Diet quality and iron status among postpartum women living in Palmerston North, New Zealand.

Mother and Infant Nutrition Investigation (MINI) Study

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Abstract

Background: Iron deficiency (ID) and anaemia are prevalent among postpartum women and represent an important public health concern. During the postpartum period, inadequate iron status can contribute to fatigue, impaired cognitive function and reduced quality of life, with potential consequences for both maternal and infant well-being. Despite the recognised importance of nutrition during this life stage, there is limited research on the relationship between overall diet quality and iron status among postpartum women in New Zealand (NZ).

Objective: To investigate the relationship between diet quality and iron status in postpartum women in New Zealand.

Methods: This secondary data analysis used the data collected from 87 postpartum women living in Palmerston North, New Zealand. Participants were recruited for the Mother and Infant Nutrition Infant Investigation (MINI) study. At six months postpartum 75 participants completed a weighed four-day food diary (4DDD) to assess dietary intake. Diet quality was calculated using a modified Dietary Guideline Index (DGI) adapted to New Zealand dietary guidelines. Iron status was assessed through serum ferritin (SF) and haemoglobin (Hb) biomarkers. C-reactive protein (CRP) was used to adjust for inflammation. Statistical analysis was conducted to find associations between diet quality, iron status, and sociodemographic factors. Nonparametric data were expressed as median and interquartile range (median [Q1, Q3]), while categorical variables were expressed as frequencies and percentages.

Results: The median total dietary guideline index score (TDGIS) for postpartum women was 59.5/100 [54.1, 68.3]. Adherence to individual dietary components varied, with the highest adherence for protein (72% met recommendations) and the lowest for dairy (12%). Only 30.7% of participants met vegetable recommendations, 33.3% for fruit, and 22.7% for grains. The median diet variety score was 26 [23.0, 29.0] out of a possible 65, with participants achieving on average 43.6% of the highest possible variety score. Iron insufficiency (SF <30 µg/L) was confirmed in 12.9% (n=9) of participants. Participants with iron sufficiency had significantly higher total dietary guideline index scores (TDGIS) (60.9 [55.0, 69.1]) compared to iron-insufficient participants (53.6 [46.1, 61.4], p=0.026) out of 100. Grain intake was

significantly higher in iron-sufficient participants (4.5 [3.9,5.8]) compared to iron-insufficient participants (3.2 [1.8,4.4], p=0.014). Higher education attainment was positively associated with iron sufficiency and higher total dietary guideline index scores (p<0.001).

Conclusion: This is the first study in NZ to investigate the association between diet quality and iron status among the postpartum population in NZ, to the best of our knowledge. The findings of this study suggest that a lower diet quality is associated with an increased risk of insufficient iron levels. This finding reinforces the importance of postpartum nutrition. The positive relationship between diet quality and education highlights the role of community-based nutrition education to support postpartum women, with targeted public health interventions targeted for those at higher risk. Future research should continue to prioritise diet quality while incorporating distinctions between haem and non-haem iron sources and other dietary factors influencing iron absorption to further understand the relationship between diet and iron status in postpartum women.

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List of Abbreviations

4DDD	Four-day diet diary
CRP	C-Reactive Protein
DCYTB	Duodenal cytochrome B reductase
DGI	Dietary Guideline Index
DMT1	Divalent metal transporter 1
EBF	Exclusively Breastfed
EAR	Estimated Average Requirements
Hb	Haemoglobin
ID	Iron Deficiency
IDA	Iron Deficiency Anaemia
IDE	Iron Deficiency Erythropoiesis
Mb	Myoglobin
MINI	Mother and Infant Nutrition Investigation
NZ	New Zealand
PBF	Partially Breastfed
PPA	Postpartum Anaemia
PPD	Postpartum Depression
PPID	Postpartum Iron Deficiency
RBC	Red Blood Cell
RDI	Recommended Dietary Intakes
SES	Socioeconomic Status
SF	Serum Ferritin
sTfR	Soluble Transferrin Receptor
TDGIS	Total Diet Guideline Index Scores
Tf	Transferrin
TfR1	Transferrin Receptor 1
TIBC	Total Iron-Binding Capacity
TSAT	Transferrin Saturation
WHO	World Health Organisation

Chapter 1: Introduction

1.1 Background

The postpartum period is a nutritionally vulnerable phase characterised by an increase in physiological demands, hormonal changes, and lifestyle adjustments. Adequate nutrition during this time is critical to support maternal recovery, lactation and overall health (University of Otago and Ministry of health, 2011, van der Pligt et al., 2016). Previous research identified that many postpartum women worldwide do not meet national dietary guidelines, which may have implications for their health (van der Pligt et al., 2016, Lebrun et al., 2019). In New Zealand (NZ), national data indicates poor dietary habits among women of reproductive age, specifically low intakes of fruits, vegetables, dairy and whole grains, alongside a high consumption of energy-dense foods. These trends are especially prevalent among certain populations such as younger adults, Māori and Pacific populations, and those living in high-deprivation areas (Ministry of Health, 2022). In addition to increased nutritional demands, the postpartum period is also marked by significant psychological and behavioural changes that impact dietary habits. Many women report changes in appetite, food preferences and eating patterns. Sleep deprivation, limited time, and competing priorities also contribute to changes in eating habits postpartum and reliance on convenience foods (Jin et al., 2025). The Ministry of Health (2022) reported fewer than 40% of breastfeeding women meet the fruit and vegetable intake guidelines.

Iron is one micronutrient of concern during the postpartum period. Factors such as pre-existing iron stores, blood loss during delivery, and increased nutritional demands contribute to the risk of iron deficiency (ID) and iron deficiency anaemia (IDA). ID and IDA may impact maternal health by increasing fatigue, impairing cognitive function, and raising the risk of postpartum depression (PPD) (Beard et al., 2005). While severe IDA is less common, mild to moderate iron insufficiency is still prevalent in NZ. A recent observational study across three District Health Boards in NZ, reported that 38% of women tested during the postpartum period had anaemia (Haemoglobin (Hb) <100g/L), highlighting the ongoing risk in this population (Calje et al., 2023). Earlier national data from the 2008/2009 New Zealand Adult Nutrition Survey found that approximately 10.4% of women aged 15-49 were classified as iron-deficient (University of Otago and Ministry of Health, 2011)

Diet quality refers to how well an individual's overall dietary intake aligns with nutrition guidelines and recommendations. It encompasses multiple aspects of eating behaviour, including variety, adequacy and balance of foods consumed (van der Pligt et al., 2016). Diet quality can be assessed through a Dietary Guideline Index (DGI). The DGI provides a composite score reflecting adherence to dietary guidelines across food groups (Ward et al., 2019). During the postpartum period, diet quality is often suboptimal. Research from Australia and NZ has shown low adherence to dietary guidelines among postpartum women. van der Pligt et al. (2016) and Lebrun et al. (2019) found that fruit and vegetable consumption declined following childbirth. Jin et al. (2025) also reported inadequate intake of fruit, vegetables, dairy and grains in breastfeeding women in NZ. This decline in diet quality may increase the risk of micronutrient insufficiencies, including iron status. Several individual and structural factors can influence diet quality during this life stage. Martin et al. (2020) identified barriers including time constraints, reduced motivation, economic pressures, and lack of support as key contributors to poor postpartum dietary habits. Additional factors, such as education, income, ethnicity, and breastfeeding practices, also influence dietary behaviours and potentially lead to differences in nutrient intake and overall diet quality among the postpartum population (Jin et al., 2021).

Despite the growing interest in maternal nutrition, there has been limited research specifically looking at the relationship between diet quality and iron status in postpartum women in New Zealand. Given the implications for maternal recovery, mental health, and infant development, understanding the association between diet quality and iron status in this population is essential. This research aims to address that gap by assessing diet quality using a modified DGI, evaluating iron status using serum ferritin (SF) and Haemoglobin (Hb), and exploring how sociodemographic variables influence these outcomes.

1.2 Purpose of the study

Despite the postpartum period traditionally being considered a time of low risk for iron deficiency (ID) (Bodnar et al., 2005), recent studies suggest that ID remains a concern throughout the first year postpartum (Antoine et al., 2023, Savage, 2021). Factors such as depleted iron stores from pregnancy, blood loss during delivery, poor dietary intake, and increased nutrient demands during breastfeeding can all contribute to ID during the postpartum period. ID can significantly affect maternal well-being by contributing to fatigue, reduced work capacity, impaired cognitive function, and increased risk of postpartum depression (PPD) (Beard et al., 2005, University of Otago and Ministry of Health, 2011). Despite these risks, iron status during the postpartum period is under-researched in New Zealand (NZ), and limited data exist on the dietary and sociodemographic factors associated with iron status in this population.

The research aims to build on existing knowledge by exploring the relationship between iron status and diet quality in postpartum women, specifically focusing on mothers in Aotearoa, NZ. Previous studies in NZ are limited, with only two studies assessing maternal iron status in mothers postpartum (Savage, 2021, Jin et al., 2021). Therefore, the current study aims to contribute to understanding postpartum iron status among NZ mothers and provide insights into the dietary factors influencing iron status during this period. There is a well-established relationship between maternal iron status during pregnancy and delivery. However, there is a gap in the knowledge during the postpartum period. This study aims to address this gap and contribute valuable knowledge to the literature on how maternal diet quality during the postpartum period may impact iron status.

1.3 Aim, Objectives and Hypotheses

1.3.1 Aim

To investigate the relationship between diet quality and iron status in women at 6 months postpartum living in New Zealand.

1.3.2 Objectives

1. To measure the diet quality of postpartum women using a four-day diet diary (4DDD) and modified Dietary Guideline Index (DGI).
2. To determine the prevalence of iron deficiency (ID) among postpartum women using serum ferritin (SF) and haemoglobin (Hb) as biomarkers, with SF as the primary indicator.
3. To investigate the relationship between total dietary guideline index scores (TDGIS) and iron status.
4. To investigate the relationship between factors (e.g. ethnicity, breastfeeding practices, education and household income) and diet quality.
5. To explore the predictors (e.g. education, breastfeeding practices and total dietary guideline index scores) of iron status.

1.3.3 Hypotheses

1. It is hypothesised that postpartum women will show suboptimal diet quality, indicated by low adherence to dietary guidelines across multiple DGI components.
2. Less than 15% of postpartum women will have SF levels below 30 μg/L.
3. Higher TDGIS is associated with greater likelihood of iron sufficiency.
4. European ethnicity, exclusively breastfeeding, tertiary education attainment and higher household income will be associated with higher diet quality scores.
5. Tertiary education attainment, exclusive breastfeeding and higher TDGIS will be associated with a greater likelihood of iron sufficiency.

1.4 Thesis structure

This thesis is presented in the following four chapters;

Chapter 1, Introduction to the study. This chapter summarises the background information and sets the research scene, purpose, and importance.

Chapter 2, Literature review, will include the most current literature on postpartum iron status and provide any needed definitions.

Chapter 3, Research study manuscript. This chapter presents the study. It includes the abstract, full introduction, methodology, results, discussion of the research, conclusion, and references.

Chapter 4, Conclusion, provides an overview of the study, identifying whether the aims and objectives were achieved. It also discusses the impacts of this research, any strengths and limitations of the study, and recommendations for future researchers.

1.5 Researcher Contributions

Researcher	Contribution to Thesis
Ellen Davis *Primary Researcher*	Responsible for thesis topic and study design. Led the writing, reviewing and editing. Conducted statistical analysis and interpreted the results and led submission of the thesis.
Associate Professor Louise Brough *Primary Supervisor*	Provided guidance and support for data analysis. Assisted with the interpretation and dissemination of results. Reviewed, and approved thesis chapters and the final manuscript.
Dr. Ying Jin *Secondary Supervisor*	Provided guidance and support for data analysis. Assisted with the interpretation and dissemination of results. Reviewed, and approved thesis chapters and the final manuscript.

Chapter 2: Literature Review

2.0 Introduction

Postpartum iron deficiency (PPID) and postpartum anaemia (PPA) are significant and prevalent health concerns for women worldwide, with implications for both maternal and infant well-being. Globally, PPA is estimated to affect 10-30% of women (World Health Organisation, 2024). While New Zealand (NZ) specific data is limited, one study reported NZ prevalence of PPA was 38% of postpartum women from birth to six weeks postpartum had PPA, with an overall incidence of 17% (Calje et al., 2023). The World Health Organisation (WHO) defines PPA as a public health problem when prevalence exceeds 20%, indicating that rates observed in NZ represent a notable concern (World Health Organisation, 2024). The aetiology of PPID and PPA is multifactorial. Key contributors include inadequate dietary iron intake, significant blood loss during delivery, pre-existing suboptimal iron stores, and gastrointestinal conditions that impair absorption (Lakew et al., 2024, Milman, 2011). Women from lower socioeconomic backgrounds are disproportionately affected, with lower education attainment, reduced access to healthcare, and higher levels of food insecurity increasing the risk of ID (Milman, 2011, Bodnar et al., 2001). Ethnic disparities also exist, recent research has identified higher rates of PPA among Māori and Pacific women compared to NZ European (Calje et al., 2023).

The consequences of PPID and PPA are wide-ranging. Physically, women may experience fatigue, weakness, and reduced work capacity, affecting their recovery and ability to care for their infants (Badr and Zauszniewski, 2017). There is strong evidence linking PPA with postpartum depression (PPD) and impaired cognitive function. This has an impact on mother-infant interactions (Moya et al., 2022, Beard et al., 2005, Kang et al., 2020). Optimal nutrition during the postpartum period is crucial for supporting maternal recovery, energy needs, and the demands of lactation (van der Pligt et al., 2016). However, studies indicate that many postpartum women fail to meet dietary guidelines (Lebrun et al., 2019, Martin et al., 2020b5). Barriers to adequate nutrition during the postpartum period may include physical and emotional fatigue, time constraints, and competing responsibilities, making meal planning, shopping and food preparation challenging (Opie et al., 2020).

Despite the established importance of iron status and diet quality for postpartum health, there is a lack of recent, comprehensive data describing these factors in NZ during the postpartum period. Existing nutritional surveys and targeted studies highlight ongoing challenges in achieving and maintaining adequate iron status in this population (University of Otago and Ministry of Health, 2011, Lim et al., 2020, Ferguson et al., 2001).

2.1 Role of iron in the body

2.1.1 Iron Distribution and Function

Iron is an element that is found everywhere in the body. Iron is crucial in numerous biological processes. Iron exists in the body in one of two forms: ferrous (Fe^{2+}) or ferric (Fe^{3+}) iron (Devlin, 2011). There are two dietary forms of iron: haem and non-haem iron. Iron can easily bind, and transport negatively charged elements such as oxygen, nitrogen, and sulphur, making it essential for many bodily functions (Thompson et al., 2019). In adults, approximately 70% of iron in the body is present as haemoglobin (Hb) and used for oxygen transport. The remainder is distributed to myoglobin (Mb) and other iron-binding proteins in tissues such as, ferritin and transferrin (Katsarou and Pantopoulos, 2020). Transferrin (Tf)-bound iron (transport protein) accounts for less than 1% of the total body iron (3-5g) in adults. Transferrin is highly dynamic, turning over approximately ten times per day to support erythropoiesis. Most iron is recycled from aged red blood cells, while 1-2mg/day is absorbed from dietary sources in adults. 1-2mg of iron is lost through processes such as, cell shedding and bleeding (Katsarou and Pantopoulos, 2020). Homeostasis is tightly regulated through internal recycling mechanisms and iron absorption.

The primary role of iron in the body is oxygen transport. Iron is the key component of the protein Hb in red blood cells. Hb binds to oxygen in the lungs and then delivers it to tissues throughout the body. Like Hb, iron is a component in the protein Mb, releasing oxygen into the muscles to support muscle function and metabolism (Raymond and Morrow, 2022). Beyond oxygen transport, iron is involved in energy production through its involvement in the electron transport chain with mitochondria, which generates ATP, the energy currency of cells (Devlin, 2011). Iron supports the proliferation and maturation of immune cells, contributing to the function of the immune system and playing a role in DNA

synthesis and repair. Finally, iron acts as a cofactor for enzymes influencing numerous metabolic pathways (Devlin, 2011).

2.2 Iron Metabolism

2.2.1 Iron Absorption

Iron absorption primarily occurs in the duodenum and upper ileum within the small intestine. Dietary iron absorption provides 1-2 mg daily (Camaschella et al., 2020). This is sufficient to counterbalance iron lost from shedding cells and maintain iron homeostasis (Vogt et al., 2021). The absorption of haem iron is more efficient than that of non-haem iron. Most non-haem iron is present in the ferric iron (Fe^{3+}) state, which first gets reduced to the ferrous iron form (Fe^{2+}) by duodenal cytochrome B reductase (DCYTB). This reduction occurs on the apical membrane of the enterocytes within the gut lumen before intestinal absorption can occur (Vogt et al., 2021). Fe^{2+} then gets imported via the apical divalent metal transporter 1 (DMT1) (Camaschella et al., 2020). Numerous factors influence the absorption of non-haem iron as it is not tightly bound, allowing other factors to affect its bioavailability (Anderson and Frazer, 2017). Ascorbic acid is one factor that enhances absorption by keeping Fe^{2+}in its reduced state and soluble. Compounds such as phytates, polyphenols and tannins inhibit iron absorption by binding to non-haem iron and affect its absorption (Anderson and Frazer, 2017). The absorption of haem iron is an area that needs to be better understood and is not well documented. Haem iron binds to the enterocyte brush border before getting ingested directly into the enterocyte. Once ingested, iron gets released from the haem molecule via haem oxygenase, ready for transport (Anderson and Frazer, 2017).

2.2.2 Iron Transport

Following enterocyte absorption, iron gets delivered to various cells for different bodily functions as previously identified (2.1.1 Iron Distribution and Function). Iron is first bound to plasma Tf the transport protein (Anderson and Frazer, 2017). Tf can bind up to two iron atoms and exists in three states: diferric Tf (bound to two iron atoms), mono ferric Tf (bound to one iron atom) and apo Tf (not bound to any iron atoms) (Silva and Faustino, 2015). Cellular iron uptake occurs on cell surfaces and is mediated by the transferrin receptor

1 (TfR1). The TfR1 receptor facilitates the entry of iron into cells through receptor-mediated endocytosis (Silva and Faustino, 2015). Serum Tf can be used as a biomarker for assessing iron status (Gattermann et al., 2021).

2.2.3 Iron Storage

Iron storage prevents free iron from circulating in the body. Free iron can be toxic, damaging tissues and cells by generating free radicals (Anderson and Frazer, 2017). Storage mechanisms ensure that iron is readily available during periods of deficiency. The primary storage protein is ferritin. Ferritin comprises 24 subunits arranged in a spherical shell with a central cavity. This structure allows iron to enter and exit through pores in the shell (Anderson and Frazer, 2017). One ferritin molecule can store up to 4,500 iron atoms (Waldvogel-Abramowski et al., 2014). Iron is stored as Fe^{3+}. Ferritin converts Fe^{3+} to Fe^{2+}, facilitating iron release (Waldvogel-Abramowski et al., 2014). Ferritin is primarily found in the bone marrow, liver, and spleen cells, vital sites for iron storage and mobilisation. Hemosiderin is another storage protein formed when there is an excess of iron. Hemosiderin represents a more insoluble and less readily accessible form of stored iron than ferritin. Both ferritin and hemosiderin ensure that iron is securely stored within cells, preventing oxidative damage from free iron ions (Kohgo et al., 2008). The liver plays a significant role in iron storage and regulation. Hepatocyte cells in the liver can store large amounts of ferritin and hemosiderin proteins as a reservoir to maintain systemic iron homeostasis. The spleen is important in recycling red blood cells (RBC) and storing iron from haemoglobin breakdown (Vogt et al., 2021).

2.2.4 Iron Release

Stored iron is released into circulation as needed. Hepcidin, a peptide-protein primarily produced in the liver, is crucial in regulating this process. When iron levels are sufficient, hepcidin production increases. More hepcidin triggers the degradation of the ferroportin protein. Ferroportin is responsible for exporting iron from the cells. Conversely, when iron levels are low, hepcidin production decreases allowing for more iron to be released into circulation (Vogt et al., 2021).

2.3 Measurement of iron status

Various biomarkers are used to diagnose iron status. There are three compartments, transport iron, iron stores and functional iron. Depletion in each compartment leads to different stages of ID. Serum iron concentrations measure the amount of iron bound to circulating transferrin. Serum iron is not a direct indicator of iron status and must be used with other laboratory tests (Restrepo-Gallego et al., 2021). Serum ferritin (SF) is a marker of iron stores and represents a fraction of the ferritin pool. Low SF levels indicate depleted iron reserves and iron depletion in the first stage of ID (Pfeiffer and Looker, 2017). SF is an acute-phase reactant, which means it can also be elevated in the presence of inflammation or infection, potentially masking an ID diagnosis. C-Reactive Protein (CRP) should be measured in conjunction with SF. Elevated CRP levels (>5mg/L) indicate the presence of inflammation (Pfeiffer and Looker, 2017). Hb concentration reflects the oxygen-carrying capacity of the blood and is a standard measure of iron status. Low Hb can result from other conditions and needs to be measured in conjunction with other biomarkers, such as SF (Casgrain et al., 2012). Soluble transferrin receptor (sTfR) reflects erythropoietic activity, cellular iron demand, and is an early indicator of ID, along with identifying the severity of the insufficiency. sTfR is not influenced by inflammation, making it a good marker for differentiating between chronic diseases, inflammation and ID (Casgrain et al., 2012). Total iron-binding capacity (TIBC) is a biomarker to assess iron metabolism and inflammation. TIBC measures the maximum amount of iron that can be bound by proteins in the blood, primarily Tf. When iron stores in the body are depleted, the liver produces more Tf to increase the capacity for iron transport, leading to elevated TIBC. Higher TIBC often indicates low iron levels in the body, as the body attempts to compensate by increasing the availability of transferrin to bind with any available iron (Yan et al., 2020). SF and Hb are commonly used together in assessing iron status, as they reflect iron stores and functional iron capacity. Interpreting these biomarkers alongside inflammatory markers such as CRP enhances the accuracy of diagnoses.

2.4 Dietary Recommendations for Iron

Dietary iron requirements vary based on age and physiological status. Dietary recommendations for iron are established to ensure adequate iron intake to meet physiological needs and prevent deficiency. In New Zealand, the Ministry of Health provides recommended dietary intakes (RDIs) and estimated average requirements (EAR) for iron intake based on population-specific needs (National Health and Medical Research Council. et al., 2006) (Table 1). Adequate iron intake for women is essential for replenishing depleted iron stores during pregnancy and childbirth and inadequate dietary intake.

Table 1. Estimated Average Requirements (EAR), Recommended Dietary Intakes (RDI) and upper levels (UL) for iron among women of reproductive age, during pregnancy and lactation

Women age	EAR	RDI	UL
Women of reproductive age			
19-30 yr	8 mg/day	18 mg/day	45 mg/day
31-50 yr	8 mg/day	18 mg/day	45 mg/day
Pregnancy			
14-18 yr	23 mg/day	27 mg/day	45 mg/day
19-30 yr	22 mg/day	27 mg/day	45 mg/day
31-50 yr	22 mg/day	27 mg/day	45 mg/day
Lactation			
14-18 yr	7 mg/day	10 mg/day	45 mg/day
19-30 yr	6.5 mg/day	9 mg/day	45 mg/day
31-50 yr	6.5 mg/day	9 mg/day	45 mg/day

Table adapted from National Health and Medical Research Council. et al. (2006)

2.5 Classification of Iron Status

2.5.1 Iron Depletion, Iron Deficiency Erythropoiesis and Iron Deficiency Anaemia

The initial stage is iron depletion, marked by a decrease in iron stores (Raymond and Morrow, 2022). During iron depletion, the body goes into a negative iron balance. Typically, there are no symptoms during the iron depletion stage (Raymond and Morrow, 2022). Under normal physiological conditions, iron is prioritised for RBC production, as the demand for iron in erythropoiesis exceeds that of other tissues. When this demand cannot be met, Iron deficiency erythropoiesis (IDE) occurs. In this stage, Hb concentrations remain within the normal range, but other indicators, including sTfR and transferrin saturation (TSAT), are

abnormal. Symptoms such as fatigue, weakness and poor work capacity can occur as a result of impaired erythropoiesis and reduced haem production (Thompson et al., 2019). The third state, IDA, represents the advanced phase with compromised Hb production, impaired oxygen transport, and reduced red blood cell quality and size (Thompson et al., 2019).

2.5.2 Iron Overload

Iron overload can stem from primary disorders like hereditary hemochromatosis or secondary factors such as frequent blood transfusions or chronic liver disease. Excessive iron accumulation fosters oxidative stress, causing tissue damage and heightening the risk of chronic illnesses. The presence of free iron catalyses Fenton reactions with H_2O_2 and O_2, generating hydroxyl radicals that cause harm to DNA and lipids (Coad and Pedley, 2014).

2.5.3 Iron Status in New Zealand

Due to the lack of recent data specific to postpartum women, evidence from women of reproductive age has been used to illustrate the prevalence of ID in NZ, highlighting the need for further research focused specifically on postpartum women.

ID remains a significant public health concern for NZ particularly among women of reproductive age. Recent research conducted in Auckland NZ with 170 women aged 18-45 years found a prevalence of ID of 55.8% using a SF cut-off of <30 µg/L. This prevalence decreased to 43% using a stricter cut-off defining ID of <20 µg/L (Lim et al., 2020). However, as the study sample was limited to women residing in one city, the findings may not be generalised to the wider population of women of reproductive age across NZ, particularly those in rural areas. Historical data reported suboptimal iron status in 7% to 13% of reproductive women aged 15-49 years, with a SF cut-off of <16µg/L (Ferguson et al., 2001). Furthermore, the 2008/2009 New Zealand Adult Nutrition Survey highlighted ongoing challenges, revealing a prevalence of low iron stores, defined by SF <12µg/L. Prevalence in women aged 19-30 was 7.7%, and 13.4% in women aged 31-50 years (University of Otago and Ministry of Health, 2011). These statistics emphasise this group's continued struggle to maintain adequate iron status. One study in NZ looked specifically at postpartum anaemia (PPA), defined as Hb <100g/L in 8849 postpartum women across three District Health Boards

(DHBs). Among those tested postpartum (n=1544), 38% were found to have PPA. The study also identified ethnic disparities, with Pacific women more likely and European women less likely to be affected (Calje et al., 2023). While this study did not report how many cases of PPA were directly attributed to ID, high rates of intravenous (IV) iron treatments suggest that ID may have been a presumed underlying cause in many cases.

2.6 Dietary Sources of Iron

Haem iron is predominantly found in animal-based foods and typically contributes a smaller proportion of total dietary iron intake in Western diets, while non-haem iron, present in plant-based foods and fortified products, accounts for the majority of iron consumed. Despite this, haem iron has a higher bioavailability than non-haem iron (Raymond and Morrow, 2022). Specific dietary patterns are associated with an increased risk of insufficient iron status. There is an increasing trend towards dietary patterns that do not contain meat, such as vegetarian or vegan diets, which have been shown not to meet recommendations for micronutrients such as iron due to the lower bioavailability of non-haem iron sources (Hess et al., 2025, Peddie et al., 2023).

2.6.1 Haem and Non-Haem Iron

Haem iron is found in Hb and Mb in animal tissues. Haem iron is predominantly found in red meats, poultry, and seafood. Specifically, beef, lamb, and liver are rich sources, contributing significantly to iron intake in omnivorous diets. Haem iron is absorbed through the gut more efficiently than non-haem. Greater absorption is due to specific haem transporters allowing haem iron to pass directly across the cell membrane and directly into the bloodstream (Isabel et al., 2018). The absorption rate of haem iron is approximately 25-30% and its absorption is relatively unaffected by other dietary factors, making it a reliable source of bioavailable iron (Elif et al., 2022).

In contrast to haem iron, non-haem iron is found in plant-based foods, cereals, vegetables, legumes, and fruits. This form of iron comprises the majority of dietary iron intake in vegetarian and vegan populations. Unlike haem iron, non-haem iron cannot utilise haem transporters and must be reduced from ferric to ferrous state (Fe^{3+} to Fe^{2+}) before it can be absorbed (Isabel et al., 2018). Absorption of non-haem iron is estimated to be approximately 7-9% in dark leafy greens and 4% in grains and 2% in legumes (Elif et al.,

2022). The lower absorption and bioavailability of non-haem iron is attributed to dietary inhibitors. Phytates (found in grains and legumes), polyphenols (in tea and coffee), calcium, and specific proteins inhibit non-haem iron absorption. Conversely, ascorbic acid (vitamin C) and specific organic acids can enhance non-haem iron absorption by reducing Fe^{3} to the more soluble Fe^{2+} form (Elif et al., 2022). Additionally, the meat, fish, and poultry (MFP) factor, found in animal protein, can enhance non-haem iron absorption when consumed together with plant-based foods (Hurrell and Egli, 2010).

2.6.2 Supplement and Fortification

Iron supplementation and fortification are effective strategies implemented to enhance dietary iron intake, especially in populations with increased needs or limited access to iron-rich foods. Specifically in New Zealand, iron supplements such as ferrous sulfate, ferrous fumarate and iron polymaltose are widely available over the counter and by prescription. Each supplement contains varying amounts of elemental iron (Ponen, 2019). These supplements are commonly prescribed to individuals diagnosed with ID or IDA. Supplementation is often recommended during pregnancy, infancy and other periods of increased iron demand (Ponen, 2019).

Food fortification is a public health initiative designed to improve a population's nutrient intake and reduce micronutrient deficiencies, such as the addition of iron or folic acid to staple foods like wheat flour. As of 2023, over 90 countries mandate fortification of wheat flour with iron, including many in Africa, the Americas and Asia (Food Fortification Initiative, n.d). NZ has not mandated iron fortification; only voluntary fortification of products like breakfast cereals is permitted (Food Fortification Initiative, 2015).

2.5 Postpartum Women

The postpartum period is a critical phase marked by significant physiological and hormonal changes. Postpartum has three phases. The initial acute period is the first 6-12 hours after childbirth. During this phase, there is the potential for complications such as postpartum haemorrhage. The second phase is the subacute phase, lasting 2-6 weeks. During this period, the body is going through less acute changes. The final phase can last up to 6 months with very gradual changes. It can take about six months to restore pre-pregnancy

physiology (Romano et al., 2010). Women are particularly vulnerable to ID during this period due to both physiological demands and pre-existing risk factors. Many enter pregnancy with pre-depleted iron stores. Iron demands increase during pregnancy for placental and foetal development, along with increasing RBC mass (Wassef et al., 2019). Common contributors to PPID and PPA include anaemia during pregnancy, placenta previa, multiple births and significant blood loss during delivery (typically > 1000mL) (Antoine et al., 2023). While iron losses through lactation is minimal, and menstruation is often absent in the first few months postpartum, the overall iron demands from pregnancy, coupled with delivery-related losses and menstruation, place women at continued risk for ID even after delivery (Chan et al., 2001).

2.5.1 Implications of Suboptimal Iron Status Postpartum

Suboptimal iron status postpartum can have severe implications for maternal and infant health. A comprehensive study of women during pregnancy and up to seven days postpartum across 29 countries found that women experiencing severe anaemia (Hb <70g/L) during pregnancy or in the early postpartum period had more than double the odds of maternal mortality compared to women without severe anaemia (Daru et al., 2018). While this study primarily focuses on severe anaemia, it identifies the impact on maternal health. Beyond mortality, a meta-analysis has linked anaemia with an increased risk of maternal depression and cognitive impairment, highlighting iron's essential function in brain regulation. ID disrupts dopamine metabolism by downregulating dopamine production, which can adversely affect mood and cognitive function (Kang et al., 2020). A study by Beard et al. (2005) investigating the relationship between IDA and cognition found that depression and anxiety were more evident at nine months postpartum compared to at ten weeks postpartum. The study also demonstrated that iron supplementation significantly improved measures of depression, stress and cognitive performance in mothers with IDA. In a more recent systematic review looking at PPA on maternal health-related quality of life, they found anaemia during the first year postpartum was a significant risk factor for postpartum depression (PPD) (Moya et al., 2022).

Postpartum fatigue, a common complaint among new mothers, is associated with low SF and Hb levels. Fatigue can negatively impact the physical, psychological and mental well-being of mothers, potentially negatively affecting her ability to care for her infant

and herself (Badr and Zauszniewski, 2017). The nature of postpartum fatigue makes it a critical area of concern, as it can exacerbate other postpartum challenges, including mood disorders and difficulties in daily functioning.

Beyond fatigue, suboptimal iron status may also influence the mother-infant relationship and infant development. One observational study reported that ID in mothers was associated with less responsive and more negative mother-infant interactions, which in turn were linked to slower infant developmental progress (Perez et al., 2005). However, evidence in this area remains mixed. A systematic review examining PPA and mother-child interaction reported conflicting findings, with some studies identifying negative effects of PPA on mother-infant interactions, while others found no significant associations (Moya et al., 2022).

2.5.2. Risk Factors for Iron Deficiency Postpartum

Various factors, including physiological demands, influence ID postpartum, including pre-existing low iron stores, overall dietary intake, food insecurity, and other factors. Women who have pre-existing poor iron stores or ID pre-pregnancy are at an increased risk of developing ID postpartum. One review article found that those with inadequate dietary iron intake or no iron supplementation had lower iron levels postpartum (Milman, 2011). Pre-pregnancy factors such as insufficient nutritional intake through a diet low in haem-iron content, such as vegetarian or vegan, are risk factors for ID postpartum (Te Whatu Ora - Health New Zealand, 2022). One study found a significant association between moderate to severe IDA at 28 weeks of gestation and blood loss during delivery and postpartum (Kavle et al., 2008). The result of this study highlights that women who begin with compromised iron stores are at a greater risk of more severe blood loss at delivery, further contributing to ID postpartum. Pre-existing low iron stores can also be attributed to a lack of prenatal iron supplementation (Bodnar et al., 2005).

Blood loss during delivery and postpartum s is one of the most significant contributors to postpartum IDA, which can severely deplete iron stores and lead to IDA. Postpartum haemorrhage (PPH) is defined as blood loss from vaginal birth of >500ml and >1000ml from a caesarean; during PPH, there is substantial depletion of Hb and iron reserves (Milman, 2011).

The World Health Organisation (2018), define early PPH as blood loss within the first 24 hours, blood loss after this time is, known as late PPH. Research indicates a strong correlation between the severity of blood loss and the development of ID and IDA during the postpartum period (Milman, 2011). Women who experience higher degrees of blood loss during delivery show lower Hb levels one week postpartum (Milman, 2011).

SES is a major determinant of nutritional health, including iron status, particularly among postpartum women. SES includes factors such as income, education, occupation, and access to resources. All factors influence diet quality, food choices and overall nutritional status. SES plays a role in the risk of postpartum ID, with lower-income women disproportionally affected. Research indicates that IDA persists into the postpartum period, particularly among low-income women. One study found more than one in four women in the US were found to be anaemic 4 to 26 weeks postpartum, with 48% being Hispanic-black women (Bodnar et al., 2001). Another study looking at women 0-24 months postpartum in the US found that low-income women also had four times more risk of postpartum ID than higher-income women (Bodnar et al., 2002).

Evidence from NZ also highlights sociodemographic disparities. A recent study in NZ found that pregnant women of lower SES were less likely to have their iron status tested, receive iron supplements or receive peripartum blood transfusions (Teichman et al., 2021). In addition, a NZ study examining the impact of SES on food choices and diet quality reported that women of lower SES are more likely to experience food insecurity, often leading them to rely on cheaper, less nutritious food choices, which may result in inadequate intake of essential nutrients such as iron (Starck et al., 2021).

Beyond pre-existing poor iron stores, blood loss during delivery, and SES other factors may increase the risk of ID postpartum. A study of 8849 postpartum women in three district health boards across NZ Study found that postpartum IDA rates were strongly linked to ethnicity (Calje et al., 2023). They found that Māori women were significantly more likely to be diagnosed with PPA than NZ European women, with European women having 54% lower adjusted odds of being diagnosed. Their research indicated that Māori and Pacific women were less likely to have documented symptoms of PPA compared to other ethnicities, along with a decreased likelihood of voicing symptoms to healthcare professionals than non-

Māori. The research shows the disparities in postpartum care down to reduced trust in the healthcare system (Calje et al., 2023).

Another risk factor is pre-pregnancy body mass index (BMI; kg/m^2). Women with a high BMI are at increased risk of anaemia, with the risk being twice as high for those with a BMI above 28 and three times as high for those with a BMI greater than 38. This is primarily due to a higher incidence of postpartum haemorrhage in women with elevated BMI (Bodnar et al., 2005).

Women carrying multiple foetuses, such as twins or triplets, also have a heightened risk of due to increased iron demands. Multiple foetuses place additional strain on maternal iron stores, and these women are more likely to experience excessive blood loss during delivery compared to those with a single birth (Bodnar et al., 2005).

Not breastfeeding has also been suggested as a risk factor for postpartum ID. One study found that breastfeeding women had significantly higher SF concentrations at six months postpartum than non-breastfeeding women. This was attributed to the delayed return of menstruation in breastfeeding women, as prolonged amenorrhea reduced the body's iron demands; in contrast, non-breastfeeding women experience earlier menstruation, which leads to high iron losses (Fatima et al., 2022).

2.6 Diet Quality in Postpartum Women

2.6.1 Factors Affecting Dietary Choice Postpartum

During pregnancy and postpartum, a woman's motivation for healthy eating may shift compared to her pre-pregnancy dietary habits. For some, focusing on the benefits of optimal child development and favourable pregnancy outcomes can drive healthier eating habits (Sun et al., 2023). Conversely, physiological changes during pregnancy and postpartum can trigger cravings, often for less nutritious foods, which may lead to unhealthy diet choices. It's common for women to adjust their diet during pregnancy, revert to previous eating habits after birth, or establish new dietary patterns up to a year postpartum (Sun et al., 2023). The postpartum period is often marked by physical and emotional stress, leading to fatigue and increased stress levels (Badr and Zauszniewski, 2017). These factors can adversely affect dietary intake, as new mothers may struggle to manage meal shopping, preparation, and

cooking (Opie et al., 2020). SES significantly influences dietary choices and access to nutritious foods postpartum. One study found that low-income women are at a higher risk for ID, mainly between 7 to 12 months and 14 to 24 months postpartum, compared to higher-income women. They also found that low SES is associated with inadequate prenatal and postpartum care, limiting opportunities for risk assessment education on nutrition (Bodnar et al., 2002).

2.6.2 Diet Quality Postpartum

Diet quality is particularly important during the postpartum period as it impacts both maternal and infant health. Adequate nutritional intake is essential for maternal recovery, successful breastfeeding, and overall well-being. Despite its importance, research indicates that diet quality often needs to improve during this stage, with many women unable to meet dietary recommendations. Diet quality in postpartum women refers to the nutritional adequacy and balance of the foods consumed, vital for supporting the physiological demands of recovery and lactation (van der Pligt et al., 2016). Ward et al. (2019) defined diet quality as the extent to which individuals adhere to national dietary guidelines, measured by the Dietary Guideline Index (DGI). The DGI captures the quality, quantity, and variety of foods consumed.

A study conducted by Shah et al. (2010) in Texas looked at 125 low-income women at 0 to 4 months postpartum. Results showed that women of low-income households consumed suboptimal amounts of fruits, vegetables, and whole grains during the early postpartum period, while their intake of fats and sugar was excessive. This highlights the nutritional disparities that economically disadvantaged women face during the postpartum period. Similarly, a study in the US investigated the relationship between adherence to dietary guidelines and psychosocial factors in 146 low-income women at 1-year postpartum. Results found that adherence to dietary recommendations was lower among women experiencing depressive symptoms and stress. These factors were associated with poorer diet quality, suggesting that physiological well-being plays a significant role in dietary behaviours during the postpartum period (George et al., 2005). In a more recent longitudinal study on postpartum diet quality Martin et al. (2020) found that women within 12 months of giving birth had better diet quality, including greater diet variety, than those who had given

birth more than 12 months prior. The study identified several positive influences on diet quality, including higher education levels, use of dietary supplements, regular physical activity, and greater access to maternal and child health services. Negative influences included increased time since childbirth, medium income level, and smoking. The findings also suggested that women who are early postpartum often face challenges such as sleep disturbances and stress, different compared to those in the later postpartum period, contributing to different dietary habits.

A recent study in NZ by Kruger et al. (2021) evaluated a dietary diversity questionnaire (DDQ) developed for NZ women aged 16-45. The study found that higher dietary diversity, particularly from nutritious food groups, was associated with greater micronutrient adequacy, including iron. Greater diversity in discretionary foods was associated with lower nutrient adequacy. The findings of this study highlight the value of dietary diversity as an indicator of diet quality. Recent research indicates that diet quality tends to be suboptimal postpartum. All studies concluded that fruit and vegetable intake decrease over this period (Lebrun et al., 2019, Martin et al., 2020, van der Pligt et al., 2016). One Australian study found that only half of the postpartum women studied met the recommendations for fruit intake (van der Pligt et al., 2016). A second Australian study investigating diet quality and postpartum concluded that factors such as time constraints, fatigue and other responsibilities after childbirth influence their food choices. At the same time, some women meet the nutrition guidelines, but many do not meet their postpartum fruit, vegetable, whole grain, and protein intake requirements (Martin et al., 2020). A Canadian study examining dietary intake from late pregnancy through to six months postpartum found that women's fruit and vegetable intake decreased during the postpartum period compared with late pregnancy (Lebrun et al., 2019). The study also reported a decline in overall diet quality during the postpartum period, alongside an increase in the proportion of total fat intake exceeding dietary recommendations. These findings are consistent with the national data from the NZ Health Survey, which showed that only 38.4% of women met the combined recommendation of three servings of vegetables and two servings of fruit per day. However, fruit and vegetable intake remained low in younger adults, Māori and Pacific populations, and those living in highly deprived areas (25.3%), all of which may be particularly

relevant for postpartum populations at higher risk of ID or poor diet quality (Ministry of Health, 2022).

2.8 Conclusion

The existing research on diet quality and iron status indicates that postpartum women are nutritionally vulnerable with increased physiological demands and several barriers to adequate nutrient intake. Previous research has shown that ID and IDA are common during postpartum and are influenced by factors such as pre-existing iron stores, dietary intake, blood loss during delivery, and SES. Most studies found that diet quality tends to decline postpartum, particularly with reduced fruit and vegetable intake. Few studies reported that some women improve their dietary habits due to increased awareness of maternal and infant health. There is limited research exploring diet quality and its relationship with maternal iron status among postpartum women in NZ. Improved understanding of this relationship will help to identify risk factors and inform targeted strategies for supporting postpartum nutrition.

Chapter 3: Diet Quality and Iron Status in Postpartum Women In New Zealand

3.0 Abstract:

Background: Iron deficiency (ID) and anaemia are prevalent among postpartum women, which presents a significant public health concern. ID can lead to fatigue, impaired cognitive function and reduced quality of life, impacting both maternal and infant health. Limited research exists on the relationship between diet quality and iron status in postpartum women in New Zealand (NZ).

Objective: To investigate the relationship between diet quality and iron status in postpartum women in New Zealand.

Methods: This secondary data analysis used the data collected from 87 postpartum women living in Palmerston North, New Zealand. Participants were recruited for the Mother and Infant Nutrition Infant Investigation (MINI) study. At six months postpartum 75 participants completed a weighed four-day food diary (4DDD) to assess dietary intake. Diet quality was calculated using a modified Dietary Guideline Index (DGI) adapted to New Zealand dietary guidelines. Iron status was assessed through serum ferritin (SF) and haemoglobin (Hb) biomarkers. C-reactive protein (CRP) was used to adjust for inflammation. Statistical analysis examined associations between diet quality, iron status, and sociodemographic factors. Nonparametric data were expressed as median and interquartile range (median [Q1, Q3]), while categorical variables were summarised using frequencies and percentages.

Results: The median total dietary guideline index score (TDGIS) among postpartum women was 59.5 [54.1, 68.3] out of 100. Adherence to individual dietary components varied, with the highest adherence for protein (72% met recommendations) and the lowest for dairy (12%). Only 30.7% of participants met vegetable recommendations, 33.3% for fruit, and 22.7% for grains. The median diet variety score was 26 [23.0, 29.0] out of a possible 65, with participants achieving on average 43.6% of the highest possible variety score. Iron insufficiency (SF <30 μg/L) was confirmed in 12.9% (n=9) of participants. Participants with iron sufficiency had significantly higher total dietary guideline index scores (TDGIS) (60.9

[55.0, 69.1]) compared to iron-insufficient participants (53.6 [46.1, 61.4], p=0.026) out of 100. Grain intake was significantly higher in iron-sufficient participants (4.5 [3.9,5.8]) compared to iron-insufficient participants (3.2 [1.8,4.4], p=0.014). Higher education attainment was positively associated with iron sufficiency and higher total dietary guideline index scores (p<0.001).

Conclusion: This is the first study in NZ to investigate the association between diet quality and iron status among the postpartum population in NZ, to the best of our knowledge. The findings of this study suggest that a lower diet quality is associated with an increased risk of insufficient iron levels. This finding reinforces the importance of postpartum nutrition. The positive relationship between diet quality and education highlights the need for targeted public health interventions to improve postpartum nutrition. Future research should distinguish between haem and non-haem iron sources during analysis and include dietary components that affect iron absorption to gain a better understanding of the relationship between diet and iron status in postpartum women.

3.1 Introduction

ID and anemia continue to be significant public health concerns for postpartum women, both globally and in NZ (World Health Organisation, 2024, Calje et al., 2023). The postpartum period is marked by physiological and nutritional challenges, with women facing elevated risk of iron depletion due to factors such as blood loss during delivery, increased iron demands for recovery and lactation, and in many cases, pre-existing suboptimal iron stores (Milman, 2011, Bodnar et al., 2005). National and international data consistently shows that women frequently fail to meet dietary recommendations for iron and other key macro/micro nutrients during this life stage, contributing to ongoing risks of postpartum ID (PPID) and postpartum anaemia (PPA) (Martin et al., 2020, Lebrun et al., 2019).

The consequences of inadequate iron status during the postpartum period are extensive, including increased risk of fatigue, impaired cognitive function, postpartum depression (PPD), and impacting mother-infant relationships (Moya et al., 2022, Kang et al., 2020, Beard et al., 2005). Factors such as socioeconomic status (SES), education attainment, changes in dietary patterns, and ethnicity influence both diet quality and iron status,

although the pathways and extent of these effects may differ (Calje et al., 2023, Starck et al., 2021, van der Pligt et al., 2016). Research in NZ has reported higher rates of postpartum anaemia (PPA) among Māori and Pacific women, compared to NZ European women (Starck et al., 2021). In addition, women of lower SES are at increased risk of both inadequate dietary intake and postpartum ID (Calje et al., 2023).

Despite established risks, there is a lack of recent research on iron status and diet quality specifically in NZ postpartum women. Research indicates that diet quality often declines during postpartum, with women not meeting the dietary recommendations for fruit, vegetables, grains, dairy and lean meats/alternatives (Martin et al., 2020, Lebrun et al., 2019). This study aimed to investigate the relationship between iron status and diet quality among postpartum women in NZ at six months postpartum.

3.2 Methodology

3.2.1 Materials and Methods

This present study was a secondary analysis of the Mother and Infant Nutrition Investigation (MINI) study in New Zealand. The MINI study was an observational longitudinal cohort study focusing on maternal and infant health during the first year postpartum, investigating postpartum women's iodine, selenium and iron intake and maternal thyroid function (Jin et al., 2021). The MINI study was approved by the Health and Disability Ethics Committee (15/NTA/172) in 2015 and registered with the Australian New Zealand Clinical Trials Registry [ACTRN12615001028594]. The Royal New Zealand Plunket Ethics Committee and the MidCentral District Health Board approved the study in 2016. It was conducted at the Human Nutrition Research Unit and Massey University, Palmerston North, New Zealand.

3.2.2 Recruitment and Participants

The MINI study comprised a cohort of healthy, breastfeeding women aged 16 years and older who had given birth to a healthy full-term singleton infant. Participants were excluded if they developed significant health issues, such as metabolic disease, cancer or thyroid disorders. Eligibility was restricted to women in the Palmerston North area, allowing for consistent follow-up at scheduled study visits. The recruitment strategy for the MINI study was through posters at healthcare and community locations, local newspapers, social

media platforms, and direct outreach by healthcare professionals, including midwives, childbirth educators and lactation consultants. Interested participants completed a screening questionnaire to confirm eligibility and were provided with detailed information about the study. Written consent was obtained from all participants, and unique identifier codes were assigned to maintain confidentiality. The participants were scheduled for study visits at approximately 3, 6, and 12 months postpartum. Demographic information, including age, ethnicity, educational attainment, household size, and income, was collected at the initial study visit through baseline questions. Further details on the study design, recruitment process, and data collection procedures are described in the study protocol (Jin et al., 2020). Breastfeeding status at 3 months postpartum was categorised as exclusively breastfed (EBF) or partially breastfed (PBF). EBF was defined as the infant receiving only breast milk (including expressed breast milk), PBF was defined as the infant receiving some breast milk along with infant formula (New Zealand College of Midwives, 2016).

3.2.3 Dietary Intake Assessment

Dietary intake data were collected at 3 months postpartum using a weighed 4-day diet diary (4DDD). The 4DDD captured detailed information on all foods and beverages consumed over the four days, including at least one weekend day. Participants were required to include types, quantities and brands of foods and beverages. Participants were provided with a QM-7288 electronic kitchen scale (Digitech), household measuring cups and spoons to ensure accuracy. Written and oral instructions were provided on documentation, which included a 1-day sample record. For any meals eaten out or takeaways, participants estimated portion sizes and ingredients. Dietary data was processed using Foodworks 9 Professional (Xyris Pty Ltd), incorporating information from the New Zealand Foodfiles 2016. For food items not in the file, a new item was created based on participant's information from the food packaging or international databases. A registered nutritionist reviewed all dietary data before transferring it to SPSS Statistics (IBM Corporation) version 23 for statistical analysis to ensure accuracy.

3.2.4 Dietary guideline index (DGI) Development

Diet quality can be assessed through dietary indices such as the Dietary Guideline Index (DGI), which provides a comprehensive measure of overall dietary adequacy (Ward et al., 2019). The DGI used in this study was adapted from the Australian DGI (Ward et al., 2019) to align with the Food and Nutrition Guidelines for Pregnant and Breastfeeding Women (Ministry of Health, 2006). The DGI evaluated adherence to recommended intakes of vegetables, fruits, grains, protein foods, dairy, and water while also scoring limiting components such as saturated fat, discretionary foods, and alcohol (Table 2). Once the structure of the DGI was attained, it was applied to the 4DDD collected from postpartum women (n=75) who participated in the MINI study.

3.2.5 DGI Components

There are 10 components of the DGI. The vegetable component included all fresh, frozen, and canned vegetables. Fruit included fresh, frozen, canned, 100% fruit juices and dried fruit. All grains were included in the grain component. Grains with added sugar or fat (i.e. coco pops, date scones, pastry) were excluded and added to the discretionary food's component. The protein component only included lean meats, fish, legumes, beans, tofu, eggs, nuts and seeds. Fatty cuts and processed meats were added to the discretionary food's component (i.e., bacon, ham, salami, corned beef and deep-fried). All milk, calcium-fortified milk alternatives, yoghurt, hard cheeses, soft cheeses, and coffee-based drinks (i.e., flat white with milk) were included in the dairy component. Dairy that was excluded and in the discretionary food component included, ice cream, cream, coconut cream and custard.

The saturated fat component was calculated based on the proportion of total energy intake from saturated fat, with higher intakes receiving lower scores. The recommendation for saturated fat is ≤ 10% of total energy from saturated fat (Ministry of Health, 2006). The discretionary foods component included all foods and beverages high in added sugar, salt, and/or saturated fat, as well as energy energy-dense nutrient-poor foods (e.g., cakes, biscuits, confectionery, fried foods, chips, crisps, pastries, takeaway foods, and sugary drinks) The serving of discretionary food was calculated based on the Australian discretionary food guidelines (National Health and Medical Research Council and Department of Health and

Aged Care, n.d.). One serving equated to 600kj of that discretionary food. The alcohol component assessed average daily alcohol consumption. Intakes exceeding recommended limits received progressively lower scores, with zero consumption achieving the maximum score.

The final component, diet variety scores, were adapted from the Australian Recommended Food Score (ARFS) (Ashton et al., 2017). The detailed point system for diet variety is included in Appendix 13. A 65-point checklist was used, where one point was awarded for each food consumed in different food groups, total maximum score of 65.

3.2.6 Component Scoring

Each component was scored out of 10. A higher score indicating greater compliance with dietary guideline recommendations. 7 components (Vegetable [5 servings], fruit [2 servings], grain [6 servings], protein [2 servings], dairy [3 servings], water [≥2.5L] and diet variety [65 score]) are positively scored with a maximum score of 10 awarded for consuming ≥ the recommended serving, (servings are shown in Table 2). A zero score was awarded for zero intake. A proportionate score was attained for consuming between minimum and maximum. The formula for the positively scored components were; component score = (actual intake/serving size) x 10. For example, if a breastfeeding woman consumed two servings of dairy per day, and the recommended is three servings per day, it would be scored as (2/3) x 10 = 6.7. The formula for diet variety was; component score= (actual score/65) x 10.

Three components (saturated fat [≤10% total energy], alcohol [≤2 servings] and discretionary food [≤2.5 servings]) were reverse-scored. No proportionate score was attained for reverse scores, either a 10 score was given for being at or below the recommendation, or if the recommendation was exceeded, zero score was awarded.

Table 2. Scoring Criteria for the Dietary Guideline Index (DGI) Components

Dietary Component	Description	Servings to achieve Minimum Score	Servings to achieve Maximum Score	Maximum Component Score
1.Vegetable	Total vegetables intake in serves per day	0	≥4	10
2. Fruit	Total fruit intake in servers per day	0	≥2	10
3. Grain	Total grain intake, in serves of grains per day	0	≥6	10
4. Protein	Total lean protein (animal products) and alternatives (plant-based) proteins in servers per day (excludes processed meat)	0	≥2	10
5. Dairy	Total dairy or dairy alternatives in serves per day. Includes milk, yoghurt, cheese and/or their alternatives.	0	≥3	10
6. Water	Total water intake per day (L)	0	≥2.5L	10
7. Saturated Fat	Daily Saturated fats intake a percentage of total energy intake.	$> 10\%$	$\leq 10\%$	10
8. Discretionary Foods	Limiting food intake containing saturated fat, added salt and sugar in servers per day.	> 2.5	≤ 2.5	10
9. Alcohol	Limit alcohol, in standard drinks per day of alcohol.	> 2	≤ 2	10
10. Diet Variety	Eating a wide variety from 5 core food groups.	0	65	10
	Total DGI Score			100

Component scoring was adapted from the methodology used in the study by Ward et al. (2019).
Dietary recommendations used to inform cut-off values were based on the 2006 Food and Nutrition Guidelines for Healthy Pregnant and Breastfeeding Women (Ministry of Health, 2006) , Discretionary Foods Criteria (National Health and Medical Research Council and Department of Health and Aged Care, n.d.) and the Australian Recommended Food Score (ARFS) (Ashton et al., 2017).

3.2.7 Biomarker analysis

Blood Hb concentrations were measured at six months postpartum using a handheld HemoCue Hb 201+ device. Participants provided a finger prick, ensuring the picking of capillary blood into a microcuvette. Quality control tests with external liquid controls were performed to ensure accuracy. Non-fasting venous blood samples (22 mL) were collected from participants by a qualified phlebotomist during the second visit. After centrifugation, samples were aliquoted into participant ID-labelled microcentrifuge tubes and stored at –80°C. Iron status was assessed in these samples by serum ferritin measurements using the chemiluminescent microparticle immunoassay (CMIA) method. This study did not use Hb as an indicator of iron sufficiency, as it is a point-of-care measure that is influenced by multiple factors beyond iron status (Mei et al., 2005).

SF was used as the primary biomarker of iron status, given its established role as an indicator of iron stores (Coad and Pedley, 2014). However, CRP was measured to adjust for potential confounding effects since SF can be elevated during inflammation. Participants with CRP ≥ 5 mg/L had their SF values excluded from the analysis due to the risk of inflammation-related SF elevation. Two of the 75 participants were excluded due to unsuccessful blood collection. Three additional participants had missing SF and CRP results. Eight participants were excluded due to their elevated CRP (≥5 mg/L) levels. 62 participants were included for assessing iron status.

Irons status was defined as iron insufficient if SF <30 μg/L (Lim et al., 2020). Anaemia was defined as Hb concentration <120g/L and IDA is defined as Hb concentration <120g/L with SF <15 μg/L (World Health Organisation, 2008).

3.2.8 Statistical Analysis

Statistical analyses were conducted using IBM SPSS Statistics version 29. The data was checked for completeness before analysis, and participants who did not complete the 4DDD were excluded. Statistical significance was set at $p < 0.05$. Descriptive statistics were calculated to summarise participant characteristics, including age, ethnicity, household income, breastfeeding practices, and education. If data was normally distributed, means and standard deviations (mean ± SD) were used for continuous variables. If data was not normally distributed, it was expressed as median and interquartile range (median [Q1, Q3].

Frequencies and percentages were used for categorical variables. Total Dietary guideline index (DGI) scores and components were analysed using descriptive statistics, with percentages of participants meeting dietary recommendations calculated.

The Mann-Whitney U test was used for non-normally distributed data to compare total DGI scores and components between iron-sufficient and iron-insufficient participants.

To explore potential predictors of iron sufficiency, a binary logistic regression model was performed with iron status (sufficient vs. insufficient) as the dependent variable and education attainment, breastfeeding status, and total dietary guideline index score as independent variables. The relationship between total DGI scores and sociodemographic variables was assessed using independent t-tests for binary variables (e.g., above vs. below median household income, exclusive vs. partial breastfeeding) and one-way ANOVA for categorical variables with more than two groups (e.g., ethnicity).

3.3 Results

3.3.1 Participants

A total of 75 postpartum women provided complete 4DDD with a mean age of 31.5 ± 4.2 years (Table 3). The majority of participants (77.3%) identified as Caucasian. Over half (64.9%) of the participants reported a household income above the median of NZ$75,995 in New Zealand in 2016. 82.7% were exclusively breastfeeding at three months postpartum. Most participants (78.7%) had attained tertiary education or higher.

Table 3. Demographic characteristics of breastfeeding women (n=75) at 3 months postpartum

	n (%)	Mean ± SD
Age (years), geometric mean ± SD	75	31.5 ± 4.2
Ethnicity	75	
Caucasian	58 (77.3)	
Māori	8 (10.7)	
Other (i.e. Asian, Latin American)	9 (12.0)	
Household income[a]	74	
Above Median	48 (64.9)	
Education attainment	75	
Tertiary or higher	59 (78.7)	
Breastfeeding status	75	
EBF[c]	62 (82.7)	
PBF[c]	13 (17.3)	

[a] One participant has missing household income data.
Median household income for 2016 was $75,995 (Stats NZ, 2016).
[b] SD = Standard Deviation.
[c] EBF = Exclusively Breastfed; PBF = Partially Breastfed

3.3.2 Biochemical indicators of iron status

The mean Hb concentration for participants was 131.0 ± 8.74 g/L, while the median SF level was 41.5 (26.5, 76.5) µg/L (Table 4.). 12.9% of participants were iron insufficient with SF <30 µg/L. Based on Hb concentrations alone (Hb <120g/L), 5 participants (6.9%) had anemia However, no participants met the combined criteria of low Hb (Hb <120g/L) and low SF (SF <15 µg/L) for IDA.

Table 4. Iron status of women at 6 months postpartum measured by biochemical indices

Haemoglobin (g/L)[a]	Serum Ferritin (µg/L)[b]	Iron Sufficient n (%)[c]	Iron Insufficient n (%)[c]
131.0 ± 8.74	41.5 [25.8,73.5]	53 (87.1)	9 (12.9)

[a]mean ± standard deviation (SD); n=73.
[b]median [Q1, Q3]; n=62.
[c] Based on serum ferritin (SF): Iron sufficient: SF≥30 µg/L, iron insufficient: SF<30 µg/L.

3.3.3 Diet Quality

Adherence to dietary recommendations varied by component, with the protein component having the highest adherence of 72% and dairy the lowest at 12% (Table 5). Alcohol had a 100% adherence, indicating no participants were drinking more than two standard drinks per day. Participants' median diet variety score was 26 [23,29]. Participants reached less than 50% of the highest diet variety score (65), at 43.6% on average.

Table 5. Participants (n=75) diet components measured by standard portion size for each component.

Diet component	Median intake [Q1, Q3]	Recommended intake[b]	% meeting recommendations[c]
Vegetable (serves per day)	3.3 [2.2, 4.4]	≥ 4.0	30.7
Fruit (serves per day)	1.5 [0.8, 2.3]	≥ 2.0	33.3
Grain (serves per day)	4.4 [3.6, 5.5]	≥ 6.0	22.7
Protein (serves per day)	2.4 [1.8, 3.0]	≥ 2.0	72.0
Dairy (serves per day)	1.6 [0.9, 2.3]	≥ 3.0	12.0
Water (L)	1.8 [1.2, 2.5]	≥ 2.5	21.3
Saturated Fat (% energy per day)	15.0 [12, 18.6]	≤ 10.0%	12.0
Discretionary Food[d] (serves per day)	4 [2.6, 6.9]	0.0-2.5	22.7
Alcohol (standard drinks per day)	0.0 [0.0, 0.1]	≤ 2.0	100.0
Diet Variety Score[c]	26.0 [23.0, 29.0]	65.0	43.6[e]
Total dietary guideline index score	59.5 [54.1, 68.3]		

[b] Based on New Zealand dietary guidelines for breastfeeding women (Ministry of Health, 2006).
[c] Proportion of participants whose intake met or exceeded the recommended intake level.
[d] Includes foods high in saturated fat, added sugar, and/or salt; one serve = 600kJ (National Health and Medical Research Council and Department of Health and Aged Care, n.d.)
[e] A maximum diet variety score of 65 was possible; participants achieved 43.6% on average.

Statistically significant differences in total dietary guideline index scores were observed between iron sufficient and iron insufficient groups (60.9 [55.0, 69.1] vs 53.6 [46.1, 61.4],p=0.026), suggesting that better overall diet quality is associated with iron sufficiency. The grain component median score was 4.5 [3.9, 5.8] for participants who were iron-sufficient, significantly higher than the median grain score of 3.2 [1.8, 4.4] for iron-insufficient participants (p=0.020) (Table 6). The discretionary food component was approaching significance (p=0.050) between iron-sufficient (3.9 [2.6, 5.7]) and iron-insufficient (6.0 [3.8, 7.9]).

Table 6. Comparison of total diet quality and dietary component scores between iron-sufficient and iron-insufficient postpartum women.

Diet component	Iron-Sufficient[a] (n=53)	Iron-Insufficient[a] (n=9)	P-Value[b]
Vegetable	3.3 [1.9, 4.4]	3.0 [2.2, 4.3]	0.936
Fruit	1.6 [1.0, 2.3]	1.1 [0.6, 2.3]	0.327
Grain	4.5 [3.9, 5.8]	3.2 [1.8, 4.4]	0.020*
Protein	2.4 [1.9, 3.0]	2.4 [1.7, 3.3]	0.920
Dairy	1.7 [0.9, 2.3]	1.2 [0.5, 2.0]	0.159
Water	1.8 [1.2, 2.5]	1.7 [0.9, 2.3]	0.726
Saturated Fat (% of total energy)	15.0 [12.0, 18.7]	15.9 [12.2, 18.9]	0.667
Discretionary Food[c]	3.9 [2.6, 5.7]	6.0 [3.8, 7.9]	0.050†
Alcohol	0.0 [0.0, 0.10]	0.0 [0.0, 0.0]	0.370
Diet Variety [d]	27.0 [23.0, 29.5]	25.0 [20.5, 30.5]	0.588
Total dietary guideline index score	60.9 [55.1, 69.1]	53.6 [46.1, 61.4]	0.026*

[a] Values presented as median [25th, 75th percentile].
[b] Mann-Whitney U Test used for non-parametric comparisons.
[c] Discretionary foods included those high in added sugar, saturated fat, and/or salt (National Health and Medical Research Council and Department of Health and Aged Care, n.d.).
[d] Maximum score for diet variety = 65
*Statistically significant at $p < 0.05$.
†Approaching statistical significance (p=0.05).

3.3.4 Iron status, diet quality and sociodemographic associations

Education level was associated with total dietary guideline index score (TDGIS) ($p<0.001$), where participants with tertiary education attainment or higher had a higher mean TDGIS (62.7 ± 9.6) compared to those with below tertiary education (53.3 ± 8.5) (Table 7). While household income and breastfeeding status showed trends towards higher TDGIS in higher income participants ($p=0.133$) and those EBF ($p=0.085$), these differences were not statistically significant (Table 7).

Binary logistic regression was conducted to assess the association between iron sufficiency, education attainment, breastfeeding status and total dietary guideline index score. The overall model was statistically significant (chi-square = 7.860, $p = 0.049$) and explained 21.1% of the variance in iron status (Nagelkerke $R^2 = 0.211$). TDGIS was significantly associated with iron status (OR = 0.898, $p=0.049$). For every one-point increase in TDGIS, the odds of being iron sufficient increased by approximately 11.3% (1/0.898=1.113) (Table 8).

Table 7. Association between sociodemographic factors and total dietary guideline index score (TDGIS)

Variable	Group	Mean TDGIS ± SD[a]	p-value[b]
Household Income[d]	Above Median (n=48)	61.8 ± 8.9	0.133
	Below Median (n=26)[c]	58.1 ± 11.5	
Breastfeeding status	Exclusive (EBF, n=62)	61.7 ± 9.1	0.085
	Partial (PBF, n=13)	56.3 ± 13.5	
Education attainment	Tertiary or higher (n=59)	62.7 ± 9.6	<0.001*
	Below Tertiary (n=16)	53.3 ± 8.5	
Ethnicity[e]	Caucasian (n=58)	60.6 ± 10.0	0.637
	Māori (n=8)	58.8 ± 10.1	
	Other (n=9)	54.5 ± 11.6	

[a] Values presented as mean ± standard deviation (SD).
[b] Independent t-tests used for binary variables; one-way ANOVA used for ethnicity.
[c] Household income data available for n=74 due to one missing response.
[d] Median household income in NZ in 2016 was $75,995 (Stats NZ, 2016).
[e] "other" includes Asian and Latin American ethnicities.
*Statistically significant at $p < 0.05$.

Table 8. Logistic regression assessing the association between iron insufficiency[a] and education, breastfeeding and total dietary guideline index score (TDGIS)

	B	SE	*p-value*	Exp(B) OR[b]	95% CI for EXP (B) Lower	95% CI for EXP (B) Upper
Breastfeeding[c]	-0.668	1.130	0.555	0.513	0.056	4.697
Education[d]	-0.682	0.884	0.441	0.506	0.089	2.863
TDGIS	-0.108	0.055	0.049*	0.898	0.807	0.999

[a] Outcome coded as iron insufficient (1=insufficient, 0=sufficient).
[b]OR=odds ratio; for TDGIS, the inverse OR is 1.113, indicating an 11.3% increase in odds of iron sufficiency per one-point increase in TDGIS.
[c] Breastfeeding status coded as 1 = exclusive, 0 = partial.
[d] Education coded as 1 = tertiary or higher, 0 = below tertiary.
*Statistically significant at $p < 0.05$
chi-square = 7.860, p = 0.049, Nagelkerke $R^2 = 0.211$

3.4 Discussion

To the best of the author's knowledge, this is the first study in New Zealand (NZ) to investigate diet quality in relation to iron status among postpartum women. The study investigated the relationship between diet quality and iron status in postpartum women in NZ. The findings indicate that higher diet quality is associated with likelihood of iron sufficiency.

3.4.1 Iron Status and Prevalence

This study found that 12.9% of participants had serum ferritin (SF) levels below 30 µg/L, indicating iron insufficiency. This finding aligns with earlier national estimates of iron deficiency (ID) prevalence among NZ women of reproductive age, which range from 7% to 13%, depending on the SF cut-off used with Ferguson et al. (2001) defining ID as SF <12 µg/L The 2008/2009 New Zealand Adult Nutritional Survey found that approximately 10.4% of women aged 15-49 were iron-deficient, using an SF cut-off of <15 µg/L (University of Otago and Ministry of Health, 2011). While 6.9% of participants were classified as anaemic (Hb <120g/L), no participants met the criteria for iron deficiency anemia (IDA) defined as Hb <120g/L and SF <15 µg/L. These findings suggest that while a subset of postpartum women in this cohort experienced depleted iron stores, progression to more severe deficiency may be limited, potentially due to health services available or iron supplementation, although

supplement use was not assessed in this study or natural recovery of iron stores postpartum associated with lactational amenorrhea.

3.4.2 Diet quality and diet quality components

The study identified suboptimal adherence to dietary recommendations among postpartum women, particularly for dairy (12.0%), vegetables (30.7%), and grains (22.7%). This aligns with findings from van der Pligt et al. (2016) and Lebrun et al. (2019), who reported in reduced fruit and vegetable intake during the postpartum period. Similar patterns or low adherence have also been reported the same cohort of 76 breastfeeding women, where intakes of fruits, vegetables, grains meats and dairy products fell well below the recommended levels. Five percent met grain recommendations, 0% met vegetable and 13% met dairy recommendations (Jin et al., 2025). The median diet variety score of 26 out of a maximum score of 65 (43.6% of the highest possible score) highlights inadequate diet diversity, which may contribute to nutrient insufficiencies. Grain intake was found to be significantly higher in iron-sufficient participants compared to iron-insufficient participants ($p=0.020$). Grains can contribute to iron intake, particularly when fortified, although the presence of phytates in grains may inhibit absorption (Anderson and Frazer, 2017). Further research is required to assess the impact of different grain types on postpartum iron status.

3.4.3 Diet quality and iron status

A statistically significant association was found between total dietary guideline index score (TDGIS) and iron sufficiency ($p=0.026$), with iron-sufficient participants having higher TDGIS than those who were iron insufficient. Diet quality in this study was measured using a modified Diet Guideline Index (DGI), which reflected adherence to NZ Food and Nutrition Guidelines. A higher TDGIS indicated greater consumption of nutrient-dense foods, defined as minimally processed foods from the five core food groups (vegetables, fruit, grains, lean proteins, and dairy), along with water, limited intake of saturated fat, alcohol and discretionary foods (Ward et al., 2019). These findings support previous research showing that nutrient-dense dietary patterns are associated with better iron status and maintaining iron homeostasis (Martin et al., 2020). In particular, grain intake was significantly higher among iron-sufficient participants ($p=0.020$), which may reflect iron-fortified cereals or whole

grains. Notably, the discretionary food component was approaching significance (p= 0.050), suggesting that diets high in foods containing added sugars, saturated fats and salt may be associated with lower iron status.

3.4.4 Sociodemographic factors and diet quality

Education attainment was positively associated with total dietary guideline index scores (TDGIS). Participants with tertiary education or higher had significantly higher TDGIS; this aligns with prior research indicating that higher education levels are linked to improved dietary habits and health literacy (Martin et al., 2020). While breastfeeding status showed a trend towards reaching significance (p=0.085) with TDGIS, it did not reach statistical significance. Similarly, ethnicity was not statistically significant in TDGIS (p=0.637). However, the small sample size in this study, with the majority of participants identifying as Caucasian, may have limited the ability to detect significant differences. Future research should have a more diverse and representative sample to better understand potential ethnic disparities in postpartum iron status. Future studies should also investigate the impact of education on dietary choices and iron sufficiency.

3.5 Strengths & Limitations

To the best of the author's knowledge, one key strength is that it is the first study in New Zealand (NZ) to examine the association between diet quality and iron status in postpartum women, contributing to valuable insights into this under-researched area. Using a validated dietary guideline index (DGI) modified to the NZ guidelines provides a comprehensive measure of dietary quality, and including biochemical markers for iron status enhances the reliability of the findings.

While serum ferritin was used as a primary biomarker for iron status, it can be influenced by inflammation. To account for inflammation, participants with elevated C-reactive protein (CRP) were excluded.

The sample size was small, which may have limited the ability to detect significant associations, particularly for groups such as ethnicity. Most participants identified as Caucasian, reducing the generalisability of the results for postpartum women in New Zealand. Dietary intake was self-reported using a weighed four-day diet diary (4DDD), which

is the gold standard method for dietary assessment, although it is also subject to reporting bias and may not capture habitual dietary patterns. The study did not account for supplement use, which could have influenced iron levels among participants.

3.6 Conclusion

This study identified areas for improvement in diet quality among postpartum women in NZ, with observed low adherence to dietary recommendations, including dairy, vegetables, and grains. A relationship was found between diet quality and iron sufficiency, showing that higher diet quality scores were associated with a reduced risk of iron insufficiency. Notably, grain consumption was significantly higher in iron-sufficient women, suggesting that specific dietary patterns may affect iron status. Education was a strong predictor of diet quality, reinforcing the influence of socioeconomic factors on postpartum nutrition. These findings support the need for nutrition interventions that promote diet quality and improve adherence to dietary guidelines. However, to ensure these interventions are effective and equitable, further research is needed to understand the barriers that prevent optimal diet quality in the postpartum period.

Chapter 4: Conclusion & Recommendations

4.0 Achievement of Aims, Objectives & Hypothesis

The overall aim of this study was to investigate the relationship between diet quality and iron status among postpartum women living in New Zealand (NZ). Several objectives were established to address this aim, including to measure the diet quality of postpartum women using a four-day diet diary (4DDD) and a modified Dietary guideline index (DGI), determine the prevalence of iron deficiency (ID) through serum ferritin (SF) concentrations, examining the relationship between diet quality and iron status, exploring associations between sociodemographic factors (ethnicity, breastfeeding practices, education, and household income) and diet quality, and identifying predictors of iron status.

The first objective was to define the diet quality of postpartum women in NZ. Total diet quality scores (TDGIS) were calculated from the 4DDD data based on the modified DGI. The findings of this study largely supported the initial hypothesis that postpartum women have suboptimal diet quality, indicated by low adherence to dietary guidelines across multiple DGI components. The median TDGIS was 59.5 out of 100, indicating moderate adherence to dietary guidelines. Fewer than 35% of participants met the recommended dietary guidelines for vegetables, fruit, grains, dairy, water, saturated fat and discretionary foods. This is consistent with previous research, which found that postpartum women frequently fail to meet dietary recommendations and often have reduced fruit and vegetable intake (Martin et al., 2020).

The second hypothesis, that less than 15% of postpartum women would have SF levels below 30 µg/L, was also supported, with a prevalence of iron insufficiency observed at 12.9%. While this rate is lower than that reported in premenopausal women in Auckland (55%), using the same SF cut-off of 30 µg/L (Lim et al., 2020), Differences in SF cut-offs between studies limit direct comparison. These findings suggest that iron deficiency remains a relevant public health concern for postpartum women, with 12.3% in this cohort classified as iron deficient. While lower than rates reported in premenopausal and reproductive-aged women in other New Zealand studies, it still represents a considerable proportion of the postpartum population.

The third hypothesis was that higher TDGIS would be associated with a greater likelihood of iron sufficiency. Participants with sufficient iron status had a higher median TDGIS (60.9) compared to those with insufficient iron (53.6). The statistically significant difference ($p = 0.026$) supports this hypothesis, indicating that women who had better overall diet quality reflected by greater adherence to dietary guidelines through higher variety across core food groups, lower saturated fat intake, and reduced consumption of discretionary foods, were more likely to have adequate iron stores.

The fourth hypothesis, that European ethnicity, exclusively breastfeeding, tertiary education attainment, and higher household income would be associated with higher TDGIS, was partially supported. Tertiary education attainment was significantly associated with higher TDGIS ($p < 0.001$). Participants who had tertiary or higher education attainment had a mean TDGIS of 62.7 ± 9.6 compared to 53.3 ± 8.5 among those with below tertiary education. This aligns with previous research indicating that higher education levels are associated with improved dietary behaviours and better adherence to nutritional guidelines (Starck et al., 2021, Martin et al., 2020). There were no significant associations between household income, breastfeeding practice and TDGIS. Prior literature has suggested that lower socioeconomic status and being of Māori and Pacifica ethnicity may impact dietary intake and iron status postpartum, highlighting the need for further exploration in larger, more diverse populations (Calje et al., 2023, Starck et al., 2021).

The final objective was to explore the predictors (e.g. education, breastfeeding practices and TDGIS) of iron status. It was hypothesised that tertiary education attainment, exclusive breastfeeding and higher TDGIS will be associated with a greater likelihood of iron sufficiency. While higher TDGIS was significantly associated with great odds of iron sufficiency ($p = 0.049$), education attainment and breastfeeding practices were not significant predictors in the logistic regression analysis, only partially supporting the hypothesis.

4.1 Strengths & Limitations

4.1.1 Strengths

1. To the best of our knowledge, this is the first study in New Zealand (NZ) to use a modified Dietary guideline index (DGI) to investigate the relationship between diet quality and iron status in postpartum women.
2. The use of a weighed four-day diet diary (4DDD) is considered the gold standard for dietary assessment. It provides the most accurate and detailed reflection of an individual's dietary intake, minimising the reliance on memory and reducing reporting error (Fuller et al., 2017). Participants were supplied with electronic kitchen scales and detailed instructions, further strengthening the accuracy and reliability of the dietary data.
3. Despite the small sample size, participants provided detailed sociodemographic information, completed a 4DDD, and underwent biochemical assessments for iron status, including serum ferritin (SF), with measurements excluded from analysis if C-Reactive Protein (CRP) was elevated. This allowed for a multidimensional analysis of the relationship between diet quality, iron status and sociodemographic factors.
4. The DGI was tailored to the NZ guidelines and provided an overall evaluation of the diet rather than individual nutrients. By incorporating multiple diet components, including positive and limiting dietary behaviours (such as discretionary food intake), the DGI enabled a comprehensive assessment of dietary adherence to nutritional guidelines.

4.1.2 Limitations

1. The DGI did not differentiate between haem and non-haem iron sources of iron or absorption enhancers (e.g., vitamin C) and inhibitors (e.g., phytates). This may have limited the ability to capture dietary factors specifically influencing iron status.
2. The 4DDD was completed at three months postpartum, while iron status was assessed six months postpartum. Although dietary habits are relatively stable during

the postpartum period (van der Pligt et al., 2016), there remains the potential for changes that were not captured.

3. Grain intake was analysed as a single group without distinguishing between whole and refined grains. The difference in nutrient composition and iron bioavailability between whole and refined grains may have influenced the relationship between grain intake and iron status.
4. Although the study collected comprehensive data, the small sample size limited the ability to detect significant associations, for example, when examining differences in diet quality scores across ethnic groups or between breastfeeding and non-breastfeeding women.
5. The majority of participants identified as European, limiting the generalisability of findings to other ethnic groups in NZ.
6. A key limitation of this study is the geographic restriction to Palmerston North and the wider Manawatū region. The relatively small local population may have limited participant recruitment and reduces the generalisability of the findings to postpartum women in other regions of New Zealand.
7. The literature review for this thesis did not include a formal search strategy or a detailed comparison of diet quality assessment methods. As a result, some relevant studies may not have been identified, and methodological differences between studies were not systematically evaluated.

4.2 Impact of Findings

This study contributes valuable insights into the relationship between iron status and diet quality among postpartum women in NZ. The study used a comprehensive diet quality assessment and biochemical markers of iron status. The positive association found between higher diet quality and improved iron status highlights the need for further research on the overall diet quality rather than focusing on single nutrients. These findings have important implications for developing postpartum nutrition interventions, especially considering the suboptimal adherence to nutritional guidelines observed in the study population.

4.3 Recommendations & Future Directions for Research

The following recommendations should be considered to advance future research on diet quality and iron status among postpartum women in New Zealand, with a focus on improving methodologies and addressing social determinants of nutrition.

1. Future research should include a larger sample size.
2. Recruitment of a more ethnically diverse population would strengthen the generalisability of findings and better reflect NZ's multicultural population. Feeding practices and dietary habits can vary across different cultures. Exploring these differences would provide more insights into the role of ethnicity in postpartum nutrition and iron status.
3. Future research on diet quality or dietary assessments should consider distinctions between haem and non-haem iron sources, recognising their differing bioavailability. Incorporating these distinctions as part of a comprehensive dietary analysis would strengthen the interpretation of dietary influences on iron status.
4. Including dietary components that affect iron absorption (e.g., vitamin C, calcium, phytates, polyphenols) in diet quality assessments could provide a better analysis of the relationship between diet and iron status.
5. Differentiation between whole and refined grain intake would enhance understanding of how grain type affects nutrient status, particularly iron bioavailability.
6. Recording iron supplementation intake during the postpartum period would help see the effects of diet alone.
7. Explore the barriers to achieving optimal diet quality in the postpartum period, such as time constraints, food costs, cultural preferences and nutrition knowledge.
8. Future research should also consider the broader family and social living context, including household support, family involvement, and living arrangements, to better understand how these factors may interact with dietary behaviours and iron status in postpartum women.

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Appendices

Appendix 1: Registration number ANZCTR

Dear Ying Jin,

Re: Mother and Infant Nutrition Investigation - Investigating micronutrient intake and status in mothers and babies, and their possible effects on thyroid function

Thank you for submitting the above trial for inclusion in the Australian New Zealand Clinical Trials Registry (ANZCTR).

Your trial has now been successfully registered and allocated the ACTRN: ACTRN12615001028594

Web address of your trial: http://www.ANZCTR.org.au/ACTRN12615001028594.aspx
Date submitted: 15/09/2015 1:15:17 PM
Date registered: 1/10/2015 10:29:21 AM
Registered by: Ying Jin

If you have already obtained Ethics approval for your trial, could you please send the ANZCTR a copy of at least one Ethics Committee approval letter? A copy of the letter can be sent to info@actr.org.au (by email) OR (61 2) 9565 1863, attention to ANZCTR (by fax).

mailto:info@actr.org.au

Please be reminded that the quality and accuracy of the trial information submitted for registration is the responsibility of the trial's Primary Sponsor or their representative (the Registrant).
The ANZCTR allows you to update trial data, but please note that the original data lodged at the time of trial registration and the tracked history of any changes made will remain publicly available.

The ANZCTR is recognised as an ICMJE acceptable registry (http://www.icmje.org/faq.pdf) and a Primary Registry in the WHO registry network (http://www.who.int/ictrp/network/primary/en/index.html).

If you have any enquiries please send a message to info@actr.org.au or telephone +61 2 9562 5333.

Kind regards,
ANZCTR Staff
T: +61 2 9562 5333
F: +61 2 9565 1863
E: info@actr.org.au
W: www.ANZCTR.org.au

Appendix 2: Health and Disability Ethics Committee letter

Health and Disability Ethics Committees
Ministry of Health
Freyberg Building
20 Aitken Street
PO Box 5013
Wellington
6011

0800 4 ETHICS
hdecs@moh.govt.nz

15 December 2015

Ms Ying Jin
School oF Food and Nutriton
Massey University
Private Bag 11222
Palmerston North 4442

Dear Ms Jin

Re:	**Ethics ref:**	**15/NTA/172**
	Study title:	Mother and Infant Nutrition Investigation

I am pleased to advise that this application has been *approved* by the Northern A Health and Disability Ethics Committee. This decision was made through the HDEC-Full Review pathway.

Conditions of HDEC approval

HDEC approval for this study is subject to the following conditions being met prior to the commencement of the study in New Zealand. It is your responsibility, and that of the study's sponsor, to ensure that these conditions are met. No further review by the Northern A Health and Disability Ethics Committee is required.

Standard conditions:

1. Before the study commences at *any* locality in New Zealand, all relevant regulatory approvals must be obtained.

2. Before the study commences at *a given* locality in New Zealand, it must be authorised by that locality in Online Forms. Locality authorisation confirms that the locality is suitable for the safe and effective conduct of the study, and that local research governance issues have been addressed.

After HDEC review

Please refer to the *Standard Operating Procedures for Health and Disability Ethics Committees* (available on www.ethics.health.govt.nz) for HDEC requirements relating to amendments and other post-approval processes.

Your next progress report is due by 15 December 2016.

Participant access to ACC

The Northern A Health and Disability Ethics Committee is satisfied that your study is not a clinical trial that is to be conducted principally for the benefit of the manufacturer or distributor of the medicine or item being trialled. Participants injured as a result of treatment received as part of your study may therefore be eligible for publicly-funded compensation through the Accident Compensation Corporation (ACC).

Please don't hesitate to contact the HDEC secretariat for further information. We wish you all the best for your study.

Yours sincerely,

Dr Brian Fergus
Chairperson
Northern A Health and Disability Ethics Committee

Encl: appendix A: documents submitted
appendix B: statement of compliance and list of members

Appendix A
Documents submitted

Document	*Version*	*Date*
PIS/CF	1	20 October 2015
Protocol	1	20 October 2015
Evidence of scientific review	1	20 October 2015
Survey/questionnaire: It is an index to provide an overview of all the questionnaires used in the study.	1	21 October 2015
Survey/questionnaire: V1_M2	1	21 October 2015
Survey/questionnaire: V1_M3	1	21 October 2015
Survey/questionnaire: V1_M4	1	21 October 2015
Survey/questionnaire: Health Screening Questionnaire	1	21 October 2015
Survey/questionnaire: V1_M5	1	21 October 2015
Survey/questionnaire: V1_H1	1	21 October 2015
Survey/questionnaire: V1_H2	1	21 October 2015
Survey/questionnaire: V1_H3	1	21 October 2015
Survey/questionnaire: V2_M1	1	21 October 2015
Survey/questionnaire: V2_M2	1	21 October 2015
Survey/questionnaire: V3_M1	1	21 October 2015
CV for CI	1	21 October 2015
Survey/questionnaire: Ages and Stages Questionnaires_Sample	1	21 October 2015
Investigator's Brochure	1	22 October 2015
Survey/questionnaire: V1_M1	1	22 October 2015
Survey/questionnaire: V2_H1	1	22 October 2015
PIS/CF for persons interested in welfare of non-consenting participant	1	22 October 2015
Application	1	-
PIS/CF: This is the updated version of the Information Sheet.	2	24 November 2015
PIS/CF: This is the updated version of Consent Form.	2	24 November 2015
Investigator's Brochure: This is the updated version of the Advertisement	2	24 November 2015

Appendix B
Statement of compliance and list of members

Statement of compliance

The Northern A Health and Disability Ethics Committee:

- is constituted in accordance with its Terms of Reference
- operates in accordance with the *Standard Operating Procedures for Health and Disability Ethics Committees*, and with the principles of international good clinical practice (GCP)
- is approved by the Health Research Council of New Zealand's Ethics Committee for the purposes of section 25(1)(c) of the Health Research Council Act 1990
- is registered (number 00008714) with the US Department of Health and Human Services' Office for Human Research Protection (OHRP).

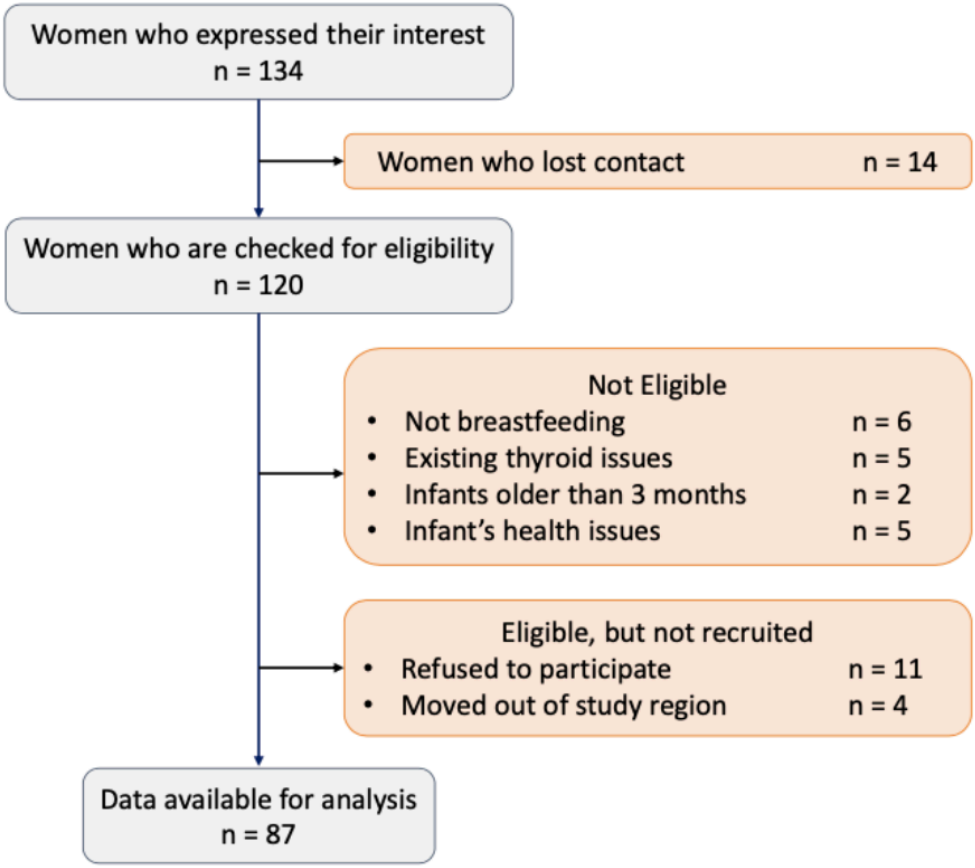
List of members

Name	*Category*	*Appointed*	*Term Expires*
Dr Brian Fergus	Lay (consumer/community perspectives)	01/07/2012	01/07/2015
Dr Karen Bartholomew	Non-lay (intervention studies)	01/07/2013	01/07/2016
Dr Charis Brown	Non-lay (intervention studies)	11/11/2015	11/11/2018
Ms Susan Buckland	Lay (consumer/community perspectives)	01/07/2012	01/07/2016
Ms Shamim Chagani	Non-lay (health/disability service provision)	01/07/2012	01/07/2016
Dr Christine Crooks	Non-lay (intervention studies)	01/07/2013	01/07/2018
Dr Kate Parker	Lay (consumer/community perspectives)	11/11/2015	11/11/2018

Unless members resign, vacate or are removed from their office, every member of HDEC shall continue in office until their successor comes into office (HDEC Terms of Reference)

http://www.ethics.health.govt.nz

Appendix 3: Flowchart of study participants



Appendix 4: Health Screening Questionnaire

MASSEY UNIVERSITY
COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

Code: _____

MINI Study - Mother and Infant Nutrition Investigation

Date of visit: _____ Day_____ Month_____ Year

First name_____ Surname_____

Primary Contact Address

Street number and name:

Suburb:

City:

Postcode [if known]:

Primary Contact Phone Number(s)

Email address

Secondary Contact information

Street number and name:

Suburb:

City:

Postcode [if known]:

Subject Identifier

This page will be detached from remainder of the questionnaire at the end of the interview. Confidential information will be stored separately.

Participants information

MASSEY UNIVERSITY
COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

Code: _____

MINI Study - Mother and Infant Nutrition Investigation

Date of visit: _____ Day_____ Month_____ Year

Health Screening Questionnaire

Thank you volunteering to take part in this study. I would like to ask you a few questions to check that you are a suitable subject and provide you with an opportunity to ask any questions that you may have about the study.

What is your age?

Are you currently breastfeeding?

When was your baby born?

Do you have any contagious blood borne disease, eg. Hepatitis A or HIV?

Do you currently have any medical conditions?

Have you ever been diagnosed with thyroid disease such as thyroid enlargement or goiter/ hyperthyroidism/ hypothyroidism?

If yes, are you currently receiving any treatment or consuming medication containing iodine? Or, are you now fully recovered?

Are you taking iodine contain supplements due to other reasons rather than pregnancy or lactation?

Are you taking any other medication? *If yes, can you please indicate the type or name of the medication(s) that you are taking?*

Does your baby have any health complications, eg. Preterm?

Preferred method of contact:

Appendix 5: MDHB Approval Form for Research Activity

MidCentral District Health Board

MDHB APPROVAL FORM FOR RESEARCH ACTIVITY

Research Practice Title: Mother and Infant Nutrition Investigation (MINI) Study : A cohort of postpartum women
Principal Investigator: Ying Jin
Designation : PHD Candidate Service Area: Womens Health
Research Practice Experience : _____
Other Researchers Involved: Lovise Brough (Massey) Jane Coad (Massey)

Brief description of research study purpose, methodology and reporting:

Purpose:

After the birth of their baby, most women continue to see their health care professionals. However, the focus is often on the infant's health. Only limited attention is given to the mother's mental health. This study will monitor the mothers' health by assessing her nutrient status, thyroid function and mental health. The thyroid is a small butterfly-shaped gland at the base of the neck which produces hormones. How a mother's health status might affect her baby's development during early life is important. The three nutrients we are studying are iodine, selenium, and iron. Understanding these nutrients will help to provide better health care to future mothers. This leads to greater knowledge about the health and wellbeing of both the mothers and their infants.

Methodology:

Advertisements and posters place at selected sites where preganat or post partum women frequently attend. Potential participants will record an expression of interest online or via telephones.Prospective participants will be sent an appropriate study information sheet. Once they indicate their willingness to participate, the researcher will conduct a screening questionnaire to ensure participants are eligible to take part in the study. Informed consent will be obtained. The target number of study participants is 180. Taking

Progress and final reporting:

Section A : Initial Registration and Approval of Research Practice

Documented evidence :

- ☐ Research purpose and parameters
- ☐ Consultation with all MDHB involved parties
- ☐ Risk and indemnity cover
- ☐ Resources required (*eg, staff, equipment, other service involvement)*
- ☐ Approved research budget

Operations Director signature to proceed : Date:

Professional approval

☑ Yes ☐ No ☐ Not applicable

Designation:	Signature:	Date:
ACTING CLINICAL DIRECTOR		14/9/16
CHARGE MIDWIFE	DHRST	15/9/16

MidCentral District Health Board

MDHB APPROVAL FORM FOR RESEARCH ACTIVITY

External approval *(eg, HDEC, Educational Institution)*

☑ Yes ☐ No ☐ Not applicable

State where from : HDEC

Documented evidence (where applicable):

☐ National application form for ethical review of a research project *(NAF- 2005- v1)*

☐ 'Participants who are unable to give informed consent to participate' form *(NAF- Part 7)*

☑ Locality assessment form

☐ 'Use of human tissue' form *(NAF- Part 5)*

☐ 'Genetic research' form *(NAF - Part 6)*

Section B : Operations Director's Endorsement to Proceed

Proposed start/end dates of research: _____

Operations Director signature _____

Service Line : Women Health Date: 15.9.16.

This submission has been considered to meet ethical and professional requirements, and clearly demonstrate potential clinical, professional and/or strategic benefit to the organisation.

Clinical Board Acknowledgement of Registration

Signed: _____ Designation: CHO/Chair Date: 22/9/16

Copy to be retained by Chief Medical Officer's office and details entered onto Register.

To be completed by the Principal Investigator and Operations Director. The Operations Director is to forward a copy of the form to the MidCentral Health Clinical Board, via Quality & Clinical Risk. All relevant supporting documentation is to be included.

MidCentral District Health Board
Te Pae Hauora o Ruahine o Tararua

Locality Assessment Sign Off for Approval of Research/Clinical Trials

Full project title:	Mother and Infant Nutrition Investigation
Short project title:	MINI

1. Declaration by Principal Investigator

The information supplied in this application is, to the best of my knowledge and belief, accurate. I have considered the potential ethical, resource and cultural issues involved in this research and believe that I have adequately addressed them for this locality.

A formal letter of consultation was sent to the Maori Health Unit on the __/__/__ (date)

Maori Consultation with Dr Maureen Holdaway, Massey University

Name of Principal Investigator (please print):	Ying Jin
Signature of Principal Investigator:	
Date:	25 July 2016

2. Declaration by Clinical Leader of Service/Department in which the Principal Investigator is located

I have read the application, and it is appropriate for this research to be conducted in this department. I give my consent for this locality to be included in the ethics committee application.

Name (please print):	Steven Sharp		
Signature:		Institution:	Palmerston North Hospital/MCH
Date:	14/9/16	Designation:	Acting C.D.

- Where the Clinical Leader is also one of the investigators, the Clinical Leader declaration must be signed by the Clinical Executive Director.

MidCentral District Health Board
Te Pae Hauora o Ruahine o Tararua

3. If the application is for a student project, the supervisor should sign the declaration.

I have read the application, and it is appropriate for this research to be conducted under my supervision. I give my consent for this locality to be included in the ethics committee application.

Name (please print):	LOUISE BROUGH		
Signature:	L. Brough	Institution:	~~Palmerston North Hospital/MCH~~ MASSEY UNIVERSITY
Date:	26/7/16	Designation:	SENIOR LECTURER.

4. Declaration by relevant Operations Director

I have read the application, and it is appropriate for this research to be conducted in this department. I give my consent for this locality to be included in the ethics committee application.

Name (please print):	NICHOLAS GLUYAS		
Signature:		Institution:	Palmerston North Hospital/MCH
Date:	23.9.16	Designation:	Ops Director.

Appendix 6: MINI Study Poster

MINI Study –
Mother and Infant Nutrition Investigation

Would you like to find out more about your dietary intake and nutrient status and its effect on both you and your new-born baby?

If you are a healthy woman aged 16 or older
Either in the late stage of pregnancy
Or have recently given birth
We would like to hear from you

What would be involved if joining this study?

- Three Visits to the Human Nutrition Research Unit at Massey University
- Complete questionnaires about food intake, use of supplements, general health
- Complete a Child Development Questionnaire when your baby reaches 4, 8 and 12 months old
- We will measure your body composition and thyroid gland size
- Collect a small urine, blood and/or breastmilk samples and toenail clippings from you
- Collect a small urine sample and nail clippings from your child

We will continue to follow you and your baby's nutritional health until your child is 12 months old

This project has been reviewed and approved by the Health and Disability Ethics Committee: 15NTA172.

Please contact:
Ms Ying Jin (PhD Scholar) through mini@massey.ac.nz
Or Go to www.massey.ac.nz/ministudy

School of Food and Nutrition, Massey University, 027 399 4138/06-951-7556

MASSEY UNIVERSITY
COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

Appendix 7: Participant's Information Sheet with Flowchart

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

THE ENGINE OF THE NEW NEW ZEALAND

Participant Information Sheet

Study title:	**[MINI - Mother and Infant Nutrition Investigation]**	
Locality:	**Palmerston North**	Ethics committee ref: **15/NTA/172**
Lead investigator:	**Ying Jin**	Contact **email**: **mini@massey.ac.nz** **Register your interest –** **www.massey.ac.nz/ministudy** **Phone: +64 (06) 9517556** **027 399 4138**

Would you like to help us?

We invite you to take part in a research study: Mother and Infant Nutrition Investigation (MINI). This sheet gives detailed information about the study. Please read it carefully before deciding whether you wish to join our study.

We need mothers and their infants to take part. It is important that you understand why we are doing this research, and what it may involve for you. Please take time to read the sheet carefully. Feel free to discuss it with other people, such as your family, whānau, friends, or your health care providers. Please ask us questions if anything seems unclear, or if you wish to know more details.

Introducing the researchers

This research is led by PhD scholar Ms Ying Jin. Ying's supervisors are Dr Louise Brough and Professor Jane Coad. They are human nutritionists in the School of Food and Nutrition, Massey University, Palmerston North. Anne Broomfield, research officer, will also assist in the study.

What is the purpose of this study?

After the birth of their baby, most women continue to see their health care professionals. However, the focus is often on the infant's health. Only limited attention is given to the mother's mental health. This study will monitor the mothers' health by assessing her nutrient status, thyroid function and mental health. The thyroid is a small butterfly-shaped gland at the base of the neck which produces hormones. How a mother's health status might affect her baby's development during early life is important. The three nutrients we are studying are iodine, selenium, and iron. Understanding these nutrients will help to provide better health care to future mothers. This leads to greater knowledge about the health and wellbeing of both the mothers and their infants.

Do I have to take part?

No. It is entirely up to you to decide whether you wish to take part. If you do agree, you will be asked to sign a Consent Form. You will be given a copy of both the Participant Information Sheet and the Consent Form to keep.

Should you change your mind about being in the study, you are free to withdraw from the study at any time without giving any reason.

What would your participation involve?

If you are interested in taking part in the study, please phone or email us. You can also enter your details on this study's "Express of Interest" webpage. We will reply immediately and arrange a brief telephone conversation. We will ask you some questions to ensure that you are eligible. You must feel totally comfortable about taking part in the study.

Soon after, we shall make an appointment for you and your baby to come into the Human Nutrition Research Unit at Massey University. If this is not possible, we may visit you either at home, at a local community Centre, or at a health professionals' clinic.

During the first visit, we shall

- ask you some questions about your nutrient supplement use, and your nutrition knowledge. We will also ask you about your health, diet and some personal information;
- measure your weight, height, and body composition;
- ask you to provide small samples of urine and breast milk which we will use to assess your nutrient status;
- measure your baby's weight, length and head circumference.
- collect a small urine sample from your baby to assess his/her nutrient status.

Your first visit should take no more than two hours.

After the first visit, you will be given

- two small paper bags for you to collect nail clippings from yourself and from your baby to assess selenium status.
- a 4-day food record diary to measure your nutrient intake.

Within a month after your first visit, at a convenient time, we will collect the samples and food diary from you at home.

The second visit will be when your baby is 6 months old. The last visit will be when your baby is 12 months old. We will ask you to complete a questionnaire to assess your child's development at 4, 8 and 12 months.

A detailed Flow Chart is on pg. 6 of this Information Sheet.

How would the required samples be collected?

A clear detailed instruction of how to collect infant or adult nail clippings would be given at the first visit. Infant urine samples will be collected by placing a pad inside the nappy, checking every 10 minutes until wet, and then urine aspirated (extracted) with a syringe. Blood samples will be drawn by experienced phlebotomist. The collected biological samples will be frozen, labelled with a unique code (no personal information will be displayed on the samples), and then stored for 10 years to allow a number of analyses to take place. After 10 years, the samples will be properly disposed in biohazard bags to be incinerated (burned) by a professional company who specialise in destroying biological samples. We acknowledge that the use and storage of tissue is a cultural concern for some Māori people. We are unable to return body fluids such as blood, urine and breastmilk due to safety (microbiological) issues. However, if you wish, the nail clippings, after analysis, will be returned to you if you request this in advance.

What are the possible risks to you?

There are small risks when taking blood samples such as discomfort, bruising, infection or fainting. To minimise any risk, your blood will only be taken by experienced and fully trained research staff.

Any risks involved in this study are very minor. All of the checks are routinely made. If you have any concerns during the study you may discuss these with any of the study team.

Any complaints you may make will be fully investigated. If you have any concerns about any aspect of this study, you should speak immediately to a member of the study team. They will do their best to answer all of your questions fully.

What are the advantages of taking part in the study?

- Your thyroid gland size, thyroid function and iron status will be monitored during the study. These are not normally covered by primary health care services;
- Repeated screening for postnatal depression during the first year after delivering a baby;
- Based on your food diary, you will receive feedback on your intake of nutrients within a month after we receive the dietary diary. This will be compared to New Zealand standard dietary guidelines.
- You will also receive information about your child's development assessments at 4, 8 and 12 months.

Will my participation in the study be kept confidential?

Yes. All information collected about you and your baby during the study will be kept strictly confidential. Each mother will be given a unique code which will be used on all data collected. No identifying details will be recorded on the interview sheets or other records.

When the study results are presented, you will not be named or recognised from any of the information given. All information will be entered into a protected database at Massey University. Information collected about you and your baby will be kept strictly confidential and secure in a locked filing cabinet. All electronic files on computers will have passwords and restricted access. Only the named members of research team will have access to detailed personal information.

Massey University maintains a central record of all research projects undertaken. This does not include personal information about those who take part. The data (without containing personal information) will be held for 10 years after the youngest person in the study has reached the age of consent or 16 years old.

What will happen to the results?

Should you wish, you will receive all the results about you and your baby. Should your results be, in any way, unusual, you will be encouraged to contact your general practitioner and seek appropriate medical advice. Once the whole study has ended, we can send you a summary of the study results, should you wish to have it. The results will also be presented at scientific meetings or published in peer reviewed journals. This ensures that a wider community, including health professionals, can know and read about the findings. You and your baby will not be identified by any of these publications or presentations.

What would happen if you were injured in the study?

If you were injured in this study, which is unlikely, you would be eligible for compensation from ACC. This would be the same as if you were injured in an accident at work or at home.

If you have private health or life insurance, you may wish to check with your insurer that taking part in this study will not in any way affect your cover.

Who has reviewed the study?

This project has been reviewed and approved by the Northern A Health and Disability Ethics Committee through the full review pathway.

Contact for further information:
If you have any further questions or if you have any concerns whilst taking part in the study then please contact:

Ms Ying Jin, Lead Investigator/PhD Scholar
Email: mini@massey.ac.nz, or go to www.massey.ac.nz/ministudy
Cell phone: 027 399 4138
Telephone: +64 (06) 9517556

Dr. Louise Brough, Principle Supervisor/Senior Lecturer
Telephone: +64 (06) 356 9099 ext. 84575

Email: L.Brough@massey.ac.nz

Where can you go for more information about the study, or to raise concerns or complaints?

If you have any questions, concerns or complaints about the study at any stage, you can contact:

Ms Anne Broomfield, Research Technical Officer
Human Nutrition Research Unit
Massey Institute of Food Science and Technology
Telephone: +64 (06) 356 9099 ext. 84566
Email: A.M.Broomfield@massey.ac.nz

If you want to talk to someone who is not involved with the study, you can contact an independent health and disability advocate on:

Phone: 0800 555 050
Fax: 0800 2 SUPPORT (0800 2787 7678)
Email: advocacy@hdc.org.nz

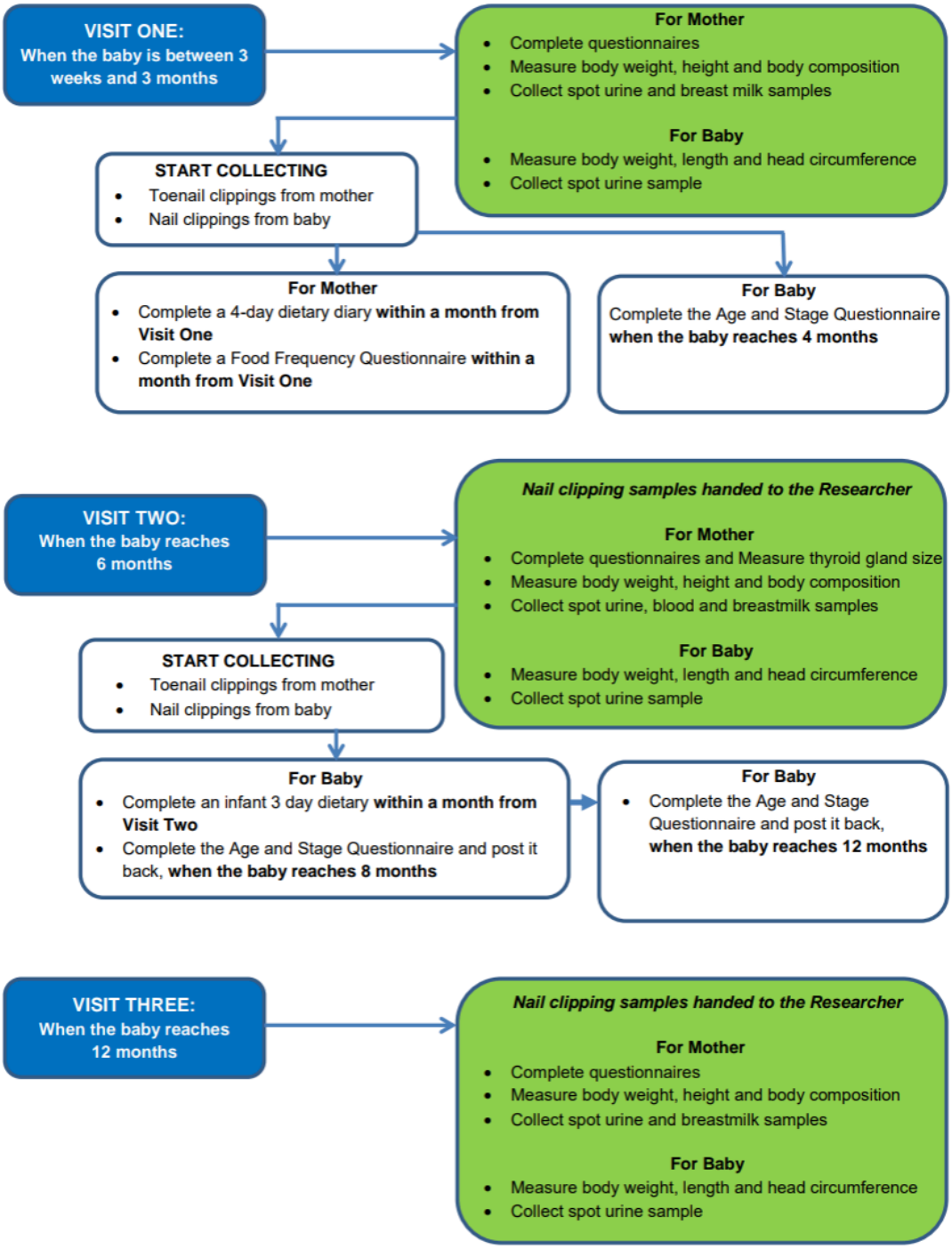
If you feel you would like to talk to a Māori health support person, please contact:

Dr Maureen Holdaway
Associate Director, Research Centre for Maori Health & Development
Telephone: +64 (06) 356 9099 ext. 85092
Email: M.A.Holdaway@massey.ac.nz

You can also contact the health and disability ethics committee (HDEC) that approval this study on:

Phone: 0800 4 ETHICS
Email: hdecs@moh.govt.nz

MINI STUDY FLOW CHART



Appendix 9: MINI Study – participant consent form

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

THE ENGINE OF THE NEW NEW ZEALAND

MINI Study - Consent Form

Please tick to indicate you consent to the following

I have been given sufficient time to consider whether or not to participate in this study.		
I have had the opportunity to use a legal representative, whanau/ family support or a friend to help me ask questions and understand the study.		
I am satisfied with the answers I have been given regarding the study and I have a copy of this consent form and information sheet.		
I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without this affecting my medical care.		
I consent to the research staff collecting and processing my information, including information about my health.		
If I decide to withdraw from the study, I agree that the information collected about me up to the point when I withdraw may continue to be processed.	Yes ☐	No ☐
I consent to my GP or current provider being informed about my participation in the study and of any significant abnormal results obtained during the study.	Yes ☐	No ☐
I understand that my participation in this study is confidential and that no material, which could identify me personally, will be used in any reports on this study.		
I know who to contact if I have any questions about the study in general.		
I wish the nail clippings to be returned to me after analysis	Yes ☐	No ☐
I wish to receive a summary of the results from the study.	Yes ☐	No ☐

Declaration by participant:

Participant's name: _____

Signature: _____ Date: _____

Declaration by a member of the research team:

I have given a verbal explanation of the research project to the participant, and have answered fully any of the participant's questions concerning this study..

I believe that the participant fully understands the details of this study and has given informed consent to participate.

Researcher's name: _____

Signature: _____ Date: _____

Appendix 10: Four-Day Diet Diary Instructions

MASSEY UNIVERSITY
COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

Code: _____

MINI Study - Mother and Infant Nutrition Investigation

Date of visit: _____ Day_____ Month_____ Year

4- day Food Dietary Diary

PLEASE READ THROUGH THESE PAGES BEFORE STARTING YOUR DIARY

We would like you to record in this diary everything you eat and drink over **4 DAYS**, including food consumed at home and outside the home. It is very important that you continue to eat and drink what you normally eat and drink during the period of recording. Please describe all the food you eat in as much detail as possible. Be as specific as you can.

When to fill in the diary

Please record the food you eat as you go, **do not list from memory** at the end of the day. Use written notes on a notepad if you forget to take your diary with you. Each diary day covers a 24 hour period, so please include any food or drinks that you may have had through the night. Remember to include foods and drinks between meals (snacks) including water.

Home-made dishes

Please record the name of the recipe, ingredients with amounts (including water and other fluids) for the whole recipe, the number of people the recipe serves, and the cooking method; record how much of the whole recipe you personally have eaten.

Take-away and eating out

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COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

Code: _____

Please record as much detail about the amount and ingredients as you can, eg. Vegetable curry containing chickpeas, eggplant, onion and tomato.

Brand name

Please note the brand name (if known). Most packed foods will list a brand name, e.g. Bird's eye, Hovis, or Supermarket own brands

Portion Size

Examples for how to describe the quantity or portion size you had of a particular food or drink are shown on pages 17-21 of this diary.

For foods, quantity can be described using:

- household measures, e.g. two thick slices of bread, 4 tablespoons (tbsp) of peas.
- weights from labels, e.g. 500g steak, 420g tin of baked beans, 125g pot of yoghurt
- number of items, e.g. 4 fish fingers, 2 pieces of chicken nuggets,

For drinks, quantity can be described using (see page 21 for a real size glass):

- the size of glass, cup or the volume (e.g. 300ml).
- volumes from labels (e.g. 330ml can of fizzy drink).

We would like to know the amount that was actually eaten which means taking any leftovers into account. You can do this in two ways:

- Record what was served and make notes of what was not eaten e.g. 3 tbsp of peas, 1 tbsp not eaten; 1 large sausage roll, ½ not eaten
- Only record the amount actually eaten e.g. 2 tbsps of peas, ½ a large sausage roll

At the end of each recording day, you will be prompted to tell us

Was it a typical day?

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Code: _____

After each day of recording you will be prompted to tell us whether this was a typical day or whether there were any reasons why you ate or drank more or less than usual.

Did you take any supplements?

At the end of each recording day there is a section for providing information about any supplements you took. Brand name, full name of supplement, strength and the amount taken should be recorded.

Overleaf (page 4-8) you can see an example day that has been filled in to show you how we would like you to record your food and drink.

It only takes a few minutes for each eating occasion!

Thank you for your time- we really appreciate it!

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COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

Code: _____

DAY 1		**Date: _____Day _____Month_____Year**		
Time	**Where**	**Food/drink description & preparation**	**Brand name**	**Portion size or quantity eaten**
		6am to 9am		
6.30am	Kitchen	Filter coffee, decaffeinated Milk (fresh, blue top) Sugar white Toast, multigrain bread Marmalade	Robert Harris Anchor Pams Pams Pams	Mug A dash 1 level teaspoon 1 slice 1 heaped teaspoon
		9am to 12noon		
		Did not eat or drink anything		

V1_H1 Maternal 4-day dietary diary

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TE KURA HAUORA TANGATA

Code: _____

Time	Where	Food/drink description & preparation	Brand name	Portion size or quantity eaten
		12noon to 2pm		
12.30am	Work tea room	Ham salad sandwich from home: Bread wholemeal thick sliced Margarine light Smoked ham thin sliced Lettuce, iceberg Cucumber with skin	 Pams Sunlight Supermarket	 2 slices 1 tablespoon 2 slices 1 leaf 4 thin slices
		2pm to 5pm		
3pm	Meeting room	Herbal tea Louise slice	Healthiers bakery	1 cup 1 regular slice

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Code: _____

Time	Where	Food/drink description & preparation	Brand name	Portion size or quantity eaten
		5pm to 8pm		
6.30pm	At table with husband and children	Spaghetti, wholemeal Bolognese sauce (see recipe) Courgettes Organe juice	Pams Homemade Fresh Just Juice	100g 1 serve 50g 200mls
		8pm to 10pm		
9pm	Sitting room alone	Milk Chocolates	Canterbury	25g
		10pm to 6am		
10pm	bedroom	water	tape	200mls

V1_H1 Maternal 4-day dietary diary

MASSEY UNIVERSITY
COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

Code: _____

Please record the details of any recipes or (if not already described) ingredients of made up dishes or take-away dishes.

Write in recipes or ingredients of made-up dishes or take-away dishes			
Name of Dish: Bolognese sauce		Serves: 4	
Ingredients	Amount	Ingredients	Amount
Low fat beef mince	500g		
garlic	3 cloves		
Brown onion	100g		
Sweet red pepper (capsicum)	50g		
Watties chopped tomatoes	400g		
Tesco tomato puree	1 tablespoon		
Pams canola oil	2 tablespoon		
Greggs mixed herbs	2 tablespoon		
Pams Worcester sauce	1 teaspoon		
Brief description of cooking method: Fry onion and garlic in oil, add mince and fry till brown. Add pepper, tomatoes, puree, Worcester sauce and herbs. Simmer for 30 minutes.			

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Code: _____

Use the pictures to help you indicate the size of the portion you have eaten.
Write on the food record the <u>picture number and size A, B or C</u> nearest to your own helping.

Remember that the pictures are much smaller than life size.
The actual size of the dinner plate is 10 inches (25cm), the side plate, 7 inches (18cm), and the bowl, 6.3 inches (16cm).

The tables on pages 16-21 also give examples of foods that you might eat and how much information is required about them.

Breakfast cereal

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Code: _____

Broccoli or cauliflower

Stew or curry

Battered fish

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Code: _____

Quiche or pie

Cheese

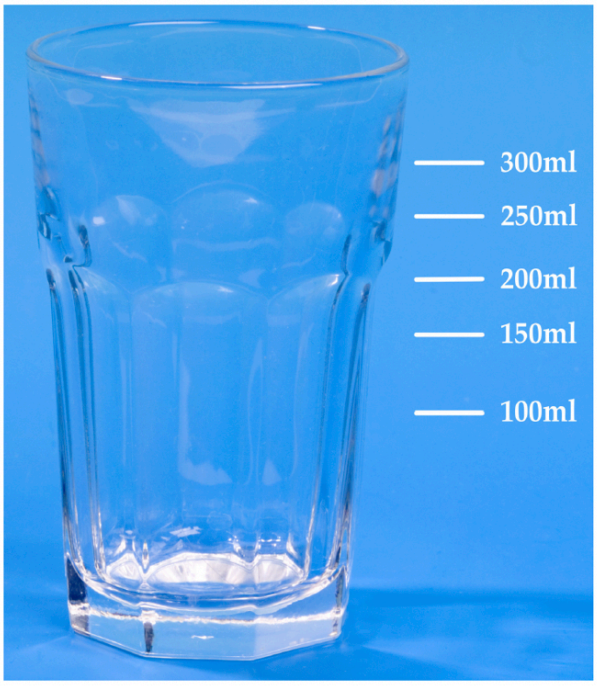
Spongy cake

V1_H1 Maternal 4-day dietary diary

MASSEY UNIVERSITY
COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

Code: _____

Life Size Glass



Appendix 11: Dietary Guideline Index (DGI) Protocol

This protocol outlines the detailed methodology for calculating the Dietary Guideline Index (DGI) as applied in this study, adapted specifically for New Zealand postpartum women based on the Australian Dietary Guideline Index (DGI). The DGI was designed to provide a comprehensive assessment of dietary quality by evaluating adherence to national nutrition guidelines using a composite score across 10 dietary components.

1. Dietary Data Collection

Dietary intake was collected using a four-day diet diary (4DDD), including at least one weekend day. Participants were provided with digital kitchen scales, measuring utensils, and written instructions to assist in accurately recording all foods and beverages consumed. Portion sizes, brands, preparation methods, and recipes were documented. Where foods were consumed outside the home, participants estimated portion sizes. Data were entered into FoodWorks 9 Professional (Xyris Pty Ltd), using the New Zealand Foodfiles 2016 database.

2. DGI Components

Ten components were included in the DGI, each scored out of 10 points to reflect adherence to dietary recommendations. These components included: vegetables, fruit, grain foods, protein foods, dairy, water, saturated fat, discretionary foods, alcohol, and diet variety.

3. Recommended Intake and Scoring Methodology

Each positively scored component was awarded a maximum of 10 points if the recommended intake was met or exceeded. Partial adherence was proportionally scored using the formula:

Score = (Actual Servings / Recommended Servings) × 10

Reverse-scored components (saturated fat, discretionary foods, alcohol) received 10 points if intake was within recommended limits and zero if exceeded. Diet variety was scored based on a 65-point food checklist adapted from the ARFS (Ashton et al., 2017):

Score = (Number of unique items consumed / 65) × 10

Table X. Dietary Component Cut-offs and Scoring

Component	Recommended Intake	Scoring Method
Vegetables	4 serves/day	Score = (actual/4) × 10
Fruit	2 serves/day	Score = (actual/2) × 10
Grains	6 serves/day	Score = (actual/6) × 10
Protein	2 serves/day	Score = (actual/2) × 10
Dairy	3 serves/day	Score = (actual/3) × 10
Water	2.5 L/day	Score = (actual/2.5) × 10
Saturated Fat	≤10% energy	10 if ≤10%, else 0
Discretionary Foods	≤2.5 serves (600kJ/serve)	10 if ≤2.5 serves, else 0
Alcohol	≤2 standard drinks	10 if ≤2 drinks, else 0
Diet Variety	65 items max	Score = (actual/65) × 10

4. Diet Variety Scoring

Diet variety was assessed using a checklist of 65 unique food items across the five core food groups: vegetables, fruits, grains, proteins, and dairy. Participants received one point for each unique food item consumed over the 4-day record. Mixed dishes were disaggregated to identify individual ingredients. A maximum of 65 points was possible, with the score proportionally converted to a 10-point scale for inclusion in the DGI (Appendix 13).

Appendix 12: Dietary guideline index Component Food List and Serving Sizes

Note: One serve of discretionary food is equivalent to approximately 600kJ, as per the Eat for Health guidelines.

Component	Food Items Included	Standard Serve (g/ml)	Reference Used
Alcohol	Beer (full strength)	375ml	Australian Guidelines
	Beer (light)	375ml	Australian Guidelines
	Red wine	100ml	Australian Guidelines
	Spirits (e.g., vodka, gin)	30ml	Australian Guidelines
	White wine	100ml	Australian Guidelines
Dairy	Cheddar cheese	40g	MOH 2006
	Cottage cheese	120g	MOH 2006
	Cow's milk	250ml	MOH 2006
	Cream cheese	120g	MOH 2006
	Custard	150g	MOH 2006
	Dips made with yoghurt or cheese base	100g	MOH 2006
	Greek yoghurt	200g	MOH 2006
	Lactose-free milk	250ml	MOH 2006
	Soft cheese (e.g., brie, camembert)	40g	MOH 2006
	Soy milk (with calcium)	250ml	MOH 2006
	Yoghurt	200g	MOH 2006
Discretionary	Cake	40g	Eat for Health
	Chips/crisps	30g	Eat for Health
	Chocolate	25g	Eat for Health
	Corn chips	30g	Eat for Health
	Crisps (potato chips)	30g	Eat for Health
	Flavoured milk (high sugar)	300ml	Eat for Health
	Fried fish (battered or crumbed)	150g	Eat for Health
	Hot chips (fried potato)	100g	Eat for Health
	Ice blocks / frozen confections	1 item (~100g)	Eat for Health
	Ice cream	50g	Eat for Health
	Lollies	25g	Eat for Health
	Muffins	40g	Eat for Health
	Pastries (e.g., sausage rolls, meat pies)	120g	Eat for Health
	Pizza (takeaway style)	200g	Eat for Health
	Processed meats (salami, sausages)	50g	Eat for Health
	Sugar (white, brown)	15g	Eat for Health

	Sugar-sweetened beverages	375ml	Eat for Health
	Sweet biscuits	30g	Eat for Health
	Sweetened condensed milk	30g	Eat for Health
	Takeaway burgers	1 item (~200g)	Eat for Health
Fruit	Apple	150g	MOH 2006
	Banana	150g	MOH 2006
	Berries (strawberries, blueberries)	150g	MOH 2006
	Canned fruit in juice	150g	MOH 2006
	Dried fruit (e.g., apricots, dates)	30g	MOH 2006
	Fruit juice (100% juice, no added sugar)	125ml	MOH 2006
	Grapes	150g	MOH 2006
	Kiwi fruit	150g	MOH 2006
	Mango	150g	MOH 2006
	Melon	150g	MOH 2006
	Orange	150g	MOH 2006
	Pear	150g	MOH 2006
	Pineapple	150g	MOH 2006
Grains	Barley (cooked)	120g	MOH 2006
	Breakfast cereal (cornflakes, weetbix)	30g	MOH 2006
	Cooked brown rice	120g	MOH 2006
	Cooked pasta	120g	MOH 2006
	Cooked white rice	120g	MOH 2006
	Couscous (cooked)	120g	MOH 2006
	Quinoa (cooked)	120g	MOH 2006
	Rolled oats (dry)	30g	MOH 2006
	White bread (1 slice)	40g	MOH 2006
	Wholegrain bread (1 slice)	40g	MOH 2006
	Wholemeal pasta	120g	MOH 2006
Protein	Baked beans	150g	MOH 2006
	Canned fish (e.g., tuna, salmon in springwater)	100g	MOH 2006
	Chicken	80g	MOH 2006
	Chickpeas	150g	MOH 2006
	Eggs	2 eggs (~120g)	MOH 2006
	Fish (salmon, tuna, white fish)	100g	MOH 2006
	Hummus	100g	MOH 2006
	Kidney beans	150g	MOH 2006
	Lean beef	65g	MOH 2006
	Lean lamb	65g	MOH 2006
	Lentils	150g	MOH 2006

	Nuts (almonds, walnuts, cashews)	30g	MOH 2006
	Peanut butter	30g	MOH 2006
	Pork	65g	MOH 2006
	Seeds (pumpkin, sunflower, chia)	30g	MOH 2006
	Tempeh	170g	MOH 2006
	Tofu	170g	MOH 2006
	Turkey	80g	MOH 2006
Vegetables	Brussels sprouts	75g	MOH 2006
	Canned tomatoes	75g	MOH 2006
	Capsicum	75g	MOH 2006
	Coleslaw	75g	MOH 2006
	Cucumber	75g	MOH 2006
	Green beans	75g	MOH 2006
	Kumara (sweet potato)	75g	MOH 2006
	Lettuce	75g	MOH 2006
	Mixed salad vegetables	75g	MOH 2006
	Peas	75g	MOH 2006
	Potato (boiled, skin on)	75g	MOH 2006
	Pumpkin	75g	MOH 2006
	Tomato	75g	MOH 2006
	Tomato (fresh)	75g	MOH 2006
Water	Black tea	250ml	MOH 2006
	Green tea	250ml	MOH 2006
	Herbal tea	250ml	MOH 2006
	Instant coffee (black)	250ml	MOH 2006
	Plain water	250ml	MOH 2006

Appendix 13: Dietary guideline index Diet Variety Component Scoring

The Diet Variety Score was adapted from the Australian Recommended Food Score (ARFS) developed by Ashton et al. (2017) to assess dietary diversity across core food groups. This score is based on the presence or absence of specific food items across the diet. Variety was calculated for each participant using dietary data collected from a 4-day weighed food record. Each unique food item consumed at least once over the 4 days was awarded a point within its respective food group.

Foods were categorised into one of five core food groups: vegetables, fruit, grains, protein foods, and dairy (including alternatives). A predefined list of common foods for each group was created, and one point was awarded per unique food item consumed, regardless of portion size. Mixed dishes were distributed into individual ingredients, and variety points were assigned accordingly. For example, a stir-fry containing broccoli, carrot, and chicken would earn one point for broccoli and carrot in the vegetable group and one point for chicken in the protein group.

A maximum score was set for each group, based on the total number of eligible items included in the predefined list. The total maximum diet variety score was 65. This total was then proportionally converted to a 0–10 scale for inclusion in the Dietary guideline index (DQI), using the formula:

DQI Diet Variety Component Score = (Diet Variety Score ÷ 65) × 10

Food Group	Examples of Items Included	Scoring Explanation	Maximum Score
Vegetables	Potato, kumara, pumpkin, cauliflower, green beans, spinach, Brussels sprouts, peas, broccoli, carrots, zucchini, eggplant, capsicum, corn, mushrooms, tomatoes, lettuce, celery, cucumber	1 point per unique vegetable item consumed over 4 days	20
Fruit	Canned fruit, dried fruit, apple, pear, banana, citrus fruits (orange, mandarin,	1 point per unique fruit item consumed over 4 days	12

	grapefruit), stone fruits (peach, nectarine, plum, apricot), mango, pineapple, grapes, berries		
Protein	Beef, lamb, pork, chicken, venison, duck, fresh fish, canned tuna/salmon/sardines, other seafood (e.g. mussels, prawns), nuts, nut butter, eggs, tofu, tempeh, edamame, legumes (beans, lentils, chickpeas)	1 point per unique protein food item consumed over 4 days	13
Grains	Muesli, porridge, cereal, oats, bread (white, multigrain, wholemeal), pita bread, toast, English muffin, bagel, crumpet, rice, other grains (e.g., couscous, bulgur), noodles, pasta, tortillas, wraps, crackers	1 point per unique grain food item consumed over 4 days; +1 bonus point if wholemeal or multigrain products included	12
Dairy	Milk (cow's, soy, lactose-free), yoghurt, Greek yoghurt, cheese (hard and soft), cream, coconut cream, frozen yoghurt, cheese spread, cottage cheese, ricotta, custard, ice cream	1 point per unique dairy or alternative item consumed over 4 days	8
Total Score			65