regeneration, as well as increased protein lysis and apoptosis. (El-Sebaie & Elwakil, 2023).

Several metabolic indicators, collectively known as metabolomics, have been found to be highly associated with muscle mass and quality in the aged. Lower plasma quantities of the branched-chain amino acids leucine and isoleucine, in particular, were identified in sarcopenic adults. Furthermore, circulating levels of essential amino acids were shown to be lower in frail older persons compared to non-frail counterparts (El-Sebaie & Elwakil, 2023).

There is a huge economic burden associated with sarcopenia also. A study was carried out in the USA to calculate the cost associated with sarcopenia. The overall estimated cost of hospitalizations among people in the US with sarcopenia was $40.4 billion, with an average cost of $260 per person. The average cost per individual with sarcopenia was higher for older people over 65 ($375) than for younger adults ranging from 40 to 64 years ($204). The overall cost of hospitalizations in people over 65 with sarcopenia was $19.12 billion equating to nearly half of the overall cost (Goates, et al., 2019)

1.7.3 Cognitive Decline

Cognitive decline is described as self-expressed chronic loss in cognitive capacity compared to previous normal status, unrelated to an acute incident (Migliaccio & Cacciamani, 2022). To understand cognitive decline, it is important to highlight that cognitive function refers to many mental aspects such as learning, thinking, reasoning, remembering, problem solving, decision making, and attention (Fisher, et al., 2019).

Oxidative stress is a key driver of cognitive decline and occurs when reactive oxygen species increase production or alternatively reduced antioxidant defences causing macromolecular damage, poor organ function, and disease development associated with cognitive decline such as dementia (Hajjar, et al., 2018). Proteins containing aminothiols are susceptible to oxidation-reduction processes. These protein switches to regulate biological organization and a variety of physiological processes. Glutathione acts as a primary antioxidant in tissues in this within the body, assisting in the removal of peroxides and the detoxification of reactive aldehydes and other harmful compounds (Hajjar, et al., 2018).

Glutathione is a product of fermented dairy products where *Streptococcus thermophilus* was the bacteria used, particularly yoghurt and has been shown to reduce oxidative stress. Glutathione is a tripeptide that is made up of glutamic acid, cysteine, and glycine. The majority of eukaryotes and gram-negative bacteria, as well as certain gram-positive bacteria, can produce it. It plays an major role in decreasing free radical concentration, maintaining the reducing environment in cells, and improving cell stress resistance which is a vital component in the antioxidant function of lactic acid bacteria (LAB), thus protecting cells from oxidative impairment and other chemical stressors (Xue, et al., 2023).

Cognitive decline is a common problem associated worldwide with aging putting a large amount of strain on families and health care systems in order to put in place the necessary

provision for the elderly who have this morbidity. Bioactive peptides such as β-Carotene and β-lactolin are also proven to promote healthy brain function during aging. With this in mind, studies have shown that people who included low fat dairy products in their diet such as yoghurt and cheese had a higher cognitive function that those who did not. The intake of low-fat dairy results in improved memory recall, increased social functioning and decreased stress. Even tests were carried out on the Japanese population aged 60-79 (1000 people) and the inclusion of dairy and fermented dairy products was shown to reduce risk of dementia (Ano, et al., 2018).

1.7.4 Cardiovascular Disease

In accordance with the National Health Service, Cardiovascular Disease (CVD) is the general term for conditions affecting the heart or blood vessels. It us typically linked with accumulation of fatty deposits in arteries and a higher risk of blood clots (National Health Service, 2022). CVDs has one of the largest mortality rates and one of the most common morbidities across the world, however this varies across age groups. There is evidence to suggest the most susceptible group to CVD's are in fact the elderly as aging leads to the natural decline of the cardiac structure and function (Yao, et al., 2021).

High dairy consumption has been linked to lower blood pressure. As hypertension was connected to a higher risk of CVD, reducing it was linked to a lower risk of CVD. Calcium is regarded to be one of the key elements responsible for the effect of dairy products on blood pressure, along with potassium and magnesium. Both casein and whey proteins are high in bioactive peptides that have been proven to inhibit angiotensin-converting enzyme, a vital step in blood pressure management, leading to a state of satiety and satiation which is a key factor in preventing overeating. Calcium and maybe its specific proteins, the peptides they release, the phospholipids linked with milk fat, or the stimulation of high-density lipids by lipids themselves may all help to reduce oxidative and inflammatory stress in adipose tissue. Dairy foods may influence circulation good cholesterol reactive protein and adiponectin levels without affecting body weight (Mishali, et al., 2019).

1.7.5 Satiety and Satiation

Appetite is significantly linked to food intake. Peptides found in dairy products signal the gut modify our attitude toward food from "hunger" to "satiation" as we eat, resulting in meal termination. When food enters the stomach, it induces distention and stimulates the release of satiety signals (Kondrashina, et al., 2020).

Satiation is known to be connected with the inter-meal time, through the suppression of hunger and the prevention of additional eating, whereas satiety is known to be associated with the intra-meal period, through the determination of meal size and the termination of a specific eating episode (Stribițcaia, et al., 2021).

Because food regulates satiety hormone release, appetite suppressing bioactive peptides from foods offer an appealing alternative to pharmacological methods for controlling hunger over a lifetime. Epidemiological studies show that consuming dairy foods, particularly low-fat dairy, milk, and yogurt, can aid in the maintenance of a healthy body weight (Kondrashina, et al., 2020).

1.8 Affordability

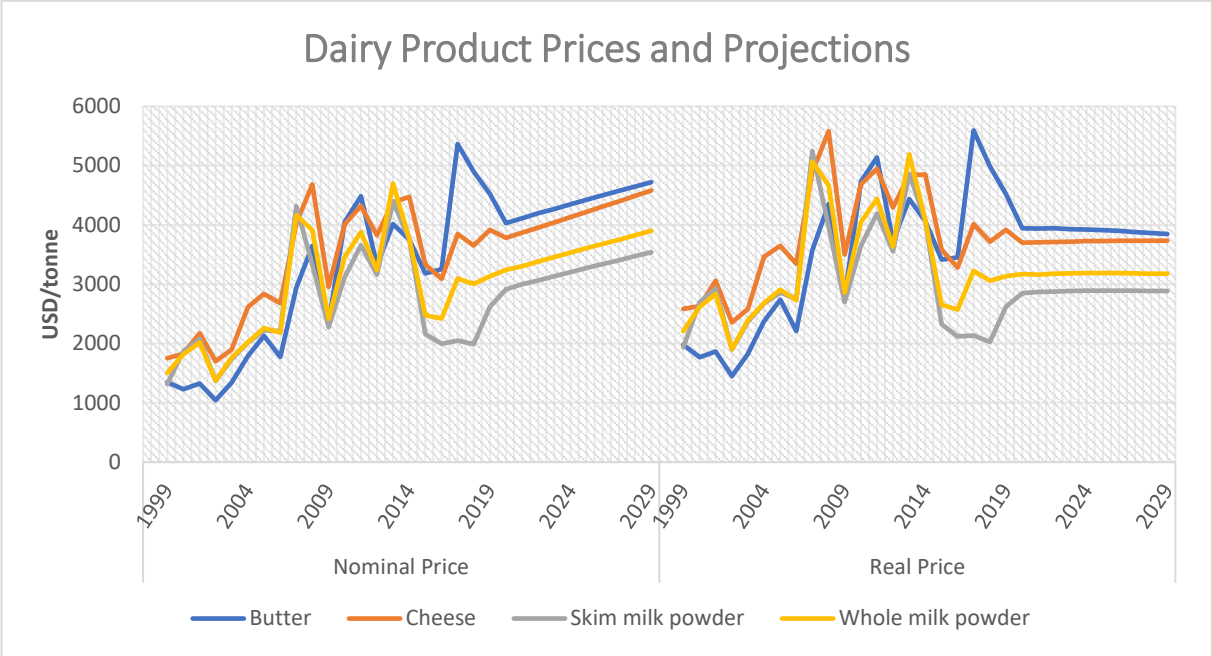


Figure 1.11: Graphical representation of international commodity price comparison between normal and retail pricing. Butter is based on 82% butterfat, SMP based Codex on 1.25% butterfat, WMP based on 26% butterfat, Cheese based on cheddar at 39% moisture. All pricing based on Free On Board (FOB) export. Data taken from OECD-FAO Agricultural Outlook 2020-2029 (OECD, 2023).

The prices reference in Fig 1.11 are based off the main exporters in Oceania and Europe. The largest margin is between SMP and butter in the dairy industry. There has been a considerably greater demand for butter since 2015 which would indicate that there is a higher demand for fat rather than protein. In accordance with Fig 1.12 SMP price is just above $3000/tonne while butter is valued at $4500/tonne. This trend is expected to continue over the next 10 years however the margin is expected to decrease (OECD, 2023).

Due to the depletion of stock in 2019, SMP price recovered due demand being greater than supply. It is projected that SMP pricing will stabilize from 2023-2023. According to

this report butter prices peaked in 2017 coupled with a sharp decline and has begun to recover in 2019. Real prices show a negative projection. WMP and cheese prices are expected to flat line as their value correlates to fat and protein values of butter and SMP. In a recent report issued by the world bank, the war between Ukraine and Russia is to blame for recent inflation in food prices in 2022 (The World Bank, 2023).

Three quarters of the countries across the globe import 50% of their fertilizer from Russia. Major dairy exporting regions such the European Union and the United States imposed sanctions importing fertiliser from Russia in an effort to prevent funding their military. This caused a scarcity in agricultural fertiliser, thus increasing price. This had a knock-on effect on the dairy industry as fertiliser is a major input into milk production causing an inflated food price (The World Bank, 2023).

From Fig 1.12 developing regions such as Mena and South East Asia are the main imports of dairy powders from Europe and the US. The inflated prices of dairy powders as a result the war in Ukraine indirectly impacted these developing regions with low to middle incomes.

1.9 Thesis Outline

This thesis will review the potential application of bovine dairy powders in supporting healthy aging of humans and associated methods. This will be achieved by defining bovine dairy and giving a brief synopsis of bovine dairy history in Ireland and current day economics and trade across the globe. Milk powders will be examined on a range of parameters such as production, quality, type, enrichment and cost. Healthy aging will be defined, aging populations will be identified with a focus on diet. The associated morbidities of these aging populations will be identified and how dairy nutrients can be used to combat these morbidities. Dairy products currently on the market with this goal in mind will be identified as well as their availability and affordability. Based on this knowledge a milk powder will be designed with the necessary nutrients to support a healthy aging population.

Chapter 2

Reviewing The Potential Application of Bovine Dairy Powders in Supporting Healthy Aging of Humans and Associated Methods

2.1 Methods - Study Design

This section outlines the methods used to show how dairy nutrients can mitigate or prevent morbidities associated with aging in the quest to support a healthy aging population. The research methods used in this desk-based study have been published journal articles of reputable source, data from government sources and global recognised sources.

2.1.1 Thesis Outline Of Research

There are many studies that have investigated the benefits of various dairy products in supporting a health aging population however shelf life is an issue for most dairy products hence why there is a specific focus on "Reviewing The Potential Application of Bovine Dairy Powders in Supporting Healthy Aging of Humans". Chapter 1 begins with the definition of Bovine dairy followed by dairy consumption and history both locally and globally. The spray drying process is discussed in detail along with current dairy powder variations and the associated cost of production. Healthy aging is defined as well as aging. Aging populations and demographics were identified as well as associated diets. Mortality and morbidity are defined and the major morbidities of an aging population are examined in detail. Current trends in the dairy industry to combat these health concerns as well as affordability of these products.

Chapter 2 will outline the materials and methods used to explore the research question while Chapter 3 will present results and findings with the 3 most prevalent aged diseases osteoporosis, sarcopenia and cognitive decline. The biochemical demand, role of dairy and current literature will be presented for each disease and the key nutrients required for a dairy product to mitigate all three will be presented. Chapter 4 will review the results relative to dairy and the 3 most prevalent aged diseases osteoporosis, sarcopenia and cognitive decline as well as the powdered dairy product. A conclusion will be drawn on the findings. Chapter 5 will summarise the key findings and future work.

2.1.2 Scope

The scope of this research focuses on ~~r~~eviewing the potential application of bovine dairy powders in supporting healthy aging of humans, focusing on demographics of aging populations, diet, most common morbidities of these regions and affordability of the associated regions.

The aged related diseases osteoporosis, sarcopenia and cognitive decline are focused on because they have been identified as the most common morbidities associated with aging by the World Health Organisation. Furthermore by 2050, it is estimated that 22% of the world's population will be over 60 years old. As defined by the United Nations, the world population will be a "Super Aged Society". Eighty percent of these people will be living in developing regions which must be taken into consideration when designing a product.

The biochemical breakdown of each disease will be examined and the dairy nutrients can prevent mitigate the disease will be identified. The dairy nutrients will be incorporated into a dairy powder in order to provide an affordable product with sufficient shelf life for developing countries and others. This product can be consumed globally supporting healthy aging and mitigate morbidities associated with aging

2.1.3 Data inclusions

The data obtained for this review was taken from published journal articles as well as observational studies. The studies used have been on going ranging from weeks to years, the longest study began in 2014 with research being progressive each year since. The type of data included in this study were vitro in vivo, cohort studies, longitudinal studies and review papers.

The data used has been recently published literature within the last 5 years however 1 review paper published in 2020 reviewed a study carried out in 2011 which is relevant to this paper.

2.1.4 Exclusions

Non peer reviewed data has been excluded for review data. Unsubstantiated data has also been excluded from the review.

2.1.5 Statistics

Only data from experimental and observational studies with significant amounts of data and a large number of research individuals were used to ensure that only statistically valid data was used. Studies typically included 2000 subjects, with a range from 104 to 19,555 subjects following screening.

Statistical analysis has not been carried out, as part of this study, as to do so would have been inappropriate, due to the lack of available raw data. Within the research material used in this study, the statistical credibility of each paper was monitored closely by ensuring the P-values were <0.05 to ensure the data was significant especially in papers used in the results section.

2.2 Materials

2.2.1 Population and Demographics

This review focused on aging populations in both developed and developing regions. There was a greater focus on the developing regions in terms of finished dairy product as statistics show the majority of the aging population will reside within developing regions.

2.2.2 Age

The focus of this study was on age profiles of 60 years and older as this cohort represent the aging population as defined by the World Health Organisation.

2.2.3 Morbidities

The morbidities associated with the aging cohorts from the regions identified were studied in detail. The most prevalent diseases were focused on throughout this study which were osteoporosis, sarcopenia and cognitive decline as outlined in 2.1.2

2.2.4 Affordability

Affordability is a major challenge faced by this study due to the majority of the aging population residing in low income, developing regions located in the middle east.

2.2.5 Male and Female

For the purpose of the review, data relating to both male and female aged persons have been included due to the prevalence of the 3 morbidities in both genders in the specified age profile.

2.2.6 Shelf Life

Shelf life is a challenge faced by this study due to the majority of dairy products sourced by developing countries in the Middle East are from Europe therefore the product has to have enough shelf life to allow for transit and allow for distribution within these regions while being shelf stable.

2.2.7 Inclusions

Only bovine dairy dietary inclusions have been used in this study. Fresh and processed dairy have been included made from bovine milk. Bovine milk and its key nutrients have been included in this study due to the global demand nutrient specific qualities that can aid human health and development.

2.2.8 Any Exclusions

Dairy sources from non-bovine sources have not been included in this study due lack of consumption on a global scale. Non-bovine dairy would have less of an effect on a global scale in terms of supporting a healthy aging population as a result.

Chapter 3

Results

The proportion of older persons aged over 60 years in the world population is increasing year on year. Sixteen percent of the world's population will be over 60 by 2030 and it is project to rise to 22% of overall global population by 2050. Aging would have been originally been experienced by high income countries such as Japan with 30% of its population currently over 60 (WHO, 2022). However there has been a shift in distribution. Low and middle-income countries are now beginning to experience this trend. Sixty-six percent of the world's aging population will reside in these regions by 2050 (WHO, 2022). Osteoporosis, Sarcopenia and Cognitive Decline are the most common morbidities identified associated with aging all linked with nutrient deficiencies as described in section 1.7. Dairy products have been shown to mitigate the morbidities. Affordability must be factored here due to the majority of this population demographic coming from low to middle income regions as highlighted in section 1.5.3. In this chapter the potential role of bovine dairy in mitigating osteoporosis, sarcopenia and cognitive decline will be explored.

3.1 Vitamin D and Osteoporosis

Osteoporosis is a degenerative illness characterized by bone structure degeneration due to Bone Mineral Density (BMD) loss causing an increase in the likely hood of fractures most common in the hip, wrist and spine. The biochemical breakdown of osteoporosis has been described in section 1.7.1 A lack of Vitamin D has shown to be a major cause of loss of BMD. Vitamin D is a bioactive nutrient associated with growth and health as well as being responsible for promoting calcium deposition. Milk contains calcium naturally and is commonly fortified with vitamin D as it does not occur naturally in milk. In the human body, these nutrients interact synergistically. If the level of ionized calcium in the blood falls, the parathyroid gland secretes parathyroid hormone, which stimulates the conversion of vitamin D to its active form, calcitriol (1,25-dihydroxyvitamin D), resulting in a decrease in vitamin D status, measured by the amount of the inactive form. Vitamin D, as calcitriol, regulates calcium absorption in the intestine, and a deficiency of vitamin D is related with decreased calcium absorption (Polzonetti, et al., 2020).

Vitamin D can occur naturally as ergocalciferol found in plants known as Vitamin D2 and cholecalciferol can be found in animal sourced foods as Vitamin D3. The action of Ultra Violet (UV) radiation on the skin converts provitamin D3 (7-dehydrocholesterol) to pre-vitamin D3 allowing it to be absorbed by skin. Factors such as longitude and latitude come in to play as certain regions would have more exposure to sunlight than others. The human body's ability to carry out this function deteriorates over time resulting in vitamin D deficiencies in the elderly leaving them at risk to a loss of BMD (Polzonetti, et al., 2020).

Age	Nutrient Intake (µg/Day)	Nutrient Intake (IU/Day)
0-3 months	8.5	340
4-6 months	8.5	340
7-9 months	7	280
10-12 months	7	280
1-3 years	7	280
>65 years	10	400
Pregnancy	10	400
Lactation	10	400

Table 3.1: Recommended daily intake of vitamin D ranging from the 0-3 months age bracket to the above 65 years of age bracket. Data extracted from the Nutrients Journal (Polzonetti, et al., 2020).

As seen in Table 3.1, the groups that require the highest vitamin D intake are the elderly (>65 years), pregnant women and lactating mothers. The most important natural vitamin D dietary sources are fatty fish, fish liver oils, and egg yolk. The best approach for determining vitamin D levels in the human body is to measure serum 25(OH)D concentrations. The optimal level of skeletal or extra-skeletal health is not the same for everyone, specially because bone mineralisation decreases following adolescence (Polzonetti, et al., 2020).

3.1.1 Dairy and Osteoporosis

The key factors that contribute to osteoporotic development include bone mineral density, falls, and lifestyle choices. Calcium consumption and general nutrition are examples of lifestyle habits that can help prevent hip fractures as described in section 1.7.1. Dairy products are known to help reduce hip fractures because they include a lot of calcium, proteins, potassium and other bioactive substances that prove beneficial for bone health (Bian, et al., 2018).

Pregnant women are also susceptible to osteoporosis requiring higher calcium intake. The demands of fatal skeletal growth during pregnancy involve hormonal changes that cause increased calcium absorption in the gut and higher calcium mobilization from maternal bone storage. Lactation, a very metabolically active time, also causes maternal bone calcium loss. Increased maternal bone synthesis during the end of pregnancy and postnatally can restore bone density, but the bone shape is permanently affected which can lead to further osteoporotic fractures further down the line particularly when they reach 65 years as required the bone density is not available to support the bodies' function or repair itself (Cathey, et al., 2023).

Dietary calcium consumption has a significant impact on calcium homeostasis in the body. The skeleton contains the majority of total body calcium in the form of crystalline molecules, which serve as mechanical support and a reservoir for the central pool of calcium (Bae & Park, 2022). Because calcium is required for bone growth and skeletal development, adequate calcium consumption is considered a requirement for sufficient linear growth especially in adolescence (1-20 years). Calcium supplements will assist young adults build their bone mineral mass and strengthen their bone structure. The bodies' ability to carry out this function declines rapidly after the adolescent period. Poor calcium intake throughout growth may result in stunted development and insufficient peak bone mass during adolescence, increasing their risk of osteoporosis later in life (Hwang, et al., 2023)

The intake of dairy throughout adolescence is key as dairy provides the calcium requirements to support bone mineral mass thus supporting healthy aging. (Hwang, et al., 2023). The recommended calcium intake for people aged from 51-70 years is 1200mg/day for females and 1000mg/day for males. For people aged 71 years and older the recommended calcium intake is 1200 mg/day as calcium absorption decreases as humans get older (International Osteoporosis Foundation, 2023),

Potassium has also proven to be essential in bone formation and skeletal bone mass, working symbiotically with calcium (Ha, et al., 2020) both naturally occurring in milk at 11 mg/100g and 120 mg/100g respectively with further processing increasing these volumes (National Dairy Council, 2022) . Potassium is required for pH regulation in the skeleton. Without the regulation of pH through the alkaline salt, this would result in bone loss and osteoporosis. Potassium salt limits bone resorption in order to maintain pH homeostasis. Furthermore, increasing potassium consumption enhances urine retention, which reduces calcium loss, resulting in a more positive calcium balance and slowing bone resorption. Potassium is also naturally occurring in dairy (Ha, et al., 2020). The recommended daily intake of potassium for adult males is 3400mg and for women it is 2600mg to help increase bone mineral density and regulates calcium absorption (National Institues of Health, 2021).

Phosphorus is another key nutrient involved in bone mineralisation and osteoporosis prevention and treatment of the elderly (Hejazi, et al., 2020) as well as being naturally occurring in milk at 96 mg/100g of Irish whole milk standardised to 3.5% fat (National Dairy Council, 2022). Appropriate phosphorus consumption is required for bone development during the growing years because low serum phosphate levels inhibit bone formation and mineralization. A high phosphorus intake, especially when combined with a low calcium intake, might be detrimental while a low serum phosphorus level can be used to diagnose malnutrition, which is a risk factor for osteoporosis and fracture. Low phosphorus intake or a negative phosphorus balance can result in decreased osteoblast effectiveness but increased osteoclast activity and consequently faster bone turnover. The ratio of phosphorus to calcium of most importance which is 0.5-1.5:1 respectively while the recommended intake of phosphorus for adults is 700mg/day (Hejazi, et al., 2020).

In terms of dairy protein, bone size, bone mass, and bone strength estimation were all favourably associated to dietary protein intake, in particular whey protein which contains branched chain amino acids that promote protein synthesis (Rizzoli, 2021). β-Lactoglobulin is a whey protein that provides a variety of functions such as ligand-binding allowing it to accommodate hydrophobic molecules such as vitamin D and calcium in their uptake to increase bone mineral density which intern aids healthy ageing and the prevention of osteoporosis (Douglas, et al., 2018).

3.1.2 Study by Bian et al, 2018

In the study carried out by Bian, et al., 2018, dairy product consumption and risk of hip fracture: a systematic review and meta-analysis was investigated. Hip fractures are one of the three most common fractures asscociated with osteoporosis. The other 2 fractures located in the spine and wrist (Koh, et al., 2023). Preveiosly to this study there had been conflicting lierature claimimg dairy increased risk of osteoporosic fractures of the hip. The literature examined was taken from the PubMed and EMBASE database in which 8 case control and 10 cohort studies. The pooled risk was estimated using random-effects models. Subgroup and dose-response analyses were used to investigate the links between milk consumption and the risk of hip fracture (Bian, et al., 2018)**.**

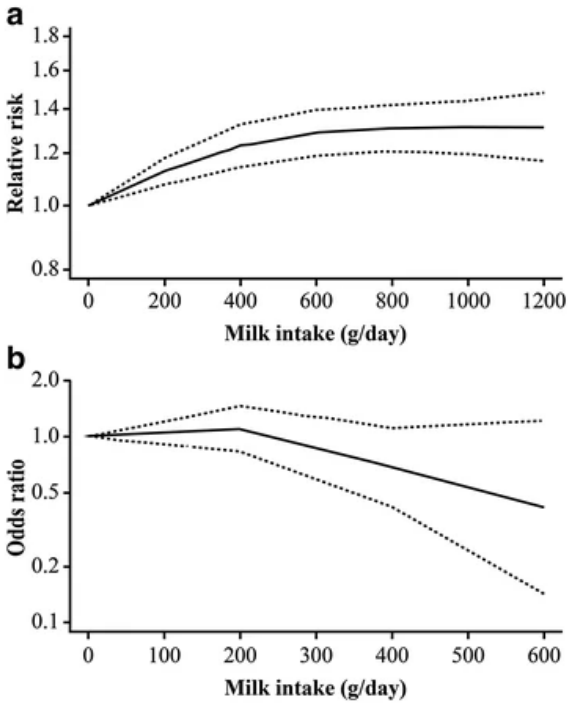


Figure 3.1: Graphic displays of (A) dose-response associations between milk consumption verses risk of hip fracture monitored in 7 cohort studies and (B) dose-response meta-analysis of the association between milk consumption verses hip fracture risk in 3 case-control studies taken from Bian et al, 2018.

As shown in Fig 3.1 (A) there was a nonlinear positive relationship between milk consumption and hip fracture risk, with a sharp rise in risk when milk consumption went from 0 to 600 g/d ($P<0.01$) and no further increase in risk when milk consumption climbed from 600 to 1200 g/d. In Fig 3.1 (B) revealed a nonlinear relationship between milk consumption and hip fracture risk ($P<0.28$) , with a reduction in risk with 200-600 g/d milk consumption. However, the confidence intervals for all outcomes were large.

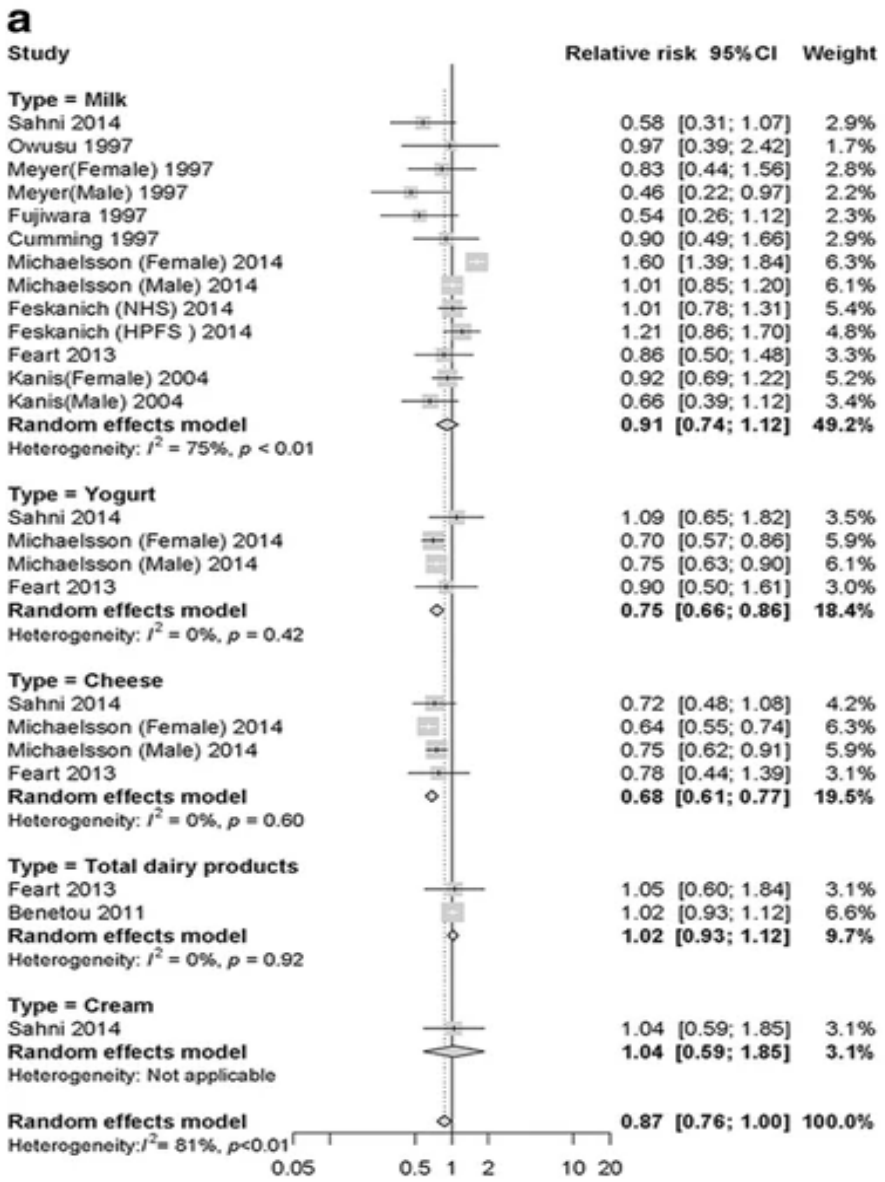


Figure 3.2: Pooled analysis of case studies(A) where relative risk (RR) of hip fracture for the highest compared with the lowest categories of dairy product consumption. The 95% confidence intervals (CIs) are indicated by the grey box. The size of the square surrounding each effect estimate represents the importance of the particular study and the data is taken from Bian et al, 2018.

As shown in Fig 3.2, the pooled RR for highest versus lowest category of milk intake and hip fracture risk in cohort studies was 0.91 (95% CI: 0.74-1.12, I2 = 75.0%) demonstrating that milk consumption had no connection with hip fracture risk. The analyses that produced the pooled estimates revealed heterogeneity (P< 0.01).

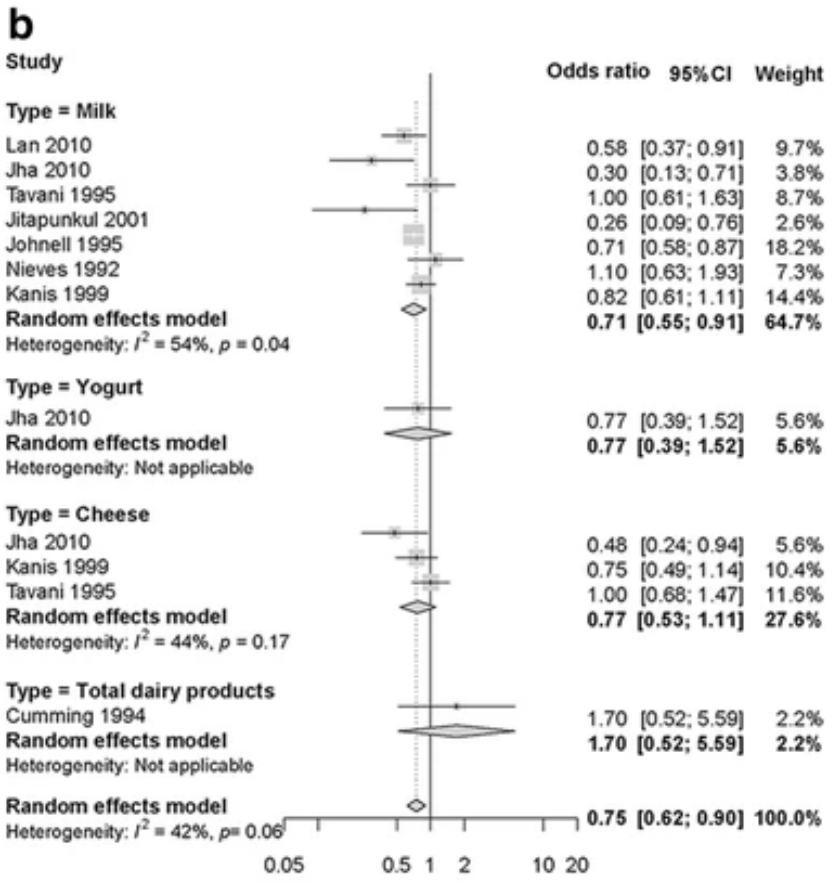


Figure 3.3: Pooled analysis of cohort studies (b) where relative risk of hip fracture for the highest compared with the lowest categories of dairy product consumption. The 95% confidence intervals are indicated by the grey box. The size of the square surrounding each effect estimate represents the importance of the particular study and the data is taken from Bian et al, 2018.

According to the case-control studies shown in Fig 3.3, persons in the highest categories of milk consumption had a 29% lower risk of hip fracture. The odds ratio was 0.71 and the 95% CI ranged from 0.55-0.91. Analysis of pooled estimates revealed heterogeneity ($P<0.04$).

The findings of this study indicate in cohort studies, yogurt and cheese consumption was linked to a decreased incidence of hip fracture. Consumption of total dairy products and cream, on the other hand, was not substantially linked with the incidence of hip fracture. The age range of the subjects in the studies was not defined. There was inadequate data

to draw conclusions about the relationship between milk consumption and the risk of hip fracture. A lower milk intake threshold of 200 g/day may have favourable effects, whereas the implications of a greater milk intake threshold are unknown.

3.1.3 Study by Wang *et al*, 2019

In the study carried out by Wang *et al*, 2019, the prevalence of osteoporosis using The Osteoporosis Self-Assessment Tool for Asians (OSTA) and its correlation with sociodemographic factors, disability and comorbidities was investigated. The aim of this study was to quantify the number of elderly people (over 60) who were at risk of osteoporosis and investigate the associated risk factors. The correlation between osteoporosis risk, chronic diseases, and disability was also investigated. The participants recruited were from Singapore's multiethnic community and were aged 60 years old and above (Wang, et al., 2019).

The OSTA was used to categorize osteoporosis risk. It is an index used by participants to define their severity of osteoporosis risk by using a formula solely based on age and body weight. See below equation:

$$OSTA = 0.2\ X\ (body\ weight\ in\ kgs - age\ in\ years)$$

People were divided into three groups based on their gender. The three categories for males were Low Risk (>-1), Intermediate Risk (-1 to -6) and High Risk (<-6). For Females the categories were Low Risk (>-1), Intermediate Risk (-1 to -4) and High Risk (<-4). The intermediate and high-risk groups were deemed “at risk” of osteoporosis (Wang, et al., 2019).

The World Health Organization Impairment Assessment Schedule 2.0 was used to assess the severity of impairment based on sociodemographic information and chronic diseases. This was a questionnaire used to assess the subjects on their performance across six

sections associated with disability. A five-point scale was included in this assessment. The scale began at 0 representing none, up to 4 representing extreme or unable. The scale was in relation to how much their impairment interfered with their lives in the previous 30 days. The scores were tallied of both assessments and converted to a scale from 0-100. A higher score representing greater disability (Wang, et al., 2019).

	Overall Sample		OSTA > −1		OSTA ≤ −1	
	n	Weighted %	Weighted %	S.E.	Weighted %	S.E.
Overall	2345	100	48.0	1.37	52.0	1.37
Age group						
60–74	1445	77.0	60.2	1.75	39.78	1.75
75–84	613	18.8	8.6	1.44	91.45	1.44
85+	287	4.2	0.3	0.17	99.66	0.17
Gender						
Males	1052	44.7	62.9	1.92	37.14	1.92
Females	1293	55.3	36.0	1.88	63.99	1.88
Ethnicity						
Chinese	935	83.6	45.7	1.62	54.32	1.62
Malay	651	9.0	59.6	1.85	40.37	1.85
Indian	723	5.9	58.7	1.67	41.25	1.67
Others	36	1.5	64.9	6.26	35.10	6.26
Marital status						
Married/cohabiting	1411	65.0	56.8	1.76	59.26	5.47
Never married	128	8.0	40.7	5.47	43.24	1.76
Widowed	703	21.3	20.4	2.37	79.62	2.37
Divorced/separated	101	5.6	63.3	6.33	36.67	6.33
Education						
None	424	15.7	22.3	3.05	77.65	3.05
Some, but did not complete primary	569	24.1	42.9	2.91	57.06	2.91
Completed primary	604	24.9	50.7	2.92	49.28	2.92
Completed secondary	492	22.7	58.2	3.09	41.81	3.09
Completed tertiary	249	12.7	65.7	4.03	34.31	4.03
Employment status						
Paid work (part-time and full-time)	684	35.3	66.0	2.46	34.02	2.46
Unemployed	31	1.6	59.9	11.80	40.08	11.80
Homemaker	714	26.0	37.6	2.71	62.42	2.71
Retired	895	37.1	37.9	2.26	62.13	2.26

OSTA: The Osteoporosis Self-Assessment Tool for Asians; S.E.: Standard Error.

Table 3.2: In person interviews representing the Osteoporosis Self-Assessment Tool for Asians results displaying the sociodemographic variables in a comparison for subjects with a low risk of Osteoporosis (>-1) versus subjects at risk of Osteoporosis (<-1) taken from Wang *et al*, 2019.

In Table 3.2 the results of the OSTA are displayed in correlation with the sociodemographic variables for the entire sample. 52% of all participants were at risk of osteoporosis. Over 40 % of participants from Milaysia and India are at high risk of osteoporosis while over 54% participants from China are at high risk of osteoporosis

highlighting the prevalence of the age-related disease. As aged increased, so did the risk percentage across the 3-age profiles (Wang, et al., 2019).

	OR+	95% CI		*p* Value
		Lower	Upper	
Age group				
60–74	^ Ref			
75–84	15.6	9.923	24.48	**<0.001**
85+				
Gender				
Male	Ref			
Female	3.5	2.406	5.112	**<0.001**
Ethnicity				
Chinese	Ref			
Malay	0.4	0.334	0.605	**<0.001**
Indian	0.5	0.382	0.666	**<0.001**
Others	0.4	0.145	0.856	**0.021**
Marital status				
Married/cohabiting	Ref			
Never married	2.2	1.265	3.835	**0.005**
Widowed	1.9	1.223	2.902	**0.004**
Divorced/separated	0.8	0.386	1.459	0.397
Education				
None	2.8	1.507	5.203	**0.001**
Some, but did not complete primary	1.8	1.047	2.959	**0.033**
Completed primary	1.8	1.084	2.958	**0.023**
Completed secondary	1.4	0.864	2.338	0.167
Completed tertiary	Ref			
Employment status				
Paid work (part-time and full-time)	Ref			
Unemployed	1.1	0.253	4.745	0.902
Homemaker	0.9	0.579	1.433	0.686
Retired	1.7	1.175	2.364	**0.004**

Bold font indicates significant *p* values; OR+: +Odds Ratios derived from multiple logistic regression using stepwise method; ^ Ref: Reference.

Table 3.3: The correlation of sociodemographics to OSTA results in Table 3.2 including ρ-values in terms of osteoporosis risk (OR)of significance in bold taken from Wang *et al*,2019.

The sociodemographic associations of osteoporosis are shown in Table 3.3. Multiple logistic regression analysis found that people aged 75-84 with an OR value of 15.6 were more likely to have osteoporosis than people aged 60-74. Due to the small sample size, the OR for individuals aged 85 and up was not calculated. Non-Chinese people were less likely to have osteoporosis than other ethnic groups however the P values would indicate that it is extremely significant in Milaysia and India, and significant in other regions. Osteoporosis is also extremely significant in correlation with subjects without education and who are retired.

	OR+	95% CI		*p* Value
		Lower	Upper	
Hypertension				
No	^ Ref			
Yes	0.6	0.4	0.9	**0.008**
Heart Problems **				
No	Ref			
Yes	0.9	0.6	1.3	0.514
Diabetes				
No	Ref			
Yes	0.6	0.4	0.9	**0.007**
TIAs				
No	Ref			
Yes	0.6	0.2	2.3	0.491
Stroke				
No	Ref			
Yes	0.9	0.5	1.7	0.859
10/66 Dementia				
No	Ref			
Yes	0.9	0.4	2	0.744
Depression ***				
No	Ref			
Yes	0.9	0.6	1.3	0.571

Bold font indicates significant *p* values; OR+: +Odds Ratios derived from multiple logistic regression adjusted for sociodemographic variables; ^ Ref: Reference; TIA: Transient ischaemic attack; ** Heart problems (heart attack, angina, heart failure, valve disease & others); *** Depression (lifetime diagnosis based on respondent/informant self-report).

Table 3.4: The correlation of clinical conditions to OSTA results in Table 3.3 including ρ-values of significance in bold between subjects with high osteoporotic risk, hypertension and diabetes taken from Wang *et al*,2019.

The results show the total incidence of osteoporosis risk among subjects over responders was 52% as seen in Table 3.2 which would support the WHO classification of osteoporosis being a global health concern among the elderly (World Health Organisation, 2023) . Those who were older aged 75-84 years old, Chinese, female, never married or widowed, had a lower education, and were retired had an increased risk of osteoporosis. The increased risk percentage of osteoporosis increased with age among the subjects confirming it is an age-related disease which is significant to this study. Diagnosis of diabetes or hypertension was found to be a risk factor for osteoporosis. The findings identified distinct risk factors for osteoporosis that could be effective in the prevention of osteoporosis and fractures. This information is statically sound and can be classed as significant for the ρ-values in bold where $P < 0.05$. The n-value was 2345 giving an acceptable range to allow for outliers. This study began in 2011 and ran over a seven-year period giving an acceptable run period.

3.1.4 Study by Lips and Van Schoof

In the review article, dietary intake of vitamin D from dairy products reduces the risk of osteoporosis carried out by Polzonetti *et al*., 2020, a clinical trial was analyses which evealuated whether vitamin D supplements can decrease the incidence of fractures. The clinical trials showed a decrease in fracture incidence in paitience that were given vitamin D suppliments.

Patients	Vitamin D Dose	Obtained 25(OH)D nmol/L	Fracture Risk Reduction
3270	800 IU/d	71	Hip: −43%
799	150,000–300,000 IU/yr	Not detected	Fractures: −24%
2686	100,000 IU/4 times per day	74	Non-vertebral fractures: −22%
9605	400 IU/d	47	Non-vertebral fractures: −16%
3195	800 IU/d	75	Fractures: −13%

Table 3.5: Clinical trials carried out by Lips and Van Schoof highlighting the fracture risk reduction when patients were given vitamin D supplementation including the number of patients, vitamin D dose, source and risk reduction percentage taken from the Polzonetti *et al*., 2020.

The results in Table 3.5 show supplementing with vitamin D 25(OH)D enhances BMD, decrease bone turnover, and reduce fracture incidence. Vitamin D dosages may range amongst patients depending on the level of calcium intake as vitamin D is responsible for calcium deposition which is key mineral in bone metabolism and increasing bone mass density leading to a reduction in fracture risk as seen in *Table 3.5*. Vitamin D fortification is most common in dairy products as dairy natural contains calcium which has a symbiotic relationship in the process of increasing bone mass and mineral density. (Polzonetti, et al., 2020).

Osteoporotic fractures are most common in the hip, wrist and spine. As seen Table 3.5 there was a 43% reduction in hip fractures, a site most commonly associated with osteoporotic fractures. This study highlights the importance of vitamin D in increasing BMD and its impact in reducing fractures on osteoporotic sites (Polzonetti, et al., 2020).

The results of this study are statistically sound as there is the n-value (sample size) was 19555 patients which were based. The ages of the subjects in this clinical trial were not defined. The ρ-values (probability of getting the same results based on the null hypothesis being true) was $P < 0.001$ deeming the findings in this study as significant (Polzonetti, et al., 2020).

3.2 Senile Sarcopenia

Protein supplementation has been shown to promote muscular anabolism and function in both young and old people (Hanach, et al., 2019). By having a high protein intake in adolescence, it can lead to being less likely to contract sarcopenia early in the aging process supporting healthy aging by supplying the essential amino acids in deficit as described in section 1.7.2.

Moreover, an increase in protein intake in elderly people has shown to mitigate sarcopenia. Dietary protein increases anabolic activity in skeletal muscle and supplies the amino acids required to drive postprandial muscle protein synthesis. Inadequate protein consumption has been linked to muscle mass loss and impaired physical function in older persons (Hanach, et al., 2019).

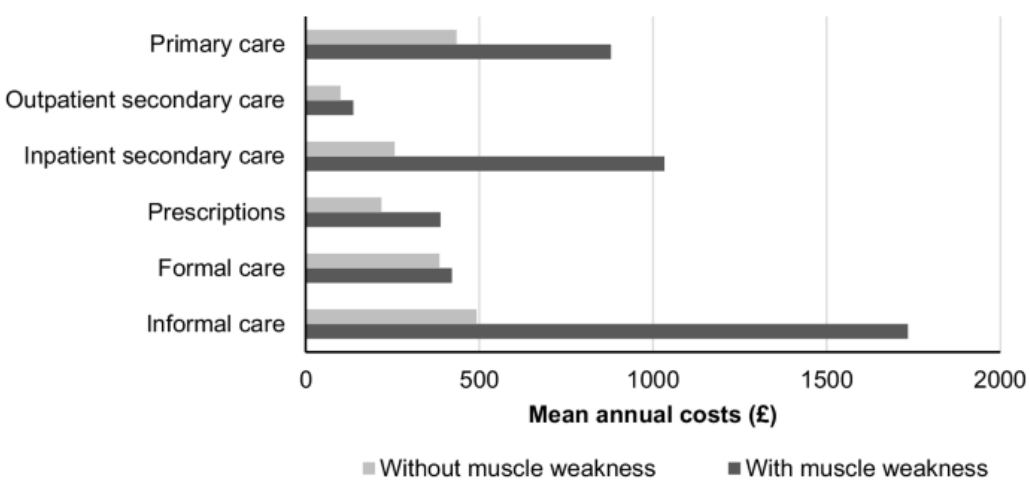
The recommended daily protein intake is currently 0.8 g/kg/day to maintain muscle mass for adults aged 40 to 59, however greater intake is advised to sustain muscle mass and physical function in old age 60 years and onwards (Coelho-Junior, et al., 2022). This guide is based on the concept that aged muscle requires more amino acids to drive muscle protein synthesis in response to hyperaminoacidemia, a phenomenon known as anabolic resistance (Coelho-Junior, et al., 2022).

Failure to appropriately activate muscle protein synthesis leads to progressive loss of muscle mass, primarily of type II muscular fibres, affecting muscle strength development and physical function (Coelho-Junior, et al., 2022) leading to frailty and sarcopenia as mentioned in section 1.7.2. Furthermore, the development of this disease also is associated with a huge economic burden highlight by Pinedo-Villanueva, *et al*., 2019.

3.2.1 Study carried out by Pinedo-Villanueva*, et al*., 2019

A study was carried out by Pinedo-Villanueva, *et al*., 2019 on associated costs with sacropenia and muscle weakness of the elderly in health care. This was a UK based study and the clients inolved were aged from 71-80 years representing an aging cohort. There were 443 patients (n = 443) who agreed to participate in this study. The aim of this study was to highlight the economic burden faced by the patients themselves and their immediate family (Pinedo-Villanueva, et al., 2019).

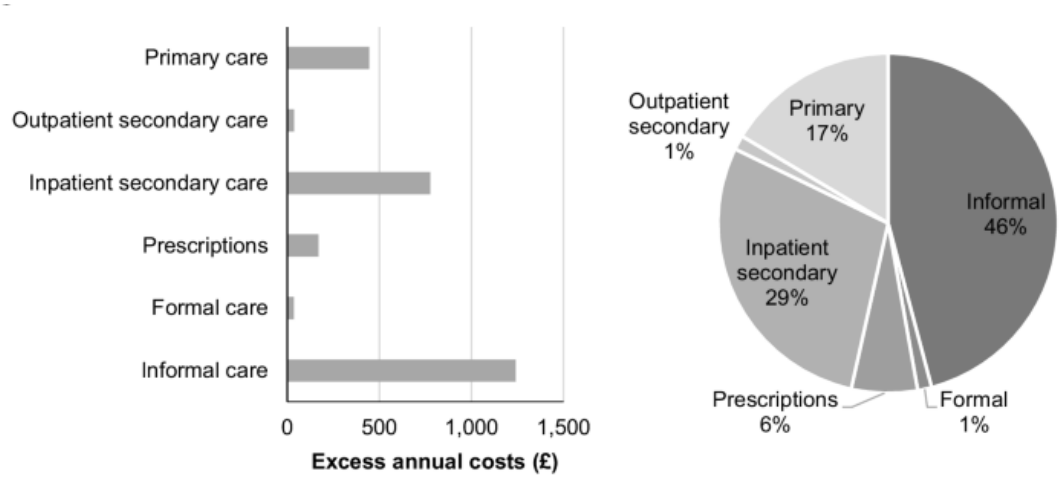
Each participant's costs for primary care consultations and visits, outpatient and inpatient secondary care, drugs, and formal which was paid as well as informal care were analysed. The mean total expenses per person and their associated components were compared in groups with and without muscle weakness to establish a null hypothesis (Pinedo-Villanueva, et al., 2019).



Annual costs per person for different uses of health and social care according to muscle strength. Muscle weakness was defined using low grip strength (< 26 kg for men, < 16 kg for women)

Figure 3.4: Bar chart displaying the costs of patients without muscle weakness (light grey) versus patients with muscles weakness (dark grey) calculated across a range of cares such as primary care, outpatient care, inpatient secondary care, prescriptions, formal care and informal care taken from Pinedo-Villanueva, et al., 2019.

The results from Fig 3.4 show that there is an increases cost across all parameters when the patient has muscle weakness. The most significant cost being informal care. This study indicated that there was a mean increase of 11 % across the board in extra cost associated with must weakness. The mean total costs for participants with muscle weakness equated to £4592 and the mean total cost for participants without muscle weakness equated to £1885.



Excess annual costs per person for individuals with muscle weakness compared to those without and proportion of costs according to types of health and social care. Muscle weakness was defined using low grip strength (< 26 kg for men, < 16 kg for women)

Figure 3.5: Bar chart showing the extra cost incurred by participants with muscle weakness compared to participants without muscle weakness. The pie chart displaying the related types of care broken down by percentages. Charts taken from Pinedo-Villanueva, et al., 2019.

The evidence in Fig 3.5 shows that a person with muscle weakness pays £2707 per person/year more than a person sarcopenia free with informal care costs accounting for 46% of the difference. Based on these figures, Pinedo-Villanueva, et al., 2019 estimated that there is an extra £2.5 billion extra spent a year on health care by individuals with sarcopnia (Pinedo-Villanueva, et al., 2019).

The evaluation of paticipants paying £2707 per person/year more is statically sound and can be deemed significant as the corresponding p-value was $p < 0.001$. Costs were calculated using data from the British National Health Service and official publication of Unit Costs of Health and Social Care. A screening process was used to reach the final sample size, starting with 2997 participants. Following analysis of dual-energy X-ray absorptiometry (DXA) scan 642 people were recruited and 443 agreed to join the study (Pinedo-Villanueva, et al., 2019).

3.2.2 Dairy and Sarcopenia

Dairy products are a source of high-quality protein, predominantly in the form of whey or casein as established in section 1.1. These dairy proteins are widely available across the globe often in the form of isolates and concentrates in powdered format. When compared to other protein-rich foods such as lean meat, chicken, fish, and eggs, dairy products, especially milk-protein supplements, do not require cooking or require relatively minor preparation. As a result, dairy products are a viable option for older persons seeking appropriate protein intake (Hanach, et al., 2019).

Several studies have shown that 1.2-1.5 g/kg body weight/day WPI combined with resistance training improves muscle mass, performance, and function in older persons with an average requirement of 90g/day (Jin Jang, 2022). Furthermore, according to the World Health Organization, the daily requirement of branched chain amino acids (BCAA) for a healthy adult is 39 mg/kg of body weight for leucine, 20 mg/kg for isoleucine, and 26 mg/kg for valine for the older population (Rondanelli, et al., 2020).

Whey protein found in dairy products is high in leucine and can help minimize sarcopenia. Protein leucine content and necessary amino acids are crucial factors in preventing sarcopenia (Martínez-Arnau, et al., 2019), as described in 1.7.2, low leucine levels are a metabolic indicator in sarcopenia. Low vitamin D levels are linked to decreased muscle mass and poor physical performance. The effects of combining leucine and protein, as well as vitamin D, have been studied. In sarcopenic older individuals, vitamin D in addition to leucine-rich whey protein improves lean body composition and muscle function (Jin Jang, 2023) as they prevent inflammation, increase protein regeneration and decrease protein lysis as described in section 1.7.2 (El-Sebaie & Elwakil, 2023). Furthermore, leucine can stimulate insulin release through pancreatic cells, indicating that, in addition to improving skeletal muscle glucose absorption, it is an important anabolic signal in skeletal muscle (Martínez-Arnau, et al., 2019).

3.2.3 Study by Hanach, et al., 2019

In the study carried out by Hanach, et al., 2019, The Impact of Dairy Protein Intake on Muscle Mass, Muscle Strength, and Physical Performance in Middle-Aged to Older Adults with or without Existing Sarcopenia: A Systematic Review and Meta-Analysis was investigated. As sarcopenia is an age-related disease associated with progressive muscle and strength loss, protein supplementation is required to improve muscle anabolism in both middle aged and older adults. This paper reviews the effectiveness of dairy proteins in particular on functions associated with sarcopenia in middle aged and older adults aged 61 to 81 years (Hanach, et al., 2019).

For this study PubMed, CINAHL/EBSCO, and Web of Science databases were used to source randomised control trials. Each study was evaluated and the last search was carried out on the 10th of May 2017. A random-effects model was used to pool the findings of appendicular muscle mass and muscle strength of handgrip and leg press. The Short Physical Performance Battery (SPPB) was assessed also (Hanach, et al., 2019).

The SPPB is a typical physical performance assessment that evaluates an individual's balance, strength, gait, and endurance. The score is obtained by adding the results of three equally weighted tests. Secondary outcomes were adverse events and the tolerance of dairy protein supplementation. The inclusion criteria were met by 14 studies including 1424 adults (Hanach, et al., 2019).

Study (ref)	Region	Study Period	Age	Subject	Sex	Health status	Type of protein	Total protein	Measured outcomes
Aleman-Maeto et al,2017	Mexico	3 mo	> 60	40	F, M	Sarcopenic	Ricotta cheese	1 5.7 g/d	AMM; MS of handgrip; AES
Bauer et al,2015	Germany	13 wk	≥65	380	F, M	Sarcopenic, limited mobility	Whey protein	40 g/d	AMM, MS of handgrip, SPPB
Rondanelli et al,2016	United States	12 wk	≥65	130	F, M	Sarcopenic	Whey protein	22 g/d	MS of handgrip
Björkman et al,2011	Finland	20 wk	50	46	F, M	Polymyalgia	Whey protein	14 g/d	AMM, MS of handgrip
Tieland et al,2012	Netherlands	24 wk	≥65	65	F, M	Frail	MIPC	30 g/d	AMM; MS of handgrip; MS of le press; SPPB,AE
Chalé et al,2012	United States	6 mo	70-85	67	F, M	Limited mobility	Whey protein	40 g/d	MS of leg press
Aleman-Maeto et al,2014	Mexico	3 mo	> 60	90	F, M	Healthy	Ricotta cheese	15.7 g/d	AMM; MS of handgrip; SPPB, AE
Arnarson et al,2013	Iceland	12 wk	65-91	141	F, M	Healthy	Whey protein	20 g/d	AMM
Verreijen et al,2015	Netherlands	13 wk	>55	65	F, M	Obese	Whey protein	20-40 g/d	AMM; MS of handgrip
Karelis et al,2015	Canada	135d	65-88	80	F, M	Healthy	Cystene-nc whey protein	20 g/d	MS of leg press
Zhu et al, 2015	Australia	2 Y	70-80	181	F	Healthy	Skim milk-based high protein	30 g/d	AMM; MS of handgrip
Leenders et al,2013	Netherlands	24 wk	70± 1	57	F, M	Healthy	MIPC	15 g/	MS of leg press
Verdijk et al,2009	United States	12 wk	72 ±2	28	F, M	Healthy	Casein hydrolysate	20 g/d	MS of leg press
Norton et al, 2016	Ireland	24 wk	45-60	60	F, M	Healthy	milk-based protein matrix	0.33 g/kg	AMM

AE: Adverse Event, AMM: Appendicular Muscle Mass, MPC: Milk-Protein Concentrate, MS: Muscle Strength, NA: Not Available, RT: Resistance Training,SPPB: Short Physical Performance Battery

Table 3.6: Studies used from PubMed, CINAHL/EBSCO, and Web of Science databases characterised by region, study duration, age, subjects, sex, health status and protein adapted from Hanach, et al., 2019.

The following results were found based on the evidence supplied from table 3.6 which were dairy protein increased appendicular muscle mass giving a $P<0.05$ which can be deemed of significance among older people. Alternatively, the results were not consistent enough to show an increase in hand grip strength at $P = 0.13$ and similarly the leg press was inconclusive also ($P = 0.89$). The effect of dairy protein on short physical battery was inconclusive also. Nine out of the fourteen studies reported dairy protein to have no side effects (Hanach, et al., 2019).

The studies ranged from ranged from 12 weeks to two years. The age range was 61 years and upwards with the majority of participants over 65 giving a fair representation of an aging population. Male and females participated in all testing bar 1 study show no bias towards sex. Nine different regions were used giving moderate regional distribution.

Fermented dairy was used across the board therefore fermented dairy is responsible for the increase in muscle mass. The specific dairy protein responsible requires further study as there was whey protein, Ricotta cheese, MPC and casein hydrolysate used in this review.

3.2.4 Study by Yongsoon *et al,* 2018

The study carried out by Yongsoon *et al*, 2018 investigated the effectiveness of protein as a nutrition dairy whey supplement to decrease frailty in the elderly with sarcopenia. This study took place over a 12-week period involving 120 elderly patients aged 70-85 years of age who met the frailty criteria from the mini nutrient assessment (MNA) scoring (≤23.5) (Yongsoon, et al., 2018).

The MNA nutritional assessment tool that has been verified. Anthropometric measurements, general assessments, and dietary questionnaires are all part of the MNA. An electronic cales is used to measure body weight in kg to one decimal place. An extensometer was used to measure height in centimetre. Arm size was measured using a tape on the non-dominant, relaxed bicep. The non dominant calf was measured using a tape also while the muscle was relaxed (Yongsoon, et al., 2018).

Cardiovascular Health Study (CHS) frailty criteria was required in the screening process also. Prefrailty and frailty were characterized as meeting the modified CHS frailty criteria ≥1 and ≥3, respectively. Unintentional decrease in weight of more than 4.5 kg in the previous year, tiredness, poor physical activity and slowness were among the criteria. The protein powder had 0.2 g of cocoa powder, 0.5 g of fat and 9.3 g of whey protein per 10g pack, while placebo powder had 0.2 g of cocoa powder, 0.5 g of fat and 9.3 g maltodextrin per 10g pack (Yongsoon, et al., 2018)

With hidden allocation and intention-to-treat analysis, participants were randomly assigned to one of three groups: 0.8, 1.2, or 1.5 g protein /kg/day. This study was dose dependant with a focus on appendicular skeletal muscle mass (ASM) and skeletal muscle mass index (SMI) measured by dual-energy X-ray absorptiometry (Yongsoon, et al., 2018). SMI came in four varieties:

ASM adjusted for height $= \left(\frac{ASM(kgs)}{Height(m)^2}\right)$

ASM adjusted for weight height $= \left(\frac{ASM(kgs)}{Weight(kgs)}\right) x\ 100$

ASM adjusted for Body Mass Index (BMI) = $\left(\frac{ASM(kgs)}{BMI(kg/m^2)}\right)$

Ratio of skeletal muscle to body fat= ASM adjusted for body fat mass (kg)

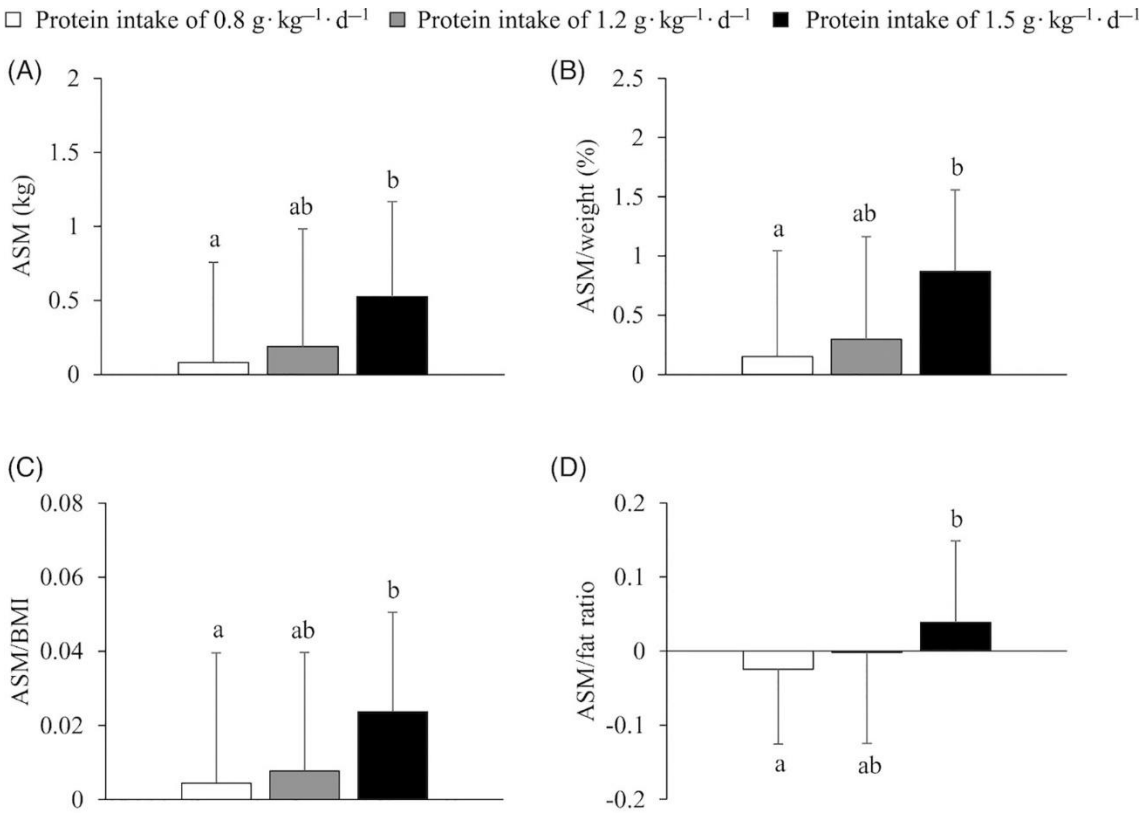


Figure 3.6: ASM and SMI indicators: ASM/weight, ASM/BMI, and ASM:Fat ratio**,** in the 0.8-, 1.2-, and 1.5-g protein groups. Values are means ± SDs; n = 120 (40/group). Different letters indicate a statistically significant difference between the 3 groups ($P < 0.05$). Data showing the effectiveness of whey peptide supplementation taken from Yongsoon *et al*, 2018.

Following the 12-week period it was shown that the 1.5-g protein group had a greater ASM and SMI values across the range of tests then the 0.8-g and 1.2-g groups. This data is significant as $P \leq 0.039$ for all tests indicating dairy whey protein intake of 1.5 g/ kg/ day has the most benefit in terms of preventing sarcopenia and frailty which can be seen in Fig 3.6. This study shows that the optimum dairy whey protein intake is 1.5 g/kg/day to increase ASM and SMI to decrease frailty among elderly subjects aged 70-85 years with sarcopenia. The use of a placebo in this study increases credibility as it allows for a comparison. The subjects tested were from Korea which is an example of a developing region with an aging population.

3.3 Biochemical Changes in Cognitive Decline

Cognitive decline and dementia are becoming a growing burden not just on patients and their families, but also on national health care systems however there are very few studies with a quantitate figure. According to recent epidemiological studies, consuming specific dairy products lessens the incidence of cognitive decline in the elderly and may even prevent Alzheimer's disease (Ano, et al., 2018). Alzheimer disease (AD) is defined neuropathologically by abnormal extra-cellular β-amyloid plaques combined with intraneuronal tau aggregation (Migliaccio & Cacciamani, 2022).

Several mechanisms, ranging from trans neuronal dissemination of misfolded proteins to metabolic needs in coactive areas, to shared nodal vulnerability or trophic failure, have been proposed to explain degenerative patterns within selectively sensitive neural networks. Although clinicopathologic connections corroborate these pathways, they do not fully account for temporal fluctuations in dynamic brain states as contributors to symptoms and pathologic development in AD (Karageorgiou & Vossel, 2017).

Blood-brain barrier breakdown degradation is linked to faster cognitive deterioration. Cell adhesion, neutrophil migration, lipid metabolism, and angiogenesis are all possible inflammatory processes leading to oxidative stress causing dementia and AD (Bowman, et al., 2018). Oxidative stress is as an excess of reactive oxygen species generation and/or a decrease in antioxidant generation, resulting in pathophysiological changes related to the general adaptation syndrome of cellular stressors. Three primary natural occurring antioxidants are glutathione, superoxide dismutase, and catalase which were discussed in section 1.7.3 (Lane, et al., 2023).

In most observational research, epidemiological data suggests that dietary intake of single nutrients such as antioxidants (carotenoids, C, and E), B vitamins (B9, B6, B12), and long chain n-3 fatty acids is related with decreased cognitive decline (Prinelli, et al., 2019)

3.3.1 Dairy and Cognitive Decline

Milk and dairy products are a critical part of the human diet because they contain higher biological value proteins particularly whey, acids, amino acids, calcium, essential fatty fat, water soluble vitamins, and several bioactive peptides that are important for several biochemical and physiological functions, particularly reducing oxidative stress due to the level of antioxidants they contain. Milk and milk products' antioxidant capacity is primarily due to its high amino acids content which include cysteine, phosphate, vitamins A, E, carotenoids, zinc, selenium, enzyme systems such as superoxide dismutase, catalase, glutathione peroxidase, milk oligosaccharides, and peptides produced during fermentation (Khan, et al., 2019).

Whey protein specifically in dairy has been proven to improve memory function. In a study carried out by Ano *et al*,2019 on mice, it was found the peptides containing (tryptophan-tyrosine) WY suppressed monoamine oxidase-B activity and boosted dopamine levels in brain tissue. Pretreatment with a dopamine receptor antagonist prevented the WY-containing peptides from improving memory performance. These findings imply that WY-containing peptides in fermented dairy products raise monoamine levels via blocking monoamine oxidase-B activity, hence aiding in the prevention of age-related cognitive decline.

Whey proteins are commonly traded as a variety of protein-rich components, including whey protein concentrate (35% to over 80% protein), whey protein isolate (over 90% protein), and refined specific protein fractions such as B-Lactoglobulin (98% protein) (Sharma, 2019).

3.3.2 Clinical Trial carried out by Kita, *et al*., 2019

In this study, the objective of Kita, *et al*., 2019, Supplementation With Whey Peptide Rich in β-Lactolin Improves Cognitive Performance in Healthy Older Adults: A Randomized, Double-Blind, Placebo-Controlled Study was investigated. A similar study has already been complete however it was carried out using mice which came back

positive allowing progression to human trails. This trial was a randomized, double-blinded, placebo-controlled trial.

104 Japanese people took part in this clinical trial (N=104) aged between 50 and 75 representing an elderly population. These people have self- diagnosed cognitive decline displaying traits such as forgetfulness and carelessness. Subjects with relatively low scores in repeatable battery tests of neuropsychological status (RBANS) were preferentially included.

For 12 weeks, participants were given either the whey peptide tablet containing 1 g of whey peptide, 1.6 mg of β-lactopeptide of glycine-threonine-tryptophan-tyrosine (GTWY), β-lactolin or a placebo, and changes in cognitive function were measured using neuropsychological tests at weeks 0, 6, and 12. Neuropsychological exams included memory function assessments, attention function assessments, and general cognitive function assessments. After 6 weeks of treatments, cerebral blood flow was also measured using near-infrared spectroscopy (NIRS).
(Kita, et al., 2019)

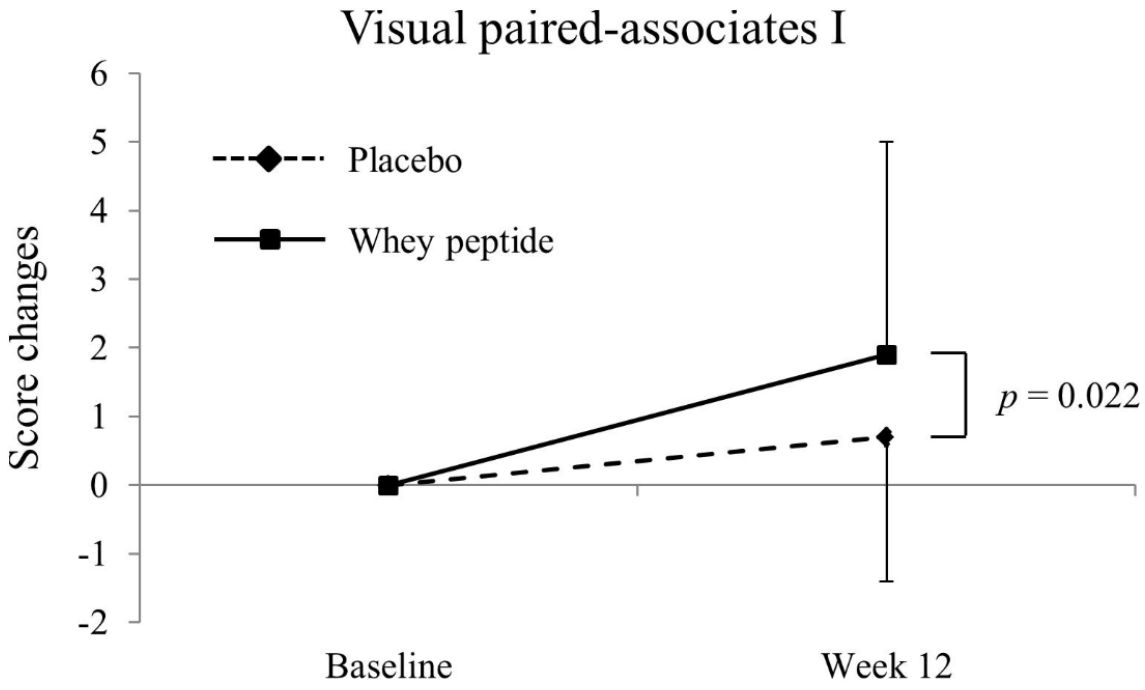


Figure 3.7: Comparison between subjects who received the placebo versus subjects who received the whey peptide supplement showing an increase in cognitive score with those who received whey peptides. Dotted line represents placebo subjects (n = 53) and the full line represents the whey peptide subjects (n = 51). Data was calculated using a mean and standard deviation value taken from Kita, *et al*., 2019.

The test conducted was a memory test where the subjects were shown 32 unfimilar faces from The Karolinska Directed Emotional Faces data base. In the recognition stage of this test subjects were shown the 32 faces they saw previosly along with 32 new distractor faces. Each face they guessed correctly and incorrectly was recorded (Kita, *et al*., 2019). The test tablets containing 1 g of whey peptide, which included 1.6 mg of β-lactopeptide of GTWY, β-lactolin showed significant imporvement in memory which can be seen in Fig 3.7.

This data is significant with a P value of 0.022 which is less that 0.05. The applicants went through a screening process where 294 applicants took part in of which 138 were accepted. Candidates were then excluded from the study if there was any new found information or daviation to reach the sampl size of 104. A placebo was used in this blind

test made to the same shap and sixe to the whey tablet so clients were unaware if they had th suppliment or not.

3.3.3 Canadian Longitudinal Study by Tessier, *et al*., 2021

In the study by Tessier, *et al*., 2021, Dairy products such as milk, cheese and yoghurt were tested to see if there was a positive correlation with cognitive executive functions (outlined in section 1.7.3) in older adults aged 68-86 in this Canadian longitudinal study with an emphasis on providing nutrients such as calcium and vitamins B12 and D, and include bioactive peptides and fermented products (Tessier, et al., 2021).

Three cognitive domains were tested in this study which were executive functions, memory, and psychomotor speed. Executive function was assessed using using verbal fluency tests which were the Animal Fluency Test and the sum of the Controlled Oral Word Association Test of the letters F, A, and S. This study took place from 2011 to 2015. A food frequency questionnaire was used to evaluate the frequency of consumption of cheese, milk, yogurt, regular-fat, low-fat, and fermented dairy products; participants were divided into quartiles. To estimate differences, multivariate analyses of covariance models were used (Tessier, et al., 2021).

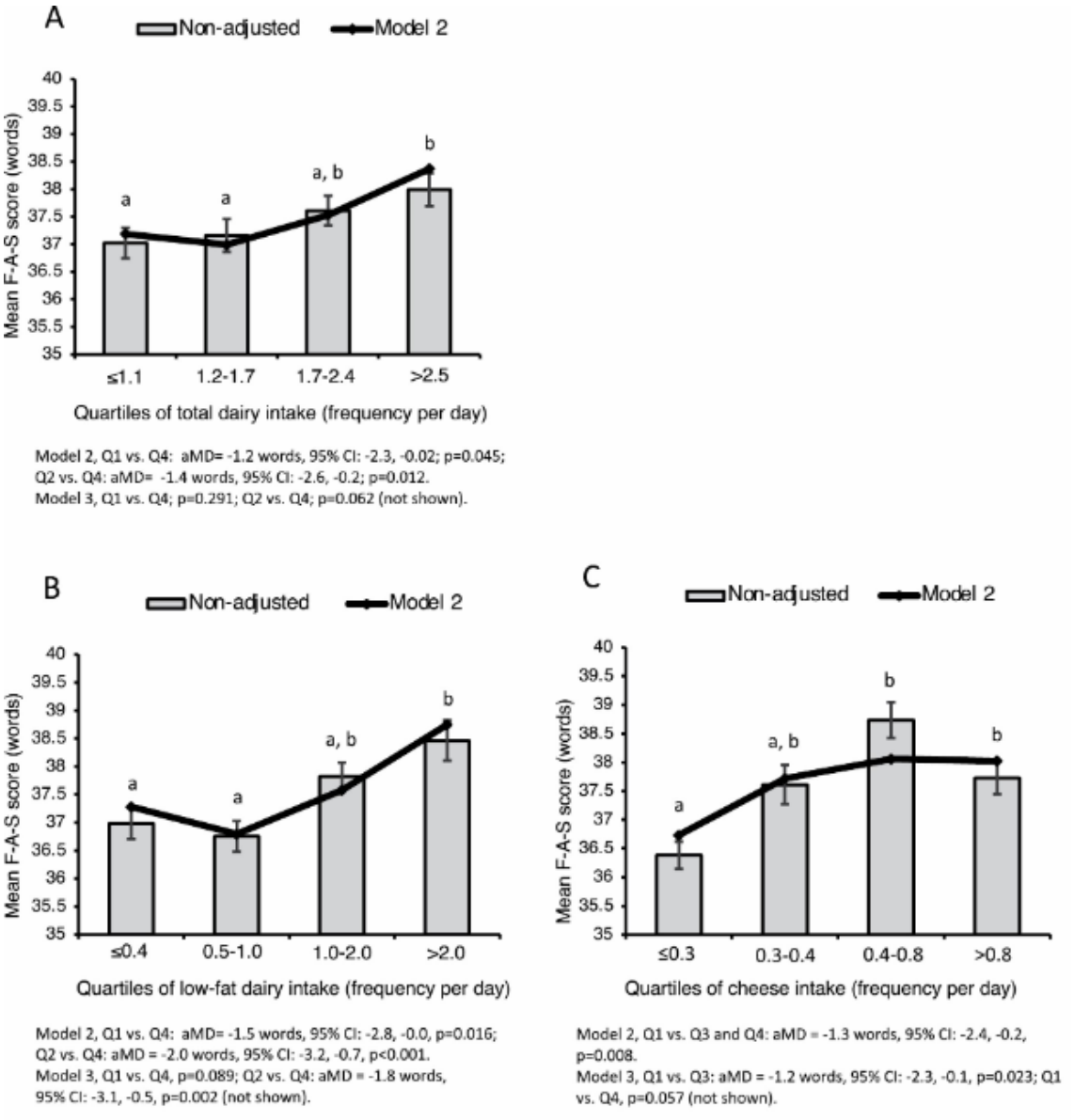


Figure 3.8: Bar charts displaying executive function where bye the F-A-S executive function test score is plotted against the dairy consumption groupings. Chart A represents total dairy intake, chart B represents low fat dairy intake and chart C represents cheese intake. aMD = adjusted mean difference; CLSA = Canadian Longitudinal Study on Aging; COWAT = Controlled Oral Word Association Test. Data taken from Tessier, *et al*., 2021.

In this study 7945 people took part (n=7945). Participants were aged 68-86 years of age representing an older Canadian population and the 49% of these people were women providing an acceptable man: women ratio. Subjects were divided based on their dairy consumption (Q1: ≤ 1.1 times/d, Q2: 1.2–1.7 times/d, Q3: 1.7–2.4 times/d, Q4: > 2.5

times/d) for total dairy intake. When segregated for specific dairy products, 4 groups were made based on the amount that products were consumed daily. For the memory and executive function domains, multivariate analysis of covariance (MANCOVA) was used, while for the psychomotor speed test, univariate 1-way analysis of covariance (ANCOVA) was used.

Total dairy product, cheese, and low-fat dairy product intake were all positively correlated with executive function testing which can be seen in Fig 3.8. This is due to a higher F-A-S score and yogurt intake with memory testing showing a p- value of less than 0.05, irrespective of age, gender, education, or diet quality. Total dairy product, cheese, and low-fat dairy product consumption were all linked with verbal fluency ($p < 0.05$). Participants who consumed dairy products more than 2.5 times per day scored higher than those who consumed less. There were no connections detected with psychomotor speed. This study was conducted over a 4 period and subjects were screened following their application to avoid anyone already diagnosed with a disease or medical condition. This study was supported and approved by McGill University Research Ethics Board (Tessier, et al., 2021).

3.3.4 African Longitudinal Study by Bassil, et al., 2022.

The Health and Aging in Africa Longitudinal Study of an In-depth (HAALSI) Dementia study was begun its second wave of cognitive testing in 2019 to investigate the prevalence, incidence, and risk factors of cognitive decline and dementia in South Africa, in light of the expected rise in dementia burden in Sub-Saharan Africa. See results of previous first wave of this study (Kobayashi, et al., 2019) :

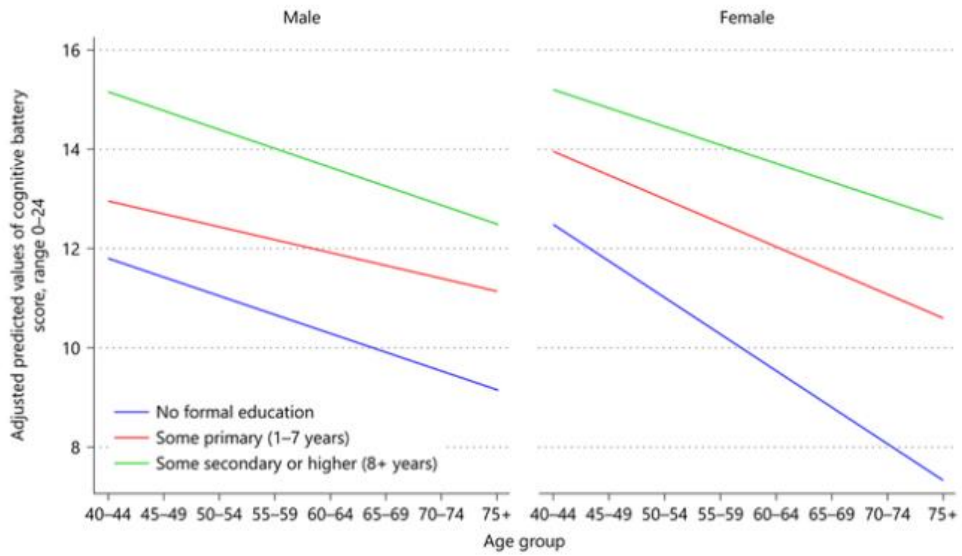


Figure 3.9: Line chart male versus female where the cognitive battery score is plotted against age taken from Kobayashi, et al., 2019.

The results in Fig 3.9 show a decline in in cognitive battery score as age increases in Sub Saharan Africia in 2019 investigated by Kobayashi, et al. the current study is the follow-up of the data obtained from 2019.

The rationale behind this study was that Sub Saharan Africa has a rapidly aging population (over 60) and is estimated to have 3.5 million people suffering from dementia by 2030. This figure is predicted to increase to 7.6 million by 2050 however there is very few population-based studies in recent times (Bassil, et al., 2022) .

The primary goal of HAALSI Dementia is to determine the incidence and prevalence of dementia, particularly Alzheimer's Disease and Related Dementias (ADRD), as well as biological and social correlates, determinants, and risk factors connected to age-related cognitive decline and dementia in a population-based cohort of Agincourt, South African, older adults (Bassil, et al., 2022) .

The sample contained 635 participants who where more than 50 years old. Diagnostic protocols 10/66 and Harmonized Cognitive Assessment Protocol (HCAP) were used to assess acute dementia in this study. Subjects were grouped according to risk of dementia: lowest risk, low risk, moderate risk, highest risk and participants who required a proxy in HAALSI main. All study components were completed by 582 participants in total which included cognitive battery, informant interview, and neurological testing. The other 53 participants had incomplete data; four did not complete the cognitive battery, four did not have an informant accessible, 44 refused the neurological evaluation, and one did not complete both the informant and the neurological examination.

The key findings of this report are as follows: of the participants tested, the average age of participants was 69.87. Sixty-two percent of participants were women of which 40% were married and 43% were widowed. Eighty-seven percent of the total cohort were unemployed and 55% were without formal education. According to vision tests, more than 90% of individuals had impaired vision. The mean IQCODE score was 3.3 (SD = 0.44), with 6% and 20% of individuals reporting impairment in at least one ADL and 20% reporting impairment in at least one IADL, respectively. The prevalence of cognitive impairment was around 8%, increasing with age to 24% in people aged 75 and up. The information from this study will be used to investigate the relationship between magnetic resonance imaging (MRI) scan results of the participants and the diagnostic outcomes (Bassil, et al., 2022).

This study is of significance because a multidisciplinary panel were assembled of expert US and South African neurologists, neuropsychologists, and geriatricians with clinical and research experience in dementia to assign dementia diagnoses based on neuropsychological, neurological, and informant data to improve diagnostic reliability and accuracy in the sample. Also, this study was sanctioned by the University of the Witwatersrand Human Research Ethics Committee, Harvard T.H. Chan School of Public Health Institutional Research Ethics Board and Mpumalanga Provincial Research and Ethics Committee to ensure its validity. The first wave of this study began in 2014 addressing cognitive decline in Africa which provided a base for the ongoing research. One observation from this study is that there were no p-values given with the

corresponding data perhaps because hypothesis testing is based on assumption whether it is known there is cognitive decline in Africa (Bassil, et al., 2022).

3.3.5 A Study by Villoz et al,2023

In the study by Villoz, et al., 2023, dairy intake and risk of cognitive decline and dementia: A systematic review and dose-response meta-analysis of prospective studies was investigated. Due to conflicting literature in previous years, this paper wanted to clearly define the relationship with dairy, aging and cognitive decline with a focus on incidence of dimentia. Embase, Medline, Cochrane Library, Web of Science, and Google Scholar databases were used for prospective studies with a 6-month follow-up on cognitive decline or dementia incidence in older individuals without known chronic illnesses from inception to July 11, 2023. A random-effects model was used to assess the dose-response relationship. The review protocol was aligned and registered with the International Prospective Register of Systematic Reviews (PROSPERO) (Villoz, et al., 2023).

Initially 3663 records were found and following the PRISMA screening process, 15 cohort studies were identified including 312,580 subjects (n=312,580). The mean age of participants ranged from 53 – 91 years. Seven studies were based in Europe, six studies were based in Asia, one study from Australia and one from the USA. The follow up period carried out by these studies ranged from 4.8-30 years with a mean average of 11.4 years. Five studies included dementia incidence outcome using ICD 8-10 or DSM-IIIR/DSM-IV criteria. The majority of studies evaluated cognitive function using mini mental state examination testing and the remainder used neuropsychological tests. Two research only looked at milk intake and one looked at cheese intake, the majority of studies looked at total dairy intake (Villoz, et al., 2023).

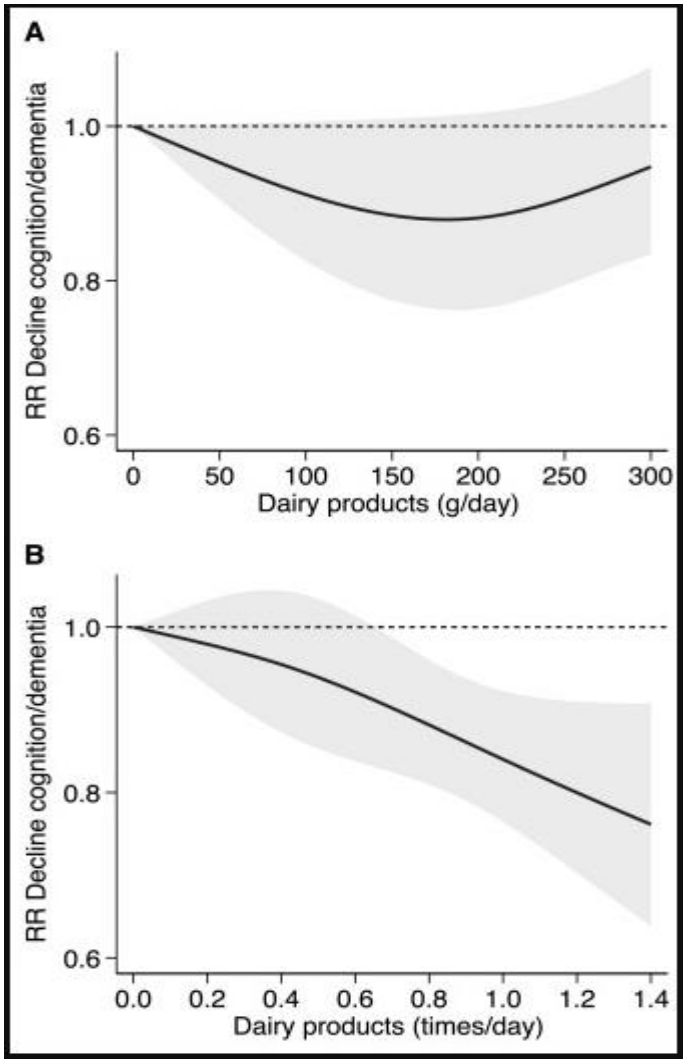


Figure 3.10: Graph A is a dose response analysis where the RR Decline cognition/dementia is plotted against the grams/day of dairy consumed which included 6 studies representing Asia (3 studies) and Europe (3 studies). Graph B shows the RR Decline cognition/dementia plotted against of consumption of dairy products in times/day from 5 studies from regions Europe (2 studies) and Asia (3 studies). Both graphs taken from Villoz, et al., 2023.

In Fig 3.10 A there is a non linear associattion between consupmtion and relaitive risk of cognitive decline and dimentia until 150g/day and then a incline be seen at a 95% CI when the daily intake in grams is increased. In Fig 3.10 B there was an alomost linear negative association between increasing dairy intake and RR coggnition/dimentia.

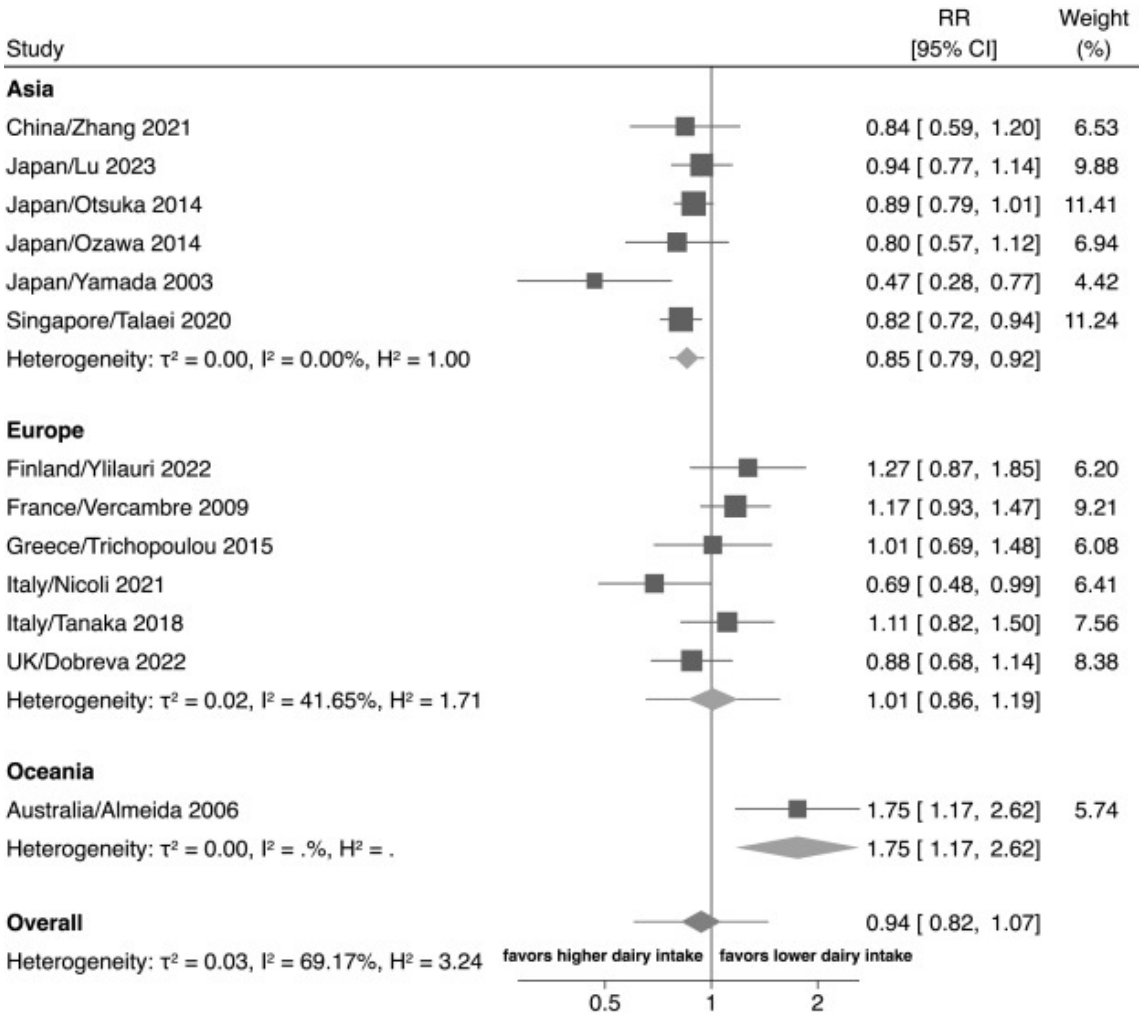


Figure 3.11: Forest plot displaying meta-analysis of dairy intake and cognition differentiated by geographical location illustrating the highest versus lowest exposure. RR and CI are shown. Each grey square's area is equivalent to the inverse of the variance of the estimated log RR (i.e. weight in%), and the horizontal line represents the 95% CI of each individual study. The grey diamonds' vertical axis reflects the point estimate of the overall RR, while the horizontal line represents the 95% prediction confidence intervals (CIs). RR=1 is represented by the solid vertical line.

From Fig 3.11, it can be seen In Asian studies, the highest dairy intake was associated with a lower risk of cognitive decline or dementia compared to the lowest dairy intake. In contrast, there was no link between dairy and cognitive decline or incident dementia in European studies, although there was a higher risk with the greatest dairy intake compared to the lowest dairy intake in a single study from Oceania. However overall, the study favours higher dairy intake.

In summary this study showed a negative non-linear association between cognitive decline/dementia incidence and dairy intake as measured by quantity consumed, with the lowest point at around 150 g/day. There was also an almost linear negative association when frequency of consumption was considered and cognitive decline/dementia risk. The negative correlation was limited to Asian populations with relatively lower dairy product use, as opposed to the null association observed by European studies.

This study is statistically sound due to the screening process at the beginning where 3664 studies were identified and on 15 were deemed relevant. There was an acceptable sample size and follow through as mentioned previously. An acceptable geographical spread was used based on 4 major regions. The NUQUEST assessment revealed that 14 out of the 15 papers used were rated “good “in the nutrition domain. The age profile was representative of an aging population.

3.4 Dairy Product Tailored for Healthy Aging

From the findings of studies reviewed, the dairy product needs to contain vitamin D to mitagate osteoprosis by increasing bone mineral density as well as other key dairy nutrients such as calcium, phosphorus and potassium. The product must contain good quality protein such as whey protein to increase muscle mass and minize sacopenia. Whey peptides must be included to reduce oxidateive stress and combat cognitive decline, which is most prevelnt in Africa which will account for the majority of the aging population by 2050. In this section an Irish whey proetin isolate powder will be examined in relation to its ability to supply the required nutrienets to the global health concerns mentioned.

The cost of producing 1 tonne of whey protein isolate powder to the dairy manufacturer is €6600/tonne which equates to €6.60/kg including packaing (25kg bag) (Tipperary Co-Operative Creamery, 2023). This price – the cost of manufacture-includes raw material, milk cost, energy costs associated with processing including pausterisation, separation, membrane filtration and spray drying, as well as labour costs.

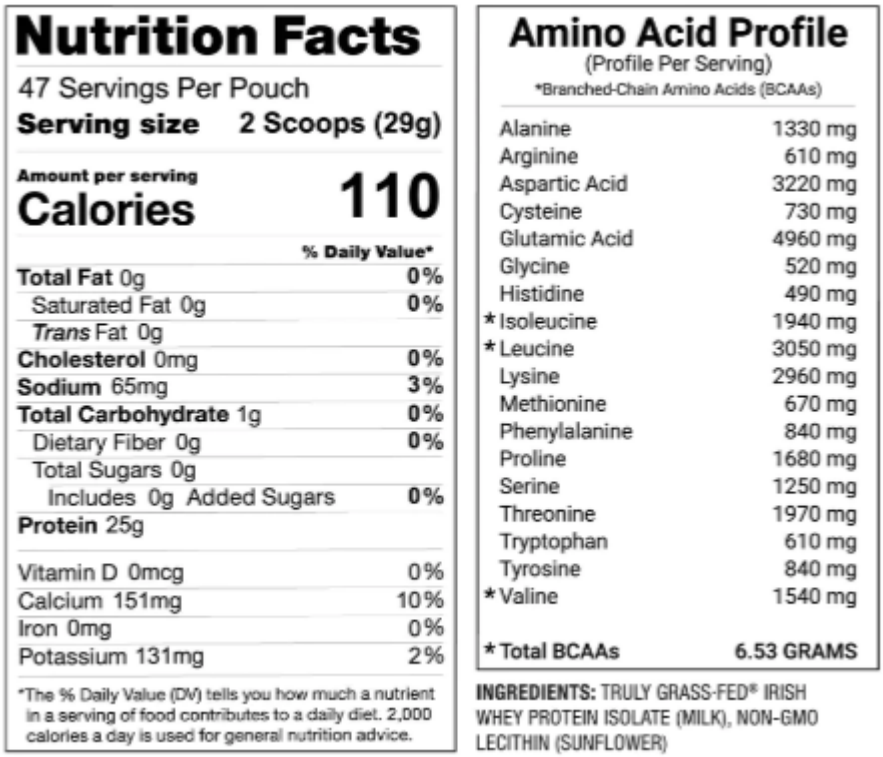
Retail prices in the market place for WPI have been reported by the company AGN Roots, who produce an Irish Grass-Fed Whey protein Isolate with a retail price of €57.95 for a 1361g bag (AGN Roots, 2023). This equates to €42.43/kg of unflavoured WPI made from Irish milk.There is a huge margin made between manufacture(Tipperary Co-Op) and reatil (AGN Roots Brand) making this powder unnaffordable for developing regions such as Africa. See below profit margin percentage made by AGN roots on their WPI.

$$Profit\ margin = \frac{Profit}{Cost\ Price}\ x\ 100 = \%$$

$$Profit\ margin = \frac{(42.43 - 6.6)}{6.6}\ x\ 100 = 543\%$$

There are additional costs associted with getting a product to a region like Africa such as transport. To ship a 40ft container to south Africa from the UK, it costs almost €11,000 (£9,290) which can hold up to 25 tonnes of powder equating to 44c/kg (Comparemymove, 2023). At this price, this product would require a government subsidy for a developing region like Africa, however the nutrient profile of the product could be extremely benificial not only to one region but to all 3 morbidities associated with aging.Governmental intervention is not uncommon as seen in Mexico where the Mexican Government provided a cash tranfer to families in order to increase purchasing powder allowing them to pay for health care and nutrition. Included was fortified whole milk suppliments to adress micronutrient dificiencies and anemia (Lynnette M, et al., 2019)

3.4.1 Nutrient Analysis of Natural WPI



Nutrition Facts

47 Servings Per Pouch

Serving size 2 Scoops (29g)

Amount per serving	
Calories	**110**
	% Daily Value*
Total Fat 0g	**0%**
Saturated Fat 0g	**0%**
Trans Fat 0g	
Cholesterol 0mg	**0%**
Sodium 65mg	**3%**
Total Carbohydrate 1g	**0%**
Dietary Fiber 0g	**0%**
Total Sugars 0g	
Includes 0g Added Sugars	**0%**
Protein 25g	
Vitamin D 0mcg	0%
Calcium 151mg	10%
Iron 0mg	0%
Potassium 131mg	2%

*The % Daily Value (DV) tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.

Amino Acid Profile

(Profile Per Serving)

*Branched-Chain Amino Acids (BCAAs)

Alanine	1330 mg
Arginine	610 mg
Aspartic Acid	3220 mg
Cysteine	730 mg
Glutamic Acid	4960 mg
Glycine	520 mg
Histidine	490 mg
* Isoleucine	1940 mg
* Leucine	3050 mg
Lysine	2960 mg
Methionine	670 mg
Phenylalanine	840 mg
Proline	1680 mg
Serine	1250 mg
Threonine	1970 mg
Tryptophan	610 mg
Tyrosine	840 mg
* Valine	1540 mg
*** Total BCAAs**	**6.53 GRAMS**

INGREDIENTS: TRULY GRASS-FED® IRISH WHEY PROTEIN ISOLATE (MILK), NON-GMO LECITHIN (SUNFLOWER)

Figure 3.12: Nutritional content of a whey protein isolate powder made from Irish grass-fed milk produced by AGN Roots per 29g serving taken from AGN Roots, 2023.

The label displayed in Fig 3.12 shows the nutritional content of a whey protein isolate powder made by AGN Roots representing a natural WPI. Lecithin is commonly used throughout the dairy industry as an emulsifier in whey powders for stability, most commonly in the infant formula sector for the fortification of essential nutrients such as vitamin D (Ma, et al., 2023). While the nutrient content of natural WPI may not meet the full requirement of the daily nutrients needed by the elderly to mitigate the 3 morbidities identified, it has the potential to be fortified. See below table for a comparison.

Source	Nutrient	Form	Value/kg	RDI for Age Related Illnesses/g	Natural WPI/90G	Fortification Required to Meet RDA/kg	Price/kg
(Polzonetti, et al., 2020)	Vitamin D	Vitamin D^	€ 3.38	10 ug/day		0.00001	€ 0.000003
(International Osteoporosis Foundation, 2023)	Calcium	Calcium Carbonate^	€ 0.38	1.1	0.47	7.02	€ 0.24
(National Institues of Health, 2021)	Potassium	Potassium Carbonate^	€ 1.12	3.4	0.41	33.26	€ 3.35
(Hejazi, et al., 2020).	Phosphorus	Phosphate salt^	€ 1.12	0.7	0.42	3.16	€ 0.32
(Jin Jang, 2022)	Whey Portein Isolate	Whey Portein Isolate	€ 6.60	90	77.59		€ 6.60
(Rondanelli, et al., 2020)	BCAA's	BCAA's^	€ 24.99	2.34	20.27		€ -
* Based on a body weight of 60KG							€ 10.51
^Sourced from Chem Analyst Pricing							

Table 3.7: Breakdown of the recommended daily intake of nutrients identified to prevent the 3 chosen age-related diseases, compared to the nutrients in the natural WPI with a calculation showing the cost of fortification to the natural WPI to achieve the recommended daily intake of each nutrient.

The calculation shown in Table 3.7 displays the additional cost to fortify the natural WPI to be €3.91/kg using a base cost of production of €6.60/kg (Tipperary Co-Operative Creamery, 2023), giving a sum total of €10.51/kg. The reccommedned daily in take of 90g of proetin was based off an average body weight (over 65 years) of 60 kg and a recommended intake of 1.2-1.5 g/kg of body weight (Jin Jang, 2023) where the upper limit was chosen to allow for the fortification increase for people over 65 years (Jin Jang, 2023). The nutrient source prcing was taken from the most recent European trade prices (ChemAnalyst, 2020). The natural WPI is included only for base cost purposes only. The BCAA requirements are met by the natural WPI and did not require fortification as it exceeds the RDA of 2.3g (Rondanelli, et al., 2020). The daily requirement of vitamin D is too small to show a cost however is still an important nutrient (Polzonetti, et al., 2020)

With the cost price of the fortified WPI being €10.51/kg and the shipping cots to countries such as Africa being 44c/kg (Comparemymove, 2023), this brings the sum total to €10.95/kg and this is without a profit margin. While this powder is not limited to Africa, there is an initiative being developed called Dairy Nourishes Africa (DNA) that could possibly provide a subsidy to such a product like fortified WPI. DNA is currently seeking investment to improve nutrition and food security in East Africa as it recognises the rapid population growth (Global Dairy Platform, 2023)

3.5 Synopsis of Major Findings

With the aged related diseases identified (Osteoporosis, Sarcopenia and Cognitive decline) and the studies shown that dairy nutrients can support healthy aging, it is important to identify which specific nutrients are needed to mitigate all three morbidities associated with aging in the most suitable format from most recent studies and literature.

In relation to osteoporosis, the meta-analysis study carried out by Bian et al, 2018, found yogurt and cheese consumption was linked to a decreased incidence of hip fracture in the elderly. The study by Wang et al, 2019 highlighted the prevalence of osteoporosis among the aging population in which was identified as a global health concern, particularly China where it was calculated that 52% of the aging chinses population were at risk of osteoporosis (Wang, et al., 2019). Following on, the review article by Polzonetti, et al., 2020 conclueded vitamin D sourced from dairy can reduce the prevelnce of osteoporosic fractures sihnificantly (Polzonetti, et al., 2020) showing vitamin D is an essential dairy nutrient allowing calcium absorbtion that can be used to mitigate osteoporosis which is a global health concern.

With regard to sarcopenia, the Study carried out by Pinedo-Villanueva, *et al*., 2019 highlighted the extra cost incured by elderly patients suffering from sarcopenia associated muscle weakness in the UK. The study by Hanach, et al., 2019 showed that fermented dairy can increase in muscle mass. The The study by Youngsoon et al,2019 showed the effectiveness of whey protein supplimentation in preventing sarcopenia by increasing skeletal muscle mass in an aging cohort (Yongsoon, et al., 2018) . These studies would indicate that whey is essential to combat sarcopnia which can result in a huge financial burden.

The clinical trial carried out by Kita et al,2019 showed an increase in cognitive function due to whey peptide suplimentation. Similarly the Canadian longitudinal study by Tessier et al,2021 showed how the intake of low fat fermented dairy was linked with a higher cognitive function in an aging candian population. The region most linked with an aging population and increasing cognitive decline is Africa which was confirmed by the

longditudinal study carried out by Bassil et al,2022. In the study by Villoz et al,2023 dairy was shown to decrease cognitive decline dementia incidince.

With the finding of these stuidies and the information from previous lierature in mind , a suitable natural dairy product was fortified to mitigate the 3 morbidities identified with associated regions and prevelnce incorporated. A dairy based WPI was fortified to achive the daily nutrient requirements needed by the aging population at a cost €10.51/kg. The cost was found to be expensive for developing regions (Lynnette M, et al., 2019) and would require possible government subsidisation (Rondanelli, et al., 2020).

Chapter 4

Discussion

The purpose of this study was to review the potential application of bovine dairy powders in supporting healthy aging of humans. There have been many studies which have given a general view on how dairy, or the vast range of dairy products that can support healthy aging people. However there have been few studies focused in on one particular dairy product that can prevent the most common diseases associated with aging, the associated regions and cost of these aged related diseases. The aim of this study was to provide a good understanding of the dairy industry and the spray drying process, define healthy aging and identify aging populations, identify the morbidities associated with these aging populations and provide a product with the key dairy nutrients to mitigate these diseases.

The definition of dairy was defined initially in this study with a breakdown of milk profile and its natural nutrients. Dairy consumption was examined on a global scale with an emphasis on economic growth where fresh and processed dairy consumption has evolved over a 10-year period. Current dairy economics such as the main milk producing regions was assessed, as well as the self-sufficient and alternatively, regions that cannot produce enough dairy to support themselves. The market availability of the various different products such as butter, cheese and powder were shown. The development of dairy imports over a 10-year period were provided by the OECD-FAO Agricultural Outlook 2020-2029. This was followed by a brief analysis of bovine dairy history in Ireland and its relationship with EU. Implementation and abolition of milk quotas analysis was given to finish off the background of bovine dairy industry.

Milk powder was defined followed by a synopsis of the powder manufacturing process as seen in Figure 1.5, primarily with a focus on heat treatment, evaporation and spray drying. Shelf life was examined, where it is identified that a higher heat treatment of milk is used to extent shelf life of milk products (Rauh & Xiao, 2022) and this is a required by developing countries importing product to allow for shipping and storage time (D'Incecco, et al., 2021) while also increasing holding time to minimize the microbial load (Li, et al., 2019). Nutrition, fortification and reconstitution were discussed with an emphasis on powder solubility and particle size being key to a functional powder (Wahyu N. Nugroho, et al., 2021). Whey protein concentrates and isolates were focused on at this

point, highlighting the demand for higher protein content, economic value and further processing required. This section is closed out by a breakdown of the cost of production which is influenced by milk price, energy costs and overall margin influenced by GDT and market demand.

Healthy aging was defined and broken down into physical and mental categories. The term aging was defined and in accordance with Kim, 2023 anyone aged 65 and older is considered elderly or part of the aging population in terms of populations and demographics. A key point that was made here was that by 2050, twenty-two perecent of the worlds poulation will be over 60 in relation to this study and of this cohort, 80% will reside in developing regions. Ireland and Japan were shown to have aging populations currently (Central Statistics Office, 2023) (Okamoto, 2021).

Deloping regions were predicted to have the highest percentage of the world's aging population by 2050, Africa with the highest percentage of this cohort. It was also highlighted that people of Africa currently suffer from cognitive impairment and associated diseases such as diseases such as Alzheimer's and dementia with this number on the rise (Kobayashi, et al., 2019). Obesity was identified as a concern in the USA, leading to cardiovascular disease and also due to grow in line with the population increase (Ford, et al., 2023). Both regions and associated diseases were linked to hidden hunger and poor nutrient (Lenaerts & Demont, 2021). Hidden Hunger was explained in detail highlighting malnutrition as a cause. Food security was correlated with a countries economic growth highlighting why developing regions may have this issue (Lenaerts & Demont, 2021). The high nutrient status and food security of dairy was identified in order to mitigate hidden hunger and associated diseases (Shi, et al., 2023).

Diet followed with a focus on health in an effort to reduces the DALY's lost as a result of hidden hunger and malnutrition. Dairy was show cased in the food pyramid issued by the Irish Department of Health, with a recommended intake of 3 times daily. Dairy was also identified to mitigate common morbidities associated with aging (Cuesta-Triana, et al., 2019) and a comparison was made with the Mediterranean diet which is also

considered healthy but uses alternative protein sources to dairy (Shu, et al., 2019). Challenges were identified opposing dairy consumption such as plant-based alternatives and lactose intolerances. Current trends were evaluated showing strong demand for dairy. In particular, clean labelled-fermented dairy products with a low-fat content such as yoghurt were sought after for its protein content, bioactive and high nutrient profile in general (Chelladhurai, et al., 2023).However shelf life seems to remains an issue (Gantumur, et al., 2024).

Morbidity and mortality were then defined. Osteoporosis, sarcopenia and cognitive decline were identified as the most common global health concerns associated with aging (World Health Organisation, 2023). Osteoporosis is defined and described in detail with regard to bone development and remodelling. Several nutrients found in dairy were linked to bone mass density and reduced risk of osteoporosis as well as vitamin D (Matía-Martín, et al., 2019). The cost associated with osteoporosis were highlighted also (Cui, et al., 2020). Sarcopenia was then identified and described with regard to muscle loss and frailty. Nutrients found in dairy linked to increase muscle mass and mitigate inflame aging were BCAA's such as leucine (El-Sebaie & Elwakil, 2023). The cost associated with sarcopenia was identified cost (Goates, et al., 2019).

Cognitive decline was defined and described in detail with oxidative stress being a key driver. Glutathione found in fermented dairy protein was shown to reduce oxidative stress (Hajjar, et al., 2018). Bioactive peptides were also shown to promote health brain function and reduce cognitive decline (Ano, et al., 2018). Cardiovascular disease was defined and identified as an aged related disease. While there is evidence to show the dairy can reduce oxidative and inflammatory stress in adipose tissue (Mishali, et al., 2019), there were too many conflicting studies with this disease and it was not pursued. Satiety and Satiation were then defined. Bioactive peptides found in dairy products were found to have a positive effect preventing over eating (Kondrashina, et al., 2020).

Affordability of dairy was examined and fluctuations in prices were seen in the OECD-FAO Agricultural Outlook 2020-2029 report. There has been a higher demand in fat then protein in recent years using butter and SMP pricing as indicative figures. Adverse events such as the war in Ukraine can have a huge effect on diary prices as seen in 2022 (The World Bank, 2023).

Osteoporosis was investigated firstly in the results section. The paper written by Bian et al, 2018 investigated the relationship between hip fractures and dairy consumption due to previous conflicting literature. The meta-analysis review showed low fat dairy consumption to lower risk of hip fracture by 29%. While the age range was not defined, it supports the principal that fermented dairy consumption can provide the key nutrients to increase bone mineral density and mass preventing fractures conquering with the literature discussed by Hwang, et al., 2023.

The study by Wang *et al*, 2019 found that over 52% of people over the age of 60 are at high risk of osteoporosis from China, Milaysia, India and other regions which would support the WHO classification of osteoporosis being a global health concern among the elderly and is an age-related disease (World Health Organisation, 2023). This study also identified that diabetes and hypertension were risk factors associated with osteoporosis. Literature previously discussed by Lane, et al., 2023, highlighted both diabetes and hypertension can be caused by oxidative stress. Lane, et al., 2023 also mentioned that glutathione is an natural antioxidant that can reduce oxidative stress which is naturally present in dairy whey protein thus linking whey proetin to reduced risk of osteoporosis (Khan, et al., 2019).

The results of study by Lips and Van Schoof were highlighted in the review paper carried out by Polzonetti *et al*., 2020 showrd supplementing with vitamin D 25(OH)D enhances BMD, decrease bone turnover, and reduce fracture incidence. There was there was a 43% reduction in hip fractures which was the highest risk reduction in the study by far (19% higher than the next study) at 800 IU/day. Hip fractures are one of the 3 most common

fractures associated with osteoporosis as identified in section 3.1 which would indicate vitamin D supplementation would decrease osteoporosis hip fracture risk.

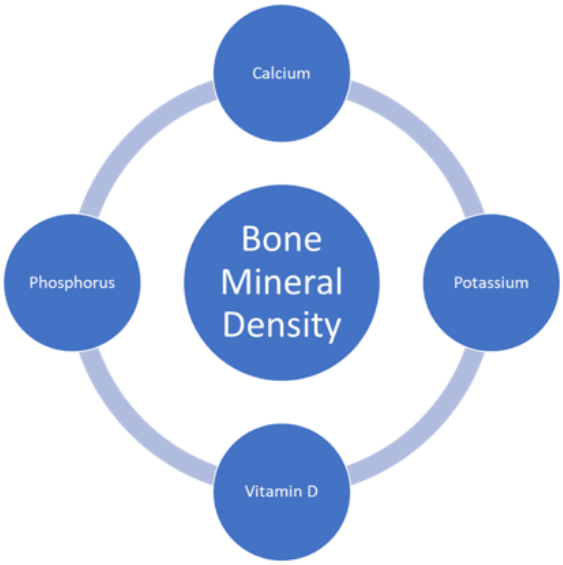


Figure 5.1: A schematic diagram of the nutrients required to support bone mineral density and mitigate osteoporosis which are calcium, vitamin D, potassium and phosphorus adapted from Hwang, et al., 2023, Polzonetti, et al., 2020, Ha, et al., 2020 and Hejazi, et al., 2020.

Furthermore, Vitamin D has a symbiotic relationship with calcium allowing for calcium deposition and other key nutrients identified in section 3.1.1 such as potassium and phosphorus naturally occurring in dairy required to support bone mineral density and mass. Therefore, these nutrients can reduce risk of osteoporosis which is a global health concern in an aging population and are required for healthy aging as shown in Fig 5.1 by Hwang, et al., 2023, Polzonetti, et al., 2020, Ha, et al., 2020 and Hejazi, et al., 2020.

Senile Sarcopenia was investigated in section 3.2 of the results chapter. The study carried out by Pinedo-Villanueva, et al., 2019 highlighted the health care cost for patients with sarcopenia in the UK. Patients with muscle weakness are paying £2707 per person/year more than more than a person sarcopenia free with informal care costs accounting for 46% of the difference as demonstrated in Fig 3.5. This data is significant to this study

because the financial burden associated with sarcopenia is extremely high and is one of the reasons why this age-related disease is recognised as a global health concern by the WHO as established in section 1.7 (World Health Organisation, 2023).

Similarly, the study by Goates, et al., 2019 in section 1.7.3 highlighted the ecomonic burden faced by sarcopenic paiteints in the USA. The total estimated cost of hospitalizations among people in the US with sarcopenia was $40.4 billion and $19.12 billion was directly associated with sarcopenic patients over 65. The cost for these patients increase from $204/year to $375/year for individuals over 65 showing the financial burden increases with age and deterioration.

The study by Hanach, et al., 2019 found that dairy protein increased appendicular muscle mass in older adults aged 61-81 years with or without existing sarcopenia. Nine regions were used in this this study which would indicate that fermented dairy can mitigate sarcopenia on a global scale. See below results:

Of the 9 studies that measure AMM, every dairy product used contained whey proteins as seen in Table 3.6 which was not acknowledge in the study (Hanach, et al., 2019). This would agree with the study by Jin Jang, 2022 where it was found that WPI increases muscle mass where it was also reported vitamin D in addition to leucine-rich whey protein improves lean body composition and muscle function in sarcopenic older individuals as described in section 3.2.2.

Additionally, the study Yongsoon et al, 2018, 2018 investigated the effectiveness of protein as a nutrition dairy whey supplement to decrease frailty in the elderly with sarcopenia. This study shows that the optimum dairy whey protein intake is 1.5 g/kg/day to increase ASM and SMI to decrease frailty among elderly subjects aged 70-85 years with sarcopenia. The fact that dairy whey protein only was used in this study shows it is responsible for increase muscle mass would indicate the whey protein in the dairy products used in Hanach, et al., 2019 were responsible for the increase in muscle mass

and decreasing frailty among sarcopenic individuals over 65 which is a key principle of this study.

Cognitive decline was investigated in section 3.3 of the results chapter. The first study examined in detail was a clinical trial carried out by Kita, et al., 2019. This study involves a whey supplement enriched with whey peptide GTWY and a placebo similar to the test previously carried out by Yongsoon et al, 2018 however this study investigated effects of whey peptide on cognitive function in older adults. Cognitive decline based on traits such as forgetfulness and carelessness were assessed via a memory test as mentioned in section 1.7.3.

As seen in Fig 3.7 there is a significant increase in score in the group that received the whey peptide showing this cohort memorised more faces than the group that received the placebo over the 12-week period showing superior cognitive function. The study by Ano et al,2019 highlighted that whey peptides containing WY suppress monoamine oxidase-B activity and boosts dopamine levels in brain tissue improving memory which is a cognitive function.

In the Canadian Longitudinal Study by Tessier, et al., 2021, fermented dairy was investigated to see if there was a positive correlation with cognitive executive functions in older adults aged 68-86. Dairy products were all positively correlated with executive function in memory and verbal fluency tests with p- value of less than 0.05 in older Canadian adults. The results are in line with the principal of this thesis that dairy nutrients can support healthy aging population, mitigating cognitive decline among the elderly which is a global health concern identified in section 1.7.1.

The African Longitudinal Study by Bassil, et al., 2022 highlight the prevalence of cognitive decline in Africa. Ninety percent of individuals had impaired vison and cognitive impairment increases with age among the elderly. The study also highlighted

that Africa has a rapidly aging population and estimates 3.5 million people will be suffering from dementia by 2030 and predicted to increase to 7.6 million by 2050.

The prevalence of cognitive impairment and dementia in Africa and other developing regions was first highlighted in section 1.5.3 of this study by Mavrodaris, et al., 2018 and Kobayashi, et al., 2019 when population and demographics were discussed in detail. More over 80% of the world's aging population will reside in these developing countries by 2050 which is why there is an emphasis on the age-related diseases associated with cognitive decline in Africa such as dementia and Alzheimer's in this study.

Oxidative stress has been shown to causes both cognitive diseases by Hajjar, et al., 2018 and Bowman, et al., 2018 in this study. Dairy nutrients found in whey proteins such as glutathione have been shown to act as an antioxidant reducing oxidative stress by Hajjar, et al., 2018 and Xue, et al., 2023, thus showing whey protein can be used to mitigate cognitive decline in developing regions such as Africa.

The concept that dairy nutrients can reduce risk of cognitive decline and disease was further investigated by Villoz et al,2023in the results section. This study investigated dairy intake and risk of cognitive decline and dementia. The study showed a negative non-linear association between cognitive decline/dementia incidence and dairy intake as measured by quantity consumed, with the lowest point at around 150 g/day. Participants in this study were 53 – 91 years which would resemble an aging population. The study also found highest dairy intake was associated with a lower risk of cognitive decline or dementia compared to the lowest dairy intake in Asian studies. Asia being a developing region highlighted in section 1.5.3, shows the positive effects dairy has on cognitive decline in these regions in an aging cohort in line with scope of this study.

Section 3.4 of the results section investigates tailoring a dairy product to support healthy. A WPI was chosen as it contains all the trace elements required to mitigate the 3 chosen morbidities. Calcium, phosphorus and potassium were all shown to be naturally occuring

in milk and a required to increase bone mineral density in section 3.1.1 as well as their recommended daily intakes. Table 3.7 shows each of these elements in natural WPI. Vitamin D fortification is required as required for promoting calcium deposition highlighted in section 3.1.1. The study by Lips and Van Schoof showed vitamin D fortification to decreased hip fractures by increasing bone mineral density. Hip fractures are one of the most common fractures associated with aging and Osteoporosis. The study by Wang et al, 2019 confirmed osteoporosis being an age-related disease in developing regions.

Whey protein was included to increase muscle mass and minimize sarcopenia The study by Yongsoon et al, 2018 showed the whey protein supplementation increases muscle mass in older patients with sarcopenia. In this study 1.5 g/ kg/ day of the whey supplement was found to be most effective which would concur with the RDA prescribed by Jin Jang, 2022. Whey protein is natural occurring in WPI as established in section 1.4.8 and can be seen in Fig 3.12.

Whey peptides were included to reduce oxidative stress and combat cognitive decline in an aging demographic. This was highlighted in the Clinical Trial carried out by Kita, et al., 2019 where participants aged 50 and over who were given a whey peptide supplement showed superior cognitive function. WPI contains these peptides naturally as confirmed by Sharma, 2019 and Ano et al,2019. The amino acids that make up these peptides are all listed in Fig 3.12. For example, glutathione is a tripeptide comprised of glutamic acid, cysteine, and glycine which can reduce oxidative stress which are all listed (Xue, et al., 2023). β-Lactolin is a peptide that contains tryptophan and tyrosine which improves cognitive function as shown by Kita, et al., 2019 and listed in Fig 3.12. Leucine and isoleucine are amino acids identified by Martínez-Arnau, et al., 2019 in preventing sarcopenia in section 3.2.2 which are also listed in Fig 3.12.

Due the majority of the aging population residing in developing regions such as Africa by 2050 as identified in section 1.5.3, cost of the product was examined. At a production cost of €6.60/kg, natural Irish WPI sold on the market today €42.43/kg with a 543% profit

margin. These price levels are far too high for developing regions and also do not supply the required daily nutrients to support an aging population. Government subsidies were introduced by Mexico in an effort to improve health and nutrition by subsidising fortified WMP for residents (Lynnette M, et al., 2019) which could be the case in Africa but not at these price levels.

In section 3.4.1 cost of fortifying a standard WPI to provide the RDA of the key dairy nutrients was examined. The additional cost of manufacture was calculated in Table 3.7 to be €3.91/kg based on a body weight of 60kg and will require just over 3 servings per day. This gave a total cost price of €10.51/kg. The additional cost of transport to Africa was 44c/kg (Comparemymove, 2023) which brought the sum total to €10.95/kg. While this fortified WPI wass not limited to Africa there is a dairy initiative in Africa that could provide a subsidy called Dairy Nourishes Africa (Global Dairy Platform, 2023) once there is not a substancial margin put on this product.

Chapter 5

Conclusion

In conclusion, the potential application of bovine dairy powders in supporting healthy aging of humans has been reviewed. Bovine milk is a highly nutritious product that is consumed around the world. Europe showing to have the highest dairy output and MENA importing dairy products from Europe. Milk is highly functional and is the main ingredient in dairy products such as butter, cheese and milk powders. The spray drying process used to manufacture milk powders is complex. With the correct heat treatment, spray drying can increase the shelf life of milk powders. This also more cost effective for shipping and storage while providing key nutrients. Healthy aging is the process of developing and maintaining the functional ability that enables wellbeing in older age however and can be achieved through a balanced diet. Alternatively aging is the molecular and cellular damage over time leading to deterioration of both cognitive and physical health as a result of malnourishment. This can lead to age related diseases. A person is considered elderly after their 65^{th} birthday.

Aging is considered a global health concern by the WHO as 2 billon people will be over 60 by 2050 in the world's population, Africa with the heist percentage of this cohort. World population and demographics were examined certain aged related illness resided in specific populations. Japan was shown to have a healthy aging population. Obesity was linked with the USA and cognitive impairment was most prevent in Africa. Diet was examined and dairy was shown to be required in a healthy balanced diet. Current trends show a strong demand for dairy due to its protein content and nutrient profile

Osteoporosis, sarcopenia and cognitive decline were defined as global health concerns associated with aging by the WHO. Osteoporosis was defined and prevalent in subjects with a low bone mass density. Sarcopenia was defined and prevalent in subjects low muscle mass. Both diseases had additional costs associated. Cognitive decline was associated with oxidative stress. There was a lack of literature on the cost associated with cognitive decline, possibly because it is more commonly associated with developing regions who cannot afford health care.

Following investigation calcium, phosphorus and potassium were all shown to be naturally occuring in dairy and required to increase bone mineral density mitigaing

osteoporosis along with vitamin fortification. The additional costs of paitents with osteoporosis were outlined. Dairy Whey protein was shown to increase muscle mass, mitigating sarcopenia. The additional cost of patients with sarcopenia was defined. Whey peptides and amino acides and whey itself was correlated with improving cognitive function. The dairy product that contains all these nutrients naturally is WPI , except vitamin D which is not naturally occuring in milk. The product must be in powdered format for a longer shelf life and affordability due to the majority of the aging population residing in Africa by 2050.

The cost of prodcution was found to be €6.60/kg for a natural WPI made in Ireland however the retail price was €42.43/kg with a 543% profit margin. The additional cost to fortify this product to meet the RDA to combat the 3 age related morbidities was €3.91/kg based on a body weight of 60kg bringing the sum total to €10.95/kg production and shipping cost to Africa. Government subsidies will be required for developing regions which has been impliment by Mexico previosly to improve health an dcombat disease. The lierature in this study shows the potential application of bovine dairy powders in supporting healthy aging of humans.

Chapter 6

Future Work

Future work in relation to this study would be produce this product in a pilot trial lab-based setting. Moorepark Technology is research and development facility located in Fermoy, Co. Cork. This facility has a miniature evaporator and spray drier which would be required in the manufacturing process of this product and also has the capacity to produce commercially depending on the scale (Moorepark Technology, 2023).

Clinical trials would be required following the success of the development phase of the product. Subjects would require one of the 3 diseases outlines in order to see if the product successfully combats their disease. The study would need to be ran over an acceptable period of time with a large sample size. A screening process would be required to examine any underlying conditions other than what is focused on and the age requirement would be over 65 to represent an aging population.

Docosahexaenoic acid has been used in fortified milk powders for infants to enhance brain and cognitive function (Salioni Camargo Novaes, et al., 2019). It would be beneficial to the concept of this study as cognitive decline is most prevalent in developing regions where the majority of the aging population will reside in 2050 (Kobayashi, et al., 2019).

Chapter 7

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