What factors contribute to chronic disease in Australia and New Zealand and how can food science and technology improve health? – A Scoping Review

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Abstract

Nutrition-related chronic diseases are driven by external factors such as environmental, socio-economic and political factors in Australia and New Zealand. These external factors determine food accessibility, availability, and affordability, ultimately shaping the food environment and diet, imposing substantial health and economic loss with inconsistencies between indigenous and non-indigenous populations. These factors need to be understood so food science and technology innovations can be inserted to create a solution.

The objectives of this scoping review were to examine what and how current technology in New Zealand and Australia is being invested in to improve nutrition and reduce chronic disease and to inform where research is required by identifying gaps in the literature. This scoping review followed the 2020 JBI scoping review guidance and the PRISMA-Scr guidelines.

11 studies were included in the review and grouped by the population researched as either healthy or at-risk and then into sub-themes of nutrition biomarkers. Results showed current food science and technology innovations focus on fortifying and supplementing everyday food products, including bread, noodles, spread and biscuits with nutraceuticals and functional foods such as curcumin, polyphenols, phytosterols, oat β-glucans, vegetables and fish oil through well-researched nutraceutical activities. These innovations aim to reduce the risk of chronic disease by improving nutrition biomarkers such as glucose tolerance, insulin sensitivity, inflammation, appetite, HbA1c and lipid parameters in healthy and at-risk populations. However, current innovations do not consider external drivers of chronic disease or Māori and indigenous populations. When analysing future innovations, these factors need to be considered, and the target population must be identified as differing responses were found depending on the population studied.

This scoping review has highlighted the need for plant and food research and development companies to focus on emerging trends, including personalised nutrition and nutrigenomics, plant-based foods, sustainable food systems, vertical farming and nutritional immunology. These fields are new and complex, and if invested in, New Zealand and Australia could be amongst the first to implement these trends. These innovations can successfully reduce chronic disease by making healthy and sustainable diets more available, accessible and affordable, thus improving diet factors and chronic disease.

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First of all, I would like to give special thanks to my supervisor Dr Rajshri Roy for her feedback and guidance throughout this project. Without Dr Roy’s help, I would not have been able to complete this research.

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Glossary

BMI: body mass index

COPD: chronic obstructive pulmonary disease

CRP: c-reactive protein

CSIRO: The Commonwealth Scientific and Industrial Research Organisation

CVD: cardiovascular disease

DALY: disability-adjusted life year

FV: fruit and vegetables

GDP: gross domestic product

GI: glycemic index

HbA1c: haemoglobin A1c

HDL-C: high-density lipoprotein cholesterol

ICAM-1: plasma intercellular adhesion molecule 1

IGF-1: insulin-like growth factor 1

JBI: Joanna Briggs Institute

LDL-C: low-density lipoprotein cholesterol

MUFA: monounsaturated fatty acid

PCC: population, concept, context

PRISMA-ScR: preferred reporting for systematic review and meta-Analyses extension for scoping reviews

PUFA: polyunsaturated fatty acid

SFA: saturated fatty acid

SSB: sugar-sweetened beverage

T1D: type 1 diabetes mellitus

T2D: type 2 diabetes mellitus

TC: total cholesterol

TG: triglycerides

WHO: World Health Organization

CHAPTER 1 Introduction

1.1 Thesis overview

The format of this thesis is in line with the University of Auckland guidelines for thesis and dissertations. Chapter one includes an introduction, background, problem statement, research questions, and the significance of this research. Chapter two is a literature review that summarises and evaluates the literature supporting the scoping reviews purpose and aim of the research. Chapter three describes the specific methodology used in this thesis project. Chapter four presents an overview of the key findings and data from the research. Chapter five describes what the data means and what can be drawn from the results, including gaps in the literature and implications for future research. Chapter five also includes study limitations. Chapter six is a conclusion entailing the main summary of the overall scoping review and key findings. Chapter six also includes funding sources from the articles used in the scoping review and the authors involved in this research.

1.2 Theoretical framework

This thesis investigates what factors contribute to chronic disease in Australia and New Zealand and how food science and technology can improve health.

New Zealand’s and Australia's external drivers of chronic disease are environmental, political, and socio-economic drivers. Each driver is complex and needs to be accounted for to reduce the chronic disease burden. Drivers of chronic disease influence New Zealand’s and Australia’s food environment and diet by determining these populations' food accessibility, availability, and affordability.

Nutrition can enormously impact the risk of developing obesity, metabolic syndrome, and nutrition-related chronic diseases. This means that chronic disease can be prevented or enhanced due to nutrition. Elements of the diet that pose the most significant risks are sugar, fat, sodium, fruit and vegetables (FV), ultra-processed, and fast-food intake. New Zealand and Australian populations are not meeting recommendations for any of these factors, indicating that diet should be considered when seeking to improve chronic disease prevalence.

The most prevalent chronic diseases in New Zealand and Australia are cardiovascular disease (CVD), cancer, chronic respiratory disease, and diabetes mellitus. Chronic diseases significantly contribute to health loss and mortality in New Zealand and Australia. An enormous cost is associated with chronic disease which imposes a significant financial stress on the health care system as well as individuals and families with chronic disease. Chronic disease prevalence is inconsistent between indigenous and non-indigenous populations in New Zealand and Australia. Figure 1-1 maps the theoretical framework which aided in conveying the information in this scoping review.

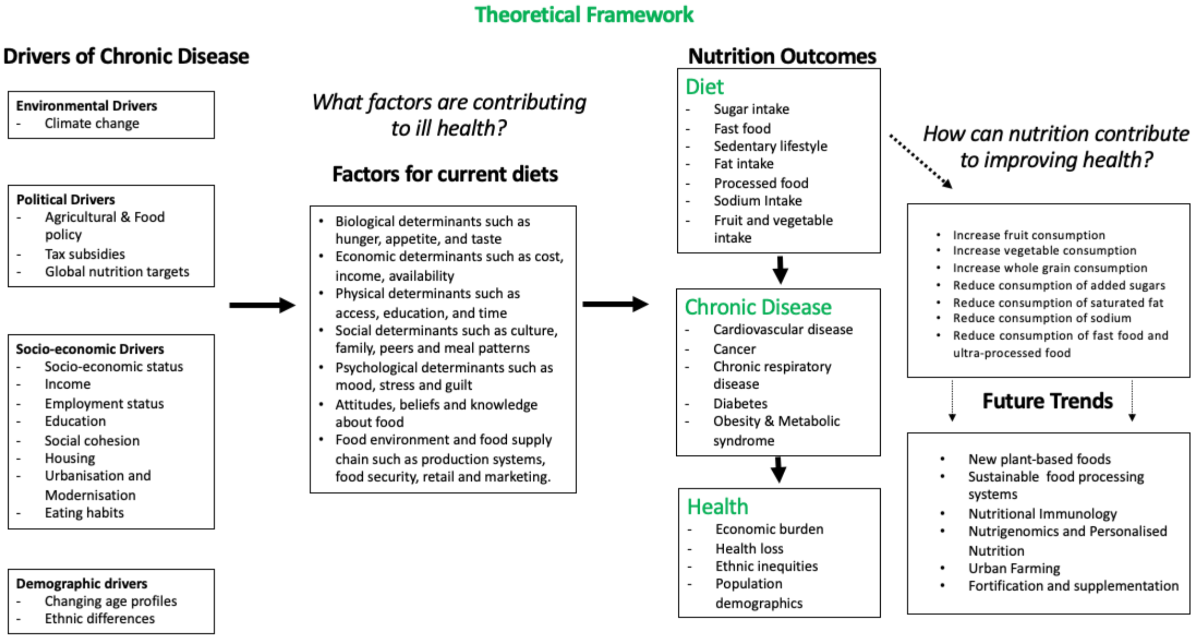

Figure 1-1 Theoretical framework.

1.3 Diet factors of chronic disease

Environmental, political and socio-economic drivers influence populations' surrounding environments and contribute towards populations' diets. Main aspects of the diet that have been shown to contribute the strongest to chronic disease are sugar intake, fat intake, sodium intake, FV intake, and ultra-processed and fast-food. These diet factors are an outcome of food accessibility, availability and affordability, influenced by external factors (Figure 1-2) (Larson et al., 2020; Loth et al., 2016).

These dietary factors can increase the risk of developing metabolic disorders and, eventually, metabolic syndrome, further increasing the risk of chronic disease (Figure 1-2) (Afshin, Sur, et al., 2019). It is essential to understand the current diet trends in New Zealand and Australia for these nutrients and food trends to identify where technology is required to improve the nutrition in these populations.

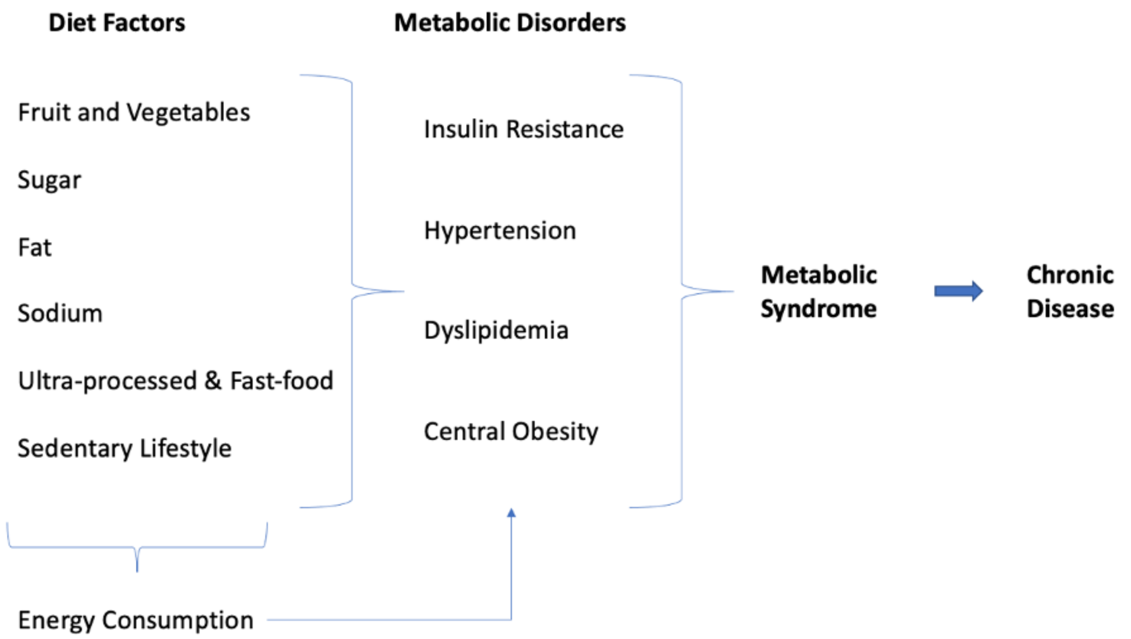

Figure 1-2 Relationship between dietary outcomes and metabolic disorders.

1.3.1 Sugar

Sugar has no nutritional value and lacks micronutrients (Ebbeling et al., 2003). Therefore, consuming a high-sugar diet is less likely to meet dietary requirements and adds excess energy to the diet (Ebbeling et al., 2003). In a meta-analysis and systematic review, dietary sugars and sugar-sweetened beverages (SSB) were a determinant of body weight and excess energy intake (Te Morenga et al., 2013).

Added sugar is of particular interest due to containing high amounts of sucrose (Ebbeling et al., 2003). Added sugar does not occur naturally and is added to food and drinks during processing or preparation. Foods high in added sugar tend to have a moderate-high glycemic index (GI) due to higher concentrations of sucrose (Ebbeling et al., 2003). This means that added sugar can cause a high glucose load on the body affecting glucose tolerance and increasing the risk of type 2 diabetes mellitus (T2D) development (Malik et al., 2010; Rahelić et al., 2011).

Increased sugar intake has also been correlated with other chronic diseases such as heart disease (Huang et al., 2014). A review of the literature investigating the link between heart disease and sugar concluded that sugar could have a detrimental effect on cholesterol which can determine heart disease risk (DiNicolantonio et al., 2016). The review also found that replacing fat with sugar increased the risk of CVD (DiNicolantonio et al., 2016).

The WHO recommends that sugar is less than 10% of energy intake (50g of sugar per day) and less than 5% of energy intake for better health for adults and children (World Health Organization, 2015). These recommendations concentrate on added sugar and exclude sugar from milk and FV (World Health Organization, 2015). Dietary trends in New Zealand show that only 42% of adults consume less than 10% daily energy from sugar (Kibblewhite et al., 2017). This infers that even fewer people would meet the recommended less than 5% to reduce the risk of chronic disease (Kibblewhite et al., 2017).

In Australia, there has been a slight decline in added sugar consumption from over 50% in 1995 to less than 46% in 2011-12 (Australian Bureau of Statistics, 2011). In 1995 over half of the Australian population did not meet the WHO recommendations for added sugar intake. Results from 2011-12, only 46% of Australians are over the WHO recommendations (Australian Bureau of Statistics, 2011). Although Australia has seen a decrease in added sugar consumption, the population still consumes approximately 10.9% of their daily energy from added sugar which is over the recommendation (Australian Bureau of Statistics, 2016).

SSB consumption has been thoroughly investigated due to containing such high amounts of added sugar. Results have shown that SSB consumption significantly impacts energy consumption and risk of obesity and metabolic syndrome (Malik et al., 2010; Schulze et al., 2004). Results indicate that there have been minimal affective changes in the sugar content of SSB in New Zealand over the years despite reduction recommendations (de Castro et al., 2021). Australia has only seen a 7% decrease in sugar in drinks between 1995 and 2011-12 (Australian Bureau of Statistics, 2016).

New Zealand and Australia exceed sugar intake recommendations and minimal interventions have been implemented to reduce sugar consumption. These findings indicate that sugar in the diet could impact chronic disease prevalence in New Zealand and Australia.

1.3.2 Fat

Dietary fat intake is correlated with cholesterol. It has been shown that people who consume a high amount of saturated fat have more elevated total cholesterol (TC) and low-density lipoprotein cholesterol (LDL-C) than those who consume less saturated and total fat (Law, 2000). Dietary fat intake is strongly associated with the development of chronic disease. Saturated fat intake is strongly associated with CVD due to the relationship between TC, LDL-C and CVD (Hooper et al., 2011).

Blood pressure, cholesterol and obesity are critical factors in developing metabolic syndrome and chronic disease. Therefore, dietary fat intake is a risk factor for ill health. A systematic review of dietary fat intake and metabolic syndrome in adults found that reducing saturated fatty acids (SFAs) can decrease the risk of metabolic syndrome when replaced by specific nutrients such as monounsaturated fatty acids (MUFAs) and polyunsaturated fatty acids (PUFAs) (Julibert et al., 2019). This emphasises that the type of fat consumed should be the focus rather than decreasing total fat intake.

Less than 10% of daily energy from SFA is recommended for the New Zealand and Australian populations. New Zealand has a high intake of saturated fat and a low intake of unsaturated fats. Although SFA intake has decreased since 1989, New Zealand is still well over the current recommendations (Miller et al., 2016). In 2008-09 the median daily intake of SFA was approximately 13% of adults' daily energy intake (Ministry of Health, 2011). PUFA intake has not changed between 1997 to 2008-09 at about 5% of the diet, which is relatively low compared to the population’s SFA intake (Ministry of Health, 2011).

Fat intake in Australians’ diets has not been investigated since the 2001-12 Australian Health Survey (Australian Bureau of Statistics, 2011). Results showed that over one-third of the population’s total energy consumed was discretionary foods high in SFA. This indicates that people could be well over the recommendation of less than 10% daily energy from SFA. This same survey showed that fats and oils were consumed by only 46% of the population, most of which was saturated fat.

1.3.3 Sodium

Sodium intake is a crucial target to reduce chronic disease outcomes. Sodium plays a role in CVD by increasing blood pressure (Farquhar et al., 2015). Hypertension has been shown to affect those with diabetes mellitus and a salt reduction could reduce this effect (Feldstein, 2002; Horikawa & Sone, 2017). Sodium intake is associated with an increased incidence of gastric cancer, and the risk increases with consumption levels (D’Elia et al., 2012; Ge et al., 2012).

Sodium intake is correlated with an increased risk of obesity, mainly due to SSB consumption, and consumption is higher in those overweight or obese independent of energy intake (Horikawa & Sone, 2017; Ma et al., 2015). Sodium intake has been associated with metabolic syndrome by affecting insulin resistance and blood pressure. A recent meta-analysis of observational studies revealed that those with metabolic syndrome have significantly higher sodium levels than healthy controls (Soltani et al., 2019). Therefore, sodium intake can be a predictor of metabolic syndrome.

New Zealand's and Australia's suggested dietary target for sodium in adults is 2,000mg/day, equivalent to approximately one teaspoon salt (Ministry of Health, 2012). The WHO also recommends a population average be less than 2,000mg/day (World Health Organization, 2012). Although there is minimal data available on sodium intake in New Zealand, it has been estimated that the population consumes 3,500mg of sodium per day which is 70% higher than this recommendation (Skeaff et al., 2013). Australia's 2011-12 Health Survey revealed the adult population consumes approximately 2,400mg of sodium intake from food per day (Australian Bureau of Statistics, 2011). However, this did not include salt added to food. A reported 64% of the people surveyed said they added salt to their food during preparation or at the table (Australian Bureau of Statistics, 2011). This will push the population's sodium intake over the recommendations set.

1.3.4 Fruit and vegetable

FV intake is another nutrition-related risk factor for chronic disease. An increased FV consumption can reduce blood pressure and improve vascular function, reducing the risk of CVD and mortality (Chapman et al., 2016). 16 cohort studies were included in a meta-analysis (Wang et al., 2014). It was found that increased FV of up to five serves per day decreased the risk of mortality, especially for CVD (Wang et al., 2014). Studies have shown that FV intake is weakly associated with a reduced risk of diabetes mellitus. A systematic review and dose-response meta-analysis of cohort studies concluded a decreased risk of T2D when comparing low vs high intakes of FV. They found that subtypes of FV were associated with reduced risk. Still, others imposed an increased risk of T2D, inferring that the subtype of FV consumed should be considered rather than FV intake in general (Halvorsen et al., 2021).

Cancer and FV consumption has been controversial and may only be associated with an elevated risk when FV consumption is very low (P Terry et al., 2001). A meta-analysis has shown that a higher intake of FV of up to five serves per day decreased the risk of mortality (Wang et al., 2021). Cancer, CVD and respiratory disease risk were also the lowest when participants consumed two servings of fruit and three serves of vegetables per day. However, starchy vegetables such as potatoes and corn were not associated with a decreased risk of mortality (Wang et al., 2021).

FV consumption also relates to metabolic syndrome, which may be an underlying factor causing chronic disease risk. A systematic review and meta-analysis of observational studies found a dose-response relationship between fruit intake and risk of metabolic syndrome but not vegetable intake (Lee et al., 2019). However, another meta-analysis found that intake of subgroups of vegetables such as green leafy vegetables and yellow vegetables showed a healthier food pattern and decreased risk of metabolic syndrome (Rodríguez-Monforte et al., 2017).

In Australia, FV intake is well below the recommendations of five servings of vegetables and two servings of fruit per day. Between 2007 and 2018, the proportion of the adult population meeting FV intake has remained the same at about 49-52% of the population not meeting the recommendations (Australian Institute of Health and Welfare, 2019). When considering vegetable intake on its own, 94% of the adult population did not meet vegetable guidelines (Australian Institute of Health and Welfare, 2019).

In New Zealand, it is recommended to consume at least three servings of vegetables and at least two servings of fruit per day (Ministry of Health, 2020). The percentage of the New Zealand population meeting FV recommendations decreased between 2011-12 to 2020-21. The percentage of the population meeting fruit recommendations has dropped from 58.5% to 48.2%, and meeting vegetable recommendations has fallen from 68.5% to 50.9%. Meeting both FV intake has fallen from 44.5% meeting FV recommendations to a disappointing 30.1% (Ministry of Health, 2021).

It is clear Australia and New Zealand are significantly below FV intake recommendations and this could be imposing a significant dietary risk factor for chronic disease burden in both countries.

1.3.5 Ultra-processed and fast-food

Ultra-processed foods are highly modified and undergo multiple processes and adding ingredients to develop the food product. These types of food are created to be low-cost, convenient and palatable to enhance consumer popularity and consumption (Monteiro et al., 2019).

Diets high in ultra-processed foods have been shown to promote obesity and chronic disease due to nutrition concerns such as increased energy, SFA content, low fibre and low micronutrient content (Ludwig, 2011). These aspects influence high portion sizes and an increased glycemic load with the consumption of ultra-processed foods (Ludwig, 2011). A systematic review of ultra-processed food consumption showed that increased consumption of ultra-processed food is associated with all five metabolic disorders that define metabolic syndrome, chronic disease and all-cause mortality (Mullen, 2020).

Fast-food traditionally contains highly processed components high in sodium, sugar, SFA, and energy. This reflects a Western dietary pattern that has been found to increase the risk of metabolic syndrome (Asghari et al., 2015; Rodríguez-Monforte et al., 2017). A dietary pattern reflecting high fast-food consumption is involved in chronic disease risk, especially diabetes mellitus and CVD (Bahadoran et al., 2015). Fast-food drives an unhealthy lifestyle by decreasing the frequency of meals cooked at home, which has been shown to lower the quality of the diet and increase the financial burden of purchasing food (Mackay et al., 2017).

The level of processing in packaged food products in New Zealand supermarkets was examined, and results found that most of these foods were ultra-processed. Highly processed packaged food had a lower nutrient profile and was cheaper to purchase than less processed packaged foods (Luiten et al., 2016). Fast-food meals in New Zealand have been shown to provide 88.6% of daily sodium recommendations and over half of daily energy recommendations (Mackay et al., 2021). New Zealand fast-food products' energy density has increased over the past five years, contributing to poor nutritional intake. A larger portion size means increased sodium, saturated fat and added sugar consumption in fast-food meals (Eyles et al., 2018).

In Australia, ultra-processed foods contribute the highest energy to the population's diet. Ultra-processed foods in Australia have also been shown to drive excess sugar intake (Machado et al., 2020). A similar study also found that intake of ultra-processed foods was correlated with increased trans and saturated fat, sodium and diet energy density (Machado et al., 2020). The study of fast-food consumption in Australian school students found that approximately 40% consumed fast-food at least once a week. Fast-food intake was associated with a low intake of FV and a higher intake of SSBs (Scully et al., 2020).

These fast-food and ultra-processed food trends are increasing New Zealand and Australia's energy, fat, sugar and sodium intake, thus driving chronic disease prevalence.

1.3.6 Sedentary lifestyle

It has been shown that physical inactivity and a sedentary lifestyle have been independently associated with an increased risk of chronic disease (Admiraal et al., 2011; Cadilhac et al., 2011; Reddigan et al., 2011). A sedentary lifestyle and physical inactivity are associated with the risk of metabolic syndrome (Edwardson et al., 2012). Exercising has been investigated in a meta-analysis, and results have shown that exercising can improve metabolic outcomes in people with metabolic syndrome. However, the intensity of exercise required was not established (Ostman et al., 2017). Studies have shown that increasing physical activity by only 10% can reduce annual expenditure on health (Cadilhac et al., 2011).

Recommendations for physical activity in New Zealand and Australia are to be active most days of the week and consist of moderate (2.5 hours per week) and vigorous physical activity (1.25 hours per week). Muscle-strengthening exercises are also recommended at least two times per week (Department of Health, 2021c; Ministry of Health, 2020).

The annual update of key results in the 2020-21 New Zealand Health Survey showed that physical activity levels have barely changed over the past decade (Ministry of Health, 2021). Over half of New Zealand adults were classified as physically active, 34% were insufficiently physically active, and 13% undertook little or no physical activity per week (Ministry of Health, 2021).

Research has shown that more than half of Australian adults do not meet the recommended physical activity guidelines (Australian Bureau of Statistics, 2011; Department of Health, 2021c). Approximately 44% spend their working day sitting, making it challenging to meet these recommendations (Australian Bureau of Statistics, 2011).

A sedentary lifestyle on top of poor diets is yet another factor contributing to chronic disease in New Zealand and Australia that is not improving over time.

1.3.7 Summary

New Zealand and Australia populations' diets are high in sugar, fat, sodium, ultra-processed food and fast-food and low in FV and physical exercise. These unhealthy eating habits and external drivers in the surrounding environment form a detrimental combination that increases metabolic syndrome and nutrition-related chronic disease risk (Figure 1-2). When considering innovations to reduce chronic disease, the influence innovations have on diet factors should be considered for the transition towards healthy and sustainable diets.

1.4 Chronic disease

Chronic disease accounts for 71% of deaths globally. Chronic disease is defined in numerous ways, all with a similar consensus that chronic disease is progressive and decreases the quality of life substantially (World Health Organization, 2021b). Figure 1-3 shows the definitions of chronic disease (Anderson, 2010; McKenna & Collins, 2010; World Health Organization, 2021b).

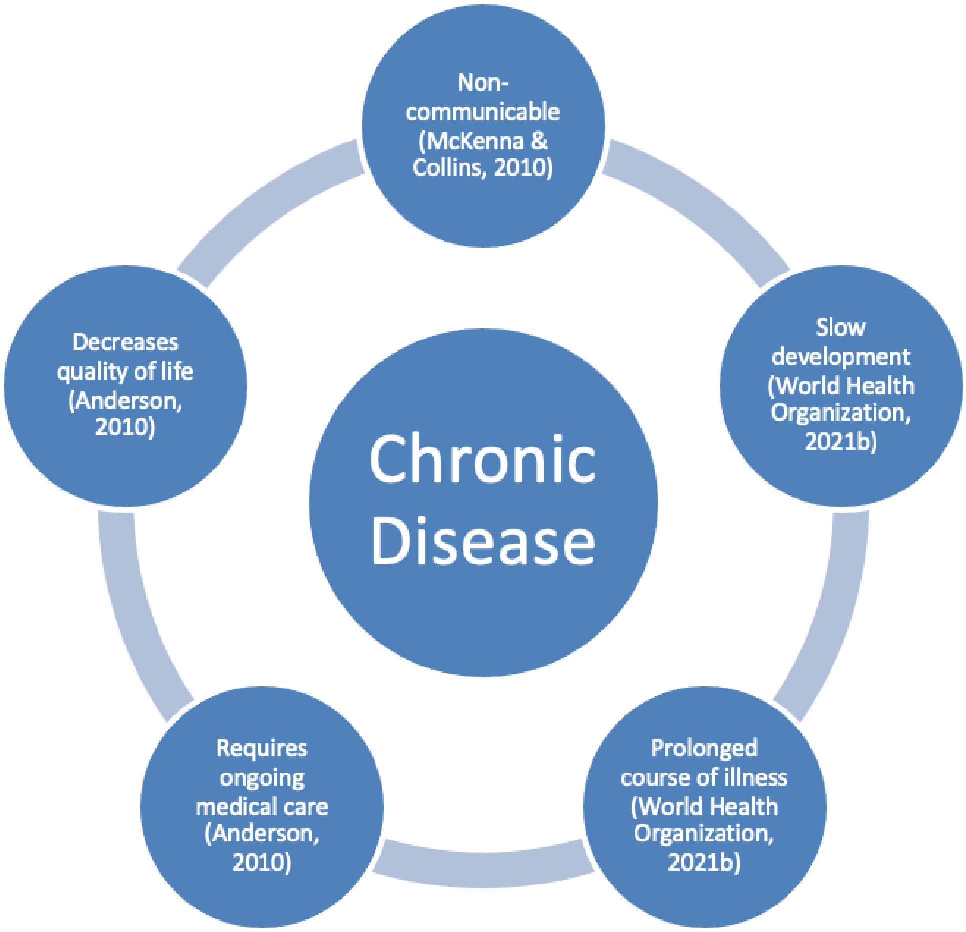

Figure 1-3 Definition of chronic disease.

Many conditions can be placed under the term "chronic disease". Diabetes mellitus, CVD, cancers, and chronic respiratory disease are the most prevalent chronic diseases worldwide. They will be included in this literature review (World Health Organization, 2021b).

A consistent theme between cancer, chronic respiratory disease, CVD, and diabetes mellitus is they share similar nutrition-related risk factors. These nutrition-related risk factors can also be termed metabolic disorders, which can lead to the development of metabolic syndrome (Figure 1-4). Metabolic syndrome is a causative factor for most chronic diseases (Grundy, 2008; O'Neill & O'Driscoll, 2015). Metabolic syndrome is categorised as having three or more metabolic disorders (Figure 1-4) (Grundy, 2016; Rao et al., 2014).

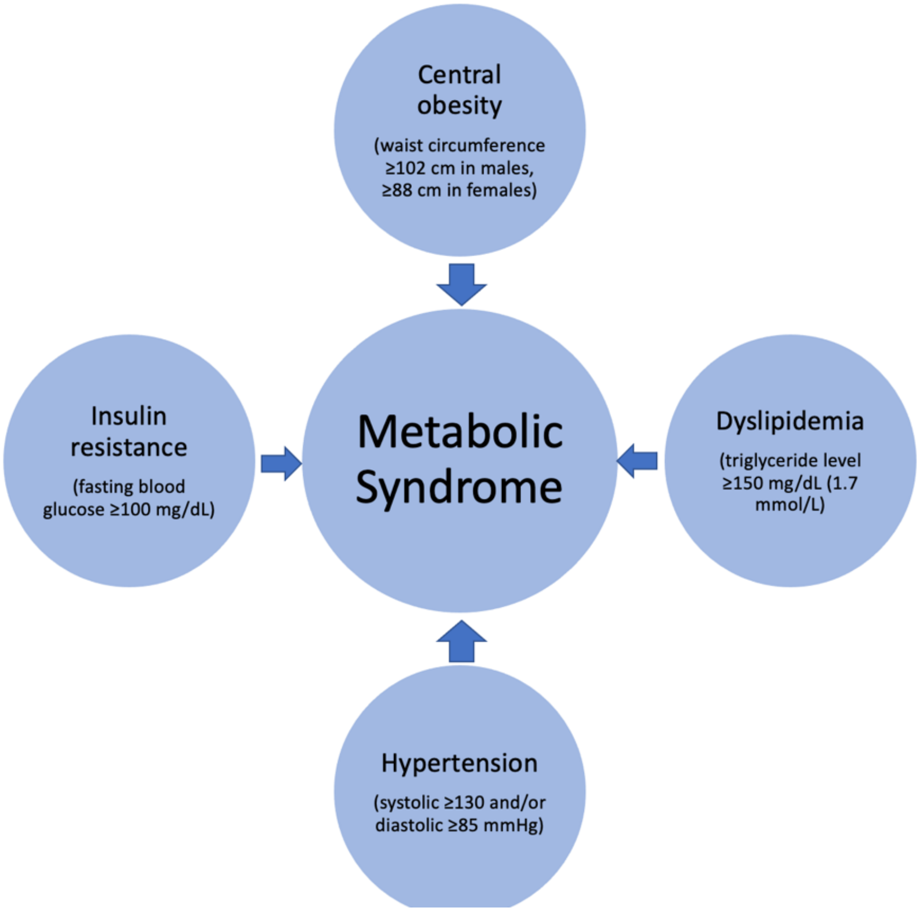

Figure 1-4 Metabolic disorders present in metabolic syndrome (Alberti et al., 2005; Grundy, 2016).

There is minimal information on the prevalence of metabolic syndrome in New Zealand. However, the prevalence in Pacific and Māori populations has been investigated. Results showed that Māori and Pacific populations had a significantly higher incidence of metabolic syndrome than New Zealand Europeans (Friend et al., 2013; Gentles et al., 2007; Grant et al., 2008).

A survey of 11,000 Australians revealed that 13% to 30% of the population had metabolic syndrome, depending on the definition used (Cameron et al., 2007). This wide range indicates that defining metabolic syndrome is challenging, and it is hard to estimate what proportion of populations have it.

1.4.1 Prevalence of chronic disease in New Zealand and Australia

1.4.1.1 Diabetes mellitus

Type 1 diabetes mellitus (T1D) occurs when the body does not produce insulin (Atkinson et al., 2014; Bluestone et al., 2010; Todd, 2010). T2D occurs when the body does not produce enough insulin or does not recognise insulin, causing high blood sugar levels (Chatterjee et al., 2017; Olokoba et al., 2012). This happens due to pancreatic β-cell dysfunction and insulin resistance in the target organs (Chatterjee et al., 2017; Olokoba et al., 2012).

A global burden of disease report revealed that health loss from diabetes mellitus has increased from 1.6% in 1990 to 2.6% in 2019 (Global Burden of Disease Collaborative Network, 2021). The incidence of diabetes mellitus is predicted to grow tremendously, and by 2030 an estimated 400 million people will have T2D worldwide (Wild et al., 2004).

Diabetes mellitus prevalence in New Zealand has stayed relatively stable over the past 10 years. Most recent survey data shows diabetes mellitus prevalence is 5.5% of the population, estimated to be 226,00 adults (Ministry of Health, 2021). However, it has been reported that by 2040, 7% of the total population (approximately 430,000 people) will have T2D (Price Waterhouse Coopers, 2021).

Diabetes mellitus prevalence is also increasing in Australia. Data released stated that approximately 1 in 20 Australians had a form of diabetes mellitus, and 4.1% of the population suffered from T2D in 2017-18 (Davis et al., 2018). The prevalence of diabetes mellitus has increased from 3.3% in 2001 to 4.9% of the total population in 2018-19 (Australian Institute of Health and Welfare, 2018). A predicted two million Australians would have diabetes mellitus if current trends continue (Magliano et al., 2009).

The predicted increased prevalence of diabetes mellitus in New Zealand and Australia has been influenced by increased obesity rates. The most recent New Zealand Health Survey found that 34% of adults were obese, which increased by 3% from the previous year (Ministry of Health, 2021). Obesity trends in Australia are also growing, with approximately 30% of adults being obese (Australian Institute of Health and Welfare, 2020d). Obesity has a significant role in a triad of factors that cause metabolic syndrome (Després & Lemieux, 2006; Engin, 2017; Tchernof & Després, 2013). Metabolic syndrome has been shown to contribute to the increased risk of T2D in numerous reviews solidifying its position in the development of chronic diseases (Eckel et al., 2005; Ford et al., 2008; Wilson et al., 2005).

1.4.1.2 Cardiovascular disease

CVDs are a group of heart and blood vessel disorders that can increase the risk of heart attack or stroke (Gaziano et al., 2006). The health and independence report 2020 reported that CVD accounted for 15.1% of all health loss in New Zealand (Ministry of Health, 2022). Ischaemic heart disease and stroke are the leading CVDs in New Zealand. Stroke prevalence in 2018-19 was 1.6% of adults, and this prevalence has not varied over the past 10 years (Ministry of Health, 2022). In 2017-18, in Australia, 6.2% of the population suffered from heart, stroke, or vascular disease (Australian Institute of Health and Welfare, 2021d). In 2019 the government reported that 25% of all deaths were due to CVD (Australian Institute of Health and Welfare, 2021d).

Numerous meta-analyses have shown metabolic syndrome can significantly increase the development of CVD (Galassi et al., 2006; Grundy, 2016; Lakka et al., 2002; Mottillo et al., 2010; Qiao et al., 2007). One review showed that metabolic syndrome could double the risk of CVD and a 50% increased risk of all-cause (Mottillo et al., 2010). A decreasing trend of CVD is seen in New Zealand and Australia, and the two countries have similar rates. However, an increasing number of those at risk of developing CVD globally (Dahlöf, 2010). The main risk factors associated with CVDs is nutrition related. Nutrition-related risk factors connected to CVD are cholesterol, overweight or obesity, smoking, diabetes mellitus and high blood pressure. All these factors are involved in developing metabolic syndrome (Berry et al., 2012; May et al., 2012).

1.4.1.3 Cancer

Cancer is a group of chronic diseases where the body’s cells divide and grow uncontrollably (Sung et al., 2021). Cancer can cause tumours, damage the immune system, and often be fatal. All cancers combined are the leading cause of death worldwide (Jemal et al., 2010; Sung et al., 2021).

Over the last decade, the mortality rate for all cancers has declined in New Zealand and Australia (Australian Institute of Health and Welfare, 2021b; Ministry of Health, 2021). In 2017-18, 1.8% of Australia’s population suffered from cancer, accounting for 18% of the country’s total disease burden. Although cancer rates are declining, there is an increased number of people living with cancer, indicating that cancer is not being treated but the management of cancer has improved. This means that the disease burden in both countries is expected to rise in the future (Australian Institute of Health and Welfare, 2021a).

Common nutrition-related cancer risk factors are overweight or obesity from a diet high in SFA, sugars and processed foods (Dossus & Kaaks, 2008; Key et al., 2004). Australia has estimated nearly half of the country's cancer burden is due to personal and behavioural risks (Australian Institute of Health and Welfare, 2021b). A review of New Zealand's lifestyle factors contributing to colorectal cancer incidence has shown consuming processed meat, smoking, obesity, and physical activity can significantly impact the incidence of colorectal cancer in New Zealand (Richardson et al., 2016).

It is now evident the insulin resistance and the role of insulin-like growth factor 1 (IGF-1) seen in metabolic syndrome can play a role in several types of cancer development such as colorectal, breast, endometrial, pancreas and liver (Calle & Kaaks, 2004; Hernandez et al., 2015; Uzunlulu et al., 2016).

1.4.1.4 Chronic respiratory diseases

Chronic respiratory diseases are diseases of the airways and structures of the lung (World Health Organization, 2021a). The most common respiratory diseases are chronic obstructive pulmonary disease (BMI: body mass index

COPD), asthma and bronchiectasis (World Health Organization, 2021a). Asthma is more prevalent in children, with 15.5% of New Zealand children having asthma and on medication in 2020 (Ministry of Health, 2022). Respiratory disease is the third most common cause of death in New Zealand and has one of the highest hospitalisation rates compared to other chronic diseases (Telfar Barnard, 2021).

BMI: body mass index

COPD prevalence in Australia was estimated to be 2.5% of the population and was the fifth leading cause of death in 2017-18. In Australia, hospitalisation rates for BMI: body mass index

COPD were the highest compared to other chronic diseases (Australian Institute of Health and Welfare, 2020b).

Rates of BMI: body mass index

COPD have been decreasing over time which has been attributed to a reduction in smoking rates (Australian Institute of Health and Welfare, 2020c). However, there are periods when this incidence has fluctuated, and smoking rates do not reflect this pattern. This indicates other risk factors are associated with respiratory diseases, such as being overweight or obese caused by poor diet (Australian Institute of Health and Welfare, 2020c).

Metabolic syndromes' role in chronic respiratory conditions is not as clear-cut as CVD and diabetes mellitus; however, a systematic review showed a correlation between metabolic syndrome and BMI: body mass index

COPD, mainly due to central obesity and hyperglycemia disorders (Cebron Lipovec et al., 2016). There is also evidence that metabolic syndrome can be a risk factor for respiratory disease through systemic inflammation and physical inactivity (Watz et al., 2009). Overconsumption of energy can drive obesity and increase the risk of chronic respiratory disease and adverse outcomes (Guerra et al., 2002; O'Donnell et al., 2015; Peeters et al., 2003; Poulain et al., 2006). There is also an increased mortality rate if underweight due to the increased energy requirement in chronic respiratory diseases (Eisner et al., 2007; Flegal et al., 2007; Schols et al., 2005). Minimal literature on the exact nutrients that increase the risk of chronic respiratory diseases exists. Still, literature has revealed that chronic respiratory disease is affected by overall energy consumption.

1.4.1.5 Summary

Diabetes mellitus, CVD, cancer and chronic respiratory disease are prevalent in New Zealand's and Australia's populations. Reviewing the literature revealed a strong relationship between metabolic syndrome, obesity and the development of chronic disease prevalence, which has already been discussed to have a high correlation with diet factors influenced by the food environment. Chronic disease affects poor health outcomes, including health loss, ethnic inequities and economic outcomes, all driven by external factors.

1.5 Societal outcomes from chronic disease

Chronic disease contributes significantly to health loss and economic outcomes in New Zealand and Australia. Chronic disease can disproportionally affect different populations, so it is vital to investigate the differences in health outcomes between Māori and non- Māori in New Zealand and indigenous and non-indigenous people in Australia in chronic disease before discussing future research. It is essential to consider the impact of chronic disease on health outcomes and ethnicities within these countries to achieve a greater understanding.

1.5.1 Health loss

The impact of chronic disease on Australia and New Zealand can be looked at from the perspective of health loss. Health loss is the gap between a population's actual health and ideal health. A way to measure disease burden and health loss is by assessing disability-adjusted life years (DALYs). Chronic disease contributes approximately 16,000 DALYs per 100,000 people in 2019 (Global Burden of Disease Collaborative Network, 2021). These numbers have had minimal change since 2015. Chronic diseases are among the top 10 contributors to health loss worldwide (Global Burden of Disease Collaborative Network, 2021). Chronic disease comprises 80% of New Zealand and Australia's health loss (Global Burden of Disease Collaborative Network, 2021). DALYs from dietary risks are the second-highest risk factor in New Zealand and the third-highest risk factor in Australia (Australian Institute of Health and Welfare, 2020a; Ministry of Health, 2020). These results show that if dietary risk factors can be reduced, New Zealand and Australia's DALYs would significantly reduce and the population's health would impove.

1.5.2 Ethnic inequities and chronic disease

From investigating sub-populations within New Zealand, statistics show evident disparities between Māori and non- Māori populations and the prevalence of chronic diseases. The death rate of Māori from ischemic heart disease was almost double that of non- Māori and accounted for 30% of death per 100,000 population in 2018 (Ministry of Health, 2022). Māori death rates from diabetes mellitus were four times higher than non- Māori in 2018 (Ministry of Health, 2022). Māori and Pacific adult populations have a two to three times higher prevalence of T2D compared to New Zealand Europeans (Ministry of Health, 2021).

Ethnic inequities also exist in cancer mortality. Cancer mortality risk for Māori is significantly higher in lung, stomach and breast cancers than non- Māori (Ministry of Health, 2022). Chronic respiratory disease is more prevalent in Māori populations. Results have shown that Māori are twice as likely to be hospitalised due to asthma. BMI: body mass index

COPD was approximately three times higher than non- Māori populations (Ministry of Health, 2021).

Australian chronic disease statistics also show ethnic inequities in chronic disease prevalence. BMI: body mass index

COPD prevalence among indigenous people is 2.3 times higher than among non-indigenous people, and indigenous people are three times as likely to have diabetes mellitus than non-indigenous people in Australia (Australian Institute of Health and Welfare, 2020b). Indigenous populations are also 14% more likely to be diagnosed with cancer, and their survival rates are lower than non-indigenous populations (Australian Institute of Health and Welfare, 2021b). CVD rates in indigenous adults are 6% higher than in non-indigenous adults. Indigenous adults have much higher hospitalisation rates from CVD and 1.5 times higher mortality rates from CVD than non-indigenous Australians (Australian Institute of Health and Welfare, 2015).

A review of the prevalence of chronic disease between non-Māori and Māori has shown inequities in the four major chronic diseases in New Zealand. Differences in chronic disease prevalence between indigenous and non-indigenous populations in Australia were also established. These inequities must be considered when identifying what is being invested in and future implications for reducing the burden of chronic disease in New Zealand and Australia.

1.5.3 Economic outcomes

Chronic disease enormously impacts populations and individuals from an economic perspective. The cost of illness defines the value of resources spent on health and chronic disease. The cost of illness in New Zealand is estimated to be more than $100 million for each condition or risk factor per year. In Australia, CVD alone cost the economy $10.4 billion in 2015-16 (Australian Institute of Health and Welfare, 2021c).

There are also macroeconomic impacts of chronic disease. Chronic disease negatively impacts gross domestic product (GDP) due to health care expenditure associated with chronic disease causing economic losses worldwide (Abegunde & Stanciole, 2006). More frequent and extended hospital stays are associated with chronic disease, contributing to the financial burden of chronic disease further (Arsenault-Lapierre et al., 2021).

Chronic disease imposes a severe economic burden on individuals and families of those with chronic disease and those who require long-term management. As well as the financial costs associated with chronic diseases, there is a decreased quality of life with established disease (Suhrcke et al., 2006).

These findings show a tremendous economic impact of chronic disease on health resources, macroeconomics, and on families and individuals due to chronic illness, which is relevant to New Zealand and Australia.

1.5.4 Summary of health outcomes and chronic disease

Chronic disease impacts populations and imposes a significant economic burden on countries. When quantified by DALYs and GDP, this puts the impact on Australia and New Zealand into perspective. Ethnic inequities in chronic disease reflect the disparities seen in external drivers of chronic diseases, such as socio-economic drivers. These health outcomes solidify the need for targeted innovations to reduce the burden of nutrition-related chronic disease with the consideration of external drivers of chronic disease and diet factors.

1.6 Significance of research

Results from this scoping review can be used to understand what food science and technology are currently invested in to reduce chronic disease outcomes in New Zealand and Australia. This research can detail where future research is required to reduce chronic disease in New Zealand and Australia. Food science and technology can inform future trends affecting the accessibility, affordability and availability of a healthy and sustainable lifestyle, thus impacting these populations' health.

This chapter introduced the thesis topic and the significance of this research. The theoretical framework was discussed so that the relationship between chronic disease, diet and health outcomes could be understood. In the next chapter, external drivers of chronic disease will be discussed to aid in identifying current and future food science and technology that can improve health in Australia and New Zealand.

CHAPTER 2 Literature Review

2.1 External drivers of chronic disease

This literature review aims to identify factors driving chronic diseases in New Zealand and Australia. The surrounding environment strongly influences health and correlates with diet, obesity, metabolic syndrome, and chronic disease. Reviewing these external factors will inform where future research should be implemented to reduce the risk of nutrition-related chronic disease. Due to such a broad scope of drivers that can be covered, this literature review focuses on environmental, political, and socio-economic factors (Figure 2-1).

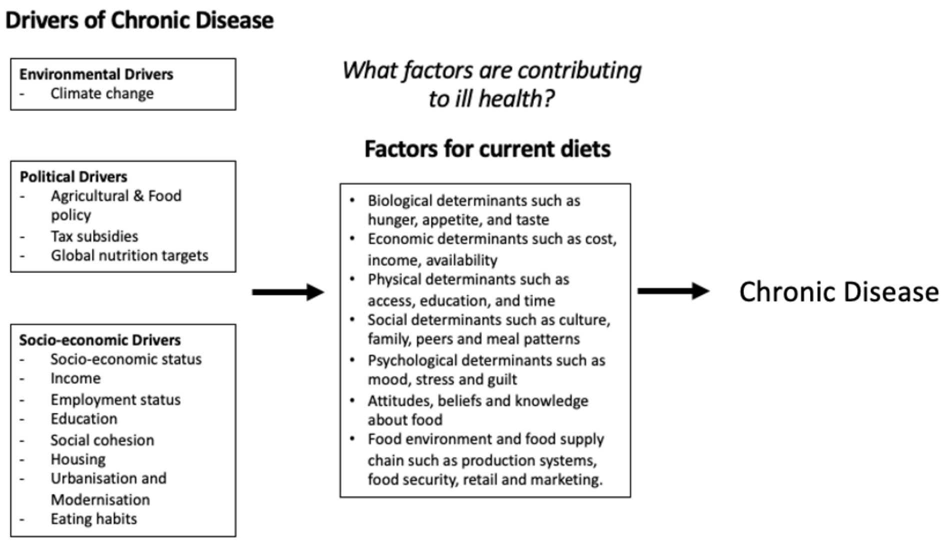

Figure 2-1 Relationship between drivers and factors of chronic disease.

2.1.1 Environmental drivers

Climate change is a well-documented threat to health and chronic disease worldwide (Costello et al., 2009; McMichael & Lindgren, 2011; Watts et al., 2015; Watts et al., 2021). The impact of climate change on food and nutrition availability and chronic disease is of particular interest in this literature review.

New Zealand and Australia's sea and air temperatures will increase, resulting in increased extreme heat events and fewer cold periods. Rainfall is expected to decrease (Royal Society, 2017). However, it is likely that when rain does occur, it will be heavy. Climate change can affect exposure to heat waves, weather events, flooding, and fires. There are also indirect environmental effects of climate change, such as exposure to microbial contamination, pollen, and air pollutants (Royal Society, 2017).

Climate-sensitive infectious diseases in Australia have been predicted to increase chronic disease rates and the disease burden, especially in areas of low socio-economic status (Weaver et al., 2010). Food consumption and sustainability have been investigated in Australia, and it was proposed that environmental recommendations should be created alongside intake recommendations to have a synergistic effect (Friel et al., 2014; Hoek et al., 2017).

This predicted climate change will have a flow-down effect and disrupt health services, cause socio-economic deprivation, and create health inequity. Climate change could impact the nutritional quality of the diet and increase metabolic factors associated with chronic disease. Food security is also indirectly affected by climate change which causes reductions in food availability, with fruit and vegetable (FV) availability already being impacted (Costello et al., 2009; Royal Society, 2017).

2.1.2 Political drivers

A key prevention strategy for chronic disease is to create policies that eliminate risk factors associated with chronic disease (Beaglehole & Yach, 2003; Gaziano et al., 2007; Thow et al., 2010). One aspect that can targeted for prevention is addressing the diet of New Zealand and Australians and implementing policies that seek to improve the nutrition of these populations. Policies strongly influence production systems involved in the food supply chain by dictating what food can be produced and, therefore, what food is available for consumers to choose from which can reduce chronic disease (Afshin Sur, et al., 2019; Gordon-Larsen, 2014; Hawkes, 2006; Malik et al., 2013; Young & Hobbs, 2002).

The WHO sets global targets for nutrition to reduce chronic disease, mainly focusing on overweight and obesity in children for 2025 (World Health Organization, 2014). Australia has recently introduced The National Preventative Health Strategy 2021-2030 policy, which aims to improve Australians' health through prevention and minimise determinants of health over the next 10 years (Department of Health, 2021a).

Australia and New Zealand share many similar initiatives, such as the Health Star Rating, nutrient reference values, dietary guidelines, and food formulation voluntary targets (Capra, 2006; Federal Register of Legislation, 1991; Food Standards Australia New Zealand, 2015, 2021a).

New Zealand has a healthy food and drink policy to target obesity and promote good health to reduce the prevalence of chronic diseases (National District Health Board Food and Drink Environments Network, 2019). This policy encourages a healthy food environment for all health sector facilities, contractors and staff (National District Health Board Food and Drink Environments Network, 2019). Australia has a similar policy, but this only applies to public schools (Department of Education, 2014).

There are no policies in New Zealand or Australia to reduce sodium intake. There are only optional reduction targets that The Heart Foundation New Zealand supports (The Heart Foundation, 2021). Processed foods are also largely unregulated, and there are no limits to salt or sugar in products manufactured in New Zealand. Australia has a partnership reformulation program that includes sodium reduction in its goals which is also voluntary (Department of Health, 2021b).

Tax and subsidy interventions to reduce the consumption SSBs are recommended by the WHO to reduce the burden of chronic disease (World Health Organization, 2017). An SSB tax has already been shown to improve the diet and reduce SSB consumption in Chile, Mexico, and the United Kingdom (Colchero et al., 2016; Nakamura et al., 2018; Pell et al., 2021). Modelling is currently underway in New Zealand and Australia (Veerman et al., 2016). Paying an extra fee to consume SSBs will increase the awareness of the price and will influence consumers' food choices to select a lower sugar drink.

Australia and New Zealand have the Food Standards Australia New Zealand Act 1991, which is national legislation that aims to protect public health and safety and ensure the population is informed when making choices about what they consume and that they are not misled by food companies (Federal Register of Legislation, 1991). Food Standards Australia New Zealand governs this legislation to uphold the act.

The Children and Young People's Advertising Code was introduced in New Zealand by the Advertising Standard Authority in 2017 (Advertising Standard Authority, 2017). This was implemented to limit children's exposure to unhealthy food marketing (Advertising Standard Authority, 2017). Recent research has shown that complaints to companies breaking this code are not being upheld, and food marketing continues to be unregulated (Swinburn & Vandevijvere, 2017).

In 2018, the Food Industry Taskforce on Addressing Factors Contributing to Obesity released that the main areas to focus on to reduce obesity are food and beverage reformulation, marketing and increased labelling of products such as the Health Star Ratings (Food Industry Taskforce, 2018).

Policies impact the food environment and supply chain and form factors for current diets. Policies can promote food reformulation and change in production systems. For example, with the healthy food and drink policy, retail outlets follow this guideline and supply in alignment with this policy. This policy influences what people purchase and eat. This will also cause retail outlets to buy the food they can sell, and suppliers must adjust production to suit. Reviewing the literature on policies in New Zealand and Australia has shown that there are already many policies working towards global targets to reduce the burden of nutrition-related risks of chronic disease and promote a healthy food environment for these populations through the alteration of factors for current diets.

2.1.3 Socio-economic drivers

Socio-economic drivers of chronic disease are complex and contain multiple domains that contribute to chronic disease prevalence. This driver includes socio-economic status, income, employment status, education, housing, urbanisation and modernisation. These socio-economic factors influence current diets and eating habits in New Zealand and Australia, which flow down and determine the risk of chronic disease. Socio-economic factors strongly influence the food environment (Vlismas et al., 2009). Those of lower socio-economic status have less money available to spend on food and therefore tend to purchase processed foods which are cheaper and have higher amounts of sugar, salt and fat, rather than more expensive, higher nutritional quality foods (Darmon & Drewnowski, 2015; Drewnowski & Darmon, 2005).

2.1.3.1 Socio-economic status

Socio-economic status can strongly determine chronic disease outcomes in New Zealand and Australia. Cancer mortality rates of those in the most disadvantaged areas in Australia are over 40% higher than those most advantaged (Australian Institute of Health and Welfare, 2021b).

A systematic review including Australia has shown that those of lower socio-economic status are at a greater risk of significant risk factors for chronic diseases such as obesity, physical inactivity and smoking (Stringhini et al., 2017). Lower socio-economic status was associated with increased chronic disease risk factors such as smoking, alcohol abuse, physical inactivity, and excess weight in Australia (Glover et al., 2004). However, the study found that chronic disease prevalence differed depending on the chronic disease (Glover et al., 2004). Food security and socio-economic status are strongly correlated and result in low consumption of FVs and economic constraints (Ministry of Health, 2019). Therefore, contributing to the disparities seen between socio-economic status and chronic disease.

Statistics in New Zealand show similar results when comparing the most and least deprived populations. The 2020-21 health survey showed ischemic heart disease is twice as prevalent in most deprived areas (Ministry of Health, 2021). The same study revealed diabetes mellitus is over three times more prevalent in most deprived areas than in the least disadvantaged areas (Ministry of Health, 2021). Asthma and body max index (BMI) are also significantly lower in areas of high deprivation (Ministry of Health, 2021).

There is a strong relationship between poor health choices and increased retail and marketing exposure (Pearce et al., 2007). In areas of high deprivation in New Zealand, there are more fast-food outlets compared to other regions (Pearce et al., 2007). This drives an obesogenic environment in areas of high deprivation. However, healthy foods available at outlets such as supermarkets in New Zealand were highly prevalent in these areas (Pearce et al., 2007). This suggests food availability in these areas is one of many factors influencing food choices.

Reviewing current chronic disease statistics has revealed a strong relationship between areas of deprivation and shaping the food environment. Socio-economic status influences chronic disease prevalence by determining food accessibility to fast-food outlets and supermarkets and influencing marketing exposure driving an obesogenic environment.

2.1.3.2 Income

Income is strongly linked to food security, and lower-income groups have decreased food security which can determine chronic disease outcomes (Nord et al., 2010). A case-control study was conducted in Auckland to determine the relationship between income and chronic disease (Brown et al., 2005). Average household income in New Zealand was the most significant influence on chronic disease and was a predictor for early-onset stroke (Brown et al., 2005). Income level was also shown to predict obesity and smoking. Community income was examined, and it was found this could also be a predictor of smoking, obesity, heart disease, and diabetes mellitus (Brown et al., 2005). Although cancer survival rates are gradually increasing, there is a difference in survival rates between high-income and low-income populations in New Zealand. In 2018, 29% of all deaths in New Zealand were from a type of cancer (Ministry of Health, 2022).

The cost of a healthy diet recommended by the Australian Dietary Guidelines is less affordable for low-income households, driving food insecurity in Australia (Lee et al., 2020). Low-income groups also spend more of their disposable income on food (Lee et al., 2020). There is a rising price of FVs in New Zealand and Australia, which increases the burden of gaining adequate nutrition and limiting food choices (Department of Agriculture Water and the Environment, 2022; Stats NZ, 2021). Time constraints also contribute to higher food expenditure in low socio-economic areas (Venn et al., 2018).

This relationship between income, time, food affordability and food insecurity are critical factors driving chronic disease in New Zealand and Australia. Current literature has shown both populations struggle to meet diet recommendations, thus influencing differences between income status and their risk of chronic disease.

2.1.3.3 Employment status

Employment status is a strong predictor of income and socio-economic status. Unemployment decreases physical health, mental health and health status, which increases chronic disease outcomes (McKee-Ryan et al., 2005; National Health Committee, 1998; Yildiz et al., 2020). On the other hand, employment can improve social status, enhance community participation, and improve health and well-being (Modini et al., 2016; Virtanen et al., 2002). Employment also contributes to social cohesion and brings people together (Modini et al., 2016). Australia has claimed to have a higher social cohesion than New Zealand, but it will be challenging to maintain this due to the country's rapid growth and increased social pressures (Australian Human Rights Commission, 2015).

Reviewing employment status in New Zealand and Australia has revealed that employment status is an indicator of health through influencing income, social cohesion, health, and well-being.

2.1.3.4 Education

Education is critical in determining people's health and social position (Choi et al., 2011). The importance of having nutrition education surrounding healthy eating has been reviewed (Pem & Jeewon, 2015). When nutrition education is provided, it was found that this can significantly improve behaviour and indicators for chronic disease (Pem & Jeewon, 2015). Unfortunately, there is limited literature on New Zealand and Australia's nutrition education levels and their interaction with chronic disease. Education can impact populations' awareness of the impacts of their food choices. Studies have shown higher educational attainment is correlated with a healthier diet and higher consumption of FV (Azizi Fard et al., 2021). Lower education level has been associated with increased sugar and red meat intake (Azizi Fard et al., 2021).

The relationship between education and chronic disease could be due to the relationship between education and socio-economic status (Marks et al., 2006; Thomson, 2018). Therefore, education level could be more determinant of socio-economic status than chronic disease.

2.1.3.5 Housing

Housing is another social determinant of chronic disease prevalence. Housing characteristics can predict socio-economic status (Dunn, 2002; Juhn et al., 2011; Macintyre et al., 2003; Shaw, 2004). A New Zealand study assessed housing conditions (crowding, dampness, mould, and injury hazards) between 2010-17 and related this to health disorders (Riggs et al., 2021). The study concluded that wet and mouldy housing increased the disease burden in New Zealand (Riggs et al., 2021). Health outcomes and the quality of houses were studied in Australia (Baker et al., 2016). Those who live in poor-quality housing have adverse health effects and have a higher risk of chronic disease (Baker et al., 2016). The literature shows that housing is another key determinant of socio-economic status in Australia and New Zealand and contributes to the development of chronic disease through the effects of housing quality.

2.1.3.6 Urbanisation and modernisation

A study in urban areas of New Zealand on the food environment was undertaken over 10 years (Hobbs et al., 2021). Although there was minimal change in fast-food outlet access, this research found supermarkets are becoming more accessible in areas of high deprivation (Hobbs et al., 2021). A study in Australia found that discretionary foods allocate shelf space was more significant in areas of higher deprivation. Therefore, increased supermarket availability does not necessarily mean increased availability of healthier foods (Schultz et al., 2021).

Rural versus city location has also been examined in Australia (Black et al., 2012). This study found that long-term urban residents in Australia were more likely to have a chronic disease than those living in rural locations. This higher incidence in urban areas was due to higher environmental stressors (Black et al., 2012).

Modernisation also influences the food supply chain. An analysis of Australia's food supply chain has shown a greater demand for convenience foods, and households have a smaller budget for food (Department of Agriculture, 2012). This infers it is becoming increasingly challenging to meet consumer demand cost-effectively. There is an increased frequency of eating meals out and shopping trip frequency in Australia (Department of Agriculture, 2012). Retailers respond to these trends and market their products to suit consumer behaviour. These trends promote unhealthy diets towards fast-foods due to an increased need for convenience at a decreased cost.

New Zealand and Australia's food environments constantly evolve with urbanisation and modernisation, impacting the population's health. There is a disproportion in the availability of food throughout urban and rural areas in New Zealand. A study found that healthier foods were more available in urban areas but more expensive than in rural areas (Wang et al., 2010). In Australia, access to supermarkets and fast-food outlets in urban areas influenced access to a healthy diet (Burns & Inglis, 2007).

Modernisation has influenced an open food market resulting in a change in food service sectors throughout New Zealand and Australia (Baker & Friel, 2016). A transition from traditional whole foods to overly processed foods and the over-promotion of unhealthy foods has become increasingly prevalent over the past decade (Baker & Friel, 2016).

Urbanisation and modernisation impact chronic disease prevalence by influencing the food supply chain, determining access to fresh food and supermarkets and the cost of a healthy diet, shifting the diets of those in urban areas,

2.1.3.7 Eating habits and socio-economic factors

New Zealanders are consuming meals out of the home more frequently, which could decrease kitchen sizes in homes, resulting in even less cooking at home (The Restaurant Association of

New Zealand, 2018). This finding aligns with urbanisation and the decreasing size of houses, leaving less room for a fully functioning kitchen (The Restaurant Association of New Zealand, 2018).

It has been shown that healthy homemade meals are cheaper than ordering takeaway meals (Mackay et al., 2017). Even when adding the cost of time to prepare meals, half of the homemade meals were more affordable than takeaway options in New Zealand (Mackay et al., 2017). This shows that making home-cooked meals is cost-friendly if time is invested into cooking these meals over choosing takeaways for convenience.

The frequency of family meals was studied in Pacific communities in New Zealand (Utter et al., 2008). Results showed having family meals at home was associated with a positive food environment and nutrition behaviours, such as increased FV intake in adolescents. Findings also show an inverse relationship between eating at home and the consumption of high-sugar and fatty meals, indicating that eating in a home environment could limit the consumption of foods high in sugar and fat in Pacific populations (Utter et al., 2008).

The Australian population shows similar meal habits. Skipping breakfast was correlated with a less adequate diet than adults who did not skip breakfast in an Australian study (Williams, 2005). A cross-sectional study in Australia investigated main meal patterns and accounted for factors such as education level, BMI and age group. This study found those of a higher education level in all age groups cooked a wider variety of meals than those of lower education (Wang et al., 2013). Snacking frequency has also increased over time in Australia of fruit as snacks and less discretionary foods. Snacking now contributes significant energy to the typical Australian diet (Fayet-Moore et al., 2017).

Studies in both New Zealand and Australia on eating habits have shown factors associated with socio-economic status can significantly impact dietary outcomes related to chronic disease due to the transition towards less nutritious diets with increased snacking, skipping meals and the increased tendency to eat out rather than at home.

2.1.3.8 Summary

Socio-economic factors are substantial external drivers of chronic disease. There is a causal pathway between socio-economic factors and health status. Socio-economic status influences the ability to gain employment, social cohesion, education, housing, and income. New Zealand

and Australia are constantly evolving, and food environments are heavily impacted by modernisation, urbanisation, and eating habits.

2.1.4 Conclusion and scoping review rationale

There is a complex interplay between environmental, political and socio-economic drivers of chronic disease and food availability, food accessibility and food affordability. External factors drive eating habits, affecting diet factors and ultimately determining chronic disease risk in New Zealand and Australia (Figure 2-1). If these driving factors can be addressed and minimised early, the outcomes can flow down and reduce chronic disease outcomes. Due to the link between metabolic syndrome, obesity, and an unhealthy diet, it is also essential to consider the main aspects of the diet that influence metabolic syndrome and chronic disease. Dietary factors influencing nutrition-related chronic disease are sugar, fat, sodium, ultra-processed and fast-food intake, and a sedentary lifestyle. These diet factors can be used with information on external drivers of chronic disease to inform future trends and innovations towards reducing the risk of diet-related chronic disease.

It needs to be clarified what information is available in the literature about food service and technology trends and what impact this has on diet outcomes and nutrition. For these reasons, a scoping review was conducted to map research in this area, identify gaps in knowledge, and inform recommendations for future research.

This chapter summarised and evaluated the literature supporting the research question of environmental, political, and socio-economic factors contributing to chronic disease in Australia and New Zealand. This chapter supports the research aim to investigate current and future food science and technology trends to improve health in these populations. The methodology of the scoping review used in this thesis project will be specified in the next chapter.

CHAPTER 3 Methodology

3.1 Methodological approach

The methodological framework for this study was a scoping review. Scoping reviews are for research that seeks to identify available evidence and highlight knowledge gaps in a specific area. (Munn et al., 2018; Tricco et al., 2018). Scoping reviews bring together knowledge on a given topic, look broadly at articles, inform understanding of current research and provide a basis for further research. Scoping reviews are not deep or specific; they look at the big picture to find out what we know about a subject (Aromataris & Pearson, 2014). A scoping review can also identify unpublished papers and grey literature that is often not part of a systematic review process (Levac et al., 2010).

This research suited a scoping review as it aimed to identify current evidence, key characteristics, and knowledge gaps in the food science and technology field in New Zealand and Australia. This scoping review can guide how to apply research, develop policies and be a starting point for where resources should be spent (Armstrong et al., 2011). Consumers of interest in scoping reviews can be researchers looking to identify research needs and can direct people to topics and concerns in certain areas. Scoping reviews can also stimulate clinicians thinking and serve as a guide to giving the latest information and research to consumers and patients.

This scoping review followed the most recently updated 2020 Joanna Briggs Institute (JBI) scoping review guidance (Peters et al., 2020) and the Preferred Reporting for Systematic review and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) (Tricco et al., 2018). This scoping review framework follows a nine-step process detailed in Table 3-1.

Table 3-1 The nine steps of a scoping review (Peters et al., 2020).

Step number	Description
1	Defining and aligning the objective/s and question/s
2	Developing and aligning the inclusion criteria with the objective/s and question/s.
3	Describing the planned approach to evidence, searching, selection data extraction, and presentation of the evidence.
4	Searching for the evidence.
5	Selecting the evidence.
6	Extracting the evidence.
7	Analysis of the evidence.
8	Presentation of the results.
9	Summarising the evidence in relation to the purpose of the review, making conclusions and noting any implications of the findings.

The PRISMA-ScR includes 20 essential items and two optional items to include in a scoping review. This was used with the JBI guide to ensure this research met reporting standards in this scoping review (Appendix 1.) (Peters et al., 2020; Tricco et al., 2018).

Step five in the PRISMA-ScR involves protocol and registration but was not done due to the scoping review being a Master's thesis. Steps 12 and 16 involve a critical appraisal which was not included in this scoping review, so the articles were not discriminated against, and the quality of the articles were not discussed. It was appropriate not to include a critical appraisal due to the aim of the scoping review to identify innovations rather than assess the quality of the innovations.

3.2 Step one: objective and questions

3.2.1 Scoping review purpose

The purpose of this scoping review was to investigate within existing research and grey literature what and how types of food science and technology are currently invested in and how they contribute to reducing chronic disease risk in New Zealand and Australia.

This scoping review provided an understanding of how food science and technology can improve nutrition outcomes and support interventions and future trends to promote healthy and sustainable diets in an available, accessible, and affordable way in New Zealand and Australia to reduce chronic disease.

3.2.2 Objectives

The objectives of a scoping review articulate why the research is conducted, what will be investigated and what the review will add to the current literature in that field (Peters et al., 2020).

The objectives of this research were:

To examine what and how current food science and technology innovations are being invested in to reduce nutrition and chronic disease risk in New Zealand and Australia.

To inform where research is required by identifying gaps in the literature on food science and technology in New Zealand and Australia.

3.2.3 Review question

What food science and technology are currently invested in to improve nutrition and reduce chronic disease risk in New Zealand and Australia?

The research question for this scoping review used the population, concept, context (PCC) framework. The PCC framework is suggested for scoping reviews to indicate to readers the core elements of the review as well as aid in identifying the eligibility criteria and search strategy (Peters et al., 2020). The PCC framework for this scoping review aided in developing the research questions in Table 3-2.

Table 3-2 PCC framework for this scoping review.

Framework variable	Core element
Population	New Zealand and Australia
Concept	Food science and technology
Context	Nutrition and chronic disease risk

3.2.4 Review sub-questions

Sub-questions in scoping reviews aided in outlining how the evidence was mapped. Sub-questions must be answered to meet the review's primary question and objectives (Peters et al., 2020).

The following sub-question was developed:

How can current food science and technology innovations influence environmental, socio-economic and political factors towards improving health in New Zealand and Australia?

3.3 Step two: eligibility criteria

Eligibility criteria consist of inclusion and exclusion criteria (Table 3-3). The criteria specify characteristics of sources of evidence to identify if the evidence will be included or excluded in the scope of the review (Peters et al., 2020). The eligibility criteria were altered and refined to suit the study as it progressed and pilot testing was completed.

Table 3-3 Eligibility criteria for the scoping review.

Criterion	Inclusion	Exclusion
Publication time period	Studies published from 2018 to 2022	Studies published outside of the inclusion dates
Language	English.	Non-English
Type of article	All types of evidence including grey literature	N/A
Study focus	Food science and technology innovations	No reference to food science or technology innovations
Innovation aim	Mentions chronic disease risk or nutrition outcomes	No mention of chronic disease or nutrition outcomes
Geographical area	Studies including New Zealand and/or Australia data	Studies in countries outside of New Zealand and/or Australia
Study population	Healthy or at-risk (metabolic risk factors)	Not a healthy or at-risk population

A period of five years for the publication date was chosen because this review sought to understand current innovations and anything older than five years might have no longer been considered recent or relevant. Only articles written in English were included in this review because the review focused on New Zealand and Australia, which are primarily English-speaking countries. All types of evidence were considered, so the scope of the review was not limited and missed unpublished evidence that was of interest to minimise the study's limitations. The articles included in the review focused on food science or technology innovations in New Zealand and Australia. They aimed to impact the four most prevalent chronic diseases in New Zealand and Australia and nutrition outcomes. Since this review focused on New Zealand and Australia, the articles included investigated these populations. The review focused on the populations classified as healthy or at-risk of nutrition-related diseases. At-risk populations were included in the review to avoid excluding potential eligible studies.

3.4 Steps three and four: describing the planned approach to evidence, searching, selection data extraction, presentation of the evidence, and searching for the evidence.

3.4.1 Information sources

Table 3-4 outlines the databases and dates information that was searched. PubMed, Scopus, Medline and Google scholar were searched initially at the end of April 2022. After articles were screened for eligibility from these databases, grey literature was searched via Google in August 2022.

Table 3-4 Information sources.

Database	Date searched
PubMed	27.04.2022
Scopus	27.04.2022
Medline (Ovid)	27.04.2022
Google Scholar	27.04.2022
Google	18.08.2022

3.4.2 Search strategy

Search strategies were derived from the review question and used the JBI three-step search strategy (Peters et al., 2020). This process was followed for the identification of published articles in this review.

An initial limited search of at least two appropriate online databases relevant to the topic was carried out. Analysis of the text words in the title and abstract of retrieved articles and index terms was then used to describe the articles.

A limited search was undertaken on the databases PubMed and Scopus. Index terms and synonyms were identified and organised in categories relating to the scoping review question. The list of terms identified is in Appendix 2.

The second search involved all keywords and index terms across all databases. The terms identified in the second step were combined to develop a search strategy using Boolean operators ‘AND’ and ‘OR. The search strategies for each database were peer-reviewed by the research supervisor.

The following databases, available free through The University of Auckland, were included as resources: PubMed, Scopus, Google Scholar and Medline (Ovid). Examples of search strategies used for PubMed and Scopus are in Appendix 3.

PubMed was selected as it contains articles from all research fields and, therefore, has a broad scope. Scopus was selected as it is the most extensive database for peer-reviewed articles. Google Scholar was selected as it contains literature on science and technology. Google Scholar also contains grey literature, including citations in the articles. Medline (Ovid) contains journal articles from various fields of interest, such as health science, allied health and biomedical science, which was relevant to this review.

The reference list of articles included after abstract screening were also searched for additional sources, including grey literature. Unpublished articles were also searched using the Advances Google search to fill gaps in the published articles. The referencing software Endnote was used to manage the results of the search. The search strategy results were drafted and results exported to EndNote, and duplications were removed.

3.4.3 Selection of sources of evidence

The process in which sources of evidence were selected for all collection stages should be included in a scoping review, as well as the procedures for overcoming disagreements between reviewers to reach a consensus (Peters et al., 2020).

The complete list of articles collected from PubMed, Scopus, Google Scholar and Medline (Ovid) was title screened by the researcher and research supervisor using the eligibility criteria. The researcher and supervisor met at this stage to discuss any discrepancies in the articles included or excluded to form a consensus. Once an agreement was reached, the researcher and supervisor repeated the same process for abstract screening. The researcher then independently assessed the full text of the remaining articles for eligibility and then reviewed the final inclusion list with the supervisor. Studies that did not meet the criteria were excluded; the reason for exclusion is in Figure 4-1.

Grey literature was also screened for eligibility. The reference lists of articles selected for inclusion in the scoping review, and reviews that had been excluded, were screened. The articles that cited the included articles were screened for eligibility. An Advanced Google search was done fill gaps in articles already included. The researcher and supervisor met to discuss the articles found from these techniques before they were included in the scoping review.

3.4.4 Data charting process and data items

Data charting is also termed data extraction and is the part of the review that provides a summary of the results related to the objectives and research questions of the scoping review (Peters et al., 2020). A charting table was designed to record information from the included articles in the review to aid in the analysis of results.

The researcher independently charted the data using Excel, discussed the results with the supervisor and continuously updated and refined the data-charting table to gather all relevant information. Two charts were developed, one for a healthy study population and another for an at-risk study population (Appendix 4). Charting this information allowed uniform comparisons (Table 3-5).

Table 3-5 Data charted for each included article.

Category
Article title
Author(s)
Year of publication
Country of origin
Study design
Participant number and characteristics
Aim of article
Type of food science/ technology innovation
Variables measured
Impact on nutrition biomarkers
Chronic disease prevention risk
Study conclusion

3.4.5 Synthesis of results

Organising the evidence outlined how results were synthesised to collect and answer the research questions and objectives after data charting was complete. Identifying sub-themes in the articles aided in analysing complex data from multiple sources of evidence. The software NVivo was used to determine themes and sub-themes. Articles were coded in the software, allowing comparisons between the articles. Australia and New Zealand articles were combined and categorised into healthy or at-risk populations. Sub-themes identified were nutrition biomarkers measured in each article (Table 3-6).

Table 3-6 Sub-themes identified using NVivo.

Sub-theme
Blood glucose
Plasma insulin
Appetite
Ghrelin and incretin
Lipid profile
Inflammation
CVD risk
HbA1c

Organising the included articles allowed for easy comparison between healthy and at-risk population innovations and their impact on nutrition biomarkers and potential disease risk reduction. Articles were coded in NVivo depending on the sub-themes, and several articles included multiple sub-themes.

Once data was organised into themes and sub-themes, weighted maps were designed via the online platform Visme. Using weighted maps allowed for a visual interpretation of the results, how each sub-theme was related, and how frequently the sub-theme was included in the articles. The weight was calculated by the number of studies that included a sub-theme. These themes and sub-themes were reported to answer the research question. Filtering through the information of each article to accurately identify the nine sub-themes identified was challenging and resulted in missing other potential outcomes. Organising the data this way allowed for identifying how these innovations can be inserted into New Zealand and Australia and what influence the innovations will have on environmental, political, and socio-economic factors in New Zealand and Australia.

Throughout the discussion, comparisons were made between the outcomes of healthy and at-risk populations and nutrition biomarkers within each population. Comparisons aided in assessing each nutrition biomarker's effect. Future implications of the type of innovation were used to identify the potential impact on environmental, political, and socio-economic factors and how these innovations could improve health in New Zealand and Australia. By assessing these results, gaps in the literature were discussed, and what emerging trends food research and development companies in New Zealand and Australia should investigate to improve nutrition-related disease outcomes.

CHAPTER 4 Results

4.1 Step five: selecting the evidence

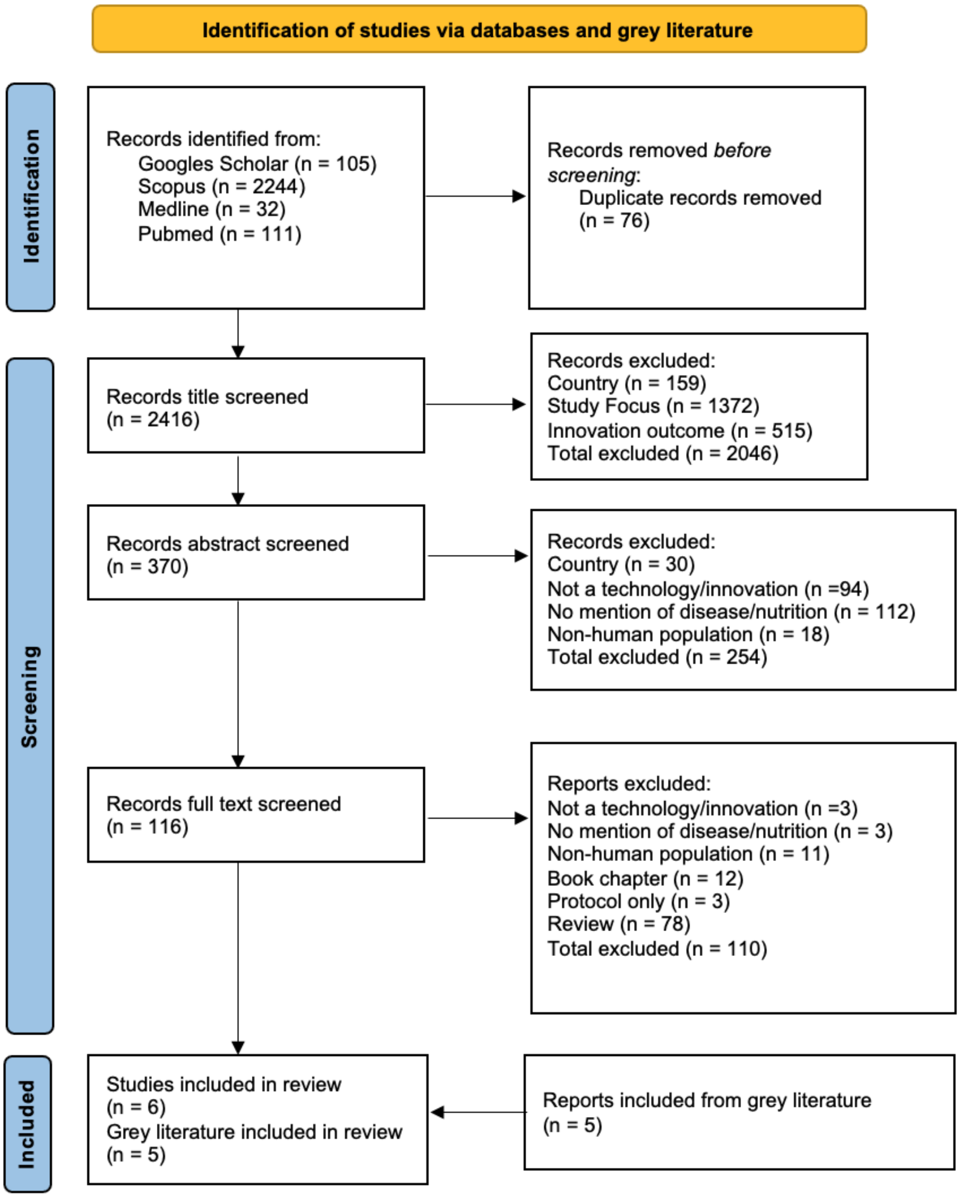

Figure 4-1 PRISMA-ScR flowchart of the study selection process.

After title screening, abstract screening and full-text screening articles for eligibility criteria, six studies met the inclusion criteria. Reference list screening was carried out on the included studies, reviews and book chapters, and various google searches were completed. From these grey literature searches, five studies were added to the scoping review (Figure 4-1). The total number of articles included in this scoping review was 11.

4.2 Steps six and seven: extracting and analysing the evidence

4.2.1 Characteristics of sources of evidence

Out of the 11 studies included in the review, 10 were specific to Australia, and one was specific to New Zealand. For ease of comparison, it was initially decided that articles would be grouped by country. However, since only one study was found specific to the New Zealand population, both countries were considered together. Articles were grouped by the population the innovation investigated. The two population groups were healthy and at-risk. At-risk populations were those with hypercholesterolemia, at risk of CVD, T2D or overweight or obese. Table 4-1 and Table 4-2 gives a brief outline of each included study summarised from charting the data (Appendix 4). This part of the results section relates to objectives by summarising the types of innovations currently being studied that contribute towards reducing the risk of chronic disease, which will also inform research gaps.

Table 4-1 Summary of included studies on healthy populations.

Citation	Population	Innovation	Nutrition biomarkers investigated	Conclusion
(Ang et al., 2020)	Healthy	High-amylose noodles	Postprandial blood glucose	Reduces postprandial glucose response in healthy adults
(Belobrajdic et al., 2019)	Healthy	High-amylose bread	Postprandial blood glucose, plasma insulin, ghrelin and incretin, appetite, inflammation	Lowers glucose and insulin response
(Murray et al., 2018)	Healthy	Polyphenol rich brown seaweed extract	Postprandial blood glucose and plasma insulin	No effect on postprandial glucose or insulin responses
(Murray et al., 2019)	Healthy	Polyphenol extract from algae (Fucus *vesiculosus*)	Postprandial blood glucose and plasma insulin	No effect on postprandial glucose or insulin response
(Thota et al., 2018)	Healthy	Curcumin and fish oil supplementation	Glucose, plasma insulin and triglycerides	Reduces postprandial glucose and insulin in curcumin, not fish oil

Table 4-2 Summary of included studies on at risk population.

Citation	Population	Innovation	Nutrition biomarkers investigated	Conclusion
(Amoah et al., 2021)	At-risk	Vegetable-enriched bread	Blood glucose, plasma insulin and, appetite	Reduced postprandial insulin release and increased fullness
(Ferguson et al., 2020)	At-risk	High molecular weight β-glucan and phytosterols in biscuits	Fasting lipid profile	Complementary effect of lowering cholesterol between oat β-glucan and phytosterols
(Ferguson et al., 2019)	At-risk	Phytosterol and/or curcumin supplemented bread	Fasting lipid profile and, CVD risk	Phytosterols lowers cholesterol, curcumin had no influence on lipid profile
(Ferguson et al., 2018)	At-risk	Phytosterol (fat spread) and curcumin supplementation (tablets)	Fasting lipid profile and blood glucose	Combined supplementation lowered fasting lipid profile
(Murray et al., 2021)	At-risk	200 mg/day powdered F. *vesiculosus* seaweed extract	Lipid profile, blood glucose, plasma insulin, inflammation	No changes in aspects of lipid profile, blood glucose, plasma insulin or inflammation
(Thota et al., 2019)	At-risk	Curcumin and fish oil supplementation	HbA1c, fasting blood glucose and, plasma insulin	Combination reduced insulin and aspects of lipid profile. No difference in blood glucose

4.2.2 Results of individual sources of evidence

Each included article data was extracted and charted as relevant to the review questions and objectives. The complete data charting for the included articles is in Appendix 4.

4.3 Step eight: presentation of the results

4.3.1 Synthesis of results

The studies included in the review were grouped into sub-themes according to the technology or food science innovation studied to aid in answering the review objective to examine what food science and technology innovations are invested in. The results were further categorised into nutrition biomarkers and populations the study investigated to answer how the innovation will reduce nutrition and chronic disease risk. Organising the results in this way allowed for the identification of gaps in the articles. Gaps were identified to understand what food science and technology should be researched in the future, answering the second research objective.

Each innovation measured numerous nutrition biomarkers and fell into multiple categories (Table 4-3, Table 4-4 and Table 4-5). Nutrition biomarkers identified were; blood glucose, plasma insulin, appetite, ghrelin and incretin, lipid profile, inflammation, CVD risk and haemoglobin A1c (HbA1c). Weighted diagrams were generated to visualise how often a nutrition biomarker was investigated for each population (Figure 4-2 and Figure 4-3).

Table 4-3 Nutrition biomarkers investigated in each population.

Nutrition biomarkers	Number of studies on a healthy population (n = 5)	Percentage	Number of studies on an at-risk population (n = 6)	Percentage
Blood glucose	5	38%	4	23%
Plasma insulin	4	30%	3	17%
Appetite	1	8%	1	6%
Ghrelin and incretin	1	8%	0	0%
Lipid profile	1	8%	5	30%
Inflammation	1	8%	2	12%
CVD risk	0	0%	1	6%
HbA1c	0	0%	1	6%

Table 4-4 Study population and innovation investigated.

Innovation	Number of studies on a health population (n = 5)	Percentage	Number of studies on an at-risk population (n = 6)	Percentage
Phytosterols + oat β-glucan enriched biscuits	0	0%	1	16.5%
Curcumin + fish oil supplement	1	20%	1	16.5%
Curcumin + phytosterol spread and bread	0	0%	2	34%
Polyphenol seaweed extract	2	40%	1	16.5%%
Vegetable-enriched bread	0	0%	1	16.5%%
High-amylose enriched bread or noodles	2	40%	0	0%

Table 4-5 Technology and food Science innovations and the nutrition biomarkers measured in both populations.

Nutrition biomarker	Phytosterols + oat β-glucan	Curcumin + fish oil supplement	Curcumin + phytosterol spread and bread	Polyphenol seaweed extract	Vegetable-enriched bread	High-amylose enriched bread or noodles
Blood glucose		✓	✓	✓	✓	✓
Plasma insulin		✓		✓	✓	✓
Appetite					✓	✓
Ghrelin and incretin						✓
Lipid profile	✓	✓	✓	✓		
Inflammation		✓		✓		✓
CVD risk			✓			
HbA1c		✓				

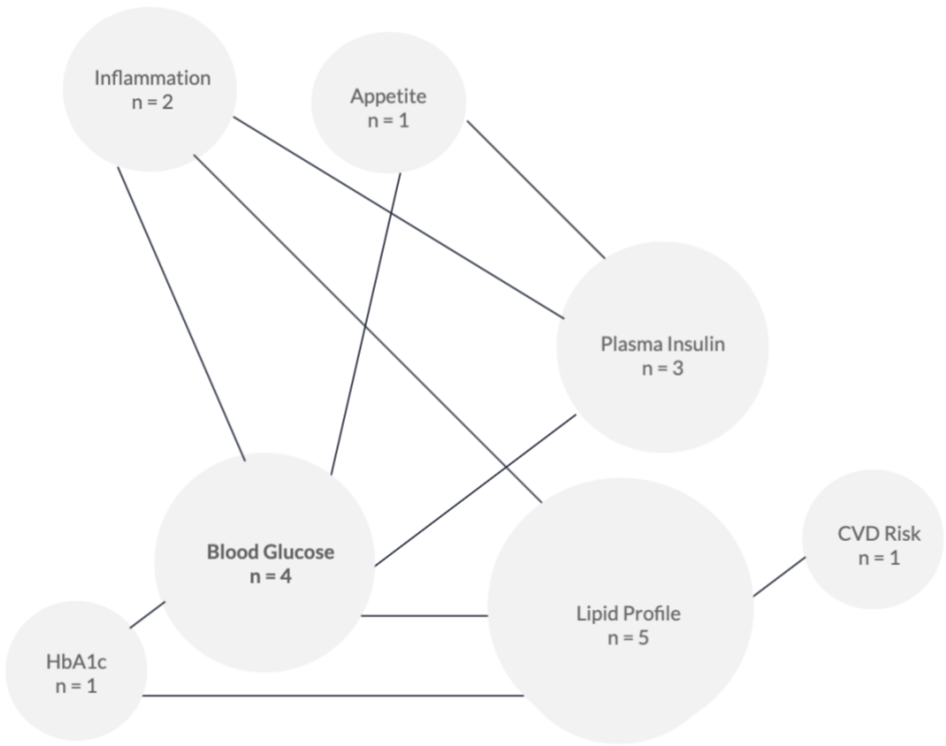

Figure 4-2 Weighted diagram of nutrition biomarkers measured for innovations investigating at-risk populations.

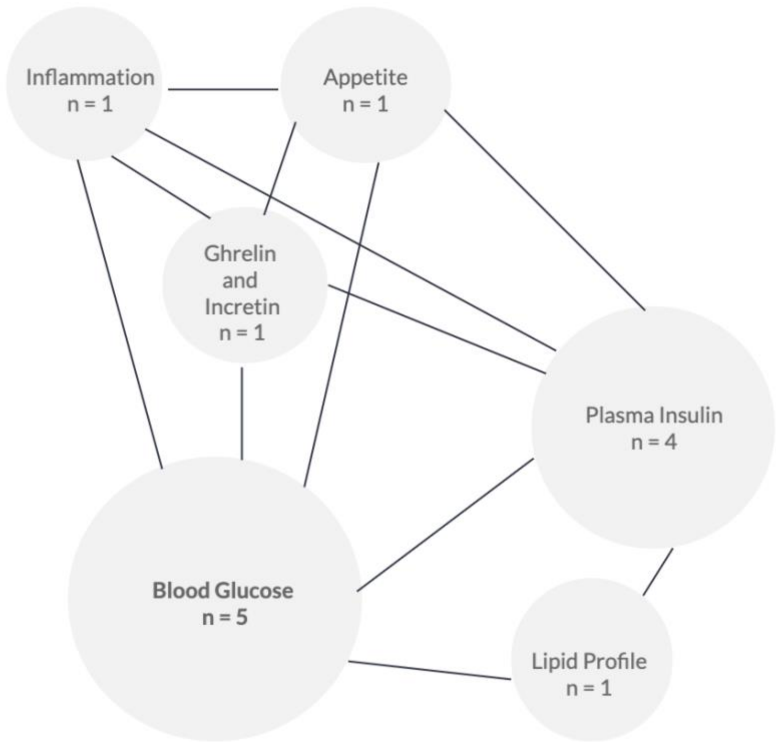

Figure 4-3 Weighted diagram of nutrition biomarkers measured for innovations investigating healthy populations.

4.3.2 Results and findings related to healthy populations

There were five articles focused on a healthy population. Two investigated polyphenol extracts, two investigated polyphenol-rich bread or pasta, and one investigated curcumin plus fish oil supplement (Table 4-4). The nutrition biomarkers that were identified in innovations for healthy populations were blood glucose (n = 5), plasma insulin (n = 4), appetite (n = 1), ghrelin and incretin hormones (n = 1), lipid profile (n = 1), and inflammation (n = 1) (Table 4-3).

4.3.2.1 Blood glucose

The polyphenol-rich F. *vesiculosus* extract measured postprandial blood glucose response over three hours in the evening and morning post a 50g carbohydrate meal (Murray et al., 2019). There were no differences in blood glucose levels between the placebo and polyphenol-rich extract groups. Therefore the study concluded the polyphenol-rich extract did not affect postprandial glucose. Another study also investigated low (500mg) and high (2000mg) polyphenol-rich extracts of F. *vesiculosus* and blood glucose at baseline and three hours post meal (Murray et al., 2018). The study found neither dose significantly lowered postprandial glucose compared to the placebo, which was 2g of cellulose fibre.

Curcumin and fish oil supplementation also investigated postprandial blood glucose responses one and two hours after a standardised meal (Thota et al., 2018). This study found the highest reduction in blood glucose concentration was in the curcumin-only group. The increase in blood glucose concentration was lower in the curcumin treatment groups at all time points compared to the placebo group, with the highest reduction 30 mins post-meal (15.7%). The curcumin plus fish oil group had a 51% reduction, and the fish oil only group had a 30% reduction in blood glucose compared to the placebo group at 60 mins post-meal. The change in blood glucose from 0 to 120 minutes was significantly lower in the curcumin and curcumin plus fish oil group than in the placebo group. The study concluded curcumin without fish oil affected postprandial blood glucose concentrations.

The innovation of high-amylose wheat in bread investigated postprandial blood glucose over three hours after consumption (Belobrajdic et al., 2019). The study found that the blood glucose response was 39% less than low-amylose wheat bread. The high-amylose wheat bread also produced a 33% lower rise in blood glucose than the low-amylose wheat bread. The study also investigated wholemeal and refined flour and found consuming wholemeal and refined flour bread resulted in a similar blood glucose response. The study concluded either refined or wholemeal bread made with high-amylose flour effectively reduced postprandial blood glucose concentrations. Another study investigated high-amylose wheat in noodles (Ang et al., 2020). The noodles tested were 15%, 20% and 45% amylose, and postprandial blood glucose concentrations were measured over two hours post-meal. The 45% amylose noodles had the most significant reduction in blood glucose concentrations compared to all groups at all times. The study concluded noodles made with high-amylose wheat reduced postprandial blood glucose concentrations by 3.4% compared to low-amylose wheat noodles.

4.3.2.2 Plasma insulin

The innovations investigating polyphenol-rich extracts also measured plasma insulin responses, and both found no difference in plasma insulin levels of treatment groups compared to the placebos (Murray et al., 2018; Murray et al., 2019).

The curcumin and fish oil innovation investigated plasma insulin levels (Thota et al., 2018). The study found the changes in plasma insulin were lower at all times compared to the other groups, but there were no significant results. However, the overall change in plasma insulin was significantly lower in the curcumin and curcumin plus fish oil groups but not the fish oil-only group compared to the placebo. The study concluded that curcumin lowered the overall change in plasma insulin but not fish oil.

High-amylose wheat in bread also measured plasma insulin responses (Belobrajdic et al., 2019). The study found plasma insulin response was 24% lower for high-amylose wheat bread than for low-amylose wheat bread. However, the plasma insulin response was only lower at 60 and 120 minutes compared to low-amylose wheat bread.

4.3.2.2.1 Appetite

Appetite was investigated using a visual analogue to measure subjective satiety and cravings when consuming high-amylose wheat bread (Belobrajdic et al., 2019). The study found no difference between test bread and levels of cravings and satiety, concluding the amylose content of bread did not influence appetite.

4.3.2.2.2 Ghrelin and incretin

Ghrelin and incretin hormone concentrations were investigated in high-amylose wheat bread (Belobrajdic et al., 2019). The study found high-amylose wheat bread had a 30% lower incretin response than low-amylose wheat bread. Ghrelin hormone did not decrease in response to high-amylose wheat bread consumption.

4.3.2.3 Lipid profile

The curcumin and fish oil innovation was the only study investigating the effect on the triglycerides (TG) (Thota et al., 2018). The study concluded there were no significant differences between TG concentrations between all treatment groups and the placebo group over the two hours measured.

4.3.2.4 Inflammation

High-amylose wheat in bread was the only study that measured inflammatory markers (Belobrajdic et al., 2019). The study measured plasma intercellular adhesion molecule 1 (ICAM-1) and nitrotyrosine concentrations used as inflammation and oxidative stress markers. The study found high-amylose wheat in bread did not affect inflammation biomarkers during the three-hour postprandial period.

4.3.2.5 Summary

High-amylose wheat bread reduced blood glucose levels and plasma insulin response compared to traditional low-amylose products in a healthy population (Ang et al., 2020; Belobrajdic et al., 2019). High-amylose wheat bread significantly reduced incretin but did not affect appetite, ghrelin or inflammatory markers. High-amylose noodles significantly lowered blood glucose responses (Ang et al., 2020). Polyphenol-rich seaweed extract did not influence blood glucose or plasma insulin levels (Murray et al., 2018; Murray et al., 2019). The curcumin and fish oil innovation showed that curcumin was responsible for reducing blood glucose and plasma insulin levels (Thota et al., 2018). The innovation did not affect the lipid profile in a healthy population.

4.3.3 Results and findings related to at-risk populations

Six articles focused on at risk-populations. At-risk populations included obesity (n = 1), hypercholesterolemia (n = 4) or, had impaired fasting glucose and/or tolerance (n = 1). There were five innovations in this group; phytosterols and oat β-glucans (n = 1), curcumin and fish oil supplement (n = 1), curcumin and fish oil spread bread (n = 2), polyphenol seaweed extract (n = 1) and, vegetable-enriched bread (n = 1) (Table 4-4). Nutrition biomarkers investigated in at-risk populations were blood glucose (n = 4), plasma insulin (n = 3), appetite (n = 1), lipid profile (n = 5), inflammation (n = 2), CVD risk (n = 1) and HbA1c (n = 1) (Table 4-3).

4.3.3.1 Blood glucose

The curcumin and fish oil supplement article found no significant changes in fasting glucose after 12 weeks of supplementation (Thota et al., 2019). The article investigating the innovation of curcumin and phytosterols in the form of a spread and supplement found only curcumin supplementation significantly reduced blood glucose concentrations after four weeks of supplementation (Ferguson et al., 2018). No significant difference in postprandial glucose concentrations was found between the consumption of vegetable-enriched bread and placebos (Amoah et al., 2021). The article concluded polyphenol-rich seaweed extract supplementation did not affect blood glucose after 12 weeks of supplementation (Murray et al., 2021).

4.3.3.2 Plasma insulin

Plasma insulin was measured in the curcumin and fish oil supplementation innovation, and results showed that insulin sensitivity was significantly increased in the curcumin supplementation group (Thota et al., 2019). There was no combined effect between curcumin and fish oil. Vegetable-enriched bread produced a lower postprandial insulin response of 38% compared to white and wholemeal bread (Amoah et al., 2021). Polyphenol-rich seaweed extract supplementation showed no difference in plasma insulin levels between the treatment and placebo groups (Murray et al., 2021).

4.3.3.3 Appetite

Vegetable-enriched bread measured appetite using subjective questions about hunger levels (Amoah et al., 2021). Over the two hours, vegetable-enriched bread had the lowest hunger rating and increased satisfaction compared to white and wholemeal bread.

4.3.3.4 Lipid profile

Five out of the six articles on at-risk populations investigated the lipid profile of the innovation. The bread enriched with phytosterols and curcumin measured TC, LDL-C, high-density lipoprotein cholesterol (HDL-C), TC: HDL-C ratio, TG, LDL-C and HDL-C particle size

(Ferguson et al., 2019). Bread enriched with curcumin alone or combined with phytosterols had no additional cholesterol-lowering effects, so instead, comparisons were made between bread with or without phytosterols. Bread enriched with phytosterols significantly reduced TC, LDL-C, and TC: HDL ratio over the four weeks. HDL-C, HDL-C particle size and TG were unchanged between all enriched bread and placebo. LDL-C particle size was also investigated, and the diameter was significantly lower in the bread enriched with curcumin (Ferguson et al., 2019). Curcumin and phytosterols were also studied as a fat spread (phytosterols) and tablet (curcumin) (Ferguson et al., 2018). This study measured TC, LDL-C, HDL-C, TC: HDL ratio and TG. Curcumin without phytosterol supplementation did not influence lipid profile compared to the placebo. TC, LDL-C, TC: HDL ratio was significantly reduced in the phytosterol and curcumin spread group compared to the placebo and curcumin-only supplement group. There was no difference between any groups in HDL-C or TG. The study concluded curcumin could have a synergistic effect with phytosterols.

Curcumin and fish oil supplementation measured TC, TG, LDL-C, HDL-C and TC: HDL-C ratio (Thota et al., 2019). The study found TG levels were significantly reduced in the fish oil supplementation group and the fish oil plus curcumin group. No significant differences were found between TC, LDL-C, HDL-C and TC: HDL-C ratio between all groups. Curcumin did show a reduction in TG, but fish oil supplementation had a higher reduction (Thota et al., 2019).

Biscuits fortified with high molecular weight oat β-glucans and phytosterols measured TC, TG, LDL-C, HDL-C and TC: HDL-C ratio (Ferguson et al., 2020). The study found no differences between treatment groups and placebo in TC: HDL-C ratio, HDL-C or TG. The phytosterol and high molecular weight β-glucan group significantly lowered TC and LDL-C.

Polyphenol-rich seaweed extract supplementation measured TC, TG, LDL-C, HDL-C and TC: HDL-C ratio (Murray et al., 2021). The study found after 12 weeks of supplementation, there was an increase in HDL-C, but this did not reach significance. There were no changes in LDL-C, TC or TG post-supplementation. There was an increase in TC and HDL-C in the first six weeks of supplementation, but after 12 weeks, this was no longer significant (Murray et al., 2021).

4.3.3.5 Inflammation

The innovation of curcumin and fish oil supplementation investigated inflammation by measuring the c-reactive protein (CRP) (Thota et al., 2019). The study concluded supplementation for 12 weeks did not affect CRP levels.

4.3.3.6 Cardiovascular disease risk

Cardiovascular risk was measured in the consumption of bread enriched with curcumin and phytosterols using the Framingham Risk Algorithm (Ferguson et al., 2019). Phytosterol-enriched bread reduced CVD risk by 8% compared to non-phytosterol bread.

4.3.3.7 HbA1c

The curcumin and fish oil supplementation innovation was the only article that investigated HbA1c and did not find any significant changes between the groups compared to the placebo (Thota et al., 2019).

4.3.3.8 Summary

At-risk population innovations show polyphenol-rich seaweed extract did not change blood glucose or plasma insulin concentrations (Murray et al., 2021). The innovation did not find any significant differences in any lipid parameters measured.

Curcumin and fish oil supplementation found no significant differences in blood glucose levels, HbA1c, or inflammation (Thota et al., 2019). The study found curcumin improved insulin sensitivity but fish oil did not, and there was no combined effect. TG levels were the only lipid parameter reduced from this innovation, and were only in the fish oil-containing group.

Vegetable-enriched bread did not affect blood glucose concentrations; however, the innovation lowered plasma insulin response compared to standard bread (Amoah et al., 2021). Vegetable-enriched bread decreased hunger and increased satisfaction.

Phytosterol-enriched bread reduced CVD risk compared to non-phytosterol-enriched bread. Curcumin-enriched bread did not change the lipid profile of an at-risk population. However, phytosterol-enriched bread reduced TC, HDL-C, and TC: HDL-C (Ferguson et al., 2019). Curcumin without phytosterols also did not influence the lipid profile in the curcumin and phytosterol supplement and spread innovation. Curcumin and phytosterol combined, and the phytosterol-only group significantly reduced TC, LDL-C, and TC: HDL-C ratio (Ferguson et al., 2018). Supplementation of curcumin reduced blood glucose levels, but not from the phytosterol-rich spread. Biscuits fortified with high molecular weight oat β-glucans significantly lowered TC and LDL-C (Ferguson et al., 2020).

4.3.4 Comparison between healthy and at-risk populations

Two innovations investigated healthy and at-risk populations: polyphenol-rich seaweed extract and curcumin and fish oil supplementation (Murray et al., 2021; Murray et al., 2018; Murray et al., 2019; Thota et al., 2019; Thota et al., 2018). Polyphenol-rich seaweed rich extract did not change any nutrition biomarkers measured in healthy or at-risk populations. Curcumin and fish oil showed varying results. The healthy population's blood glucose levels decreased, but at-risk populations' levels were unchanged. Curcumin-only supplementation improved insulin sensitivity in at-risk and curcumin and fish oil improved insulin sensitivity in healthy populations. The at-risk population had reduced TG from fish oil supplementation, but the innovation did not affect the lipid profile in a healthy population.

This chapter summarised the findings from the data collected in the scoping review. The data was organised by population studied (healthy or at-risk) and then sub-grouped by nutrition biomarkers studied. In the next chapter, these findings are evaluated in more detail to identify gaps in the literature and the future implications of this research.

CHAPTER 5 Discussion

5.1 Step nine: summarising the evidence concerning the purpose of the review, making conclusions and noting any implications of the findings

To answer this scoping review's purpose and research questions, evidence was discussed by answering the research objectives.

Comparisons were made between healthy and at-risk populations to distinguish differences and similarities between the innovation outcomes. Innovations that only focused on healthy or at-risk population outcomes were discussed to determine the individual populations' influence on health factors. The implications of each type of innovation are then discussed concerning their potential influence on New Zealand and Australia's environmental, political, and socio-economic factors to improve health.

These two discussion points answer the research objective of examining what and how current food science and technology innovations are being invested in to improve nutrition and reduce chronic disease risk in New Zealand and Australia.

Gaps in the literature and implications and suggestions for food and research development companies were made based on emerging food science and technology towards improving health. This section answers the second research objective of informing where research is required by identifying gaps in the literature on what food science and technology are invested in, in New Zealand and Australia.

5.1.1 Comparisons between healthy and at-risk population innovation outcomes

Initially, findings from the scoping review were to be compared between innovations in Australia and New Zealand. Due to the small number of articles found and only one of the studies conducted on a New Zealand population, it was decided that comparisons would be made between healthy or at-risk populations.

Five articles investigated healthy populations, and six articles investigated at-risk populations. Curcumin and fish oil supplementation and polyphenol-rich seaweed extract were the only innovations studied in both healthy and at-risk populations (Murray et al., 2021; Murray et al., 2018; Murray et al., 2019; Thota et al., 2019; Thota et al., 2018). High-amylose enriched bread and noodles were investigated in healthy populations (Ang et al., 2020; Belobrajdic et al., 2019). Phytosterols and oat β-glucan, curcumin and phytosterol spread and bread and vegetable-enriched bread were investigated in at-risk populations (Amoah et al., 2021; Ferguson et al., 2018; Ferguson et al., 2020; Ferguson et al., 2019).

In this section of the discussion, each innovation is discussed in relation to the nutrition biomarkers investigated, how the innovation could influence nutrition to improve health and if the innovation has been researched outside of New Zealand and Australia. It is essential to understand how innovations influence nutrition to improve health, as shown in the theoretical framework (Figure 1-1). Where possible, comparisons are made between healthy and at-risk population findings.

5.1.1.1 Phytosterols and oat β-glucan enriched biscuits

The innovation of phytosterols and oat β-glucan effect investigated an at-risk population with hyper-cholesterol and measured lipid profile over six weeks (Ferguson et al., 2020). Phytosterols and oat β-glucan acted together in a synergetic way and significantly lowered TC and LDL-C when combined. These outcomes show that a combined effect of phytosterols and oat β-glucan could influence lowered TC and LDL-C in at-risk populations. This innovation contributes to reducing the risk of nutrition-related chronic disease by improving the metabolic risk factor of dyslipidemia.

Oat β-glucans have been well-researched and shown to have positive effects on lowering cholesterol in several meta-analyses involving hypercholesterolemic and non-hypercholesterolemic populations (Othman et al., 2011; Queenan et al., 2007; Xu & Sun, 2020). One meta-analysis found the cholesterol lowering effects of β-glucans were ineffective in baked products such as muffins, cereals and bread, relating this to the alteration of the food matrix with heating (Othman et al., 2011). However, the innovation in this scoping review did find a cholesterol-lowering effect in baked biscuits. This suggests the addition of phytosterols could have influenced this reduction in cholesterol (Ferguson et al., 2020).

A meta-analysis showed that β-glucan reduced LDL-C but no change in HDL-C. This outcome was also found in the phytosterol and oat β-glucan innovation (Whitehead et al., 2014). However, the meta-analysis did not measure a decrease in TC, which was found in this innovation. Conflicting results could be due to the additive effects of the phytosterols.

Phytosterols lower blood glucose levels by decreasing cholesterol absorption (Ostlund Jr, 2002, 2004). One study found phytosterols can be effective in a dose-dependent manner in lowering blood cholesterol levels (Racette et al., 2010). It was challenging to find studies that investigated enriching baked products with phytosterols. Different methods for including phytosterols in baked foods products have been studied, and results show phytosterols are retained in baked products (Menéndez-Carreno et al., 2016). This finding is promising for biscuit fortification and could explain the biscuits' effect on cholesterol levels (Menéndez-Carreno et al., 2016).

Results from this innovation, supported by evidence outside of New Zealand and Australia, show a synergistic effect on lowering blood cholesterol of biscuits enriched with oat β-glucans and phytosterols in populations with hyper-cholesterol and potentially those without hyper-cholesterol to reduce the risk of chronic disease by improving diet factors of chronic disease.

5.1.1.2 Curcumin and fish oil supplementation

Curcumin and fish oil supplements were investigated in healthy and at-risk populations with impaired fasting glucose (Thota et al., 2019; Thota et al., 2018). Blood glucose, plasma insulin, and TG were investigated in both populations. TC, HDL-C, LDL-C, TC: HDL-C ratio, inflammation and HbA1c were measured in the at-risk population. This innovation is related to improving the diet factor fat by increasing the amount of PUFA in the diet.

Only in healthy populations blood glucose and plasma insulin concentration were significantly reduced by curcumin, and neither curcumin nor fish oil affected TG (Thota et al., 2018). Blood glucose was unchanged in an at-risk population. Only the curcumin supplementation group had an increased plasma sensitivity (Thota et al., 2019). TG levels were significantly reduced in the combined curcumin and fish oil group and the fish oil group for at-risk populations (Thota et al., 2019). No significant differences were found in the other lipid biomarkers measured, inflammation or, HbA1c. No change in HbA1c was expected since there was no change in blood glucose concentrations.

Curcumin and fish oil supplementation reduce the risk of nutrition-related chronic disease due to several mechanisms. Curcumin and fish oil reduce the risk of insulin resistance by improving insulin sensitivity for healthy and at-risk populations and blood glucose concentrations for healthy populations (Thota et al., 2019; Thota et al., 2018). This innovation also reduces the risk of the metabolic risk factor of hyperlipidaemia by improving the lipid profile of at-risk populations only (Thota et al., 2019).

Curcumin is a bioactive compound in turmeric, a phytochemical compound with well-documented anti-inflammatory and antioxidant properties (Duttaroy, 2014). Curcumin is a nutraceutical and affects many conditions, including obesity, metabolic disease, diabetes mellitus, cancer and cardiovascular diseases (Duttaroy, 2014; Srinivasan, 2013). Some of the mechanisms of curcumin reducing disease risk are the inhibition of pro-inflammatory cytokines (Duttaroy, 2014). Curcumin reduces the risk of cardiovascular disease by lowering TC and LDL-C levels (Alwi et al., 2008; Gupta et al., 2013). Curcumin reduces metabolic disease risk by lowering blood glucose levels, decreasing inflammatory cytokines, and decreasing nutrition-related chronic disease (Aggarwal, 2010; Shehzad et al., 2011; Yang et al., 2014).

Curcumin has been shown to reduce blood glucose and increase insulin sensitivity by stimulating glucose uptake and stimulating the pancreas to release insulin (Ghorbani et al., 2014). A systematic review found curcumin supplementation decreased fasting blood glucose levels in those with dysglycemia but not in non-diabetic individuals which showed similar results to what was found in this scoping review (de Melo et al., 2018).

Fish oil lowers TG in healthy and at-risk populations by reducing cholesterol absorption, especially LDL-cholesterol (Abbey et al., 1990; Lindsey et al., 1992; Nestel, 2000). A systematic review investigating fish oils' effect on insulin sensitivity shows short-term supplementation of fish oil increased insulin sensitivity in those with metabolic disorders (Gao et al., 2017). In a population with hyper-cholesterol, long-term fish oil supplementation reduced TG and LDL-C (Rivellese et al., 1996). Interestingly this study found no effect of fish oil supplementation on insulin sensitivity (Rivellese et al., 1996). Glucose and insulin concentrations were also unchanged when investigating a population with impaired glucose tolerance (Fasching et al., 1991). Glucose tolerance or insulin sensitivity after supplementation of fish oil in healthy populations was also unchanged (Giacco et al., 2007).

Apart from the studies in this scoping review, minimal research has investigated the combined supplementation of curcumin and fish oil and the effect on nutrition biomarkers and metabolic disease. From researching curcumin and fish oils' mechanisms and considering the outcomes from innovations in this scoping review, findings show that curcumin affects blood glucose concentrations in healthy populations but not at-risk populations. Comparing at-risk and healthy populations shows curcumin positively affects insulin sensitivity in healthy and at-risk populations. The effect on blood glucose and insulin in the innovation in this scoping review was from curcumin due to no difference found in the fish oil supplementation group (Fasching et al., 1991; Giacco et al., 2007). At-risk populations had significantly reduced TG levels from fish oil and fish oil plus curcumin supplementation, but no changes in healthy populations. This suggests only at-risk populations benefit from fish oil supplementation to improve TG levels. There is no combined effect of curcumin and fish oil in healthy and at-risk populations.

These findings suggest the population type and pre-existing conditions can mean they will respond differently to curcumin and fish oil supplementation. Therefore, it is essential to consider the target population when implementing innovations to improve nutrition-related chronic disease outcomes.

5.1.1.3 Curcumin and phytosterol spread and bread

Curcumin supplements, phytosterol spread, and bread were investigated in at-risk populations with hyper-cholesterol (Ferguson et al., 2018; Ferguson et al., 2019). Both spread and bread measured lipid profiles (TG, TC, HDL-C, LDL-C, TC: HDL-C ratio).

Bread enriched with curcumin produced no change in lipid profile, so results were only discussed comparing phytosterol or non-phytosterol supplementation. Phytosterol-enriched bread significantly reduced TC, LDL-C, and TC: HDL-C ratio lipid biomarkers compared to the placebo group (Ferguson et al., 2019). Phytosterol as a fat spread and curcumin had a combined effect and significantly reduced TC, LDL-C, and TC: HDL-C ratio (Ferguson et al., 2018). These findings suggest phytosterols influence lipid biomarkers no matter the form. However, curcumin's effects could be altered depending on its form.

Phytosterol supplementation as a fat spread or enriched in bread is a practical innovation towards lowering TC, LDL-C, and TC: HDL-C ratio in those with hyper-cholesterol and therefore reducing the metabolic risk factor of hyperlipidemia. Since both the fat spread and bread resulted in similar changes in lipid parameters investigated, different nutrition biomarkers measured in the two studies could likely be transferrable.

Phytosterol spread and curcumin supplement measured fasting glucose (Ferguson et al., 2018). Only the curcumin supplementation group had a reduced glucose concentration, suggesting that phytosterols do not affect blood glucose. These results show the innovation could also reduce insulin resistance.

Enriched bread also measured HDL-C and LDL-C particle size and number and CVD risk (Ferguson et al., 2019). LDL-C particle size significantly reduced compared to non-phytosterol bread, but HDL-C particle size was unchanged. CVD risk decreased by 8% in phytosterol-enriched bread compared to placebo.

Curcumin and phytosterols have been discussed previously for their beneficial impact on blood cholesterol. Therefore, it is not surprising that combining the two in spread and bread produced an effect in this innovation. Curcumin and phytosterol spread and bread improve nutrition by targeting insulin resistance and hyperlipidaemia in metabolic syndrome and influencing the risk of cardiovascular disease in at-risk populations.

Apart from the studies in this review, it was challenging to identify other innovations that investigated the combined supplementation of curcumin and phytosterols. Food enriched with curcumin or phytosterols has been studied in healthy populations, hypercholesterolemic populations, and populations with metabolic syndrome and has found significant reductions in LDL-C (Abumweis et al., 2008; Qin et al., 2017; Ras et al., 2013; Wu et al., 2009). The innovations combining curcumin and phytosterols have shown that they have a potential complementary effect on lowering blood cholesterol in at-risk populations.

5.1.1.4 Polyphenol seaweed extract

Polyphenol-rich seaweed extract supplementation from *F. vesiculosus* was tested on both healthy (n = 2) and overweight or obese and hyper cholesterol populations (n = 1) (Murray et al., 2021; Murray et al., 2018; Murray et al., 2019).

All three articles measured blood glucose and plasma insulin. Results produced no difference between supplementation and placebo on blood glucose and plasma insulin concentrations in healthy and at-risk populations (Murray et al., 2021; Murray et al., 2018; Murray et al., 2019).

The article instigating polyphenol-rich seaweed extract on at-risk populations also investigated lipid profile (TC, TG, LDL-C, HDL-C and TC: HDL-C ratio) (Murray et al., 2021). Although there was a slight improvement in some of these lipid parameters, none of the differences reached significance after 12 weeks of supplementation.

Polyphenols are in multiple foods such as fruits, vegetables, legumes, oils and spices. There is a vast amount of evidence investigating the effect of polyphenols and their influence on cardiovascular disease, T2D and metabolic syndrome. Polyphenols improve cardiovascular disease outcomes through their antioxidant mechanisms and endothelial function (Quiñones et al., 2013; Vita, 2005). Dietary polyphenols can decrease the risk of T2D. A review of the current and prospects of polyphenols documented polyphenols' effect on T2D was due to antioxidant and anti-inflammatory effects, protecting pancreatic beta-cells against glucose toxicity, and decreasing starch digestion (Xiao & Hogger, 2015). A systematic review investigated dietary polyphenols and metabolic disorders based on factors such as oxidative stress, inflammation and vascular integrity (Amiot et al., 2016). The review found controversial results depending on the food source of polyphenol, poor absorption and differential effects on inflammatory and vascular functions.

A review criticised using polyphenols to reduce chronic disease risk (Visioli & Davalos, 2011). Most research is on the whole food source, which includes other nutrients and not only polyphenols. Since polyphenols are in foods with various vitamins and minerals, it is challenging to claim that polyphenols alone can decrease the risk of chronic disease and could be due to a combination of increased fibre, lower calorie food and increased nutrients.

Findings from this scoping review suggest that polyphenol-rich seaweed extract from *F. vesiculosus* produces no differences in blood glucose, plasma insulin or lipid biomarkers in healthy and at-risk populations. This could be due to being supplemented independently and not with other nutrients or a decreased bioavailability.

5.1.1.5 Vegetable-enriched bread

Vegetable-enriched bread was only investigated in an obese population (Amoah et al., 2021). Nutrition biomarkers investigated for this innovation were blood glucose, plasma insulin and appetite. Vegetable-enriched bread produced no significant differences in blood glucose concentrations. The enriched bread produced a lower insulin response, lower hunger ratings, and higher satisfaction ratings than white and wholemeal bread. These results suggest vegetable-enriched bread could effectively improve insulin sensitivity and appetite in obese populations (Amoah et al., 2021). Vegetable-enriched bread could reduce the risk of chronic disease by decreasing the risk of the metabolic disorder insulin resistance and obesity through reducing appetite. This innovation contributes to improving health by increasing vegetable intake.

A diet rich in FV is well-established to reduce blood pressure, the risk of heart disease and stroke. A study on populations with hypertension showed the intake of FV is inversely related to blood pressure (Alonso et al., 2004). A randomised control trial on healthy populations where FV intake was at least five portions per day (John et al., 2002). The study found that plasma antioxidants increased and blood pressure significantly reduced after six months and concluded that these results would influence a decrease in CVD.

FV consumption decreases the risk of some cancers. Reviews and meta-analyses have shown a dose-dependent effect of FV intake on the risk of colorectal cancer and breast cancer (Gandini et al., 2000; Paul Terry et al., 2001). An important finding in the literature showed minimal FV intake has the highest reduction in cancer risk, but above moderate levels of FV intake, reduction in cancer risk tends to plateau (Key, 2011; Vainio & Weiderpass, 2006).

FV intake and metabolic syndrome were investigated by measuring the inflammatory marker CRP (Esmaillzadeh et al., 2006). The study concluded a higher intake of FV lowered the risk of metabolic syndrome and cardiovascular disease by decreasing CRP concentrations (Esmaillzadeh et al., 2006). FV are high in fibre and could influence metabolic syndrome risk through fermentation in the gut and have a higher effect on satiety levels (Delzenne & Cani, 2005).

The innovation of enriching bread with vegetables is a new concept recently studied outside of New Zealand and Australia and is showing promising results. Bread has been enriched with vegetable leaves to reduce oxidative stress and, therefore, chronic disease risk. It showed the bread had more antioxidants and polyphenols than standard bread (Alashi et al., 2019). There was concern that baking the bread would destroy the beneficial properties of the enriched bread. However, a study has shown that this can be mitigated to retain the functionality of the enriched bread, which results in a higher phenolic and antioxidant content than standard bread (Betoret & Rosell, 2020).

5.1.1.6 High-amylose enriched bread and noodles

High-amylose bread and noodle innovations were investigated in healthy populations only (n = 2) (Ang et al., 2020; Belobrajdic et al., 2019). High-amylose wheat bread and pasta measured blood glucose. Both bread and noodles significantly reduced the blood glucose response compared to low-amylose wheat bread and noodles.

Plasma insulin, incretin and ghrelin hormones, appetite and inflammatory markers (ICAM-1 and nitrotyrosine) were measured in the high-amylose bread (Belobrajdic et al., 2019). High-amylose wheat bread had a lower insulin and incretin response than the placebo. There was no change in ghrelin, appetite or inflammation responses between supplementation and placebo groups.

High-amylose wheat bread and pasta are high in resistant starch, which could reduce the risk of insulin resistance by improving blood glucose, insulin responses. This innovation can also reduce obesity through incretin hormones in healthy populations. Diets that are high in fibre and have a low GI, decrease HbA1c, fasting blood glucose and cardiovascular disease risk factors in a randomised control trial on a population with T2D (Jenkins et al., 2008). It has been well documented that low GI, high fibre diets can improve glucose tolerance and insulin sensitivity, therefore, contributing to a decreased risk of metabolic syndrome and T2D (Björck & Elmståhl, 2003; Lau et al., 2005; Liese et al., 2005; Rizkalla et al., 2004). The innovations in this scoping review investigating high-amylose bread and noodles confirm this reduction in blood glucose response (Ang et al., 2020; Belobrajdic et al., 2019). Low GI and high-fibre diets also contribute to metabolic syndrome and weight management. A systematic review and meta-analysis revealed long-term low GI diets have a beneficial effect on fat-free mass reduction, insulin sensitivity and inflammation, which could effectively reduce obesity-associated diseases such as metabolic syndrome (Schwingshackl & Hoffmann, 2013).

A systematic review and meta-analysis has shown low GI diets reduce LDL-C (Goff et al., 2013). Cholesterol was not measured in the innovations in this scoping review, but this could be a future aspect to consider to further contribute to the innovations' impact on reducing metabolic and cardiovascular disease.

Fortification of products with amylose was investigated in populations outside New Zealand and Australia. High-amylose rice has been studied, but the structure was investigated, and nutrition biomarkers were not included (Steiger et al., 2014). High-amylose maise starch has been investigated when fortified in muffin tops in healthy adults in Canada (Stewart & Zimmer, 2018). Consuming the muffin top showed a reduction in postprandial glucose and insulin response, which aligns with the high-amylose innovations in this review. The high-amylose enriched muffin innovation results were from the high fibre content compared to standard muffins (Stewart & Zimmer, 2018).

Fortifying high-amylose wheat into products such as bread and noodles could reduce blood-glucose response through its low GI and high fibre mechanisms.

5.1.1.7 Summary of outcomes of innovations

Blood glucose, plasma insulin and lipid profile were the most investigated nutrition biomarkers measured in the innovations. Blood glucose and insulin were the most frequently measured in healthy populations, while lipid profile and blood glucose were the most commonly studied in at-risk populations (Table 4-3). Glucose tolerance, insulin sensitivity, lipid profile, and appetite nutrition biomarkers measured across these innovations significantly impact the risk of developing metabolic syndrome and nutrition-related chronic disease.

Discussing each innovation in terms of its influence on nutrition biomarkers and the mechanisms behind it has revealed the innovations that produced an effect could reduce nutrition-related chronic disease outcomes and improve diet factors if implemented in New Zealand’s and Australia’s markets. These innovations are practical as they improve the nutritional profile of products through fortifying food such as bread, spread, noodles and biscuits with nutraceuticals that positively affect chronic disease risk. Where improvement in biomarkers was not measured, the process of creating the innovation could have decreased the nutraceutical activity. It is important to note that when healthy and at-risk populations' outcomes were compared for the same innovation, the nutrition biomarkers showed different results. This indicates researchers should understand their target population for the innovation. Combining various nutraceuticals into food products is a new field, and it was challenging to find previous articles that investigated the same innovations and populations.

5.1.2 Current innovation implications and impact on external drivers of chronic disease

After analysing the results of each innovation about the population investigated and the nutrition biomarker measured, these outcomes were put into context. How each innovation could impact nutrition drivers of chronic disease was discussed. The innovations identified did not include the impact the innovation would have on drivers of chronic disease, only the impact on nutrition biomarkers. Understanding how these innovations could intersect with healthy and at-risk populations in New Zealand and Australia is challenging. The innovations discovered in this scoping review involve fortifying staple foods such as bread, spreads, noodles and biscuits or supplementing with functional foods and nutraceuticals. Therefore, in this section of the discussion, the type of innovation will be considered to determine how it could impact external drivers of chronic disease.

5.1.2.1 Environmental

The environmental impact on chronic disease was previously discussed as being related to climate change disrupting health services, food quality, and food security (Royal Society, 2017). Innovations involving fortification and supplementation can be implemented in the New Zealand and Australian markets to increase the nutritional quality of food, especially those that are widely available such as noodles, spread bread and other baked products (Backstrand, 2002; Chadare et al., 2019; Steyn et al., 2008). Fortification and supplementation of products with vegetables, phytosterols, oat β-glucans, curcumin and fish oil will increase the nutritional quality of these products. Increasing the nutritional quality of food could aid in reducing the impacts of food availability with climate change. If people consume more nutrients from fortified products than standard products, this may result in less of a product required to meet nutrition recommendations meaning supplies go further. However, these innovations only target specific nutrients and people will still require carbohydrates, protein, fibre and other nutrients to meet their nutrition requirements. Future research should investigate other forms of fortification and supplementation so populations can meet their nutrition and energy requirements with less food.

5.1.2.2 Political

Innovations identified in this scoping review could be implemented in New Zealand and Australia via policies. Australia and New Zealand have food standards for mandatory or voluntary fortification for certain food products. It is mandatory to fortify wheat flour with thiamin and folic acid (Australia only) and replace salt with iodised salt in bread (Food Standards Australia New Zealand, 2015). Australia also requires the addition of vitamin D to margarine and spreads (Food Standards Australia New Zealand, 2016). Voluntary fortification standards make it optional for manufacturers to include vitamins and minerals in food (Food Standards Australia New Zealand, 2021b).

There are supplemented food standards, and criteria must be met before making a health claim on products (Food Standards Australia New Zealand, 2018). Due to minimal research in this field, it would also be challenging to introduce standards to make the fortification of products possible.

There are policies on how supplements are sold and the evidence required to sell them to consumers, but there are no policies for taking supplements (New Zealand Government, 1985).

There are advice and guidelines for supplementation, such as when pregnant. However, there is no subsiding research that can provide recommendations and guidelines, making introducing a curcumin and fish oil supplement challenging (Ministry of Health, 2018). This innovation also had conflicting results between at-risk and healthy populations, making introducing these products even more difficult.

5.1.2.3 Socio-economic drivers

The articles in this scoping review discussed each innovations nutrition outcomes and how these could influence chronic disease. This makes it challenging to understand how innovations might affect the socio-economic factors of chronic disease. Therefore, this section includes assumptions about possible outcomes from implementing these innovations in New Zealand and Australia. Housing conditions were not discussed in this section as they are not modifiable by the innovations in this scoping review but can be secondary outcomes of other improving drivers.

5.1.2.3.1 Income and socio-economic status

Socio-economic status and food security and their strong influence on shaping the food environment have been discussed previously. Innovations discovered would only benefit New Zealand and Australian populations if reasonably priced. The cost of a healthy diet tends to be more expensive than current diets (Vandevijvere et al., 2018). Therefore, the cost is essential when considering interventions to improve health. The government could fund these innovations to allow for increased accessibility. For example, fortified products such as bread, noodles and baked products could be subsidised to be the same price or at a reduced rate compared to other available products in the same market. This would reduce the burden associated with the cost of a healthy diet and help consumers get more nutrition out of these staple products for the same price. Fortified products have a higher nutritional value than standard products, reducing the amount of food required to meet certain nutrient recommendations. These innovations would therefore help to shape a positive food environment by increasing food affordability and food security in areas of low-income and socio-economic status.

5.1.2.3.2 Employment status

Employment status influences income, health and well-being but was not considered to be influenced by the innovations in this scoping review (McKee-Ryan et al., 2005; Stronks et al., 1997). New products and supplements could create job opportunities and improve health through increasing income and affordability of healthy foods.

Suppose the innovations reduced the burden of socio-economic factors and decreased chronic disease risk. In that case, this could reduce the burden of being unable to work because of illness, increasing the employment rate as a secondary benefit. However, it is an assumption only as although these innovations showed a promising effect on nutrition biomarkers. Since socio-economic drivers were not considered in the innovations, it is difficult to relate this accurately to employment status.

5.1.2.3.3 Education

Innovations and future trends require increased food literacy. This is challenging as food literacy levels can influence food security through shopping, planning, preparation and cooking (Begley et al., 2019). Suppose these fortification and supplementation innovations are implemented in New Zealand and Australia. In that case, care needs to be taken so people are well-informed about the innovations and their benefits (Butcher et al., 2021). Food fortification is easier for consumers as it does not require much change, especially since the innovations in this scoping review are in staple products such as bread and noodles. People may be required to swap the brand or product of bread, which may look different than previously. For example, vegetable-enriched bread was a different colour than conventional white bread (Amoah et al., 2021). The curcumin and fish oil supplementation and curcumin and phytosterol innovation require tablets, which could impose an increased burden on people to remember and understand how and why to take the supplements (Ferguson et al., 2018; Thota et al., 2019; Thota et al., 2018). Educating populations on these innovations would encourage the uptake to achieve healthier diets.

5.1.2.3.4 Urbanisation and modernisation

Implementing fortified staple foods and supplementation in New Zealand and Australia will impact the food environment. Fortifying bread, noodles and baked products with phytosterols, oat β-glucan, curcumin, vegetables and high-amylose wheat will increase the availability of products of higher nutritional value than before (Hobbs et al., 2021). Implementing these innovations will increase population’s accessibility nutraceuticals and functional foods and products they are already familiar with (bread, noodles, and biscuits). The literature view section of this thesis discussed that urban areas in Australia have a higher chronic disease prevalence compared to rural areas (Black et al., 2012). These innovations could target the high consumption of takeaways and increased frequency of eating out seen in urban populations from the occurrence of urbanisation and modernisation. Restaurants and fast-food outlets could ensure they use foods with these innovations and increase the nutritional quality of the meals they provide. However, this is challenging due to the unknown costs of the nutraceutical innovations. The focus should be on increasing meals prepared at home with fresh ingredients as this has shown to result in healthier, nutritious meals at home (Utter et al., 2008).

5.1.2.3.5 Eating habits and socio-economic status

Innovations involving fortification and supplementation do not require people to change their eating habits drastically. Since the innovations identified investigate fortifying existing products, populations could continue to have staple products with an added nutritional quality without changing their lifestyles or eating habits.

Bread is the number one source of carbohydrates, energy, protein and fibre due to such high quantities consumed (University of Otago and Ministry of Health, 2011). The Australian Health Survey in 2011-12 statistics shows that 66% of the population consumes bread, and it is also the number one contributor to energy intake (Australian Bureau of Statistics, 2011). On average, Australians consume 60g of bread per person per day. Grains and pasta are also consumed in large amounts. Grains and pasta are the second highest contributor to energy and carbohydrates in New Zealand. Australians consume about 18g of pasta per day (Australian Bureau of Statistics, 2011; University of Otago and Ministry of Health, 2011). Enriching bread and pasta with vegetables, curcumin and polyphenols, as some of the innovations in this scoping review have done, will significantly impact the nutrition consumed in New Zealand and Australia.

Table spreads were fortified with polyphenols in one innovation (Ferguson et al., 2018). The New Zealand adult nutrition survey showed New Zealanders are more likely to use margarine and table spread than butter, and Australians consume 3g of table spread per day (Australian Bureau of Statistics, 2011; University of Otago and Ministry of Health, 2011). Biscuits were enriched with phytosterols and oat β-glucans in another innovation (Ferguson et al., 2020). Biscuits were the 10th highest source of total sugar, fifth highest contributor of sucrose and 12th highest source of carbohydrates in the diet (University of Otago and Ministry of Health, 2011). Australians consume 8g of sweet biscuits per day (Australian Bureau of Statistics, 2011). These statistics indicate that introducing innovations aimed at enriching staple products in New

Zealand's and Australia's diets, such as pasta, spreads and biscuits with amylose, increases the availability of nutrition these populations receive.

5.1.2.4 Summary of external drivers of chronic disease

Innovations in this scoping review target fortification of everyday products consumed by New Zealand and Australia populations, such as bread, noodles, spreads and biscuits or supplementation, allowing for increased availability, accessibility and affordability of foods with an improved nutritional value. Implementing any of these innovations will improve diet factors and external drivers of chronic disease. Environmental drivers from climate change will be less severe due to populations being able to meet their nutrition requirements easier with fortified and supplemented products. Policies and subsidies could increase the accessibility of these innovations.

The focus should be on implementing these innovations so products are affordable and accessible for those of low income. Explanations and information provided on the innovation should meet the food literacy levels of the population. Since the innovations involve everyday products consumed by New Zealand and Australian populations, they will positively impact the nutritional quality of the diet and food environment without altering eating habits. Housing conditions are not modifiable by the innovations in this scoping review but can be secondary outcomes of other improving drivers.

Although these innovations show promising potential in reducing chronic disease in New Zealand and Australia, there is an increased need for innovations targeting food availability, accessibility, and affordability. Implementing innovations to minimise the impact of factors such as climate change and socio-economic factors will aid in improving the food environment and enhance the sustainability of a healthy diet.

5.1.3 Gaps in the literature and future suggestions for food and research development companies

From conducting this scoping review, several gaps are evident for future research that food research and development companies would benefit from investigating. Food and research industry stakeholders that would benefit from these recommendations are Plant and Food Research, Food Innovation Network and AgResearch in New Zealand, Plant and Food

Research, and The Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia.

5.1.3.1 Gaps in the literature

During the screening process of the scoping review, articles were excluded at the relevant full-text screening stage but investigated non-human populations (n = 11). This suggests future research that is yet to progress to human testing. Future research should explore innovations yet to be tested on humans to capture up-and-coming innovations.

Of the six innovations identified, this review only allowed for comparisons between outcomes of curcumin and fish oil supplementation and polyphenol seaweed extract innovations in healthy and at-risk populations. It would be beneficial for future research to investigate different people so comparisons can be made between them depending on their health status.

There was only one article on the New Zealand population. Therefore the scoping review focused on healthy or at-risk populations. Future research should compare these countries' innovations to understand what each country is investigating.

The articles included in the scoping review did not investigate what impact each innovation would have on factors contributing to chronic disease. There was also no mention of indigenous or Māori populations. They only investigated nutrition biomarkers and outcomes, which led to various assumptions about what effect the innovation could have on each driver of chronic disease. Identifying how the innovation will not only impact chronic disease risk in terms of nutrition biomarkers but also what impact they could have on external drivers of chronic disease and Māori and indigenous populations is an important consideration to make during research and would have expanded and sustained this review's objectives.

5.1.3.2 Future trends

When food research and development companies investigate new trends and innovations to improve nutrition and health, external drivers of chronic disease must be considered. Implementing innovations such as plant-based foods, sustainable food production systems, vertical farming, personalised nutrition, and nutritional immunology will allow for a transition to healthier diets with increased availability, accessibility and affordability of nutritious foods. These innovations can alleviate socio-economic factors such as employment, education and income, as well as reduce food insecurity with climate change. These innovations will therefore improve diet factors and reduce chronic disease risk.

5.1.3.2.1 Plant-based foods and sustainable food Systems for climate change adaption

Current innovations in New Zealand and Australia that involve fortification and supplementation could help populations meet their nutritional needs despite low food availability, thus contributing towards climate change adaption. However, if food and research companies focused on climate change adaptation innovations, specifically sustainable production and processing systems, this would make a significant difference to human and planetary health by alleviating the food availability disruption with climate change.

Plant-based foods are a trend that can contribute to planet sustainability with the reduction of meat-based diets (Pimentel & Pimentel, 2003). Meat-based food systems use more energy, land and water resources than plant-based diets, so researching plant-based foods and alternatives to meat will contribute to more sustainable diets (Carlsson-Kanyama & González, 2009; Pimentel & Pimentel, 2003).

Implementing sustainable food systems and plant-based foods will reduce the impact of climate change on disrupting the nutritional quality of foods, improving diet factors and reducing the risk of metabolic factors and chronic disease in New Zealand and Australia.

5.1.3.2.2 Vertical farming

Urbanisation and modernisation in New Zealand and Australia decrease the land available for growing and producing food. Recent innovations involving vertical farming seek to alleviate the pressure of providing food for increasing populations and reducing space (Kalantari et al., 2018). Vertical farming allows crops to be grown in vertically stacked layers using hydroponic and aeroponic growing methods, allowing land optimisation and growth in challenging conditions, contributing to climate change adaption in food systems (Benke & Tomkins, 2017; Kalantari et al., 2018).

There is minimal urban farming in New Zealand, with farming seen as a rural component (Hanna & Wallace, 2022). The discussion of urban farming is increasing, but procedures are yet to be implemented. There are no plans for vertical farming, indoor replicated farming, aquaponics or hydroponics and it is not provided for in district plans apart from Christchurch (Hanna & Wallace, 2022). Australian cities such as Melbourne, Brisbane and Sydney are beginning to adopt urban farming strategies into their planning. Brisbane encouraged communities to turn their roadsides into gardens. Melbourne has community gardens and development projects to increase food security (Amato-Lourenço et al., 2021). In Sydney, a community greening program has developed hundreds of community gardens throughout New South Wales (Kingsley et al., 2021).

Growing produce in urban areas such as community gardens, buildings, and schools will allow food to be grown precisely where it is needed. Increasing the availability and accessibility of fresh food in urban areas could aid in reducing the price of fresh produce and decreasing the cost of a healthy diet. Due to current eating habits being those of convenience foods, if fresh FV were made more available through vertical farming, this would improve the eating habits of New Zealand and Australia without compromising convenience.

Suppose vertical farming was placed in areas of high deprivation. In that case, this will shape a positive food environment by increasing the availability and accessibility of fresh FV, thus contributing towards decreasing the risk of chronic disease and reducing the inequities seen between chronic disease and areas of deprivation. Involving communities in vertical farming allows vulnerable populations to learn how to grow food themselves and how to cook and prepare meals from what is produced. This means that vertical farming has the opportunity to improve populations' education on healthy diets, further impacting the reduction in chronic disease.

5.1.3.2.3 Personalised nutrition, nutrigenomics and nutritional immunology

Personalised nutrition and nutrigenomics are a growing field worldwide but has yet to be investigated in New Zealand or Australia. Personalised nutrition and nutrigenomics allow for personalised nutrition advice based on the individual characteristics of a person (Ordovas et al., 2018). There is growing evidence that this is an effective way to reduce the risk of developing chronic disease and is a targeted approach instead of a system-wide approach for improving health (Gibney & Walsh, 2013; Mathers, 2019). Recent evidence shows using nutrigenomics and personalised nutrition will effectively reduce metabolic disease since there is a strong interaction between genetic and environmental factors in the development and disease (Phillips, 2013). Science and nutrition research companies would benefit tremendously from investigating this new growing industry and could be among the first to test this on human populations.

Nutritional immunology is another field of research not yet explored in New Zealand or Australia. This new concept involves investigating how dietary components interact with the immune system and considers pathogens and gut microbiota (Ponton et al., 2011). Nutritional immunology is not a new concept, but due to the complexity of the field, there is minimal research or application in human populations. Nutritional immunology can contribute to population health by balancing nutrients in the body and avoiding deficiencies and has been investigated to reduce the risk of some cancer and obesity by preventing immune dysfunction (Çehreli, 2018; Leischner et al., 2015; Raqib & Cravioto, 2009).

Personalised nutrition, nutrigenomics and nutritional immunology will reduce the risk of chronic disease by decreasing the impact of external drivers of chronic disease. These innovations can increase populations' education and awareness of their health. Educating people on how their characteristics are influenced by nutrition will influence positive food choices on what foods are best for their health, thus reducing their risk of chronic disease. Personalised nutrition and nutritional immunology will allow for targeted nutrition and a reduction in costs. If people can focus on specific foods they know are beneficial for them, this could decrease the cost of buying multiple foods and not knowing if they are benefiting from them, thus increasing the affordability of a healthy diet. These innovations could also improve New Zealand and Australia's eating habits since these populations have a high snacking and eating-out lifestyle. Suppose the populations were given personal nutrition advice and educated on nutritional immunology. In that case, this could lead to more beneficial eating choices when eating away from home, thus positively influencing diet factors of chronic disease.

These innovations are upcoming fields, so bringing these innovations to New Zealand and Australia could allow for increased employment opportunities for these populations, influencing income status. New trends could alleviate the trade-off between income, time and food affordability of a healthy diet and lifestyle in these populations.

5.1.3.3 Future political implications

Implementing new food science and technology in New Zealand and Australia calls for new policies and considerations for current guidelines. Policies aid in identifying tasks and procedures and ultimately dictate expectations and guidelines to be followed.

Tax subsidies for SSBs and sodium reduction targets were discussed in the introduction chapter and will contribute to improving the diet of these populations. The innovations discussed in this chapter, such as vertical farming and plant-based foods, aim to increase FV intake and decrease processed and fast-food consumption. These innovations will improve the diet and reduce sodium and SSB consumption.

Although schools and communities throughout New Zealand and Australia have implemented vertical farming, this technology is yet to be included in infrastructure planning in New Zealand and is only beginning in Australia. Decreasing space in urban areas with rapid urbanisation and modernisation calls for new policies to allow for the implementation of vertical farming in New Zealand and Australia. Implementing policies and plans for vertical farming will ensure growth in this area and improve nutrition in urban areas throughout New Zealand and Australia.

The New Zealand Healthy Eating Guidelines already include recommendations for a plant-based diet with a small to moderate amount of animal sources (Ministry of Health, 2020). New Zealand and Australian dietary guidelines suggest legumes, nuts and seeds as a source of protein. This creates an opportunity to create plant-based foods in line with current guidelines, and companies could use the Healthy Star rating to promote their innovations.

Personalised nutrition, nutrigenomics, and nutritional immunology are novel concepts in New Zealand and Australia, with no policies or guidelines for implementing this technology. If this innovation were introduced, healthy eating guidelines might no longer be appropriate as individuals will have specific nutrition advice to follow depending on their genetics. This will make it challenging to introduce policies and procedures as specific nutrition advice will not apply to whole populations.

5.1.3.4 Summary

Future trends are emerging worldwide which New Zealand and Australia would benefit from investing in to improve nutrition-related chronic diseases. These trends focus on enhancing food system sustainability and adjusting to climate change with plant-based foods and vertical farming. Personalised nutrition, nutrigenomics and nutritional immunology are more specific approaches to improving nutrition and chronic disease risk but are equally important in improving health. These fields are new and complex, and if invested in, New Zealand and Australia could be amongst the first to implement these future trends. Planning and policies may be required to aid in implementing these innovations and will contribute towards improving diet factors associated with chronic disease. By implementing these innovations, the environmental, political, and socio-economic drivers of chronic disease will be reduced, improving food affordability, availability and accessibility, thus influencing the improvement in diet factors and diet sustainability, reducing the risk of chronic diseases (Figure 5-1).

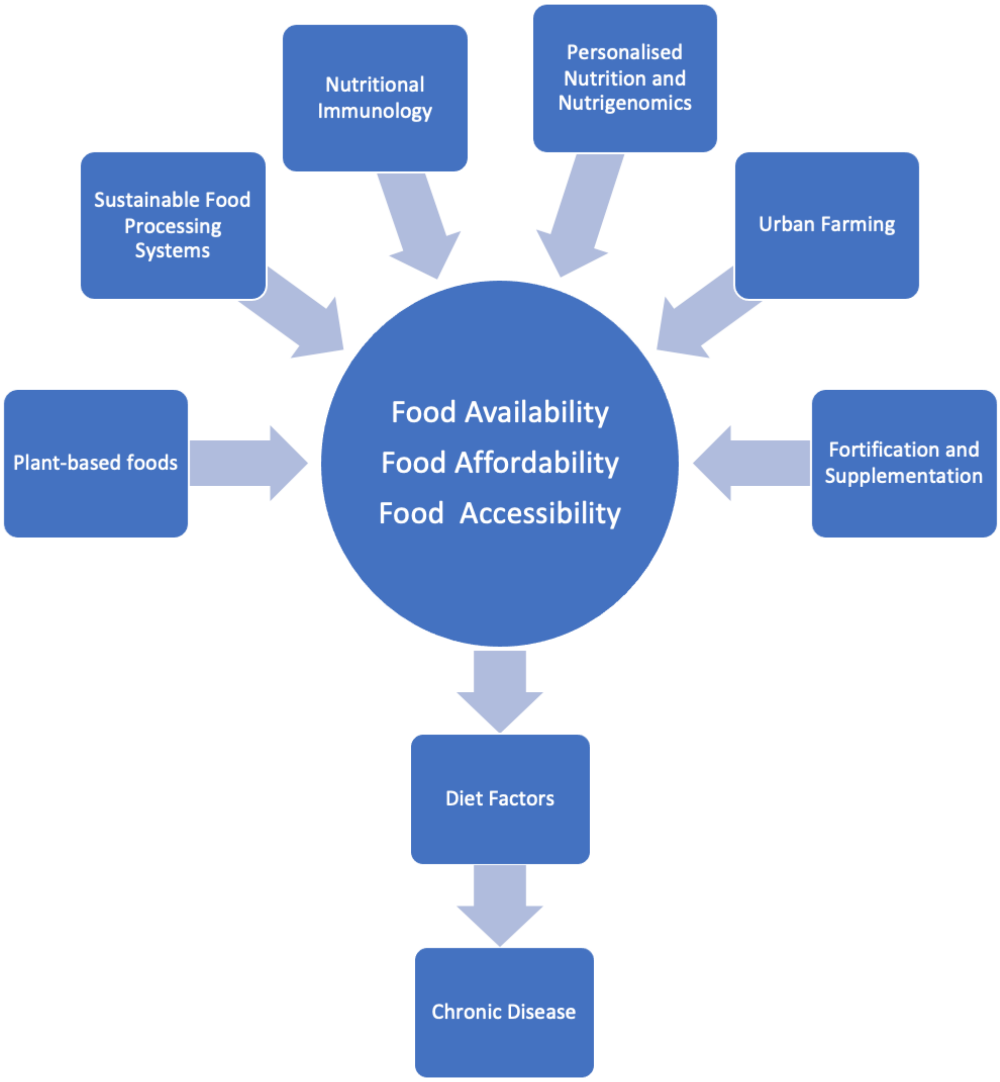

Figure 5-1 Relationship between future trends and chronic disease.

5.2 Limitations

Scoping review methods have limitations related to the methodology and the available research limitations. A review of reported limitations in scoping reviews outlines the most noted is the possibility of the review missing studies due to database selection, exclusion of grey literature, time constraints, and excluding studies in a language other than English (Anderson et al., 2008; Pham et al., 2014). This finding guided the choice to include grey literature in this scoping review and ensure that database selection was thoroughly researched. Due to this review focusing on New Zealand and Australia, it was unnecessary to include studies in languages other than English, so restricting the search to English was not a limitation. The dates of publication chosen are also a limitation. A period between 2018 and 2022 was selected to gather new and upcoming innovations, excluding innovations published before 2018. Innovations were also excluded due to being in the early stages of testing and had not completed human investigations. Since this scoping review was looking for new technology, a five year period was appropriate.

A scoping review focus can be wide and shallow, and when only collecting articles focused on a specific question, this can lead to unsystematic research. Scoping reviews do not typically evaluate evidence quality, which can decrease the strength of the evidence (Anderson et al., 2008). The food industry is a vast subject hence the chosen research method. This review sought to collect a wide range of evidence across many different fields, so a shallow focus was acceptable for this topic.

Lack of critical appraisal is another limitation frequently mentioned (Pham et al., 2014). Critical appraisal is an optional step in scoping reviews as quality assessment and was not included in this review (Pham et al., 2014). There were only 11 articles included in this review, so the quality of the articles was not discriminated against. Due to this, the quality of evidence was not discussed when interpreting the review results.

This review is a Master's thesis, and there was no way to reduce the limitation of time constraints. Time constraints resulted in excluding reviews and book chapters from this review, including evidence inside and outside New Zealand and Australia.

Human error is another limitation of this scoping review. Although the software was used to aid the collection and analysis of articles, manual screening was carried out, which could have introduced bias. Screening manually relies on researchers' perceptions and understanding, which could have resulted in articles being excluded or included inappropriately. A researcher and research supervisor conducted the screening to reduce human error as much as possible.

Results were not homogenous across innovations and, therefore, hard to compare. This made charting the data confusing and could have resulted in incorrect data added to the chart or data incorrectly compared between innovations. Comparing results across innovations and at-risk and healthy populations was challenging due to different innovations and varying effects. The results focused on healthy or at-risk people and did not differentiate further. Results were not compared between age groups, sex or ethnicity, which was done in some articles. There was no specific comparison between at-risk and healthy populations in any innovation articles, which could introduce bias from differences in sex or other characteristics of participants. Due to the nature of a scoping review, the detail gathered from each article was appropriate and sufficient to answer the research question.

Articles in the scoping review did not discuss how the innovation could minimise the influence of environmental, political and socio-economic factors contributing to chronic disease. This meant various assumptions were made when discussing this section. Information charted from each article involved nutrition biomarkers and how they were affected by the innovation and could have resulted in key findings from each innovation being excluded. Additional evidence was researched during the discussion to support these assumptions and is a field suggested for future research.

Chapter five discussed the reasons for the results found in the scoping review. By discussing these findings, gaps in the literature were identified, and implications of future research for food science and technology companies were provided to improve the health of New Zealand and Australia populations. In the following chapter, conclusions and an overall summary of the thesis will be provided. This final chapter also includes funding sources from the articles included in the review and the authors of this research.

CHAPTER 6 Conclusion

At the beginning of this research, the question was posed: What factors contribute to chronic disease in Australia and New Zealand, and how can food science and technology improve health?

This review presented evidence on current chronic disease statistics in New Zealand and Australia. Diabetes mellitus, CVD, cancer and chronic respiratory disease were identified as the most prevalent diseases in these countries. These chronic diseases have a complex relationship between metabolic syndrome and dietary factors such as sugar, fat, sodium, FV, a sedentary lifestyle, and ultra-processed and fast-food. Chronic disease costs New Zealand and Australia millions of dollars each year, and no change in DALYs since 2015, with a disproportionate effect on Māori and indigenous populations. These findings called for a deeper look into the external drivers of chronic disease in order to reduce chronic disease prevalence.

External drivers were investigated, including environmental, political and socio-economic drivers, to understand how they influenced chronic disease. A theoretical framework was designed to visualise the relationship between chronic disease and these external drivers, thus answering the first part of the research question (Figure 1-1). External drivers can be targeted by food science and technology innovations to decrease the prevalence of chronic disease.

To answer the second part of the research question, a scoping review was carried out to understand current food science and technology innovations to improve health in New Zealand and Australia. This section of the scoping review allowed for identifying gaps in the literature and informing recommendations and implications for future research to improve the health of New Zealand and Australian populations.

This scoping review revealed current food science and technology innovations focus on fortifying and supplementing everyday food products, including bread, noodles, spread and biscuits with nutraceuticals and functional foods such as curcumin, polyphenols, phytosterols, oat β-glucans, vegetables and fish oil through well-researched nutraceutical activities. These innovations aim to reduce the risk of chronic disease by improving nutrition biomarkers such as glucose tolerance, insulin sensitivity, inflammation, appetite, HbA1c and lipid parameters in healthy and at-risk populations. However, current innovations do not consider external drivers of chronic disease or Māori and indigenous populations. Assumptions were made on possible impacts on environmental, political and socio-economic factors to improve chronic disease. Still, future research should focus on investigating drivers of chronic disease as well as nutrition biomarkers. When analysing future innovations, the target population needs to be identified as differing responses were found depending on the population studied.

This scoping review has highlighted the need for plant and food research and development companies to focus on other emerging trends, including personalised nutrition and nutrigenomics, plant-based foods, sustainable food systems, vertical farming and nutritional immunology. These innovations can successfully improve chronic disease by making healthy and sustainable diets more available, accessible and affordable by influencing diet factors and external drivers of chronic disease.

6.1 Funding

This scoping review contributed to a Master of Health Science in Nutrition and Dietetics at the University of Auckland. There was no dedicated funding, and the researcher or the research supervisor declared no conflicts of interest. Plant and Food Research New Zealand Crown Research Institute funds the research supervisor. Table 6-1 shows funding sources and any conflicts of interest in the included articles in the scoping review.

Table 6-1 Funding of included references in the scoping review.

Reference	Sources of funding	Conflict of interests
(Murray et al., 2019).	Australian Government Research Training Program Scholarship Marinova Pty Ltd	None declared
(Ferguson et al., 2019)	Newtrition® Asia Research Grant by BASF	None declared
(Thota et al., 2018)	No dedicated funding Neville Eric Sansom scholarship from the University of Newcastle, Australia	None declared
(Thota et al., 2019)	No dedicated funding Neville Eric Sansom Scholarship from the University of Newcastle, Australia	None declared
(Ferguson et al., 2018)	No dedicated funding	None declared
(Amoah et al., 2021)	Riddet institute scholarship funded by the Tertiary Education Commission Auckland University of Technology, New Zealand	None declared
(Ferguson et al., 2020)	No dedicated funding Scholarship from the university of Newcastle, Australia	None declared
(Belobrajdic et al., 2019)	Arista Cereal Technologies CSIRO Food Futures Flagship	None declared
(Ang et al., 2020)	CSIRO Black Mountain	None declared
(Murray et al., 2018).	Australian Government Research Training Program Scholarship Marinova Pty Ltd	None declared
(Murray et al., 2021)	Australian Government Research Training Program Scholarship Marinova Pty Ltd	None declared

CHAPTER 7 Appendices

Appendix 1: PRISMA-ScR Checklist

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
TITLE			
Title	1	Identify the report as a scoping review.	i
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	ii
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	29
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	33 - 33
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	N/A
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	33 - 34
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	35
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	35 - 36 Appendix 3
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	36
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	37
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	37
Critical appraisal of individual	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe	N/A

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
sources of evidence§		the methods used and how this information was used in any data synthesis (if appropriate).	
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	38 - 39
RESULTS			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	40
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	41 - 43
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	N/A
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	Appendix 4
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	44 - 53
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	54 - 74
Limitations	20	Discuss the limitations of the scoping review process.	74 - 76
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	77 - 78
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	78 - 79

Appendix 2: Index Terms and Synonyms used

Keyword/index term	Food Science	Technology	Nutrition	Chronic Disease
Synonym 1	Food technology	Biomedical technology	Nutrition status	Health*
Synonym 2	Fermented food	Biotechnology	Plant based food	Wellness
Synonym 3	Nutrigenomics	Environmental sustainability	Diet	Chronic illness
Synonym 4	Nutritional immunology	Botanicals	Food	Chronic condition
Synonym 5	Genetically modified food	Bioengineering	Sugar	Diabetes mellitus
Synonym 6	Probiotics	Quality control technology	Beverage	Diabetes
Synonym 7	Food preservation	Technology Transfer	Food intake	Cancer
Synonym 8	Fortified food	Agricultural technology	Gut health	Chronic respiratory disease
Synonym 9	Organic	Industry technology	Sodium	Noncommunicable disease
Synonym 10	Food quality		Salt	Noninfectious disease
Synonym 11	Functional food		Fruit	Health status
Synonym 12	Food production		Vegetable	
Synonym 13	Nootropics		Fat	
Synonym 14	Adaptogens		Saturated fat	
Synonym 15			Unsaturated fat	
Synonym 16			Processed food	
Synonym 17			Personalised nutrition	

Appendix 3: Example Search Strategies

Scopus:

TITLE-ABS-KEY ("food science" OR "food technolog*" OR "fermented food*" OR "nutrigenomics" OR "nutritional immunology" OR "genetically modified food*" OR "probiotics" OR "food preservation" OR "organic" OR "food quality" OR "food production" OR "functional food*" OR "fortified food*" OR "nootropics" OR "adaptogens" OR "technolog*" OR "biotechnolog*" OR "quality control technolog*" OR "technology transfer" OR "bioengineering" OR "industry technolog*" OR "agricultural technolog*" OR "biomedical technolog*" OR "botanicals" OR "environmental sustainability") AND TITLE-ABS-KEY ("nutrition*" OR "nutrition* status" OR "diet*" OR "food*" OR "beverage*" OR "food intake" OR "sodium" OR "salt" OR "fruit*" OR "vegetable*" OR "fat*" OR "saturated fat*" OR "unsaturated fat*" OR "processed food*" OR "gut health" OR "sugar" OR "plant based food*" OR "personalised nutrition") AND TITLE-ABS-KEY ("health" OR "wellness" OR "chronic disease*" OR "chronic illness*" OR "chronic condition*" OR "diabetes mellitus" OR "diabetes" OR "cancer*" OR "chronic respiratory disease*" OR "noncommunicable disease*" OR "noninfectious disease*" OR "health status") AND (PUBYEAR > 2017) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (AFFILCOUNTRY , "Australia") OR LIMIT-TO (AFFILCOUNTRY , "New Zealand"))

Pubmed:

("food science"[Title/Abstract] OR "food technology"[Title/Abstract] OR "fermented food"[Title/Abstract] OR "nutrigenomics"[Title/Abstract] OR "nutritional immunology"[Title/Abstract] OR "genetically modified food"[Title/Abstract] OR "probiotics"[Title/Abstract] OR "food preservation"[Title/Abstract] OR "organic"[Title/Abstract] OR "food quality"[Title/Abstract] OR "food production"[Title/Abstract] OR "functional food"[Title/Abstract] OR "fortified food"[Title/Abstract] OR "nootropics"[Title/Abstract] OR "adaptogens"[Title/Abstract] OR "technology"[Title/Abstract] OR "biotechnology"[Title/Abstract] OR "quality control technology"[Title/Abstract] OR "technology transfer"[Title/Abstract] OR "bioengineering"[Title/Abstract] OR "industry technology"[Title/Abstract] OR "agricultural technology"[Title/Abstract] OR "biomedical technology"[Title/Abstract] OR "botanicals"[Title/Abstract] OR "environmental sustainability"[Title/Abstract]) AND ("nutrition"[Title/Abstract] OR "nutrition status"[Title/Abstract] OR "diet"[Title/Abstract] OR "food"[Title/Abstract] OR "beverage"[Title/Abstract] OR "food intake"[Title/Abstract] OR "sodium"[Title/Abstract] OR "salt"[Title/Abstract] OR "fruit"[Title/Abstract] OR "vegetable"[Title/Abstract] OR "fat"[Title/Abstract] OR "saturated fat"[Title/Abstract] OR "unsaturated fat"[Title/Abstract] OR "processed food"[Title/Abstract] OR "gut health"[Title/Abstract] OR "sugar"[Title/Abstract] OR "plant based food"[Title/Abstract] OR "personalised nutrition"[Title/Abstract]) AND ("health"[Title/Abstract] OR "wellness"[Title/Abstract] OR "chronic disease"[Title/Abstract] OR "chronic illness"[Title/Abstract] OR "chronic condition"[Title/Abstract] OR "diabetes mellitus"[Title/Abstract] OR "diabetes"[Title/Abstract] OR "cancer"[Title/Abstract] OR "chronic respiratory disease"[Title/Abstract] OR "noncommunicable disease"[Title/Abstract] OR "noninfectious disease"[Title/Abstract] OR "health status"[Title/Abstract]) AND ("New Zealand"[Title/Abstract] OR "Australia"[Title/Abstract]) AND (y_5[Filter]) AND (english[Filter])

Appendix 4: Data Charting

Number	Title	Author	Year	Country	Source type	Study design
1	Noodles Made from High Amylose wheat Flour Attenuate Postprandial Glycaemia in Healthy Adults	Ang et al	2020	Australia	Study	Randomised, single-blinded, crossover trial. Consumed 180g noodles containing 15%, 20% and 45% amylose at weekly interval after a 10hr fast. Each participant tested each meal twice over a 6-week period.
2	High-amylose wheat lowers the postprandial glycemic response to bread in healthy adults: A randomized controlled crossover trial	Belobrajdic et al.	2019	Australia	Study	Randomised, double-blinded, cross over controlled study. Over 7 weekly visits consumed a glucose drink or four different breads with either high or low amylose wheat and with white or wholemeal.
3	The impact of a single dose of a polyphenol-rich seaweed extract on postprandial glycaemic control in healthy adults: A randomised cross-over trial	Murray et al.	2018	Australia	Study	Randomised, double-blinded, placebo-controlled, cross over trial. Paricipants consumed a low (500mg) and, high (2000mg) dose of polyphenol rich brown seaweed extract, and a placebo at different sessions, 30 mins prior to consuming white bread (50g carbohydrates).
4	A Single-Dose of a Polyphenol-Rich Fucus Vesiculosus Extract is In sufficient to Blunt the Elevated Postprandial Blood Glucose Responses Exhibited by Healthy Adults in the Evening: A Randomised Crossover Trial	Ryan et al.	2019	Australia	Study	Randomised, double-blinded, placebo-controlled, three-way crossover, trial. Participants consumed a polyphenol-rich extract, a cellulose placebo and a rice flour placebo at 7.15pm before a 50g CHO meal. A subset also completed this in the morning with a cellulose placebo.
5	Curcumin alleviates postprandial glycaemic response in healthy subjects: A cross-over, randomized controlled study	Thota et al.	2018	Australia	Study	Randomised, placebo-controlled crossover study. Participants received a placebo, curcumin (180mg) tableys, fish oil (1.2g long chain omega-3 PUFA) capsules, and curcumin plus fish oil prior to a standard meal on 4 test days seperated by a week.

Appendices

Number	Participant number and characteristics	Aim of literature	Food science/ technology innovation	Variables measured
1	12 healthy young adults. No chronic disease or risk factors.	Investigate the effect of consumption of high amylose noodles on postprandial glycaemia.	High amylose noodles	Blood glucose concentration. Samples collected at baseline and postprandial (15, 30, 45, 60, 90 and 120 minutes).
2	20 healthy adult participants. No chronic disease or risk factors.	Determine if bread with high-amylose wheatand resistant starch attenuates postprandial glycermia.	High amylose bread.	Blood glucose, plasma insulin, incretin and ghreline hormones, appetite and inflammatory markers (ICAM-1) and nitrotyrosine). Samples collected at baseline and 3 hours after, appeitie questions asked every 30 mins.
3	38 healthy adult participants. No chornic disease or risk factors.	Investigate the impact of polypehnol-rich seaweed extract on postprandial glycemaic responses in healthy adults.	Polyphenol rich seaweed extract (Fucus vesiculosus).	Blood glucose and plasma insulin. Samples collected over 2 hours (fasting, 15, 30, 45, 60, 90 and 120 mins).
4	18 healthy adult participants. No chornic disease or risk factors.	Investigate if polyphenol-rich alga extract moderates postprandial glycaemia in the evening in healthy adults.	Polyphenol extract from alga (Fucus vesiculosus).	Blood glucose, plasma insulin. Samples collected at baseline and postprandial up to 3 hours (15, 30, 45, 60, 90, 120 minutes) .
5	15 healthy participants. No chronic disease or risk factors.	Evalutae the effects of a single dose of curcumin and/or fish oil on postprandial glycaemic paratmeter in healthy individuals.	Curcumin and fish oil supplementation.	Blood glucose, serum insulin and lipid profile (TG). Samples collected at baseline 1 hour and 2 hours post meal.

Number	Impact on nutrition outcomes/biomarkers	Chronic disease prevention risk	Study conclusion
1	45% amylose noodles had significantly lower blood glucose response at 15, 30 and 45 mins compared to 15% amylose noodles and had the smallest flucuation. 3.4% reduction on glycaemic response.	Reduce risk of T2D and CVD by reducing fluctuations in postprandial glycaemia and decrease risk of insulin resistance and oxidative stress due to the reduced amount of available carbohydrates and increased starch.	Noodles made from high amylose wheat reduces postprandial glucose response in healthy adults.
2	Increase resistant starch intake, high amylose wheat had a 39% lower glycemic response, and a 24% lower insulinemic response (most pronounced at 30mins). Max plasma glucose reponse of the high amylose wheat was 33% less than low amylose wheat, but time to reach max glucpse concentration was similar (40 mins, 34 mins). GIP and GIP-1 (incretin hormones) was 30% lower in high amylose wehat than low amylose wheat. Refinement had no affect on any variables measured. Cravings were not different between low amylose wheat and high amylose wheat bread, flour processing had no affect, no difference in ghrelin. Amylose content did not affect biomarkers of oxidative stress and inflammation.	Reduce risk of T2D by improving insulin sensitivity and glycaemic control. Lower total daily energy intake.	Replacing low amylose wheat with high amylose wheat in bread lowers postprandial glycaemic and insulin response in healthy participants. Due to the decreased availability of carbohydrates in the high amylose bread. These responses were similar with both wholemeal and refined flour.
3	Neither dose had an impact on glucose or insulin responses.	Reduce risk of T2D by improving glucose and insulin responses.	Polyphenol rich seaweed extract had no affect on postpranial glucose or insulin responses.
4	Elevated postprandial blood glucose response in healthy individuals when carbohydrates were consumed in the evening comparted to the morning. Polyphenol-rich extract had a non-significnat lowering effect on peak postprandial concentration in women coampred to placebos.	Reduce T2D and CVD risk by improving extended hyperglycemia overnight.	No effect of polyphenol-rich extract on postprnadial glycaemia or insulin response in the evening compared to placebos. In females peak blood glucose was reduced. Participants showed an elevated postprnaidial blood glucose in the evening compared to the morning.
5	Serum insulin and lipid profile (TG) did not significantly reduce in either groups. Postprandial glucose concentrations significantly reduced in curcmin and curcumin plus fish oil groups after 60 mins compared to baseline. Fish oil alone did not reduce postprandial glucose concentrations. Curcumin and curcumin plus fish oilsignificantly lowered postprandial insulin by 26% compared to placebo.	Reduce risk of T2D by controlling glycaemic response.	Cucrumin reduces postprandial glycaemic response and insulin demand for glucose control but, fish oil does not.

Number	Title	Author	Year	Country	Source type	Study design
6	Glycaemic and appetite suppression effect of a vegetable-enriched bread	Amoah et al.	2021	New Zealand	Article	Randomised, crossover. Three separate ocasions sperated by three days. Participants consumed a 75 g serve of white bread, wheatmeal bread or vegetable enriched bread.
7	High molecular weight oat β-glucan enhances lipid-lowering effects of phytosterols. A randomised controlled trial	Ferguson et al.	2020	Australia	Study	Randomised double-blinded, placebo-controlled trial over 6 weeks. Received a placebo or biscuits foritfied with different combinations of phytosterols, oat B-glucan.
8	Bread enriched with phytosterols with or without curcumin modulates lipoprotein profiles in hypercholesterolaemic individuals. A randomised controlled trial	Ferguson et al.	2019	Australia	Study	Randomised, double-blinded, placebo-controlled, 2 x 2 factorial trial with four parallel groups. Pariticipants received bread fortified with either a placebo, 2.3g PS, 228 mg curcumin, or a combination of 2.3g PS and 228mg curcumin daily for four weeks.
9	Curcumin potentiates cholesterol-lowering effects of phytosterols in hypercholesterolaemic individuals. A randomised controlled trial	Ferguson et al.	2018	Australia	Study	Randsomised, double-blinded, placeb-controlled, 2 x 2 factorial four week paralell trial. Participants received weither placebo, PS 2g/day, curcumin 200mg/d or a combination 2g/day PS and 200mg/day curcumin.
10	Twelve weeks' treatment with a polyphenol-rich seaweed extract increased HDL cholesterol with no change in other biomarkers of chronic disease risk in overweight adults: A placebo-controlled randomized trial	Murray et al.	2021	Australia	Study	Randomised, double-blinded, placebo-controlled, parallel trial over 12 weeks. Participants either received 200mg/day powdered seaweed extract or a placebo.
11	Curcumin and/or omega-3 polyunsaturated fatty acids supplementation reduces insulin resistance and blood lipids in individuals with high risk of type 2 diabetes: a randomised controlled trial	Thota et al.	2019	Australia	Study	Randomised, double-blinded, placebo-controlled, 2 x 2 factorial trial. Patients were allocated either placebo, curcumin and placebo, LCn-3PUFA and placebo, or curcumin and LCn-3PUFA for twelve weeks.

Number	Participant information	Aim of literature	Food science/ technology innovation	Variables measured
6	10 obese adult participants. No chronic disease.	Test the effect of vegetable enriched bread on serum glucose, insulin response and appetite supression compared to commercial white bread (over a 120min period).	Vegetable enriched bread (pumpkin and sweetcorn drum-dried powders).	Postprandial blood glucose, plasma insulin, appetite. Samples collected at basline and postprandial (15, 30, 45, 60, 90 and 120 minutes).
7	18 adults with hypercholesterol, no chronic disease.	Investigate the effects of dietary supplementation with high molecular weight Β-glucan with or without phytosterols on plasma lipids in hypercholesterolaemic individuals.	High molecular weight β-glucans to enhance phytosterols in biscuits.	Fasting lipid profile (total cholesterol, LDL, HDL, TG and TC to HDL ratio). Samples collected at baseline and post intervention.
8	75 adult participants with hypercholesterolemia. No chronic disease.	Investigate the effects of the combination of phytosterols and curcumin on plasma lipid profiles in hypercholesterolaemic indivisuals.	Bread supplemented with phytoserols and/or curcumin.	Fasting lipid profile (TC, LDL-C, HDL-C, TG, plasma HDL and LDL-particles number and size). CVD risk. Samples collected at baseline and post intervention.
9	70 adult participants with hypercholesterolemia. No chronic disease.	Investigate the effects of dietary intervetion with phytosterols or without curcumin on blood lipids in hypercholesterolaemic individuals. Determine whether curcumin complements phytosterols in cholesterol levels.	Phytosterol (enriched fat spread) and curcumin (tablets) supplementation.	Fasting lipid profile (TC, LDL-C, HDL-C, TG, TC-HDL-C ratio), fasting blood glucose. Samples collected at baseline and post intervention.
10	34 adult overweight/obese participants with hypercholesterolemia. No chronic disease.	Investigate the effect of a polyphenol-rich seaweed extract on biochemical markers of CVD risk.	200 mg/d powdered seaweed extract (Fucus vesiculosus).	Fasting lipid profile (TC, TG, LDL-C, HDL-C, TC-HDL-C ratio) blood glucose, plasma insulin. Fasting blood samples taken at baseline, weeks six and twelve.
11	64 adult participants at risk of development T2D (impaired fasting glucose and/or tolerance. No chronic disease.	Evaluate the effects of curcumin and/or omega-3 polyunsaturated fatty acid (LCn-3PUFA) supplemtation on glucaemic control and blood lipids levels in dividuals at high risk of developing T2D.	Curcumin and LCn-3PUFA supplementation.	Fasting lipid profile (TC, TG, HDL-C, LDL-C and TC : HDL-C ratio), blood glucose, plasma insulin, inflammation (CRP) and HbA1c. Samples collecetd at basline and post intervention.

Number	Impact on nutrition outcomes/biomarkers	Predicted chronic disease prevention risk	Study conclusion
6	Produced a lower insulin response than placebo. Higher fullness feeling. Increase vegetable intake. Vegetable enriched bread had higher fibre, potassium and B-carotene. No difference in glucose response, lower insulin reponse (38% compared to white). Hunger lowest for VB bread over 120min period, but not significant. Vegetable enriched bread had significantly higher appetite satisfaction and impaired ability to eat more.	Aims to reduce risk of type 2 diabetes and hypertension through increasing vegetable intake and reducing glycaemic level of bread. Reduce incidnece of diet-related non-communicale diseases.	Vegetable enriched bread reduced postprandial insulin release and increased fullness over 2hrs. This could be due to increased fibre content and texture.
7	High molecular weight oat β-glucan and phytosterol seperately lowers total cholesterol and LDL cholesterol. Phytosterols decreased TG. Phytosterols and oat β-glucan combined had highest change in TC, LDL-C, HDL, ratio, and TG.	Heart health and CVD risk reduction by improving lipid profile.	There is a complementary effect between oat β-glucan and phytosterols for cholesterol lowering in hypercholesterolaemic adults.
8	No significant difference between placebo, curcumin, phytoserol and phytoserol and cucrcumin combination on blood lipids or CVD risk, resulted were pooled and comparisoins made between groups with phytosterols (PS-C) or groups with no phytosterols (PL-C). PS-C significantly lowered TC, LDL-C and CVD risk reduced significnatly compared to Pl-C. HDL-C and TG were unchanged. PS-C had a 12.7% decreased risk of CVD compared to placebo. LDL-P significantly decreased in PS-C group compared to PL-C. LDL-P number significantly decreased in PS-C compared to PL-C. Absolute size of in LDL-P between groups was not significant. Curcumin fortification alone or in combination of phytosterols did not give any further benfefit to cholesterol levels.	Reducing CVD risk by improving lipid profile.	Regular concsumption of phytosterol encriched bread with or witout curcumin, lowers blood cholesterol. Curcumin alone did not influence blood lipids. Bread could be a means for delivering phytosterols for compliance in reducing blood cholesterol concentration.
9	Phytosterols (PS) and phytosterols + curcumin (PS-CC) supplemetation significanlty lowered TC, LDLC and, TC:HDL-C ratio. Curcumin (CC) showed no dignificnat reductions in TC or LDL-C. All groups showed a significnat difference in TC, LDL-C, TC:HDL-C ratio and, blood glucose. PS-CC showed the largest reduction in TC and LDL-C than other treatment groups. HDL-C and TG were unchanged across all groups. Plasma glucose concentration significantly reduced in CC groups only.	Reduce CVD risk by improving lipid profile and potential reduction in inflammation (inflammataory markers not measured).	Curcumin and phytosterol supplementation combined significantly reduced fasting plasma TC and LDL-C in hypercholesterolemic individuals.
10	9.5% increase in HDL-C in supplementation group after 12 weeks (not significant for actual change in HDL-C). No changed in LDL-C, TC, TG, glucose, insulin or interleukin or TNFA in blood between treatment and placebo groups.	Reduce CVD risk by increasing HDL.	Polyphenol rich seaweed extract of F. vesiculosus supplemtnetation over 12 weeks did not show any changes in LDL-C, TC, TG, glucose, insulin or inflammatory markers. A 9.5% significant increse in HDL-C compared to placebo but not significnat actual change between groups.
11	HbA1C and fasting glucose unchanged for all groups. Insulin sensitivty improved for group that was supplemted with curcumin only. Non-significicant improved insulin sensitivity for cucurmin and LCn-3PUFA group and LCn-3PUFA only group. Tryglycerides decreased in curcumin only group and curcumin and LCn-3PUFA group. The LCn-3FUFA group had the highest reduction on tryglycerdies. No significant effects on CRP in any groups.	Decrease risk of T2D by improvong glycaemic control and lipid profile.	Reduction in insulin resistance and tryglyceridses by curcumin and LCn-3PUFA could be a strategy for lowering T2D development. No benefits on glycaemic control.

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