An investigation of dietary iron intake and literacy among 11-14-year-old females in New Zealand.

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Abstract

Background: Iron deficiency (ID) is the most prevalent micronutrient deficiency globally and is a common diagnosis in adolescent females. Physiological, dietary, and behavioural challenges all impact iron status in individuals. Causal factors of ID for adolescent females include low dietary iron intake, iron bioavailability, increased iron requirements and excessive iron losses. Up-to-date information on dietary iron intake and literacy in adolescent females is not available for health professionals in New Zealand.

Aim: To determine dietary iron literacy and associations with dietary intakes of iron-rich foods in young adolescent females in New Zealand.

Methods: Females (n=286) aged 11-14 years from all-girls schools around New Zealand were recruited to complete an anonymous online questionnaire. The questionnaire comprised of demographic questions, an iron literacy questionnaire adapted from previous research and a validated iron food frequency questionnaire.

Results: The results suggest a moderate level of iron literacy in most participants (66.8%, n = 191), with 21.7% (n = 62) demonstrating low and 11.5% (n = 33) demonstrating high dietary iron literacy. Vegetarian, pescatarian, and vegan participants had higher iron knowledge scores than those not on a particular diet ($P = 0.001$). Age had a weak relationship with iron knowledge score category ($\chi^2 = 6.27$, $P = 0.044$). Significant differences were found between ethnic groups and food group consumption frequency. Seafood and legumes, eggs, nuts and seeds were eaten more frequently among Asian participants, while iron-fortified foods were eaten more frequently among Māori participants. Participants from higher decile schools were found to consume red meat ($P = 0.009$), seafood ($P = 0.024$) and fruit ($P = 0.021$) more frequently than those from moderate decile schools. There was no relationship between dietary iron literacy score and intake of iron-rich foods.

Conclusion: Our results demonstrate that iron literacy is low-moderate among adolescent females within New Zealand and is not associated with current dietary iron intake behaviours. Recommendations for future studies include objective measures of iron status and intake via biochemical data and food recalls and their association with iron literacy. Educational nutrition interventions may also be considered to support iron intake behaviours.

Keywords: Iron, iron intake, knowledge, literacy, dietary iron, dietary patterns, adolescents.

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List of Abbreviations

Abbreviation	Term
DcytB	Divalent Cytochrome B
df	Degrees of Freedom
DMT1	Divalent Metal Transporter 1
EAR	Estimated Average Requirement
EPC	Erythrocyte Protoporphyrin Concentration
FFQ	Food Frequency Questionnaire
Hb	Haemoglobin
HCT	Haematocrit
ID	Iron Deficiency
IDA	Iron Deficiency Anaemia
IMC	Irregular Menstrual Cycle
MCH	Mean Corpuscular Haemoglobin
MCV	Mean Corpuscular Volume
Mb	Myoglobin
NPD	No Particular Diet
NRVs	Nutrient Reference Values
NZ	New Zealand
OTC	Over The Counter
RDA	Recommended Dietary Allowance
RDI	Recommended Daily Intake
RNI	Recommended Nutrient Intake
SF	Serum Ferritin
sTfR	Serum Transferrin Receptor
sTfS	Serum Transferrin Saturation
TPB	Theory of Planned Behaviour

Chapter 1: Purpose

Introduction

Iron deficiency (ID) is one of the most common and widespread micronutrient deficiencies that affects around 9-16% of adolescent females (Sekhar et al., 2015). Iron is an essential nutrient that facilitates transport, storage, and utilisation of oxygen to the body's tissues and has multiple roles in growth and cellular functioning (Ministry of Health, 2014). Insufficient iron levels have a negative impact on everyday health and function, causing fatigue, weakness, difficulty concentrating, headaches, and impaired immunity (Coad and Pedley, 2014). Furthermore, when iron levels are severely low, they can lead to hospitalisation. As such, the increasing prevalence of ID and iron deficiency anaemia (IDA) has resulted in increased hospitalisation costs in New Zealand which reportedly doubled over ten years from $3,224,367 in 2008 to $6,736,508 in 2018 (Ministry of Health, 2018).

The diagnosis of ID results from being in a negative iron balance. This occurs when iron losses exceed one's dietary iron intake and absorption rates (Bermejo and García-López, 2009). The 2008/09 New Zealand Adult Nutrition Survey reported that one-third of adolescent females were not meeting their daily iron requirements of 8-15mg/day, which may contribute to their negative iron balance (University of Otago and Ministry of Health, 2011). Behavioural factors and dietary patterns, such as plant-based diets, low energy intake, or poor food selection patterns, may also contribute to low iron intake in adolescent females (Saunders et al., 2013). In addition, low iron bioavailability in the diet may influence dietary iron absorption rates. Factors that may exacerbate a negative iron balance through increased iron use or losses include the onset of menarche, increased exercise, and increased iron requirements due to rapid growth and development (Low et al., 2016). Menstruating females are more likely to have an exaggerated negative iron balance than non-menstruating females, especially if their iron intake remains unchanged or low (Ministry of Health, 2003).

Results from the last National Children's Nutrition Survey, published in 2003, showed that the median daily intake of iron for females aged 11-14 years was

9.9mg/day, which is above the recommended daily intake (RDI) of 8mg/day for females aged 9-13 years (Ministry of Health, 2014). However, the RDI increases significantly to 15mg/day for females aged 14-18 years due to the commencement of menstruation. Due to the National Children's Nutrition Survey being over two decades old, it can be assumed that the statistics surrounding iron intake for this age group are likely to be outdated and non-representative of current intakes. Additionally, the knowledge level of iron-rich foods and the effect of ID is not widely reported for New Zealand adolescents. Results from a Beef + Lamb NZ iron questionnaire for World Iron Awareness Week found that the average score of New Zealand females was 56%, suggesting low to moderate iron literacy levels (Beef + Lamb New Zealand, 2021).

Young adolescent females are recognised as a high-risk group for ID and IDA diagnosis. Therefore, there has been interest in increasing the number of studies focused on dietary iron consumption from a preventative perspective against ID and IDA in females below 15 years of age. As a result, research has focused on risk factors of ID and IDA, such as inadequate intake and knowledge in this population. However, little is still known about the level of iron literacy in this population group and how their current knowledge could contribute to their dietary iron intake and risk of ID.

Aims, objectives & hypotheses

This thesis aimed to determine dietary iron literacy and associations with dietary intakes of iron-rich foods in intermediate and secondary school females aged 11-14 years in New Zealand.

The objectives of the study were:

- To assess current habitual intakes of iron-rich foods in young adolescent females (11-14 years) through the partial administration of a validated iron food-frequency questionnaire (FFQ).
- To assess knowledge about dietary iron in young adolescent females through administering an iron literacy questionnaire.
- To determine the association between iron literacy and dietary intakes of iron-rich foods in young adolescent females.

It was hypothesised that:

1) Female students with high iron literacy scores will have higher estimated dietary intakes of iron-rich foods than those with lower iron literacy scores.
2) Iron literacy scores among female students will be low overall.

Structure of the thesis

Chapter one describes the purpose of the presented study. It introduces the topic and highlights its importance in literature. The aims, objectives and hypotheses of the study are also described. Chapter two is a literature review of iron research and knowledge in adolescent females nationally and internationally. Chapter three is a manuscript prepared for publication, in which all aspects of the current research study are described, and findings are presented and discussed. Chapter four presents the thesis conclusions, outlines the current study's strengths and limitations, and provides recommendations to consider for future studies on iron status in adolescent females.

Researcher contributions

Table 1 - Summary of contributions to the study by researchers

Name	**Role**	**Contribution**
Renee Jansen	Primary researcher and author. MSc student in Nutrition & Dietetics.	Study design, ethics submission, data collection, data analysis, manuscript write-up, and dissemination of results.
Dr Claire Badenhorst	Primary supervisor. School of Sport, Exercise and Nutrition.	Assisted with study design, ethics submission, data review, review of manuscript.
Prof Pamela von Hurst	Secondary supervisor. School of Sport, Exercise and Nutrition.	Assisted with study design, ethics submission, data review, review of manuscript.
Jerushah Keightley	Assisting researcher. MSc student in Nutrition & Dietetics.	Assisted with study design and ethics submission.
Dr Hajar Mazahery	Data consultant School of Sport, Exercise and Nutrition.	Assisted with data analysis.

Chapter 2: Literature Review

Introduction

The purpose of this literature review is to explore existing research related to iron function, iron requirements, recommended intakes, consequences of low iron status, and challenges in achieving an adequate iron status. This chapter discusses qualitative and quantitative studies focusing on iron intake, iron literacy levels and associations between the two in female adolescents. A literature search was completed between October 2021 - September 2022. The search criteria used for the literature review can be found in Figure 1. Article databases used during the search included Massey Discover, Google Scholar, PubMed, and Web of Science.

Search Criteria:

"Iron deficiency anaemia" OR "iron deficiency*" OR anaemia OR IDA OR ID

"Iron intake" OR "intake of iron" OR "iron status"

"iron knowledge" OR "iron literacy" OR "nutrition knowledge"

Female OR adolescent OR girl OR teenager

New Zealand OR Australia

Article databases: Massey Discover, Google Scholar, PubMed, Web of Science.

Research dates: October 2021 – September 2022

Figure 1 *- List of keywords used in the literature search*

Role of iron in the body

Iron is a mineral that is known for being a component of haemoglobin, myoglobin, cytochromes, and enzymes (Ministry of Health, 2014). Therefore, iron is considered essential for the proper functioning of the human body, especially given that haemoglobin enables the transfer of oxygen from the lungs to the body's tissues, and myoglobin facilitates oxygen storage and diffusion within cells (Abbaspour et al., 2014). In addition, iron is also required for its critical role in energy production, cognitive function, maintaining good immune function, and supporting growth (National Health and Medical Research Council et al., 2006).

Dietary iron recommendations

Recommended daily intake of iron

New Zealand uses the term ‘Nutrient Reference Values’ (NRVs), in which ‘Recommended Daily Intakes’ (RDIs) and ‘Estimated Average Requirements’ (EARs) are set. RDIs represent the “average daily intake level of a particular nutrient that is sufficient to meet the requirements of nearly all (97-98%) healthy individuals of a particular sex and life stage”. Alternatively, EARs represent the “average daily intake level of a particular nutrient that is sufficient to meet the requirements of 50% of healthy individuals of a particular sex and life stage” (National Health and Medical Research Council et al., 2006). RDIs are the most commonly used NRV and ensure the appropriate consumption of nutrients for various population groups.

Recommendations for dietary iron intake vary depending on sex and age group. In the NRVs, young adolescent female age groups are split into 9–13-year-olds and 14–18-year-olds. For 9–13-year-olds, the EAR for iron is 6mg/day, while the RDI is 8mg/day. In comparison, for 14-18-year-olds, the EAR is 8mg/day, and the RDI is 15mg/day. When setting these NRVs, it was assumed that females $<$14 years old did not menstruate, while those $\geq$14 years old had experienced menarche; hence the RDI is almost doubled to account for iron losses due to regular menstrual bleeding (National Health and Medical Research Council et al., 2006). Current research, however, suggests that the age of menarche occurs around 12 years old (Martinez, 2020). This is supported by the ‘NZ Food NZ Children’ 2002 report, which showed that 42% of females experienced the onset of menstruation at 12 years old (Ministry of Health, 2003). Therefore, it could be assumed that there is a significant number of females in the 9-13-year-old age bracket who have higher iron requirements than assumed in New Zealand nutrition guidelines. Subsequently, the number of menstruating females not meeting their iron requirements may be underreported in the literature.

Food sources of iron

Iron is found in various foods, both animal- and plant-based. Iron is especially prevalent in animal products due to its blood content. Commonly known iron-rich animal foods which provide both haem and non-haem iron include red meat, seafood, offal (liver and kidney), and poultry (Young et al., 2018). Commonly known iron-rich plant-based sources which provide non-haem iron include tofu, legumes, nuts and seeds, dried fruit, and fortified breakfast cereals (Samaniego-Vaesken et al., 2017).

In New Zealand, however, these iron-rich foods are not always the biggest contributors of iron to the diet of adolescents. The Ministry of Health identified in 2003 that for females aged 11-14 years old, the key sources of iron in the diet were breakfast cereals (13%), bread (12%), potatoes, kumara and taro (7%), and beef and veal (6%) (Ministry of Health, 2003). Although bread was listed as a key source of iron, it should be noted that ‘bread’ comprised sandwiches including beef and chicken in this dataset, which may be the likely reason for it being listed as a key source of iron in the diet. Results reported overseas in Belgium however, have aligned, with wholegrain bread commonly being the most significant contributor of iron to young adolescent diets when categorised exclusively (meat sandwiches were not included) (Pynaert et al., 2005). Although these foods may have lower iron content per gram (0.007mg - 0.15mg), the total iron intake may be high due to the overall high quantity of the food eaten (The New Zealand Institute for Plant & Food Research Limited and Ministry of Health, 2021).

Consequences of low iron

Adolescent females who receive inadequate amounts of iron required for growth and normal physiological functions are at risk of experiencing health complications (Kumar et al., 2022). If individuals are in a negative iron balance, they may eventually deplete their iron stores to a point where they are considered iron deficient or diagnosed with IDA (Bermejo and García-López, 2009). Both ID and IDA are known to have many adverse health consequences, not only for the individual but also for the healthcare system.

Iron deficiency is a progressive condition in which particular stages are reached when specific iron parameters are met. Specific iron parameters include decreases in serum ferritin (SF), haemoglobin (Hb), haematocrit (HCT), and mean corpuscular volume (MCV), and increases in serum transferrin receptor (sTfR) and erythrocyte protoporphyrin concentration (EPC). Stage 1 of ID is where an individual is considered to have 'low iron stores', as indicated by a low SF value and a decrease in iron-binding capacity. The second stage is called 'early iron deficiency', where along with the previously noted changes in SF and iron-binding capacity, serum transferrin saturation (sTfS) is decreased, while EPC and sTfR are increased (Ministry of Health, 2014). The increased expression of sTfR by cells occurs due to increased iron need (Coad and Pedley, 2014). In the second stage of ID, the final stage of haem synthesis may not be completed, resulting in accumulation and, therefore, an increase in EPC (Ajioka et al., 2006). An ongoing negative iron balance, which remains uncorrected, contributes to the deterioration of iron stores from stages 1 and 2 and is likely to facilitate the progression to stage 3. In Stage 3, 'IDA', Hb, HCT, mean corpuscular haemoglobin (MCH) and MCV are low (Ministry of Health, 2014).

There is a paucity in evidence discussing symptoms which arise in individuals who present with non-anaemic ID. Available literature has shown that the timeline of the adverse effects arising between non-anaemic ID and IDA is difficult to gauge (Soppi, 2018, Al-Naseem et al., 2021). When individuals present with IDA, they are likely to show common symptoms, some of which may begin when an individual is at an earlier stage of ID. These symptoms include pallor, shortness of breath, irritability, and fatigue (Coad and Pedley, 2014). Individuals may also develop multiple complications which affect various organs. Some complications include reduced cognitive ability related to attention, reasoning, memory, and comprehension (Samson et al., 2022). Reduced cognitive ability is especially crucial for adolescent females as their learning in school can be impacted significantly. Aquilani et al. (2011) found a positive association between iron status and school performance, with students who had higher iron intakes receiving higher test scores in mathematics and the Italian language. Additional complications of IDA include decreased physical capacity due to reduced oxygen consumption, and impaired immunity, due to a reduced response to infection (Abbaspour et al., 2014, Soyano and Gómez, 1999, Coad and Pedley, 2014). Other long-term complications may include poorer cardiovascular health and bone health, with IDA diagnosis related to an increased risk of left-ventricular dysfunction and osteoporosis in later adulthood (Thane et al., 2003, Hegde et al., 2006). These consequences of low iron status are prevalent in individuals who have trouble maintaining iron balance for various reasons, whether it be failing to achieve an adequate iron intake or failing to ensure that iron losses are accounted for with dietary intake.

Challenges for adolescent females in achieving an adequate iron status

The key challenges for adolescent females in achieving an adequate iron status can be identified as physiological, dietary, and behavioural. These factors can either individually or cumulatively result in a negative iron balance, increasing the risk of developing ID.

Physiological

Adolescence is defined by the World Health Organisation (WHO) as the period between childhood and adulthood, spanning from 10 to 19 years of age (World Health Organization, 2022). This period is a state of significant development physically, psychologically, and behaviourally (Rani and Rawat, 2020). Infancy is the significant physical growth period throughout one's life; however, adolescence is a longer duration of significant growth. Therefore, nutritional requirements during adolescence should be just as high, if not higher, than every other period of life (Khoirunnisa et al., 2021). Requirements for iron increase for adolescent females, along with other nutrients such as vitamin B12, calcium, and zinc, due to the pubertal growth spurt between 10-15 years of age in most females (Gibson et al., 2002, Peddie et al., 2020).

The primary physiological challenges affecting adolescent females' iron status are increased iron requirements and iron losses. Increased iron requirements are due to increased growth and development during adolescence, while increased iron losses occur most commonly due to exercise and the commencement of menstruation (Bruinvels et al., 2017). The onset of menarche typically occurs between 11-15 years, with more up-to-date research suggesting that the average age of menarche in recent generations is ~12 years of age (Martinez, 2020). The iron loss that results from blood loss is estimated to average approximately 1mg of iron per menstrual bleed (Coad and Pedley, 2014). These losses are further exacerbated (five to six times) in those with heavy menstrual bleeding (Napolitano et al., 2014). Gynaecological age is defined as “age in years at conception minus age at menarche” (Kaplanoglu et al., 2015). Gynaecological age is said to be negatively associated with an irregular menstrual cycle (IMC), with IMC rates decreasing as gynaecological age increases (van Hooff et al., 1998). Based on the average age of menarche, females aged 11-14 are likely to have a gynaecological age <2 years and therefore are more likely to experience IMC and high variability in menstrual blood loss, which may contribute to their increased risk of ID.

Furthermore, regular moderate-intense physical activity may contribute to iron loss in adolescents through exercise-induced mechanisms for iron loss and increases in inflammatory cytokines and the iron regulatory hormone, hepcidin (Peeling et al., 2008, Gibson et al., 2002, Peeling et al., 2014). The increased hepcidin expression after exercise is thought to result in the degradation of iron transporters, resulting in reduced duodenal iron absorption (Kong et al., 2014). Cumulatively, these exercise-associated risk factors may exaggerate a negative iron balance by increasing the total amount of iron lost from the body during exercise. They may also contribute to low iron absorption and recycling post-exercise. Without education on iron requirements or increased dietary iron intake to compensate for these losses, young females may be at a high risk of developing ID.

Dietary

Dietary challenges for adolescents include the type of iron consumed and the influence of dietary inhibitors and enhancers which both influence the efficacy of iron absorption for each individual (Nielsen et al., 2013).

Two forms of dietary iron exist – haem iron and non-haem iron. Haem iron is derived from animal sources, specifically from Hb and myoglobin (Mb) in animal meat in blood and muscle (Ems et al., 2022). Non-haem iron is also derived from animal meat, however, it is the only type of iron derived from plant sources, with a few exceptions, such as eggs and dairy, which are animal by-products (Mantadakis et al., 2020). Despite some foods having a higher overall iron content than others, it has been found that iron bioavailability is more important in determining how much iron is absorbed from foods (Beck et al., 2013). Haem iron is said to have approximately a 15-35% absorption rate, while non-haem iron is said only to have a 5-10% absorption rate (Mantadakis et al., 2020, Ministry of Health, 2014, Zimmermann and Hurrell, 2007, Abbaspour et al., 2014). Most individuals, who follow an omnivorous diet, will consume both haem and non-haem iron sources; however, for those who follow a vegetarian or vegan diet, non-haem iron sources will be the primary source of iron that is consumed. Therefore, these individuals will only achieve a maximum iron absorption rate of approximately 10% from a food source of iron alone.

Haem iron exists in its ferrous form, Fe^{2+}, which is soluble and does not need to be converted, therefore increasing its bioavailability. It can be absorbed into the enterocyte of the cell through haem carrier protein 1 (HCP1) (Coad and Pedley, 2014). In comparison, non-haem iron occurs in its ferric form, Fe^{3+}, which must be converted to Fe^{2+} to enter the enterocyte from the gut lumen. Non-haem iron is converted by duodenal cytochrome B (DcytB), facilitating its transport through the gut wall into the enterocyte by the proton-driven divalent metal transporter 1 (DMT1). Not only does non-haem iron require conversion before entering the cell, but it also competes with other divalent metal ions such as zinc, manganese, and copper, a result of DMT1 being the site for the transport of these ions too (Coad and Pedley, 2014). Another critical component in regulating iron status is the role of the iron regulatory hormone, hepcidin (Sangkhae and Nemeth, 2017). When iron status in the body is high, hepcidin is released from the liver. It binds to ferroportin, the only known cellular iron export channel, internalising and degrading ferroportin channels and subsequently inhibiting the release of iron from enterocytes, macrophages, and hepatocytes (Nemeth and Ganz, 2009). Therefore, when hepcidin is high, it may reduce both iron absorption and recycling. When iron status in the body is low, i.e. when an individual is presenting with ID, hepcidin secretion/production from the liver is suppressed. At this time, DMT1 and Dcyt B are also upregulated, allowing for increased iron absorption rate and replenishment of iron stores (Ems et al., 2022, Coad and Pedley, 2014, Nemeth and Ganz, 2009).

Despite the lower bioavailability of non-haem iron compared to haem iron on an individual level, many additional dietary components in food can help enhance or inhibit iron absorption further (Coad and Pedley, 2014). It is essential to note that nearly all individuals consume various foods in combination with each other, so there is an opportunity for alternative foods that are known inhibitors and enhancers of iron absorption to affect iron bioavailability in a given meal (Beck et al., 2013). Commonly recognised non-haem iron absorption enhancers are ascorbic acid (vitamin C) and meat, poultry, and fish factor (MFP factor) (Hurrell and Egli, 2010). Ascorbic acid works to enhance iron absorption through its ability to stimulate gastric acid production and reduce ferric to ferrous iron, enabling it to be absorbed into the enterocyte (Nielsen et al., 2013). Additionally, ascorbic acid is thought to have a stronger effect over potential inhibitors such as phytate and polyphenols, as the ferrous form (Fe^{2+}) is less likely to form complexes with these components (Nielsen et al., 2013, Hurrell and Egli, 2010). MFP factor is a peptide in animal tissues, such as meat, poultry, and fish, which enhances non-haem iron absorption when eaten simultaneously. However, its actions have not been widely researched (Coad and Pedley, 2014).

Food components that have inhibitory effects on iron absorption include phytates, polyphenols, calcium, oxalates, and tannins (Low et al., 2016). The most widely known inhibitor of iron absorption is dietary phytate (Hurrell and Egli, 2010). Plant-based diets are typically high in phytates due to the significant consumption of legumes and cereals (Bhatnagar and Padilla-Zakour, 2021). Phytates chelate iron and lower its solubility, restricting non-haem iron from being converted and absorbed into enterocytes (Low et al., 2016). Polyphenols act similarly on non-haem iron through iron chelation and are present in legumes, tea, coffee, cereals and some fruit and vegetables (Gaffney et al., 2004). Calcium is an inhibitor that is dissimilar to phytates and polyphenols as it decreases the absorption of both non-haem iron and haem iron (Ems et al., 2022). The mechanism is still debated; however, it is thought to be through modulation or expression of the proteins involved in iron absorption - DMT1 and HCP1 (Gaitán et al., 2011). The inhibitory effect of calcium is said to be dose-dependent, with higher amounts having a more significant impact on iron absorption; however, the amount of calcium required before adverse effects on iron absorption occurs is not yet clear. Gaitán et al. (2011) found that calcium chloride doses <800mg did not affect the absorption of 5mg of non-haem iron, whereas calcium doses >1000mg reduced non-haem iron absorption by 49.6%. In comparison, multiple other studies, such as Hallberg et al. (1991), found that 40-300mg of calcium chloride had an inhibitory effect in a dose-dependent manner on the absorption of 5mg non-haem iron. However, this study used a single meal to determine the effect on iron absorption; as such, the effects of other components have not been separated from those of calcium. Therefore, the amount of calcium needed to inhibit iron absorption is still unknown.

Behavioural

Key behavioural challenges for adolescent females in achieving a healthy iron status revolve around significant changes in their dietary patterns in recent years. In general, the diet quality of adolescents is usually relatively poor, as this is a stage in life where children have easy access to various food outlets such as the school canteen, fast food shops, and dairies (Brien et al., 2022). Poor food selection is typical during intermediate and college years, in which overconsumption of ultra-processed, energy-dense and nutrient-poor foods often occurs due to these outlets becoming more prominent around the school environment (Skolmowska and Głąbska, 2019). New Zealand is an obesogenic environment, with increasing numbers of fast-food outlets in the past ten years. A study by Eyles et al. (2018) in New Zealand showed that between 2012 and 2016, fast-food products' serving size and energy density increased significantly. Although sodium concentration has been lowered in products, the increased serving size has mainly offset this alteration (Eyles et al., 2018).

Iron content in ultra-processed foods is minimal; therefore, it can be assumed that with increased consumption among young adolescents, nutrient-rich foods are less likely to be eaten throughout the day (Sallehuddin et al., 2021). A study by Martini et al. (2021) has illustrated this point, showing that ultra-processed food consumption was negatively correlated with the consumption of unprocessed foods. Further studies in Canada and Japan have demonstrated the inverse relationship between ultra-processed foods and iron intake (Martini et al., 2021). Ultimately, these poor food choices can lead to young adolescents being at risk of not only poor iron status but poor overall health if diet quality continues to be low (Elizabeth et al., 2020). Iron-fortified foods are common in some countries, such as the United States. As a result, iron intake from these ultra-processed foods may not be low; however, in New Zealand, iron-fortified foods are limited. Available iron-fortified foods in New Zealand include baby food, breakfast cereals, and over-the-counter (OTC) supplement powders such as Vitaplan or Complan (Thomson, 2005). For young adolescent females in New Zealand in 2002, breakfast cereals contributed approximately 15% to their total iron intake, suggesting that the fortification of cereals is vital in helping to maintain an adequate iron status for this population group (Ministry of Health, 2003). Despite this, no other iron-fortified foods in New Zealand are eaten frequently or in large enough amounts to contribute significantly to iron status. International studies exploring the effects of consumption of iron-fortified foods found that iron status, specifically Hb level, increased following iron fortification of foods such as flour, breakfast cereals, noodles, salt, and sauces (Gera et al., 2012, Sadighi et al., 2019, Thi Le et al., 2006). It should, however, be noted that the fortification level of such products, especially breakfast cereals, can vary significantly and therefore have varying effects on iron status (O'Hara et al., 2004). Additionally, the iron added as fortification, to breakfast cereals for example, is of low bioavailability when compared with other iron sources such as red meat. Therefore, iron-fortified foods may not be as influential on iron status in the population as assumed (Aslam et al., 2018).

Another explanation for changes in dietary patterns in adolescent females is the influence of social media and the pressure for females to be the “perfect” body size/weight (Heather et al., 2021, Helfert and Warschburger, 2013). Such expectations around body size have resulted in many adolescent females decreasing their energy intake, restricting foods from their diet (e.g. carbohydrate-rich foods), or overexercising (Peddie et al., 2020). Dieting is known to be more common among females than males, with a lifetime prevalence for females of 2.9% for developing orthorexia or other eating disorders such as anorexia nervosa, binge eating disorder or bulimia nervosa in New Zealand (Browne et al., 2006). Disordered eating often starts in early adolescence, with research suggesting a 5.5 times greater risk of developing a diagnosable eating disorder in young females (Browne et al., 2006). With these significant food restrictions, it is likely that individuals will not be consuming enough energy, nor will they be getting an adequate intake of micronutrients such as iron. This is supported by findings showing that low total energy intake because of food restriction is negatively associated with iron levels (Rangan et al., 1997).

Furthermore, restricting iron-rich foods that either have a bad perception (e.g. from vegetarians or vegans) or are higher in calories, such as red meat, may put these females at higher risk of poor iron status (Skolmowska and Głąbska, 2019, Young et al., 2018, Rangan et al., 1997). Despite evidence showing the association between low energy intake and poor iron status, some studies, such as Mulvihill et al. (2002), have found a lack of association. However, further analysis of the study showed that a significant proportion of females across all levels of dietary restraint had low iron intake and poor iron status overall, so no significant difference was apparent. One noteworthy point from the study was that females in the high dietary restriction group tended to eat less meat, which supports the general dietary pattern that high-iron foods are often restricted in females who restrict their overall energy intake (Mulvihill et al., 2002).

The number of individuals adopting a plant-based diet has increased over the last decade (Peddie et al., 2020). It is estimated that worldwide, 4-30% of the population follow a vegetarian diet, or a similar alternative, while 0-2% follow a stricter, vegan diet, excluding all animal and animal-derived products (Paslakis et al., 2020). Well-planned vegetarian diets provide crucial nutrients such as dietary fibre, folate, vitamin C, vitamin E, and magnesium. On the other hand, they can be low in iron, zinc, calcium, vitamin D, vitamin B12 and protein if they are not appropriately planned (Peddie et al., 2020). It is well known that haem iron sources from animals are a more bioavailable source of iron than non-haem iron. It can therefore be assumed that because vegetarians and vegans do not consume meat, they will be getting less iron in their diet and may be at an increased risk of inadequate iron status (Ball and Bartlett, 1999). However, multiple studies, such as one by Gallego-Narbón et al. (2019), have shown that following plant-based diets does not necessarily imply low iron intake if they are well-planned. In a study by Ball and Bartlett (1999), results showed no significant difference in iron intake between vegetarians and omnivores; however, both groups consumed lower amounts of iron than the RDI for females. If iron-rich plant foods are accompanied by an appropriate balance of iron absorption enhancers versus inhibitors, individuals can be capable of achieving adequate iron status (Gallego-Narbón et al., 2019). Among the iron sources available to vegetarians and vegans, there has been a significant increase in meat alternatives in recent years. Imitation meats are an example of foods that can assist plant-based eaters in meeting their RDI for iron. These foods contain approximately 4-6mg of iron per 100g and may contribute significantly to one's daily requirements (Beyond Meat, 2022). The available research shows that plant-based diets can be beneficial when undertaken with a sound foundational knowledge of nutrition. These dietary patterns have been associated with a lower incidence of nutrition-related diseases such as obesity, heart disease and type 2 diabetes. When correctly planned, there are limited reasons why plant-based individuals cannot maintain sufficient iron levels in the body (Ball and Bartlett, 1999).

Iron intakes among adolescent females

Iron intakes in females have been reported more frequently for older adolescents than younger adolescents. However, the importance lies in gaining data for this younger age group as a preventative measure for ID. The earlier it is known that iron intakes are inadequate, the sooner interventions can be implemented to prevent ID. Previous studies focusing on dietary iron intake among females globally are outlined in Table 1. Widely known reports in New Zealand for nutritional intake among large population groups are the National Adult Nutrition Survey and the National Children's Nutrition Survey (University of Otago and Ministry of Health, 2011, Ministry of Health, 2003). Despite the valuable data from these reports, the last adult nutrition survey was completed in 2008/09, while the last children's nutrition survey was completed in 2002, indicating that this data is outdated and may not be representative of the current landscape in New Zealand.

The 2002 National Children's Nutrition Survey demonstrated that 5.5% of females aged 11-14 years were iron deficient, with significant ethnic differences (Ministry of Health, 2003). Participants were considered iron deficient if they had two out of three abnormal values (serum ferritin concentration (<12µg/L), red cell distribution width (>14%), and transferrin saturation (<14%)). Māori females had an ID prevalence of 11.2%, while Pasifika females had an ID prevalence of 9.6% (Ministry of Health, 2003). Results from the 2008/09 National Adults' Nutrition survey showed that in females aged 15-18 years, the median intake of iron was 9.1mg, which is 5.9mg below the RDI for this age group (University of Otago and Ministry of Health, 2011). Subsequently, 34.2% of females aged 15-18 had an inadequate iron intake, with the overall prevalence of low iron intake for all females in New Zealand more than doubling since the previous nutrition survey in 1997 (University of Otago and Ministry of Health, 2011). Another study in adolescents aged 14-18 found that 18.3% of females were iron deficient, and 11.5% were diagnosed with IDA (Schaaf et al., 2000). Again, ethnic differences appeared, with ID being 2-3 times more common in Asians, Pasifika, and Māori than in New Zealand Europeans (Schaaf et al., 2000).

The dietary pattern in females that was associated with a reduced likelihood of inadequate iron status by 41% was the "meat and vegetable" dietary pattern (Beck et al., 2013). In contrast, following a "milk and yoghurt" pattern was associated with an increased likelihood of inadequate iron status by 50% (Beck et al., 2013). A SuNDiAL project conducted in 2019/20 investigated dietary intake and nutritional status in adolescent females in New Zealand; however, results have not been published yet and therefore provide no new data on dietary iron intake in young New Zealanders (Peddie et al., 2020). The small number of age-appropriate iron studies among adolescents indicate that New Zealand data for iron status is limited. Therefore, reviewing the results from international studies is needed to gain insight into estimates of iron intake in this population.

Internationally, studies show similar patterns for low iron intakes in adolescent females. Australian data has shown that female adolescents have mean intakes of 11.2mg ± 3.8mg of iron per day, with positive associations between iron biomarkers and intake of flesh foods (Leonard et al., 2014). Ball and Bartlett (1999) and Leonard et al. (2014) found no significant difference between the overall iron intakes of vegetarians and omnivores. European studies based in both Poland and Britain found that not only is iron intake significantly lower in females than males, but that females aged 11-18 years had the poorest iron status overall, with low iron intakes occurring in 44% of this age group. Thane et al. (2003) found that vegetarians and non-Caucasians had poorer iron status than meat-eaters and Caucasians.

The prevalence of ID is frequently noted to be higher in individuals living in developing countries. Khoirunnisa et al. (2021) observed that 98.6% of female high school students living in Indonesia had an inadequate iron intake, while Sallehuddin et al. (2021) found that ~80% of Malaysian females did not meet the recommended nutrient intake (RNI) for iron. Additionally, a study by Wiafe et al. (2021) in Ghana reported a negative association between IDA and the participants' chicken and fish intake. This supports findings from Beck et al. (2013), in which intake of meat (a source of haem iron) was associated with better iron status.

Overall, various studies from within and external to New Zealand support the premise that iron intake is low amongst adolescent females worldwide. Currently, iron intake by this population of females appears to be about 60-80% of nutritional iron recommendations, with vegetarians and Asian, Pasifika, and Māori ethnicities often having poorer iron status than meat-eaters and Caucasians. In reference to food patterns, meat intake tends to be positively associated with better iron status. In contrast, the consumption of dairy foods may be negatively associated with iron status, however, findings are not currently consistent.

***Table 1** - Literature summary - Iron intake among females globally*

Title	Author/Year	Population Characteristics	Methods	Relevant Results	Comments On The Study
Sub-optimal iron status and associated dietary patterns and practices in pre-menopausal women living in Auckland, New Zealand.	Beck et al. (2013)	Pre-menopausal women aged 18-44 years old. (n=375) Based in New Zealand.	Cross-sectional analysis. Completion of a 144-item FFQ and a questionnaire on dietary practices. Factor analysis was used to determine dietary patterns and logistic regression was used to determine associations between these dietary patterns and iron status.	"Meat and vegetable" dietary pattern reduced the odds of suboptimal iron status by 41% and following a "milk and yoghurt" pattern increased the odds of suboptimal iron status by 50%.	- Strength in comparing suboptimal iron status to dietary patterns. - FFQ results were not used to measure iron intake (mg) due to no validated tool being available/used.
NZ Food NZ Children: Key results of the 2002 National Children's Nutrition Survey.	Ministry of Health (2003)	Children aged 5-14 years old. (n=3275) Based in New Zealand.	24-hour diet recall, qualitative FFQ.	The prevalence of ID in females aged 11-14 was 5.5%. The prevalence of ID was higher in Māori (11.2%) and Pasifika (9.6%) females. Key iron sources: Breakfast cereals (13%), bread (12%), potatoes, kumara, and taro (7%), beef & veal (6%), beverages (6%), vegetables (5%), fruit (4%), biscuits (4%), pies & pastries (4%), bread-based dishes (3%).	- Large sample size - Used diet recalls to calculate iron intake (mg). - Measured iron status to determine the prevalence of ID. - Conducted nationwide. - Data is outdated.
A focus on nutrition: Key Findings of the 2008/09 New Zealand Adult Nutrition Survey.	University of Otago and Ministry of Health (2011)	Individuals aged 15 years and over. (n=4721) Based in New Zealand.	Self-reported food and nutrient intake, dietary habits and eating patterns, dietary supplement use, household food security, and nutrition-related health conditions and risk factors. Measurements and collection of blood and urine samples.	The prevalence of ID among females increased from 2.9% in 1997 to 7.2% in 2008/09. The median daily iron intake was 9.1 mg for females aged 15-18. Females aged 15-18 had an inadequate iron intake prevalence of 34.2%.	- Large sample size - Used diet recalls to calculate intake - Measured iron status - Conducted nationwide - Data is outdated
The effect of nutrition knowledge and	Leonard et al. (2014)	Females aged 18-35 years. (n=107)	Cross-sectional assessment of nutrition knowledge of iron,	The mean iron intake was 11.2 ± 3.8mg/day. Significant positive correlations between higher flesh	- Measured knowledge, intake, and iron status

Title	Author/Year	Population Characteristics	Methods	Relevant Results	Comments On The Study
dietary iron intake on iron status in young women.		Based in NSW, Australia	dietary iron intake and iron status.	food intake and biomarkers of iron status were also found. No significant differences in mean iron intake were found between vegetarians and non-vegetarians.	- Participants were all from one region of NSW. - Questionnaire was validated in pre-menopausal women.
Protein and iron intake adequacy among high school girls in Depok, Indonesia.	Khoirunnisa et al. (2021)	Female senior high school students. (n=211) Based in Depok, Indonesia.	Multi-stage random sampling. Questionnaire. 3-day non-consecutive 24hr recall (one weekend day, two weekdays)	98.6% of the population had an inadequate intake of iron. Iron intake was not correlated with age, father's education, mother's education, and the number of household members.	- Conducting a 3-day food recall over two weekdays and one weekend day is typically the most accurate type when analysing dietary patterns. - Underreporting of energy intake occurred in more than 50% of the data and may skew results.
Dietary intake nutritional status and lifestyle of adolescent vegetarian and non-vegetarian girls in New Zealand (The SuNDiAL Project): Protocol for a clustered, cross-sectional survey.	Peddie et al. (2020)	Female adolescents aged 15-18 years old. (n=290) Based in New Zealand.	Clustered, cross-sectional survey. Sociodemographic and health information; dietary habits; and influences regarding food choices - via an online self-administered questionnaire. Dietary intakes - via two 24-hour diet recalls on non-consecutive days.	No results of yet – Results still to be published	- Relevant age group. - Up to date. - Results have not been published.
Analysis of heme and non-heme iron dietary sources in adolescent menstruating females in a	Skolmowska and Głąbska (2019)	Menstruating females aged 15-19 years. (n=1385) Based in Poland.	Random quota sampling Iron intakes were measured using "IRONIC-FFQ", a validated food frequency questionnaire.	Females were characterised by a lower intake of all forms of iron compared to male adolescents. 74.9% of females did not achieve the RDA for iron.	- Large sample size. - Relevant age group. - Calculated various forms of iron intake. - Used a validated FFQ with pre-translated

Title	Author/Year	Population Characteristics	Methods	Relevant Results	Comments On The Study
national Polish sample.					iron amounts per serve. - Some factors (e.g., anaemia history and BMI) were self-reported, allowing for response bias.
Calcium and iron intakes of adolescents in Malaysia and their relationships with body mass index (BMI): Findings from the Adolescent Nutrition Survey 2017.	Sallehuddin et al. (2021)	Students aged 13 to 17 years old. (n=999 (449 Males & 550 Females)). Based in Malaysia.	Cross-sectional study. Involved a 24-hr dietary recall.	Both males and females had inadequate intakes of iron in their daily diet. 80% of females did not achieve the RNI for iron.	- Relevant age group. - Factors that contributed to low iron intake were not explored.
Knowledge and practices of dietary iron and anaemia among early adolescents in a rural district in Ghana.	Wiafe et al. (2021)	Adolescents aged 10-14 years old. (n=137) Based in Ghana.	Cross-sectional study. A questionnaire was used to collect data on iron knowledge and iron intake practices. Hemocue 301, an anaemia screening tool, was used to determine haemoglobin levels.	72.1% of chicken consumers met the EAR for dietary iron intake, while only 56.6% of non-consumers met the EAR for dietary iron intake. A negative association was found between anaemia and chicken and dried fish consumption.	- Relevant age group.
Dietary intake and iron status of Australian vegetarian women.	Ball and Bartlett (1999)	Women aged 18-45 years (n=74 (50 vegetarian, 24 omnivorous)). Based in Victoria, Australia.	12-day weighed dietary records. Fasting venous blood sample for haemoglobin, haematocrit, and serum ferritin. Used age-matched omnivorous controls for each vegetarian. Vegetarian subjects recruited omnivorous controls on a “bring a friend” basis.	No significant difference was found between mean daily iron intakes of vegetarians and omnivores. Haem iron intakes were low in vegetarians. Vegetarians had higher intakes of dietary fibre and vitamin C. Mean serum ferritin concentrations were significantly lower in vegetarians than in omnivores. Similar numbers of vegetarians and omnivores had a	- Thorough dietary record method by using 12-day weighed dietary records. - Data is outdated.

Title	Author/Year	Population Characteristics	Methods	Relevant Results	Comments On The Study
				serum ferritin concentration <12µg/L.	
Risk factors for low iron intake and poor iron status in a national sample of British young people aged 4-18 years.	Thane et al. (2003)	Young people aged 4-18 years. (n=1699) Based in Britain.	7-day weighed dietary records. Blood samples were taken to measure haemoglobin, serum ferritin, and transferrin saturation.	Low iron intake occurred in 44% of adolescent girls aged 11-18 years. Low haemoglobin concentration was observed in older girls (15-18 years). Non-Caucasian or vegetarian adolescent girls had significantly poorer iron status than Caucasians or meat-eaters. Haemoglobin, serum ferritin and transferrin saturation were correlated significantly with haem, but not non-haem, iron intake. Overall: Adolescent girls showed the highest prevalence of low iron intake and poor iron status.	- Large sample size. - Relevant age group. - Data is outdated. - Thorough dietary record method by using 7-day weighed dietary records. - Underreporting of food consumption was estimated in 39% of participants.
Abbreviations: FFQ – Food frequency questionnaire, NSW – New South Wales, RDA – Recommended dietary allowance, RNI – Recommended nutrient intake, EAR – Estimated average requirement.					

Iron knowledge among adolescent females

Adolescent females' knowledge of iron is not widely reported in the literature. Most studies are based internationally, with no known New Zealand-based studies. Previous studies focusing on dietary iron knowledge among young females globally are outlined in Table 2. Knowledge questions generally cover one or more of the following: the functions of iron, symptoms of ID and/or IDA, food sources of iron, causes of low iron, and inhibitors and enhancers of iron absorption. Studies have shown that iron knowledge among young adolescents is low overall. Abu-Baker et al. (2021) and Rani and Rawat (2020) investigated knowledge about anaemia in secondary school females and discovered reasonably similar results. Abu-Baker et al. (2021) reported that only 52.4% of secondary school females had adequate knowledge of IDA. Rani & Rawat (2020) reported that only 58% of secondary school females had adequate knowledge of anaemia in general. Results from Verma and Baniya (2022) aligned with these previous studies, with just under 50% of females being able to identify the causes, signs, and treatment for ID. Wiafe et al. (2021) also had similar findings, reporting that only 40% of participants had knowledge of IDA. Interestingly, 86% of their participants identified common symptoms of IDA, while only 35% could identify the consequences of IDA (Wiafe et al., 2021).

When assessed on their knowledge of food sources of iron, adolescent females have been shown to have relatively poor knowledge. Wiafe et al. (2021) found that only 31% of participants aged 10-14 could identify food sources of iron. Additionally, only 18% knew of foods that were iron absorption enhancers, and 0.7% knew of foods that were iron absorption inhibitors (Wiafe et al., 2021). Findings by Roncolato et al. (1998) align with this study, noting that only 30% of their participants could identify good food sources of iron. In addition, they observed that only 14.6% of their participants aged 10-11 years knew of vegetarian alternatives which provided iron (Roncolato et al., 1998). Conversely, Leonard et al. (2014) showed that vegetarians had a higher knowledge of iron-rich foods than non-vegetarians. It could be suggested that this is due to vegetarians naturally being more health-conscious or having more of an interest in ensuring that they meet their nutrient needs than non-vegetarians. This is a shared viewpoint amongst many; however, this has not been investigated closely.

Studies where nutrition education interventions were undertaken, such as those by Abu-Baker et al. (2021) and Savita et al. (2013), have had success in increasing adolescents' iron knowledge. Abu-Baker et al (2021) found that their intervention group had significantly higher iron knowledge scores post-intervention than the control group. Savita et al. (2013) discovered that among adolescent females, 30% scored "low", 42% scored "medium", and 28% scored "high" in iron knowledge pre-intervention. Post-intervention, the number of "high" scores increased to 97%, with these scores staying stable one-month post-intervention. These results indicate the effectiveness of nutrition education on iron knowledge scores and demonstrate good retention of this knowledge among participants 1-month post-intervention.

Table 2 *- Literature summary - Iron knowledge among young females globally*

Title	Author/Year	Population Characteristics	Methods	Relevant Results	Comments On The Study
The impact of nutrition education on knowledge, attitude, and practice regarding iron deficiency anaemia among female adolescent students in Jordan.	Abu-Baker et al. (2021)	Female secondary school students aged 13-15. (n=363) Based in Jordan.	Quasi-experimental design (pre-test-post-test control group). One school formed the intervention group, the other formed the control group. A one-month nutrition education program was provided to the intervention group.	52.4% had adequate knowledge about IDA. 92.3% knew about easily absorbed iron-rich foods, and 76% knew about anaemia prevention. Pre-programme: No difference between the control and intervention groups was significant. Post-programme: The intervention group had significantly higher knowledge scores than the control group.	- Questionnaire was self-reported, allowing for response biases. - 8 questions measured knowledge, 3 measured practice, and 6 measured attitudes. - Knowledge of iron topics was self-reported rather than tested through a questionnaire (eg. participants answered 'know' or 'do not know'. - Questionnaire was not validated.
Prevalence and knowledge regarding anaemia among adolescent girls in selected senior secondary schools, Distt Faridkot, Punjab.	Rani and Rawat (2020)	Adolescent secondary school girls aged 11-19. (n=300) Based in Punjab, India.	Descriptive cross-sectional survey design. Used purposive sampling. Involved a knowledge questionnaire.	42% of adolescent girls had inadequate knowledge about anaemia.	- Used a 29-question multi-choice questionnaire focused on anaemia. - Questionnaire was not outlined or included in the journal article.
The effect of nutrition knowledge and dietary iron intake on iron status in young women.	Leonard et al. (2014)	Females aged 18-35 years. (n=107) Based in NSW, Australia	Cross-sectional assessment of nutrition knowledge of iron, dietary iron intake and iron status.	Mean knowledge score of 11.2 ± 3.1 out of 19 (58.9%). Low knowledge score (0-6) = 34.6% of participants, moderate iron knowledge score (7-13) = 49.5% of participants, high iron knowledge score (14-19) = 15.9% of participants. Vegetarians had higher knowledge scores than non-vegetarians.	- Measured knowledge, intake, and iron status. - Participants were all from one region of NSW. - Many iron knowledge questions were true/false.

Title	Author/Year	Population Characteristics	Methods	Relevant Results	Comments On The Study
Knowledge and practices of dietary iron and anaemia among early adolescents in a rural district in Ghana.	Wiafe et al. (2021)	Adolescents aged 10-14 years old. (n=137) Based in Ghana.	Cross-sectional study. A questionnaire was used to collect data on iron knowledge and iron intake practices. Hemocue 301, an anaemia screening tool, was used to determine haemoglobin levels.	40% of participants had knowledge of IDA, 29% knew about the causes of anaemia, 86% knew the common symptoms of anaemia, and 35% knew the consequences of anaemia. 31% knew about food sources of iron. 18% knew about iron enhancers; 0.7% knew about iron inhibitors.	- Relevant age group. - Small sample size of females with an education above primary level (therefore likely to be 10 years old). - The seven questions asked were answered with 'know' or 'don't know' – it did not test their knowledge as such.
Nutritional knowledge, food-related and body-related attitudes among pre-adolescent children.	Roncolato et al. (1998)	Adolescent children aged 10-11 years. (n=185 (129 girls, 56 boys)). Based in Sydney, Australia.	Measures used: Nutritional knowledge questionnaire (NKQ), the Children's attitudes towards eating (CATE) scale, the Children's body mapping questionnaire (CBMQ), and two subscales from the eating disorders inventory (EDI), the drive for thinness and the body dissatisfaction scales.	54.1% of children knew the functions of iron. 30.3% knew the best source of iron. 53.5% knew the nutritional needs at puberty. 14.6% knew alternative sources of iron to meat for vegetarians.	- Data is outdated. - Multi-choice knowledge questionnaire was not validated.
Prevalence, knowledge, and related factor of anaemia among school-going adolescent girls in a remote area of western Rajasthan.	Verma and Baniya (2022)	Adolescent girls aged 11-19 years. (n=625). Based in Rajasthan, India.	Cross-sectional study. Questionnaire about sociodemographic, clinical and knowledge questions about anaemia.	More than half of the participants had insufficient knowledge of the causes, symptoms, and treatment of anaemia and iron-rich food sources.	- Relevant age group. - Information and procedure for the knowledge questionnaire were not described in detail.
Impact of education intervention on nutrition knowledge of iron deficiency anaemia among post-adolescent girls.	Savita et al. (2013)	Females aged 18 to 25. (n=207) Based in Karnataka, India.	Use of a knowledge assessment tool pre-intervention, directly post-intervention, and 1-month post-intervention. The nutrition education intervention consisted of a lecture using visual aids such as flashcards, posters, and food displays (iron-rich sources, enhancers	Results before and after iron education: Pre-intervention: 30% scored low, 42% scored medium, and 28% scored high. Right after intervention: 97% scored high, and 3% scored medium.	- The intervention only provided information about iron – it did not look to analyse attitudes or practices simultaneously.

Title	Author/Year	Population Characteristics	Methods	Relevant Results	Comments On The Study
			and inhibitors of iron), followed by a discussion.	1-month post-intervention: 96% scored high, and 4% scored medium. Good retention of nutrition knowledge after the education intervention was demonstrated.	
Abbreviations: IDA – Iron deficiency anaemia, ID – Iron deficiency.					

Association between iron intake and knowledge among adolescent females

The association between iron intake and knowledge is not well evidenced in the literature, which can be due to many determining factors involved in translating knowledge into practice. It is widely assumed that knowledge effectively translates into practice; however, it has been found that knowledge is not necessarily enough to change behaviour and that attitude plays a significant role (Ajzen, 1991). The Theory of Planned Behaviour Model (TPB) is a behavioural change model used to determine the importance of factors influencing food choice. The TPB model considers attitudes, behavioural intention, subjective norms, social norms, perceived power, and perceived behavioural control (Ajzen, 1991). These collectively represent one's control over a behaviour. Therefore, knowledge can positively affect each of these factors in the context of iron education and dietary iron intake. Increased perceived behavioural control may lead to increased intention, which may result in a positive change in behaviour promoting adequate iron intake.

Previous studies focusing on the association between dietary iron intake and knowledge among young females globally are outlined in Table 3. Wiafe et al. (2021) found a positive association between knowledge of iron food sources and consumption of chicken and fish, which are classed as sources of iron with high bioavailability and have enhancing properties for iron absorption (via MPF). A positive association between knowledge and iron intake was also found by Leonard et al. (2014); however, there was no association between iron knowledge and whether the adolescent females met the RDI for iron. Additionally, no association was found between iron knowledge and iron biomarkers in adolescent females (Leonard et al., 2014). Abu-Baker et al. (2021) also demonstrated this positive association between knowledge and practice, with significant increases of both in the intervention group following a nutrition education session on the prevention and control of IDA. The attitude scores of the participants in this study increased significantly in the intervention group; therefore, the behaviour change can be explained by the change in attitude as suggested by the TPB model.

In comparison, Rastogi et al. (2019) found no significant association between general nutrition knowledge and practices in females aged 13-15 years. The study, however, found there was a weak but significant relationship between general nutrition knowledge and positive attitudes towards food. This again supports the TPB showing that increased knowledge can positively influence attitudes (Ajzen, 1991). It is likely that this study did not find any significant relationship between knowledge and intake, as the interventions provided to the students at school were strictly based around disseminating knowledge (Rastogi et al., 2019).

A health model known as PRECEDE, proposed by Lawrence Green in 1974, is commonly used in health promotion actions and can help to identify health/nutritional problems and their causes (Green, 1980). A study done by Jeihooni et al. (2021) used the PRECEDE model's factors – knowledge, attitude, self-efficacy, reinforcing factors, and preventative behaviours, and found that their nutrition programme led to improvements in participants' nutritional knowledge scores and attitude scores four months after the intervention. Overall, this study found that increased nutritional knowledge and attitude scores positively influenced eating behaviours that helped prevent the risk of developing IDA (Jeihooni et al., 2021). Previous nutrition education interventions surrounding iron have positively affected adolescents' attitudes. However, the significant number of varied results shows that many study interventions are missing crucial activities based on changing one's nutritional behaviour. Without providing activities such as skill-based interventions, one's intention of the said nutritional behaviour will likely stay the same, as will the individual's current nutritional behaviour. Therefore, for future nutrition education interventions to be implemented effectively and help reduce the risk of IDA, consideration of the link between knowledge, attitudes, intention and behaviour is necessary.

***Table 3** – Literature summary – Associations between iron intake and iron knowledge of young females globally*

Title	Author/Year	Population Characteristics	Methods	Relevant Results	Comments On The Study
Knowledge and practices of dietary iron and anaemia among early adolescents in a rural district in Ghana.	Wiafe et al. (2021)	Adolescents aged 10-14 years old. (n=137) Based in Ghana.	Cross-sectional study. Questionnaire was used to collect data on iron knowledge and iron intake practices. Hemocue 301, an anaemia screening tool, was used to determine haemoglobin levels.	A positive correlation was found between knowledge of food sources of iron and iron-rich foods and intake of chicken, fresh fish, and dried fish.	- The correlation between knowledge and intake was statistically insignificant.
The effect of nutrition knowledge and dietary iron intake on iron status in young women.	Leonard et al. (2014)	Females aged 18-35 years. (n=107) Based in NSW, Australia	Cross-sectional assessment of nutrition knowledge of iron, dietary iron intake and iron status.	A positive correlation between nutrition knowledge and iron intake was found. No association between nutrition knowledge score and whether the women met the RDI for iron was found. No association between iron knowledge and iron status was found.	- FFQ was semi-quantitative and validated amongst pre-menopausal Australian women.
The effect of nutrition education based on PRECEDE model on iron deficiency anaemia among female students.	Jeihooni et al. (2021)	Adolescent Students (n=160) Based in Iran.	Quasi-experimental study. Provided an educational intervention (6 sessions based on the PRECEDE model).	For all the PRECEDE model constructs (knowledge, attitude, self-efficacy, reinforcing factors, enabling factors, preventative behaviours), the mean score significantly increased four months after the intervention for the experimental group. Indicates the influence of the PRECEDE model on increasing knowledge and positive attitudes toward eating behaviours preventing anaemia.	- Strength in considering knowledge, attitudes and behaviours influencing iron intake, and providing an intervention that targets these areas.
Gaps in nutrition knowledge and barriers to eating healthy among	Rastogi et al. (2019)	Adolescent girls aged 13-15 years old	Cross-sectional study. Questionnaire assessing knowledge, attitudes and	There was no significant relationship between nutrition knowledge and practices.	- The provided intervention was only based on

Title	Author/Year	Population Characteristics	Methods	Relevant Results	Comments On The Study
low-income, school-going adolescent girls in Delhi.		(n=250) Based in Delhi, India.	practices, and frequency of food consumption. Focus group discussions.		disseminating knowledge and not aiming to change attitudes or practices.
The impact of nutrition education on knowledge, attitude, and practice regarding iron deficiency anaemia among female adolescent students in Jordan.	Abu-Baker et al. (2021)	Female secondary school students. (n=363) Based in Jordan.	Quasi-experimental design (pre-test-post-test control group). One school formed the intervention group, the other formed the control group. A one-month nutrition education program was provided to the intervention group.	*Iron Knowledge:* Pre-programme: No significant difference between the control and intervention groups. Post-programme: The intervention group had significantly higher knowledge scores than the control group. *Healthy Iron Practices:* Pre-programme: No significant difference between the control and intervention groups. Post-programme: The intervention group had a significantly higher practice score than the control group. Note: Positive attitudes among participants also increased post-programme.	- Strength in considering knowledge, attitudes and behaviours influencing iron intake, and providing an intervention that targets these areas. - Knowledge of iron topics was self-reported rather than tested through a questionnaire.
Abbreviations: RDI – Recommended daily intake.					

Conclusion

It can be concluded that current research in New Zealand is inadequate to estimate current iron intake and knowledge among adolescent females aged 11-14 years. Following the trends from international studies, it is evident that iron knowledge and iron intake are both low in developed and developing countries. In many studies, it has been difficult to estimate prevalence and accurate intakes due to the diverse food patterns among various countries and the varying assessment methods. Australian data is likely to provide the most closely matched conclusions to New Zealand due to the similarities in eating behaviours and the high availability of westernised foods.

While New Zealand data does exist for adult women regarding iron intake, these patterns must also be addressed in the younger generation from a preventative perspective when considering iron status and the risk of ID. No large-scale nutrition data has been produced about young New Zealand adolescents since 2002, and it is clear that the food environment and dietary patterns in New Zealand have drastically changed over the last 20 years. This highlights the importance of understanding dietary iron intake and knowledge in the current New Zealand landscape. This new data may help provide a foundation for future research and help create nutrition interventions that can benefit adolescents by improving their iron status through increased iron literacy and intake.

Chapter 3: Research Study Manuscript

Abstract

Background: Iron deficiency is the most prevalent micronutrient deficiency globally and is a common diagnosis in adolescent females. Causal factors for this population include low dietary iron intake, iron bioavailability, increased iron requirements and excessive iron losses. Iron intakes of adolescent females in New Zealand were last analysed in the 2002 National Children's Nutrition Survey, reporting an average intake of 9.9mg/day. Up-to-date information on dietary iron intake and literacy in adolescent females is not available for health professionals.

Aim: To determine dietary iron literacy and associations with dietary intakes of iron-rich foods in young adolescent females within New Zealand.

Methods: Females (n=286) aged 11-14 years from all-girls schools around New Zealand were recruited to complete an anonymous online questionnaire. The questionnaire comprised of demographic questions, an adapted iron literacy questionnaire and a validated iron food frequency questionnaire.

Results: A moderate level of iron literacy was found in most participants (66.8%, n=191), with 21.7% (n=62) demonstrating low and 11.5% (n=33) demonstrating high dietary iron literacy. Vegetarian, pescatarian, and vegan participants had higher iron knowledge scores than those not on a particular diet ($P = 0.001$). Age had a weak relationship with iron knowledge score category ($\chi^2 = 6.27$, $P = 0.044$). Significant differences were found between ethnic groups and food group consumption frequency. Seafood and legumes, eggs, nuts and seeds were eaten more frequently among Asian participants, while iron-fortified foods were eaten more frequently among Māori participants. Participants from higher decile schools were found to consume red meat ($P = 0.009$), seafood ($P = 0.024$) and fruit ($P = 0.021$) more frequently than those from moderate decile schools. No relationships between dietary iron literacy score and intake of iron-rich food groups were discovered.

Conclusion: Our results demonstrate that iron literacy is low-moderate among adolescent females within New Zealand and is not associated with current dietary iron intake behaviours. Future studies may consider educational interventions to change intake behaviours, and objective measures of iron status and food intake via biochemical data and food recalls.

Keywords: *Iron, iron intake, iron knowledge, literacy, dietary patterns, adolescents.*

Introduction

Iron deficiency is the most prevalent micronutrient deficiency globally, contributing highly to anaemia among adolescent females. Iron deficiency anaemia affects individuals directly, resulting in consequences such as fatigue, weakness, difficulty concentrating, headaches, and impaired immunity (Coad and Pedley, 2014). It also indirectly affects society through increasing hospitalisation costs, which in New Zealand have doubled from $3,224,367 to $6,736,508 over the last decade (Coad and Pedley, 2014, Ministry of Health, 2018). Poor iron balance is seen frequently among adolescent females, with recognised causal factors being reduced dietary iron intake, increased iron requirements, and excessive iron losses through menstruation and exercise (Coad and Pedley, 2014, Peeling et al., 2008, Peddie et al., 2020, Nielsen et al., 2013).

Iron intakes and literacy levels are topical and important when investigating iron status in young adolescent females. A key yet outdated study in New Zealand, the 2008/09 National Adult Nutrition Survey, showed that one-third of adolescent females were not meeting their iron requirements (University of Otago and Ministry of Health, 2011). No research studies on iron intake and status among females below the age of 18 years have been completed in New Zealand since the National Adult Nutrition Survey, except for the SuNDiAL study, which is yet to publish any results (Peddie et al., 2020). Studies conducted internationally, from both developed and developing countries, have demonstrated poor intakes of iron in female adolescents, with 28-99% of female participants having intakes of iron below the estimated average requirement (EAR) level (or equivalent) for their country (Wiafe et al., 2021, Skolmowska and Głąbska, 2019, Sallehuddin et al., 2021, Khoirunnisa et al., 2021, Thane et al., 2003). Iron literacy levels amongst adolescent females have been less reported in the literature, with no known New Zealand studies examining these. International studies such as those by Wiafe et al. (2021), Roncolato et al. (1998), Verma and Baniya (2022), Savita et al. (2013), have demonstrated that between 50-80% of adolescent females did not know of examples of iron-rich sources. Additionally, it was found that between 40-60% of adolescent females had inadequate knowledge of IDA (Abu-Baker et al., 2021, Rani and Rawat, 2020, Wiafe et al., 2021, Verma and Baniya, 2022). Based on these previous studies, it is suggested that iron knowledge may be similarly low among adolescent females in New Zealand.

Exploring current iron intakes and literacy levels among young adolescent females aged 11-14 years is crucial to not only address the gap in the literature for this age group but to identify what is needed to improve iron knowledge and reduce the risk of ID in the future. To date, studies in New Zealand have focused mainly on females over 15 years or young children (<2 years old). Up-to-date information on iron intake and literacy will help to identify changes that may have occurred over the last 10-20 years and expand the literature available amongst this population. Therefore, this study aims to determine dietary iron literacy and associations with dietary intakes of iron-rich foods in intermediate and secondary school females aged 11-14 in New Zealand.

Methods

Study design

This study was a cross-sectional, descriptive observational design. A purposive non-probability sampling method was used due to the narrowly defined population inclusion criteria. A combination of quantitative and qualitative data was collected in an online questionnaire and offered an effective way of gaining information from a larger sample size more efficiently in this population, while balancing the strengths of each method. Based on the age of the participants, it would prove difficult to gain responses through focus groups or interviews due to time constraints and participants likely being unable to travel for data collection. Conducting the study as an online questionnaire meant that greater location reach could be achieved, targeting schools throughout New Zealand rather than being restricted to Auckland. This study design was the most suitable to address the aims and objectives of the project as it helped provide an up-to-date and accurate snapshot of knowledge and intakes of iron-rich foods in these young adolescent females in New Zealand. A low-risk ethics notification for the current study was submitted to the Massey University Human Ethics Committee (MUHEC): Reference 4000025457.

Pilot study and participant recruitment

The participant recruitment procedure is outlined in Figure 2. Prior to school recruitment, pilot testing occurred, with three females aged 11-14 years completing a trial of the online questionnaire. Participants for pilot testing were recruited through word of mouth. Pilot testing ensured that all questions were written at an appropriate literacy level and could be understood by adolescents in this target age group. Feedback was requested by both the child and the parent regarding whether any questions were hard to understand, written poorly, or if there were any mistakes. Feedback provided throughout pilot testing was considered, and the questionnaire was revised accordingly before data collection commenced. Recruitment of schools was done through online research of all-girls schools in New Zealand (Education Counts, 2022). The target number of classes was 10-20, allowing for 15-30 student participants per class. Additional study recruitment aims were to receive data from various schools, ranging in decile and location, as well as the type of authority (public or private school). School principals were contacted via email, requesting participation from their school. Students were informed about the study through their teachers, and parents of the students were either emailed the study's information sheet and link to the questionnaire, or these were uploaded onto the classroom's online dashboard. The information sheet provided is attached as Appendix A1.

Participants

The research population included females aged 11-14 who attended an all-girls school in New Zealand. The recruitment method ensured that principals and/or school teachers were contacted and recruited to participate in the study. Every Girls-only school in New Zealand was targeted for ease of recruitment and to avoid male students partaking in the online questionnaire against the study's inclusion criteria. Additionally, there was a preference that students of health or nutrition classes took part in the questionnaire, however, this was not a strict requirement. This decision was based on the assumption that these students would have the highest level of dietary iron knowledge among their age group at the school. This method intended to allow the study to identify the top-end of iron knowledge among this age group.

The study aimed to conclude with a sample size of 300 participants. Using the following sample size formula: $n = [Z^2 p(1-p)]/d^2]$, at least 267 participants were statistically required, at minimum, for this study. This figure is derived from the expected prevalence of ID in this population, which was found to be 55.8% in a study by Lim et al. (2020) using a 90% confidence interval and a 5% margin of error.

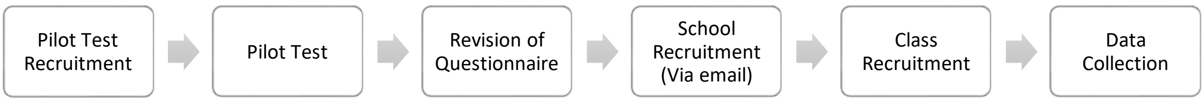

Figure 2 *- Participant recruitment procedure outline*

Outcome measures

Online questionnaire

The study was conducted in the form of an online questionnaire, with data gathered via Qualtrics Survey Software. The online questionnaire covered demographic and general health questions, iron knowledge questions, and an iron food frequency questionnaire.

Demographic and general health questions

At the beginning of the questionnaire, demographic questions were asked, such as ethnicity and age, for the categorisation of participants and to identify associations between these demographic components and knowledge score or dietary intakes of iron-rich foods. General health questions were asked, including which dietary pattern individuals followed, whether they were currently taking any supplements/medication and whether they had experienced their first menstrual bleed.

Iron knowledge

Iron knowledge was estimated using nine multiple choice questions, which covered the function of iron, iron requirements, types of iron, food sources of iron, and enhancers and inhibitors of iron absorption. Points were allocated per question, with each correct answer valued at one point, to give a total score for each participant out of 18. All questions regarding iron knowledge are listed below in Appendix A2. Several questions were adapted from a non-validated questionnaire conducted in a study by Leonard et al. (2014), which included eight knowledge questions surrounding dietary iron, but were altered for relevance and simplified to a lower literacy level suitable for 11-year-olds.

Iron intake – Food frequency questionnaire

This study used retrospective data from a food frequency questionnaire (FFQ) to estimate dietary intakes of iron-rich foods. Due to this being a non-quantitative iron FFQ, the portion size was not specified. The iron FFQ included a list of food items that were either a source of iron or a known enhancer or inhibitor of iron absorption. Nine frequency options were provided for each food, ranging from “I never eat this food” to “4+ times per day”. The iron FFQ was derived from a validated iron FFQ created by Beck et al. (2012). Particular foods were excluded due to their low iron content (≤0.5mg iron/100g) and not being a food source that contained significant amounts of iron absorption enhancing or inhibiting components. The exclusion of foods was also done to shorten the questionnaire from 144 to 106 item groups in order to maintain answering compliance. Foods excluded were fruits such as apples, bananas, pears, stone fruit, avocados, grapes and watermelon. Excluded vegetables were carrots, corn, beetroot, lettuce, mushrooms, and onions. Other food items excluded were cake, biscuits, chocolate spread, butter, oil, sugar, jam, muesli bars, potato chips and white chocolate. The alcohol category was excluded entirely as it was inappropriate for this age group. Drinking chocolate, cordial, sports drinks, energy drinks and water were also excluded.

Data handling and statistical analysis

Questionnaire data was collated in Qualtrics Survey Software and then exported into Microsoft Excel, where the data was cleaned, sorted and translated. Iron intake data was converted from the consumption frequency of each food group per month to the frequency per week, using the conversion values seen in Table 4. Following sorting, statistical analysis was completed using IBM SPSS statistics package version 28. The techniques for the analysis of data in SPSS involved both descriptive statistics and inferential statistics. Demographic variables were reported as percentages and the number of participants, with means or medians calculated for numerical variables. All variables were tested for normality. For data that followed normality, the mean and standard deviation were reported. For data that did not follow normality, it was log-transformed and re-tested. The geometric mean and 95% confidence interval were reported if log-transformed data met normality. If log-transformed data still did not follow normality, the median and 25^{th} & 75^{th} percentiles were reported. Findings were considered statistically significant if their *P* value was less than 0.05.

The coding of ethnicity followed a priority system, as participants were able to identify as more than one ethnicity. Priority order was given to 1) Māori, 2) Pasifika, 3) Asian, 4) MELAA, 5) Other, and 6) NZ European (Education Counts, 2021). Ethnicity groups were reduced down to the three prominent ethnicities – NZ European, Māori, and Asian, as these made up ~90% of the participant group. No decile 0-3 schools participated in the study; therefore, decile groups were 4-7 and 8-10. Dietary patterns derived from the general health question section of the questionnaire were grouped into four categories and prioritised as 1) No particular diet (NPD), 2) Vegetarian/pescatarian/vegan, 3) Gluten/wheat/dairy/egg-free 4) Other. Food groups detailed in the iron FFQ (Appendix A4) were further refined into ten food groups, with their included foods listed in Appendix A5.

All characteristic variables (age, ethnicity, authority type, decile, age at menarche, and dietary pattern) were entered as categorical data for analysis by chi-square against iron knowledge and non-parametric testing against food group consumption frequency. Iron knowledge score was grouped into three categories – low (0-5), moderate (6-12), and high (13-18), as well as kept as scale data (score of 0-18) for calculation of means/medians. Food group consumption frequency was considered scale data for calculating medians and testing against characteristics and iron knowledge score category.

Chi-square testing of independence was completed for characteristic variables against iron knowledge score categories. Chi-square values were only reported for tests that met the conditions in which the expected count in each cell was >5 for at least 80% of the values, none were <1, and the data was independent. The effect size was calculated for variables that showed a significance below 0.05 in the chi-square test. The effect size for chi-square tests with more than 2x2 categories per variable was calculated using Cramer's V value to identify the strength of the association. Post-hoc pairwise comparison tests were undertaken to identify if there were any significant differences between groups. Bonferroni's correction was applied to each comparison test.

As all relevant data were non-parametric, Mann-Whitney testing was completed to compare characteristic variables with two groups (e.g. age and decile category) and food group consumption frequency. Kruskal-Wallis testing was completed to compare characteristic variables with more than two groups (e.g. ethnicity and dietary pattern) and food group consumption frequency. A significance level of 0.05 was used for the above testing. Significant results from Kruskal-Wallis tests underwent multiple comparison testing to provide a significance value that had been adjusted by the Bonferroni correction for multiple tests.

Table 4 *- Conversion of food group consumption frequency values*

Iron FFQ (Beck et al., 2012)	**Consumption frequency per week**
I never eat this food	0
Less than once per month	0.125
1 to 3 times per month	0.5
Once per week	1
2 to 3 times per week	2.5
4 to 6 times per week	5
Once per day	7
2 to 3 times per day	17.5
4 plus times per day	28

Results

Study response rates

As seen in Figure 3, the recruitment process involved reaching out to 60 eligible schools around New Zealand. Out of the 60 schools recruited, seven agreed to have at least one class participate in the study, 22 declined the invitation, and 31 did not respond. Overall, 37 classes of students were sent the questionnaire link to complete. Classes were located in Auckland, Tauranga, Havelock North, Lower Hutt and Christchurch. A mixture of health, nutrition, form and PE classes were attained, contrary to the original preference of health and nutrition classes. Data collection occurred over 102 days, receiving 286 responses overall. The iron knowledge section was completed by 286 (100%) of the students, while the iron FFQ/intake section was completed by 267 (93%).

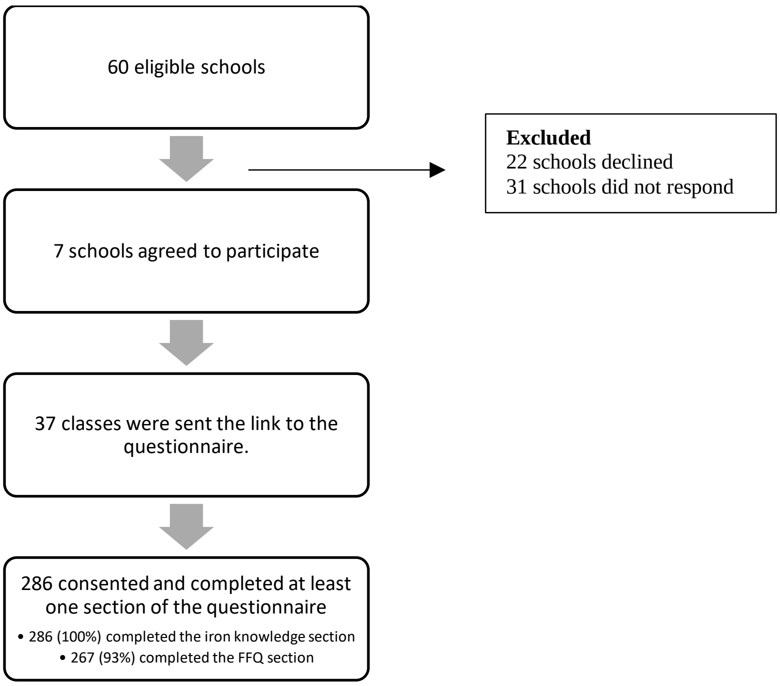

Figure 3 *- Questionnaire response rates*

Demographic and general health characteristics of participants

The demographic and general health characteristics of the study participants are listed in table 5. Among the 286 participants, the median age was 13 years (13.0, 14.0), and the dominant ethnicity of the group was New Zealand European (61.2%), followed by 16.1% identifying as Asian, 11.9% as Māori, 4.9% as Middle

Eastern/Latin American/African, 3.8% as other, and 2.1% as Pasifika. The median school decile among participants was 10.0 (6.0, 10.0), with three schools having a decile of 10, one a decile of 9, one a decile of 7, and two a decile of 6. The proportion of participants from each school authority type was similar, with 51.7% of participants attending a public school and 48.3% attending a private school. A clear majority of the participants did not follow a particular diet (87.1%). Other dietary patterns followed by participants included a vegetarian, pescatarian, or vegan diet (6.6%), a gluten/wheat/dairy/egg-free diet (3.5%), and an alternative diet classed as 'other' (2.8%). Among participants, 77.1% had experienced menarche, with the median age of menarche being 12.0 years (11.0, 13.0). One-third of participants (31.5%) used supplements or medications, of whom 13.3% took iron, 14.2% a multivitamin, and 24.2% Vitamin C. Dietary patterns among vegetarian, pescatarian and vegan participants versus participants not following a particular diet were not associated with supplement use ($\chi^2 = 2.05$, df = 2, $P = 0.359$).

Table 5 *- Participant demographic and general health characteristics (n = 286)*

Characteristic	n (%)	Median (25th, 75th percentile)
Age (years)		13.0 (13.0, 14.0)
11-12	47 (16.4)	
13-14	239 (83.6)	
Ethnicity [1]		
NZ European	175 (61.2)	
Māori	34 (11.9)	
Pasifika	6 (2.1)	
Asian	46 (16.1)	
MELAA	14 (4.9)	
Other	11 (3.8)	
School Decile		10.0 (6.0, 10.0)
4 - 7	89 (31.1)	
8 - 10	197 (68.9)	
Public/Private		
Public	148 (51.7)	
Private	138 (48.3)	
Dietary Pattern		
Not on a particular diet	249 (87.1)	
Vegetarian, pescatarian or vegan	19 (6.6)	
Gluten/wheat/dairy/egg-free	10 (3.5)	
Other	8 (2.8)	
Menarche occurrence [2]		
Yes	219 (77.1)	
No	65 (22.7)	
Age at menarche (years)		12.0 (11.0, 13.0)
8-9	6 (2.7)	
10-11	66 (30.1)	
12	80 (36.5)	
13	51 (23.3)	
14	5 (2.3)	
Don't remember	11 (5.0)	
Taking medication/supplements		
Yes	90 (31.5)	
Iron	16 (13.3)	
Multivitamin	17 (14.2)	
Vitamin C	29 (24.2)	
Other [3]	58 (48.3)	
No	175 (61.2)	
Don't know	21 (7.3)	

Abbreviations: n - number of participants, % - percentage of participants, MELAA – Middle Eastern/Latin American/African

[1] Ethnicity prioritised by: Māori, Pasifika, Asian, MELAA, Other (Education Counts, 2021)

[2] Two participants did not answer this question.

[3] Other supplements included vitamin D, vitamin B12, omega-3, probiotics, magnesium, zinc, and calcium.

Iron knowledge

Figure 4 shows the distribution of knowledge scores among participants. The median iron knowledge score was 8.5 (6.0, 11.0) out of 18. Iron knowledge score was low (0-5) in 21.7% of participants, moderate (6-12) in 66.8%, and high (13-18) in 11.5%.

The questions generally well understood among participants included those asking about iron function (59% of participants) and deficiency symptoms (78%). Of the study's participants, 72% knew which groups (female versus male and menstruators versus non-menstruators) had higher iron requirements. Approximately 40% of participants knew of vegetarian food sources of iron. The questions that received the least number of correct answers were based on haem and non-haem iron food sources (13%), iron absorption enhancers (23%) and iron absorption inhibitors (14%).

Figure 5 illustrates iron knowledge scores by characteristic. Median (25^{th}, 75^{th} percentile) knowledge score was significantly different across two dietary pattern groups, with vegetarian, pescatarian and vegan participants having a significantly higher score of 11 (10, 13) than those not on a particular diet, who had a median score of 8 (6, 10) (P = 0.001). No other differences in knowledge scores between groups were found among demographic characteristics.

Table 6 shows the frequencies of iron knowledge scores among demographic characteristics. When comparing these characteristics with iron knowledge score categories (low, medium, high), chi-square testing showed that age had a significant, weak relationship with iron knowledge score (χ^2 = 6.27, df = 2, P = 0.044, Cramér's φ = 0.148). Among 11–12-year-olds, 15/47 (32%) scored in the low knowledge category, 24/47 (51%) in the moderate category and 8/47 (17%) in the high category. In comparison, among 13–14-year-olds, 47/239 (20%) scored in the low knowledge category, 167/239 (70%) in the moderate category and 25/239 (10%) in the high category. Ethnicity (P = 0.476), school decile (P = 0.988), authority type (P = 0.115), and dietary pattern (P = 0.279) all did not have a significant relationship with iron knowledge score.

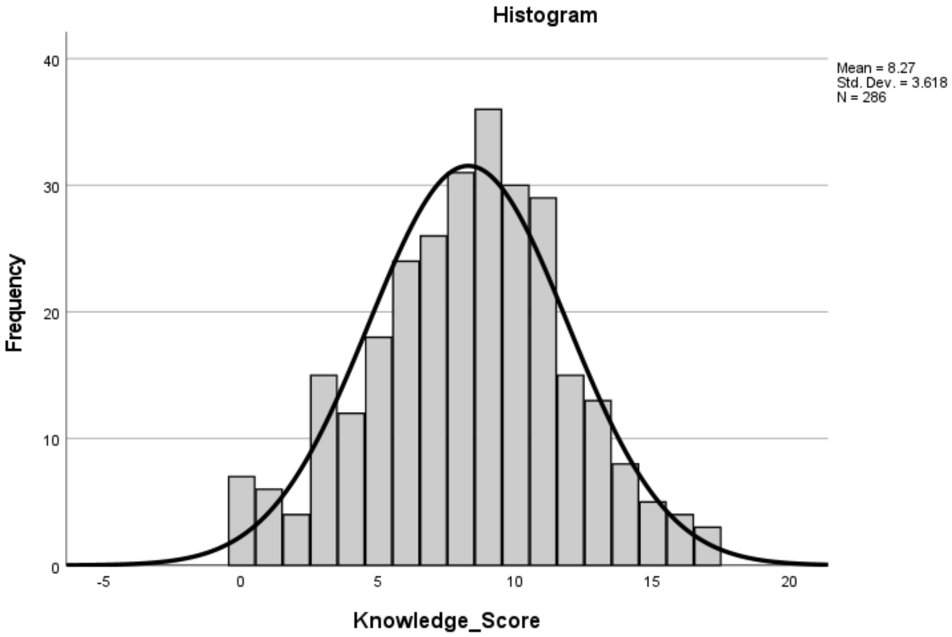

Figure 4 *– Iron knowledge score distribution*

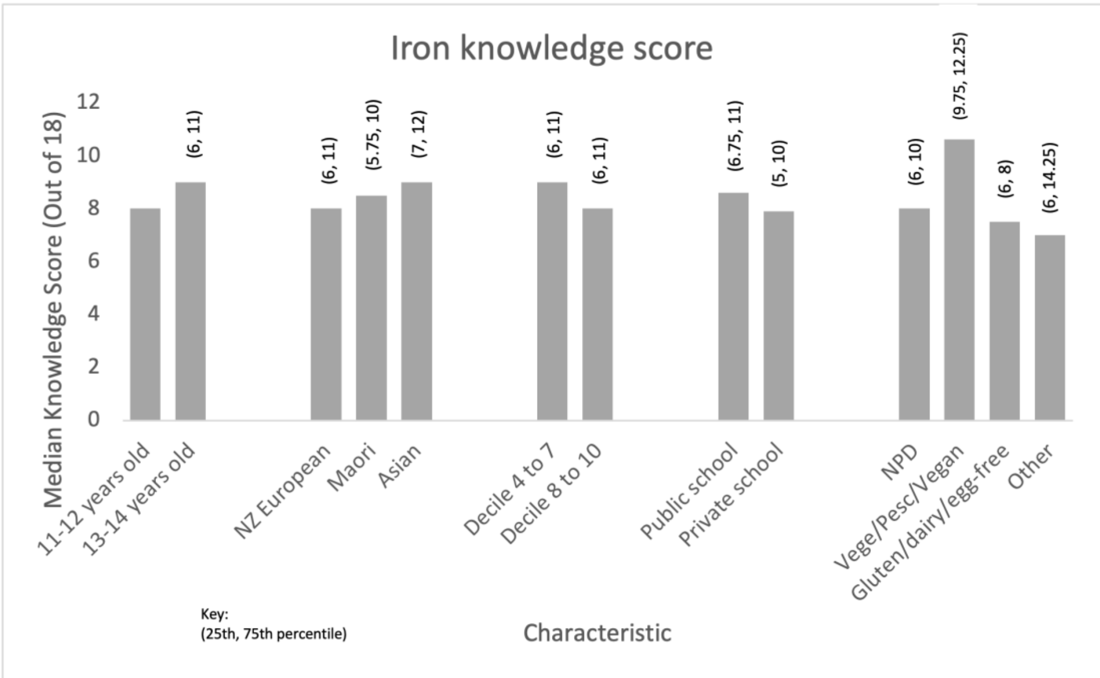

Figure 5 *– Median iron knowledge scores by characteristic*

__Table 6__ – Iron knowledge scores by characteristic

Characteristic	Low iron knowledge n (%)	Moderate iron knowledge n (%)	High iron knowledge n (%)	*P* – Value
Total	62 (21.7)	191 (66.8)	33 (11.5)	
Age (years)				0.044
11-12	15 (31.9)	24 (51.1)	8 (17.0)	
13-14	47 (19.7)	167 (69.9)	25 (10.5)	
Ethnicity [1]				0.476
NZ European	38 (21.7)	119 (68)	18 (24)	
Māori	8 (23.5)	23 (67.6)	3 (8.8)	
Asian	8 (17.4)	29 (63.0)	9 (19.6)	
School Decile				0.988
4 – 7	19 (21.3)	60 (67.4)	10 (11.2)	
8 – 10	43 (21.8)	131 (66.5)	23 (11.7)	
Authority type				0.115
Public	25 (16.9)	106 (71.6)	17 (11.5)	
Private	37 (26.8)	85 (61.6)	16 (11.6)	
Dietary Pattern [2]				NA
Not on a particular diet	56 (22.5)	167 (67.1)	26 (10.4)	
Vegetarian, pescatarian or vegan	3 (15.8)	11 (57.9)	5 (26.3)	
Gluten/wheat/dairy/egg-free	2 (20)	8 (80)	0 (0)	
Other	1 (12.5)	5 (62.5)	2 (25)	

Abbreviations: n – number of participants, MELAA – Middle Eastern/Latin American/African.

[1] The remaining 31 participants were of Pasifika, MELAA or Other ethnicity.

NA – Chi-square test was invalid due to a high expected count <5.

Iron intake

Table 7 lists all food group categories and their median consumption frequencies per characteristic group of participants. Vegetables, dairy & dairy alternatives, and breads and cereals were the food groups eaten the most frequently, with the first two having a median consumption frequency of 18.50 times per week and the latter 15.69 times per week. Red meat was the type of meat consumed most frequently, with a median of 5.81 times a week, while other meat (e.g., chicken, duck and sausage) was consumed 3.75 times a week. Participants consumed seafood 1.13 times per week. Legumes, eggs, nuts & seeds, and iron-fortified foods had similar median consumption frequencies of 7.25 and 7.38 times per week, respectively. Fruits were consumed half as much as vegetables, with a frequency of 9.63 times per week. Participants consumed tea and coffee infrequently, with a median frequency of 0.125 times per week.

No significant differences were found between age and the median consumption frequency of any food group among participants. Significant differences between ethnic groups and the median consumption frequency of food groups were prevalent. Asian participants consumed seafood significantly more frequently than New Zealand Europeans (1.88 times vs. 0.75 times per week, *P* = <0.001), as well as eating more legumes, eggs, nuts, and seeds than both New Zealand European (15.75 vs. 6.25 times per week, *P* = <0.001) and Māori participants (15.75 vs. 7.25 times per week, *P* = 0.0013). Māori participants were found to have a significantly higher consumption of iron-fortified foods than both New Zealand Europeans (11.13 vs. 7.13 times per week, *P* = 0.012) and Asians (11.13 vs. 4.19 times per week, *P* = <0.001). Breads and cereals were eaten significantly more frequently by Asians than New Zealand Europeans (21.75 vs. 15.00 times per week, *P* = 0.025). Māori participants consumed significantly more dairy and dairy alternatives than New Zealand Europeans (24.00 vs. 18.31 times per week, *P* = 0.030). Lastly, tea and coffee were consumed more frequently by Asian participants than by New Zealand Europeans (0.63 vs 0.13 times per week, *P* = 0.019).

Participants from decile 8-10 schools consumed significantly more red meat (6.00 vs. 5.13 times per week, U = 8680, *P* = 0.009), seafood (1.25 vs. 0.75 times per week, U = 8677, *P* = 0.024), and fruit (11.88 vs. 6.56 times per week, U = 8818.5, *P* = 0.021) than participants from decile 4-7 schools. Participants who followed a vegetarian, pescatarian, or vegan dietary pattern ate significantly less red meat (0.13 vs. 6.00 times per week, *P* = <0.001), other meat (0.13 vs. 4.00 times per week, *P* = <0.001), and seafood (0.00 vs. 1.13 times per week, *P* = 0.013) than those who did not follow a particular diet. Vegetarian, pescatarian and vegan participants also ate less red meat (0.13 vs. 5.88 times per week, *P* = 0.002) and other meat (0.13 vs. 3.69 times per week, P = 0.008) than gluten/wheat/dairy/egg-free participants and less other meat than the ‘other’ dietary pattern participants (0.13 vs. 4.06 times per week, *P* = <0.001). Vegetarians, pescatarians, and vegans consumed tea and coffee significantly more frequently than participants not following a particular diet (1.00 vs. 0.13 times per week, *P* = 0.002).

Table 7 – Food group consumption frequency per week by characteristic

Characteristic	Food Group Frequency									
	Red meat	Other meat	Fish & seafood	Legumes, eggs, nuts & seeds	Iron-fortified foods	Fruits	Vegetables	Breads & cereals	Dairy & dairy alternatives	Tea & coffee
Age (years) ‡										
11-12	6.00 (3.59, 10.44)	3.06 (1.53, 6.22)	1.69 (0.59, 3.09)	8.38 (4.19, 16.69)	6.07 (2.26, 11.60)	11.56 (6.00, 21.50)	18.19 (10.19, 33.81)	20.25 (6.56, 31.81)	19.69 (10.03, 23.28)	0.13 (0.00, 0.63)
13-14	5.75 (3.25, 9.00)	3.75 (2.50, 6.00)	1.00 (0.25, 2.00)	7.00 (3.75, 13.38)	7.50 (3.44, 12.57)	9.38 (4.25, 24.38)	20.25 (10.56, 31.53)	17.25 (10.81, 23.75)	18.56 (9.66, 28.22)	0.13 (0.00, 1.50)
***P*-Value [a]**	*0.682*	*0.326*	*0.134*	*0.373*	*0.970*	*0.279*	*0.872*	*0.569*	*0.767*	*0.379*
Ethnicity [1] ‡										
NZ European	5.63 (3.13, 8.63)	4.00 (2.50, 6.00)	0.75 (0.25, 1.63)	6.25 (3.50, 11.88)	7.13 (3.38, 11.75)	9.38 (4.22, 21.56)	18.81 (10.34, 29.19)	15.00 (9.63, 21.88)	18.31 (10.03, 25.31)	0.13 (0.00, 1.00)
Māori	6.13 (4.00, 10.38)	3.63 (1.69, 6.06)	1.25 (0.63, 2.00)	7.25 (4.94, 12.06)	11.13 (7.50, 19.91)	14.00 (4.06, 24.69)	24.13 (10.75, 43.19)	18.75 (10.38, 32.44)	24.00 (16.19, 40.56)	0.13 (0.00, 1.25)
Asian	9.00 (3.25, 12.63)	3.50 (1.75, 6.13)	1.88 (0.88, 4.13)	15.75 (8.09, 20.97)	4.19 (1.13, 8.01)	11.13 (6.00, 32.25)	22.63 (10.38, 35.00)	21.75 (12.00, 29.50)	16.00 (8.50, 32.0)	0.63 (0.13, 3.13)
***P*-Value [b]**	*0.034*	*0.818*	*<0.001*	*<0.001*	*<0.001*	*0.351*	*0.235*	*0.015*	*0.031*	*0.016*
School Decile ‡										
4 – 7	5.13 (3.00, 7.63)	3.75 (2.00, 6.00)	0.75 (0.25, 1.63)	6.63 (4.03, 13.38)	6.63 (1.88, 14.32)	6.56 (3.50,1 8.25).	17.13 (10.38, 28.22)	15.69 (10.59, 23.84)	19.88 (10.56, 31.66)	0.31 (0.00, 2.50)

8 – 10	6.0 (3.63, 10.13)	3.69 (2.13, 6.00)	1.25 (0.38, 2.63)	8.13 (3.8, 14.56)	7.38 (3.60, 11.72)	11.88 (5.03, 25.09)	21.56 (10.75, 33.88)	16.00 (10.19, 25.25)	18.25 (9.56, 26.44)	0.13 (0.00, 1.00)
***P*-Value [a]**	*0.009*	*0.868*	*0.024*	*0.576*	*0.893*	*0.021*	*0.234*	*0.548*	*0.202*	*0.169*
Dietary Pattern [2 ‡]										
I am not on a particular diet	6.00 (3.75, 9.75)	4.00 (2.50, 6.13)	1.13 (0.50, 2.31)	7.25 (3.75, 13.50)	7.44 (3.19, 11.72)	9.63 (4.31, 22.88)	18.38 (10.38, 30.75)	15.81 (10.13, 24.53)	19.63 (11.06, 27.81)	0.13 (0.00, 1.00)
Vegetarian, Pescatarian or Vegan	0.13 (0.00, 2.09)	0.13 (0.00, 0.84)	0.00 (0.00, 0.47)	10.69 (5.38, 29.19)	5.75 (3.25, 16.25)	11.13 (3.44, 19.44)	28.13 (22.56, 34.88)	15.00 (10.75, 21.63)	13.88 (7.69, 24.94)	1.00 (0.56, 4.38)
Gluten/Wheat /Dairy/Egg-free	5.88 (3.38, 9.72)	3.69 (1.03, 6.50)	1.38 (0.94, 7.34)	8.31 (3.13, 17.97)	6.88 (4.16, 16.53)	31.25 (8.84, 47.38)	24.50 (8.59, 44.06)	14.75 (11.53, 21.87)	4.44 (1.09, 24.94)	0.56 (0.50, 1.00)
Other	7.69 (1.63, 11.53)	4.06 (3.03, 7.13)	0.13 (0.00, 1.59)	5.56 (3.38, 13.44)	8.88 (1.47, 15.41)	13.81 (6.66, 35.66)	19.56 (13.50, 42.97)	25.19 (14.59, 29.31)	18.75 (14.06, 30.00)	0.88 (0.00, 3.13)
***P*-Value [b]**	*<0.001*	*<0.001*	*0.012*	*0.063*	*0.802*	*0.299*	*0.139*	*0.765*	*0.138*	*<0.001*

Abbreviations:
[a]*P*-value from Mann-Whitney test
[b]*P*-value from Kruskal Wallis test
‡Median (25^{th}, 75^{th} percentile)

Association between iron intake and knowledge

Table 8 illustrates food group consumption frequencies according to iron knowledge score category. No significant differences between participants' iron knowledge score category and consumption frequency of any food group were observed (P = >0.05)

__Table 8__ - Food group consumption frequency per week by knowledge score category

Iron knowledge score category	Food Group Frequency									
	Red meat	**Other meat**	**Fish & seafood**	**Legumes, eggs, nuts & seeds**	**Iron-fortified foods**	**Fruits**	**Vegetables**	**Breads & cereals**	**Dairy & dairy alternatives**	**Tea & coffee**
Low iron knowledge (0-5) ‡	5.75 (4.00, 9.19)	3.63 (1.63, 5.75)	1.00 (0.38, 1.94)	6.38 (2.88, 12.00)	8.13 (2.88, 16.57)	9.25 (4.25, 29.69)	18.38 (10.25, 34.00)	14.00 (7.31, 26.13)	20.13 (9.38, 30.69)	0.13 (0.00, 1.00)
Moderate iron knowledge (6-12) ‡	6.13 (3.25, 9.94)	4.00 (2.50, 6.13)	1.13 (0.28, 2.25)	7.56 (3.75, 14.00)	7.13 (3.38, 11.57)	10.19 (4.38, 24.38)	18.06 (10.16, 29.59)	15.63 (10.91, 24.41)	18.38 (8.63, 26.44)	0.31 (0.00, 2.50)
High iron knowledge (13-18) ‡	4.25 (2.91, 8.00)	3.38 (1.84, 4.38)	1.13 (0.44, 1.94)	7.25 (3.97, 16.22)	7.01 (3.03, 13.22)	10.44 (4.44, 21.13)	23.44 (13.91, 33.53)	19.25 (11.41, 25.72)	20.06 (11.28, 29.00)	0.19 (0.00, 1.00)
***P*- Value**	*0.126*	*0.182*	*0.826*	*0.399*	*0.671*	*0.868*	*0.330*	*0.301*	*0.553*	*0.755*

Abbreviations:
‡Median (25th, 75th percentile)

Discussion

Summary of key findings

To the best of the author's knowledge, this is the first study within New Zealand to analyse the level of iron literacy among 11–14-year-old females. It is also one of the few studies to analyse this age group's consumption frequency of iron-rich foods. The study aimed to analyse iron literacy levels and dietary intakes of iron-rich foods and any possible associations between these two variables. A key finding from this study was a median iron knowledge score of 8.5 out of 18 (47%) among participants, indicating a moderate iron literacy level. The food groups most frequently consumed per week were dairy & dairy alternatives (18.5 times), vegetables (18.5 times), and breads and cereals (15.7 times). No associations were found between iron knowledge and the consumption frequency of any food group. Overall, the level of iron knowledge currently does not relate to dietary intakes of iron-rich foods in female adolescents in New Zealand.

Iron knowledge

The median iron knowledge score from the current study was 47%, which is lower than the score concluded by Leonard et al. (2014), whose participants had a mean knowledge score of 59%. It was hypothesised that iron knowledge scores overall would be low, which these data somewhat support. The higher knowledge scores achieved by participants in the study by Leonard et al. (2014) could be explained by the age differences, with Leonard's study assessing 18-35-year-old females, whereas the current study assessed females aged 11-14 years. In addition, differences in questionnaire design, primarily the more frequent use of true/false questions compared to the multiple-choice questions used in the current study may have influenced knowledge score results. Despite this, participants from both studies followed a similar trend, with most participants scoring in the moderate knowledge score category, followed by the low knowledge score category and, lastly, the high knowledge score category. In line with Leonard et al. (2014), the results of this study demonstrated that vegetarians had higher iron knowledge scores than non-vegetarians. This is proposed to be due to vegetarians and vegans researching nutrients of concern related to their dietary pattern, or this finding may simply be due to these participants being intrinsically more health and nutrition-conscious (Bedford and Barr, 2005).

Regarding iron literacy, 59% of participants from this study knew iron function in the body, similar to Roncolato et al. (1998), whose study found that 54.1% of their participants had a good awareness of this topic. Signs of ID were understood by 78% of our participants, which is slightly lower than the results reported by Wiafe et al. (2021), where 86% of participants knew of the common symptoms of IDA. Verma and Baniya (2022) had conflicting results, with below 50% of adolescent females understanding the symptoms of ID. Lacking knowledge of iron function and IDA symptoms are concerning in this population group due to being at higher risk of developing ID or IDA. Awareness around these topics should be encouraged to help adolescent girls understand the importance of consuming enough iron and what symptoms may occur when this does not happen. Understanding symptoms of ID/IDA is especially important because these are often missed or confused with an active teenager's daily life, where they may experience some tiredness, fatigue, or even look pale.

Within our study, 40% of participants understood vegetarian sources of iron, which is significantly more than the 14.6% of participants reported by Roncolato et al. (1998). Poorly understood iron topics in the current study were surrounding haem and non-haem iron food sources (13% answered correctly), iron absorption enhancers (23% answered correctly), and iron absorption inhibitors (14% answered correctly). However, these findings were higher than those of Wiafe et al. (2021), where 18% of participants knew about iron absorption enhancers, while only 0.7% knew about iron absorption inhibitors.

A probable cause of variation between the different study results is likely due to the range of iron knowledge questionnaires used in each research study. While the topics are relatively the same, the questions for each study were different; some did not provide answer choices, some conducted multi-choice (like the current study), and some used true/false questions. The most similar questionnaire to the current study is Leonard et al. (2014); however, this study did not go into detail about knowledge of specific iron topics among their participants. Accurate comparisons of iron knowledge topics would require a validated questionnaire that could be used as a template for future studies.

The sound understanding of iron topics, such as dietary iron function, signs of deficiency, and requirements for particular groups among the participants in the current study indicates that these messages are being communicated well to this age group in New Zealand. These may be acquired from internet sources by organisations such as NZ Nutrition Foundation, Beef + Lamb NZ, or NZ Vegetarian Society. They may alternatively be acquired by teachings in the school environment. In saying this, nutrition classes (home economics) are not always available to take in schools around New Zealand and are not a compulsory subject for students in NCEA. Furthermore, dietary iron education is not specifically outlined in the curriculum for students taking home economics classes. In comparison, the topics shown to be poorly understood, such as haem and non-haem iron and iron absorption enhancers and inhibitors, indicate that the communication of knowledge is currently at a basic level. Despite being more complex topics, knowing the different types of iron, as well as foods which can enhance or inhibit iron absorption, is vital in maintaining good iron status for these young adolescent individuals in the future. The current study found that 13–14-year-olds had significantly higher iron knowledge than those aged 11-12. This finding may be due to the increased accessibility to food and nutrition classes and, therefore, education about nutritional iron, at the college education level. Alternatively, this finding could be attributed to the common assumption that older age is often associated with more complex thinking and, therefore, higher knowledge (Stanford Medicine, 2022).

Iron intake

Food group consumption frequency patterns helped to estimate dietary intakes of iron-rich foods among young adolescents in this study. Participants' most frequently consumed foods were vegetables, dairy & dairy alternatives, and breads and cereals. These findings align with the Ministry of Health food and nutrition guidelines, in which vegetables and grain foods are the groups with the highest recommended daily servings (Ministry of Health, 2020).

Food groups analysed from the iron FFQ, which have high iron content, include red meat; other meat; seafood; iron-fortified foods; and legumes, eggs, nuts, and seeds. The current study found that participants from particular ethnic groups, higher decile schools, and those following specific dietary patterns ate these iron-rich food groups significantly more frequently. Asian participants ate seafood more frequently than New Zealand Europeans and ate legumes, eggs, nuts & seeds more frequently than both New Zealand European and Māori participants. The higher consumption of seafood by Asians can be supported by data that looked into consumer purchasing behaviours of those from New Zealand and overseas. This found that Chinese and Japanese respondents were more likely to purchase seafood than those from New Zealand (Ministry for Primary Industries, 2019). Therefore, this finding could be assumed to align ethnically, with Asians living in New Zealand consuming more seafood. Māori participants ate iron-fortified foods more frequently than New Zealand European and Asian participants, likely indicating a higher intake of iron-fortified breakfast cereals, which made up the majority of the food group in the provided questionnaire.

Participants from higher decile (8-10) schools significantly consumed more red meat, seafood, and fruit than those from moderate decile (4-7) schools, indicating that they may have higher iron intakes due to eating iron-rich foods, as well as iron absorption enhancers. This finding may also align with the assumption that students from higher decile schools are more likely to be of higher socioeconomic status and are more likely to afford more expensive foods such as red meat, seafood, fruit, and vegetables. Consuming these foods could improve these students' iron status; however, we cannot extrapolate these findings, nor can it be known whether iron status would be better based on these consumption frequency findings. As such, this remains an area in need of further investigation. Lastly, vegetarians, pescatarians and vegans ate less red meat, other meat, and seafood than those not on a particular diet, which is in line with their dietary pattern's prescription. Due to vegetarians and vegans not consuming these iron-rich food groups, it could be assumed that these participants' iron status may be negatively impacted. However, iron status was not a measure in the current study; therefore, the impact of this dietary pattern on quantified iron status remains to be investigated.

Common iron enhancers are predominantly found in red meat, other meat, seafood, fruit, and vegetable food groups. As mentioned, participants from higher decile schools may have higher iron intake not only due to the high iron content in some of these groups but due to a MFP factor and Vitamin C, which are known to be key iron enhancers for non-haem iron food sources (Hurrell and Egli, 2010, Coad and Pedley, 2014). Known iron inhibitors are found in breads and cereals, dairy and dairy alternatives, legumes, eggs, nuts and seeds, and coffee and tea food groups. While legumes, eggs, nuts, and seeds are good sources of iron, the phytates in some foods, such as legumes, are simultaneously inhibitory factors. In the current study, Asian participants ate this food group and breads and cereals most frequently. Therefore, it is important for future researchers to consider the impact of iron and iron absorption inhibitors when they are both present in foods such as legumes and keep this in mind when reviewing iron status in adolescent females who consume large amounts of these.

Vegetarians, pescatarians and vegans drank significantly more coffee and tea than those not following a particular diet. Participants of these dietary patterns primarily consume non-haem sources of iron (excluding fish consumption by pescatarians), which already have a reduced absorption rate compared to haem iron (Mantadakis et al., 2020, Ministry of Health, 2014). Therefore, by having increased intakes of foods/drinks like coffee and tea, which contain iron absorption inhibitors, it can be assumed that these individuals are more likely to have poorer iron status. In saying this, minimal research has looked into the exact effect that coffee and tea consumption have on iron status (Mennen et al., 2007, Temme and Hoydonck, 2002). Future research should seek to discover this exact effect, extending knowledge that tea and coffee contain iron-inhibiting components to looking at their impact on iron status in this cohort from a dose-dependent view.

Association between iron intake and knowledge

An association between dietary intakes of iron-rich foods and iron knowledge failed to be concluded in this study and therefore conflicts with our original hypothesis; that a positive relationship between the two variables would be observed. Intakes of any iron-rich food groups, namely, red meat; other meat;

seafood; iron-fortified foods; and legumes, eggs, nuts, and seeds, were not significantly higher in participants who scored high in the iron literacy section. This finding is supported by Rastogi et al. (2019), who observed no significant relationship between nutrition knowledge and practices among their 13-15-year-old cohort. However, this current study was focused on general food groups, not specifically iron knowledge and practices. In comparison, other studies found positive associations between iron knowledge and intake, such as Wiafe et al. (2021), who observed that those with good knowledge of iron-rich foods had a higher intake of chicken and fish; however, this was an insignificant association. Similarly, Leonard et al. (2014) observed a positive correlation between nutrition knowledge and iron intake; however, they did not find an association between nutrition knowledge and whether the women met the RDI for iron or had higher iron status. The Theory of Planned Behaviour suggests that knowledge does not often translate into changes in behaviour (Ajzen, 1991). Instead, changes in behaviour require the achievement of perceived behavioural control and changes in attitude. Therefore, research that considers individuals with higher iron knowledge to have higher iron intakes essentially assumes that the participants have high perceived behavioural control or the attitude to be aware of their iron intake and consciously make efforts to motivate themselves to eat high amounts of iron-rich foods. It is often that an intervention would be necessary to change these factors, which the current and previous studies did not conduct, due to the observational nature of the methodology. As such, there is likely to be high variability in the association between iron knowledge and dietary iron intake. Additionally, students aged 11-14 do not receive mandatory nutrition education in schools, so the current study's findings were likely based on the student's knowledge of iron sourced from independent learnings.

Conclusion

In conclusion, the current study found that among the participants, iron knowledge scores were low-moderate, with a median score of 47%. Knowledge scores differed significantly among demographic groups, with higher scores seen among vegetarian, pescatarian and vegan participants, as well as the 13–14-year-old participants. The findings from this study somewhat agree with our hypothesis that iron knowledge scores would be low overall.

The most frequently consumed food groups included vegetables and dairy & dairy alternatives, followed by breads and cereals. Significant differences in consumption frequencies of food groups were found among various ethnic groups. Seafood and legumes, eggs, nuts and seeds were eaten more frequently by Asian participants, and iron-fortified foods were eaten more frequently by Māori participants. Additionally, participants from decile 8-10 schools were found to consume red meat, seafood, and fruit more frequently than those from decile 4-7 schools. Lastly, vegetarians, pescatarians and vegans consumed tea and coffee more frequently than those not on a particular diet.

Overall, no significant association was seen between iron knowledge score and intake of iron-rich food groups among participants in this study. This finding contradicts our hypothesis that those who had higher iron knowledge scores would have higher intakes of iron-rich foods.

Chapter 4: Conclusion & Recommendations

Achievement of aims & hypotheses

The overall aim of the study was to determine iron literacy and associations with dietary intakes of iron-rich foods in intermediate and secondary school females aged 11-14 years in New Zealand.

The low-moderate scores (47%) among participants in the iron literacy questionnaire suggest that iron knowledge among this age group is poor, aligning with our hypothesis that iron knowledge scores would be low. Existing literature for females aligns with this statement, observing scores of approximately 59% for a similar questionnaire, however, in a significantly older cohort (18-35 years old) (Leonard et al., 2014). Iron literacy scores from different questionnaires produced results indicating that more than half of their adolescent female participants had insufficient knowledge of dietary iron sub-topics (Verma and Baniya, 2022). These various questionnaires may therefore be a confounding factor for variability in results between studies.

Knowledge of iron sub-topics, for example, iron function in the body, was demonstrated by just over half of our participants (59%), which is in line with previous research (Roncolato et al., 1998). Results regarding signs of iron deficiency are varied in the literature, ranging from approximately 50-86%, in which the current study's result of 78% is in the upper-middle range (Wiafe et al., 2021, Verma and Baniya, 2022). Vegetarian food sources were understood by 40% of participants, showing a higher level of understanding in comparison to previous literature (Roncolato et al., 1998). Poorly understood iron sub-topics included iron absorption enhancers (23% correct) and iron absorption inhibitors (14% correct). Despite a poor understanding of these, the current study's participants had a much higher knowledge level than other reported results in the literature (Wiafe et al., 2021). Probable reasons for the current study's participants achieving higher knowledge scores could be due to the variability seen in different questionnaires. The types of questions used, whether written answer, true/false or multi-choice, would have resulted in variability due to some being more/less straightforward or suggestive than others. Another reason the current study may have shown better results could simply be an indication that adequate educational materials on dietary iron function and ID are being created and seen by this cohort in New Zealand versus overseas. Future efforts should look to investigate where adolescent females in New Zealand are obtaining their knowledge about dietary iron from. Despite this, the areas not well-understood, such as iron absorption enhancers and inhibitors, prove that further resources and teachings are required to ensure well-rounded knowledge about dietary iron among young adolescent girls.

Food group consumption frequencies retrieved from our iron FFQ were able to identify consumption patterns of key food groups and the frequency of iron-rich food groups to estimate iron intake in our participant cohort. Demographic characteristics were not associated with the overall intake of multiple iron-rich food groups or iron absorption enhancers. However, characteristic groups such as ethnicity and dietary pattern were found to have significantly different consumption frequencies among singular food groups.

No association was found between iron knowledge score and iron-rich food group consumption frequency, which is not in line with our hypothesis - that participants with a higher knowledge score would have a higher estimated iron intake. Currently, this finding only aligns with one known study which focused on this association in young adolescent females aged 11-14 years (Rastogi et al., 2019). Other research looking at similar associations between iron knowledge and iron intake has found positive, but not always significant, associations between these two variables (Wiafe et al., 2021, Leonard et al., 2014). These insignificant findings show that the link between knowledge and practice is not straightforward. Multiple steps exist in between in order to change attitudes and then behaviours in individuals, especially those who are young and have limited control over factors such as purchasing and food choice. Young adolescent females must be set up with adequate knowledge of dietary iron, but they also require practical learning and familiarisation with these iron-rich foods to practice positive intake behaviours.

Overall, the study's aim was achieved, providing a good perspective of iron knowledge among young adolescent females in New Zealand, and its relationship with the intake of iron-rich foods.

Strengths

A notable strength of the current study is that, to our knowledge, it is the first study to look at young adolescent females' iron literacy levels in New Zealand. Additionally, it is the first study in New Zealand to look at the food consumption frequency of iron-rich food groups in 11-14-year-old females since the 2002 National Children's Nutrition Survey (Ministry of Health, 2003). Overall, existing literature on the topics of iron literacy and iron intake is sparse among adolescent females, but especially among younger females <15 years old. Available and up-to-date research is essential for the young female population from an ID-preventative perspective. This study contributes a New Zealand perspective to the current international literature available.

Another strength of the current study is the ethnic and geographical distribution of participants. An ethnic distribution that accurately represents the New Zealand population was a goal of the study. The current study's participants well-reflected the diverse ethnic population of New Zealand (Environmental Health Intelligence New Zealand, 2022). Geographically, participants were from a range of cities, covering both the North and South Island of New Zealand. This sample, therefore, allows for our findings to be communicated and generalised appropriately and accordingly to adolescent females throughout New Zealand.

The use of an online questionnaire is a strength of the study due to its reach across New Zealand. All 60 eligible all-girls schools were reached out to, providing an increased opportunity for the study to meet a statistically significant sample size of 286 participants. Additionally, this method allowed for participant anonymity and accessibility on any student's device.

Limitations

The current study utilised an online FFQ to attain data on dietary intakes of iron-rich foods from participants. When using an FFQ to translate consumption frequency to nutrient intake, there are some limitations and inaccuracies. Firstly, as a non-quantitative FFQ was used, only frequencies were attained, not portion sizing. Some participants may eat multiple serving sizes of one food in one sitting, and others may eat less than one serving. This proves difficult when only reporting frequencies, as one participant's frequency may differ significantly from another's. Another consideration is that different brands and types of foods will have varying iron content, especially if the participants were unsure whether a food item was iron-fortified (O'Hara et al., 2004). It should also be noted that both the iron knowledge questionnaire and iron FFQ used in the current study cannot be acknowledged as validated tools. This is due to the amendments made to shorten the previously validated non-quantitative FFQ by Beck et al. (2012).

Another possible limitation of using an FFQ is respondent errors. Respondent errors could be frequent throughout the questionnaire due to the retrospective method, spanning over one month of eating, which can be hard to recall accurately. The potential for over- or under-estimation is also very likely. Due to the length of the FFQ covering 106 food categories, participants, especially those of this age, may have experienced survey fatigue and put less thought into their answers towards the end of the questionnaire, providing potentially inaccurate answers.

A final limitation of the current study concerning the demographic captured was that participants who attend a decile 1-3 school could not be recruited. Therefore, our findings cannot be extrapolated to assume that participants from lower decile schools have a lower intake of red meat, seafood and fruit based on the significant differences seen between decile 4-7 schools and 8-10 schools.

Recommendations

Due to the current study showing that iron knowledge scores are low-moderate among this age group, it is evident that further research and awareness around dietary iron is required among the New Zealand young adolescent population. Future research should focus on validating these findings within New Zealand, with the addition of quantitative research methods to ensure a more accurate depiction of iron intakes among young adolescent females.

- If using an FFQ, it is important to use semi-quantitative methods which measure portion sizing. Additionally, the creation and/or validation of a tool that can translate food frequencies into the corresponding iron intake (mg) for foods in New Zealand will provide a more accurate depiction of intake. Similar work has been completed by Głąbska et al. (2017), who validated a semi-quantitative FFQ using serving sizes, allowing for iron content per serving to be calculated.

- Another method that may be more accurate at measuring iron intake is using 24-hr food recalls. Despite the extra time required, these are much more accurate in seeing one's detailed food intake. To accurately depict one's usual intake, approximately 3 - 10+ days' worth of a food recall should be conducted, with suggestions of approximately 11 days to get an accurate depiction of iron intake (Willett, 1998).

- Further research on iron knowledge and intakes of iron-rich foods in this population should be conducted in New Zealand throughout schools of varying deciles and authority types. Participants should aim to be recruited from both co-educational and girls-only schools and be from a variety of subject classes.

- Iron intake should be measured against iron status to see the correlation between these two variables and to get an up-to-date estimation of iron deficiency among the young adolescent female population in New Zealand.

- If conducting iron-related nutrition interventions, the focus should be not only on the provision of iron knowledge but also on active ways of improving attitudes and intentions and enhancing perceived behavioural control to change iron intake behaviours. Examples could include interactive workshops, cooking lessons, and meal planning. These interventions would allow adolescents to retain information more effectively through practical learning while also enhancing skills and improving attitudes and behaviours towards food.

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Appendices

Appendix A: Questionnaires and material used in conducting the research

A1) Study information sheet

MASSEY UNIVERSITY
COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

SCHOOL OF SPORT, EXERCISE AND NUTRITION

Iron intakes and knowledge among female school students aged 11-14 years old in New Zealand.

INFORMATION SHEET

Researcher Introduction and Invitation

Kia Ora, my name is Renee Jansen, and I am a Master's student studying Nutrition and Dietetics at Massey University. I am completing a study for my thesis to investigate current iron literacy and iron intakes in intermediate and secondary school females aged 11-14 years in New Zealand.

This information sheet is an invitation for your child to participate in the research. Please read it fully before deciding whether you would like your child to participate. Please ensure that your child knows that you are signing this and that they are also comfortable participating.

If you would like further details about the study or if you have questions, please feel free to contact the primary researcher:

Renee Jansen
Masters' student/Primary researcher
Massey University, Albany
Email: R.jansen1@massey.ac.nz

Study Description

This research project is focused on determining dietary intake patterns and level of iron knowledge among young adolescent females aged 11-14 years old in New Zealand. It is known that almost a third of adolescent girls in New Zealand are not meeting their iron requirements each day. A consequence of persistent low iron intake is iron deficiency. Individuals that present with iron deficiency often experience fatigue, decreased concentration, poor moods, weakness, dizziness, and headaches.

Participant Identification and Recruitment

Participants for this research study are being recruited from both intermediate and secondary schools around New Zealand.

We are hoping to recruit 300 students to participate in this study. To take part in the study, your child must be:

- Female
- 11-14 years old
- Attending an all-girls intermediate or secondary school in New Zealand.

What will your child be asked to do?

This research will involve your child completing a three-part questionnaire on iron knowledge and dietary iron intake. These questions will help identify key areas where iron nutrition and knowledge could be improved in young females. By finding these gaps in education provided to young girls, we can illustrate the importance of teaching iron education, which may help achieve better iron status among children in New Zealand.

This questionnaire will take approximately 20-30 minutes of your child's time when at home. They will be able to complete the questionnaire on their own phone, tablet or laptop/computer. They will be able to access the questionnaire on their device either by QR code or through a link sent to them by the researchers via their teacher. In return for class participation, we will provide a free lunch following completion of the questionnaire.

There are no risks to your child during the data collection process of this study. However, we do wish to inform parents that there is a question about menstruation that may be uncomfortable for young females to answer. All answers will be anonymous, and your child may skip a question if they want to, as there are no forced responses.

Please be aware that this is not a test for your child. However, it is important that they answer truthfully without guessing or searching answers (e.g. using the internet). This is to help us get the most accurate information from the questionnaire. We also ask that you do not assist them in answering any of the questions.

Data Management

The data from the questionnaire will be stored securely in survey software program and on password protected computers and folders that will only be accessible by the research team.

Collected data will be used to determine iron intake and knowledge about iron among female adolescents. It will then be summarised and reported in a thesis, as well as presented to third party companies. Since all data will be anonymous no results will reveal any personal details about your child.

Data will be disposed after 10 years. A summary of the project findings will be available to all participants and their parents at their request.

Participant's Rights

Both your consent and your child's consent are required prior to the completion of the questionnaire. We ask that you both read this information sheet and that you both provide consent at the beginning of the questionnaire if you and your child are happy to be involved in the study. During the completion of the questionnaire your child has the right to decline to answer any particular question and can withdraw from the questionnaire at any point.

Project Contacts

If you have any further questions about this study, please contact the researchers or supervisors below:

Primary Researcher: Renee Jansen
R.jansen1@massey.ac.nz

Co-Researcher: Jerushah Keightley
J.keightley@massey.ac.nz

Supervisor:Dr Claire Badenhorst
C.badenhorst@massey.ac.nz

Supervisor: Professor Pamela Von Hurst
P.R.vonHurst@massey.ac.nz

Low risk ethics compulsory statement

This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher(s) named in this document are responsible for the ethical conduct of this research. If you have any concerns about the conduct of this research that you want to raise with someone other than the researcher(s), please contact Professor Craig Johnson, Director (Research Ethics), email humanethics@massey.ac.nz.

A2) Demographic & general health questions

How old are you?
- 11 - 12 - 13 - 14
What ethnicity(s) do you associate with?
- New Zealand European - Māori - Samoan - Cook Islands Māori - Tongan - Niuean - Chinese - Indian - Other
What is the name of your class and what school do you go to?
(Text entry)
How would you describe the way you prefer to eat?
- Vegetarian (Doesn't eat meat or fish but does eat other animal products such as dairy and eggs). - Vegan (Doesn't eat any animal products – eg. no meat, dairy or eggs). - Pescatarian (Doesn't eat meat but will eat fish and other animal products such as dairy and eggs). - Gluten/Wheat Free - Dairy Free - Egg Free - Low FODMAP - Diabetic Diet - Other (Text entry) - I am not on a particular diet
Are you taking any vitamins or medication?
- Yes – what are they called? (Text entry) - No - Don't know
Have you had your first menstrual bleed/period?
- Yes (Can you provide the age you were when you had it?) (Text entry) - I have not had my first period yet

A3) Iron literacy questionnaire section

What does iron do in the body?
- Helps you see in the dark, increases your memory. - **Increases energy, immunity, brain function, growth, and development. (1 point)** - Prevents cancer, strengthens bones and speeds up your metabolism. - It is an antioxidant and helps to lower blood pressure. - Don't know
What are three things that may happen if you don't get enough iron from food? Choose three answers from the list below:
- **Weakness (1 point)** - **Poor concentration (1 point)** - Coughing - Dry skin - **Tiredness (1 point)** - Itchiness - Oily hair - Don't know
Do females or males need more iron?
- **Females (1 point)** - Males - Don't know
Do menstruating females (females who have their period) or non-menstruating females (females who do not have their period) need more iron?
- **Menstruating females (1 point)** - Non-menstruating females - Don't know
What is the difference between haem iron and non-haem iron? Choose two answers from the list below:
- Haem iron is found in plant foods, whereas non-haem iron is found in animal foods. - **Haem iron is found in animal foods, whereas non-haem iron is found in plant foods. (1 point)** - **Haem iron is more easily absorbed by humans than non-haem iron. (1 point)** - Non-haem iron is more easily absorbed by humans than haem iron. - Don't know

Which of these foods are good sources of iron? Choose any of the food below that you think contains iron.
- **Chickpeas (1 point)** - Apples - **Lamb (1 point)** - **Oysters (1 point)** - Milk - Green beans - **Chicken (1 point)** - Don't know
Which of these vegetarian foods are good sources of iron? Choose any food below that you think contains iron.
- Onions - **Baked beans (1 point)** - **Lentils (1 point)** - Vegetable stock - **Spinach (1 point)** - **Eggs (1 point)** - Cheese - Don't know
Which of these foods do you think helps to increase iron absorption?
- Dairy foods (milk, cheese, yoghurt) - Grain foods (bread, pasta, cereal) - Peanuts, almonds, cashews - **Tomatoes, oranges, capsicum, strawberries (1 point)** - Don't know
Which drink decreases iron absorption?
- **Tea (1 point)** - Fizzy drink - Water - Fruit juice - Don't know

A4) Iron food frequency questionnaire

Meat and chicken	**I never eat this food**	**Less than once a month**	**1 to 3 times a month**	**Once per week**	**2 to 3 times per week**	**4 to 6 times per week**	**Once per day**	**2 to 3 times per day**	**4 plus times per day**
Beef (eg. roast, steak, chops, schnitzel, silverside, casseroles, stir fry, curry, hamburger meat, mince dishes)									
Chicken, turkey or duck (eg. roast, fried, steamed, BBQ, casseroles, stir fry, curry, fried takeaway chicken)									
Lamb, hogget or mutton (eg. roast, steak, chops, BBQ, casseroles, stir fry, curry)									
Pork (eg. roast, chops, steak, casserole, casseroles, stir fry, curry)									
Veal									
Liver, kidney, other offal (including pate)									
Ham, bacon									
Game meats (eg. venison, mutton bird, rabbit)									
Corn beef, canned									

Prepared meat	**I never eat this food**	**Less than once a month**	**1 to 3 times a month**	**Once per week**	**2 to 3 times per week**	**4 to 6 times per week**	**Once per day**	**2 to 3 times per day**	**4 plus times per day**
Beef Jerky / Biltong									
Sausages, frankfurters, saveloys									
Luncheon sausage, salami, brawn, pastrami									
Black pudding									
Meat pies									

Fish and seafood	I never eat this food	Less than once a month	1 to 3 times a month	Once per week	2 to 3 times per week	4 to 6 times per week	Once per day	2 to 3 times per day	4 plus times per day
Fresh and frozen fish (eg. snapper, terakihi, gurnard, flounder, hoki, salmon, white bait, shark, eel)									
Battered and crumbed fish (eg. fish fingers, fish cakes)									
Canned and bottled fish (eg. tuna, salmon, herrings, sardines)									
Mussels, pipi, paua, cockles, oysters									
Scallops, crab sticks, crab, squid, crayfish, kina									
Prawns, shrimps									

Eggs	I never eat this food	Less than once a month	1 to 3 times a month	Once per week	2 to 3 times per week	4 to 6 times per week	Once per day	2 to 3 times per day	4 plus times per day
Eggs – boiled, fried, poached, scrambled, raw and egg-based dishes including quiche, soufflés, frittatas, omelettes									

Nuts	I never eat this food	Less than once a month	1 to 3 times a month	Once per week	2 to 3 times per week	4 to 6 times per week	Once per day	2 to 3 times per day	4 plus times per day
Peanuts, mixed nuts, macadamias, pecans, hazelnuts, brazil nuts, walnuts, cashews, pistachios									
Almonds									
Pumpkin seeds, sunflower seeds, pine nuts									
Sesame seeds, tahini									

Legumes	I never eat this food	Less than once a month	1 to 3 times a month	Once per week	2 to 3 times per week	4 to 6 times per week	Once per day	2 to 3 times per day	4 plus times per day
Tofu, soybeans, tempeh									
Beans in sauce (eg. baked beans, chilli beans)									
Beans (canned or dried) (eg. black beans, butter beans, haricot beans, red kidney beans, white kidney beans, refried beans)									
Lentils									
Peas (eg. chickpeas, hummus, falafels, split peas, cow peas)									
Dahl (all varieties)									

Dairy products	**I never eat this food**	**Less than once a month**	**1 to 3 times a month**	**Once per week**	**2 to 3 times per week**	**4 to 6 times per week**	**Once per day**	**2 to 3 times per day**	**4 plus times per day**
Cheese (eg. Cheddar, Colby, Edam, Tasty, blue vein, camembert, parmesan, gouda, processed)									
Cottage cheese, ricotta cheese									
Cream, sour cream, cream cheese, cheese spreads, fromage frais (all varieties)									
Milk (cow's milk) **as a drink** (eg. flavoured milk, milk shakes)									
Milk (cow's milk) (all varieties) **added to drinks** (eg. in tea, coffee)									
Milk (cow's milk) (all varieties) **added to food** (eg. cereals, dishes such as macaroni cheese, milk puddings such as rice pudding, custard, semolina, instant puddings, dairy food)									
Soy Milk									
Coconut milk									
Yoghurt									
Ice cream									

Fruit	**I never eat this food**	**Less than once a month**	**1 to 3 times a month**	**Once per week**	**2 to 3 times per week**	**4 to 6 times per week**	**Once per day**	**2 to 3 times per day**	**4 plus times per day**
Citrus fruits (eg. orange, tangelo, tangerine, mandarin, grapefruit, lemon)									
Green kiwifruit									
Zespri gold kiwifruit									
Feijoas, persimmon, tamarillos									
Mango									
Pawpaw (papaya), other melons (eg. honey dew, rock melon)									
Pineapple									
Fruit salad, canned									
Strawberries, blackberries, cherries, blueberries, boysenberries, loganberries, cranberries, gooseberries, raspberries									
Sultanas, raisins, currants, figs									
Dried apricots, prunes, dates, mixed dried fruit									

Vegetables	I never eat this food	Less than once a month	1 to 3 times a month	Once per week	2 to 3 times per week	4 to 6 times per week	Once per day	2 to 3 times per day	4 plus times per day
Potato (eg. boiled, mashed, baked, roasted, fried, chips)									
Kumara (eg. boiled, mashed, baked, roasted, fried, chips)									
Green beans, broad beans, runner beans, asparagus									
Broccoli (all varieties)									
Red cabbage									
Cabbage (all varieties), Brussel sprouts									
Capsicum, peppers (all varieties)									
Cauliflower									
Courgette/Zucchini, cucumber, gherkins or marrow (all varieties)									
Radishes (all varieties)									
Tomatoes (all varieties)									
Peas, green									
Spinach, silver beet, swiss chard (all varieties)									
Other green leafy vegetables (eg. watercress, puha, Whitloof, chicory, kale, chard, collards, Chinese kale, Bok Choy)									
Pumpkin, squash, yams									
Parsnip									
Taro leaves (palusami)									

Breakfast cereals or porridge	**I never eat this food**	**Less than once a month**	**1 to 3 times a month**	**Once per week**	**2 to 3 times per week**	**4 to 6 times per week**	**Once per day**	**2 to 3 times per day**	**4 plus times per day**
Porridge, rolled oats, oat bran, oatmeal									
Muesli (all varieties)									
Weetbix (all varieties)									
Cornflakes or rice bubbles									
Bran based cereals (all varieties eg. All Bran, Sultana Bran)									
Light and fruity cereals (eg. Special K, Light and tasty)									
Chocolate based cereals (eg. Milo cereal, CocoPops)									
Sweetened cereals (eg. Nutrigrain, Fruit Loops, Honey Puffs, Frosties)									
Breakfast drinks (eg. Up and Go)									

Grains	**I never eat this food**	**Less than once a month**	**1 to 3 times a month**	**Once per week**	**2 to 3 times per week**	**4 to 6 times per week**	**Once per day**	**2 to 3 times per day**	**4 plus times per day**
White rice									
Brown rice									
Instant noodles									
Pasta, noodles (white)									
Pasta, noodles (whole wheat)									
Couscous, polenta									
Bulgur wheat (eg. tabbouleh)									
Wheat germ, wheat bran (flakes)									

Breads, cakes, biscuits and crackers	**I never eat this food**	**Less than once a month**	**1 to 3 times a month**	**Once per week**	**2 to 3 times per week**	**4 to 6 times per week**	**Once per day**	**2 to 3 times per day**	**4 plus times per day**
White bread and rolls (including specialty breads such as foccacia, panini, pita, naan, crumpets, pizza bases, tortilla's, burrito, roti)									
Brown bread and rolls (including multigrain, wholegrain, whole meal breads)									
Breads fortified with iron (eg. Mighty White Tip Top bread)									
Fruit and currant bread / buns									
White flour muffins (all varieties)									
Whole meal muffins (all varieties)									
Crackers (eg. crisp bread, water crackers, rice cakes, cream crackers, Cruskits, Mealmates									
Iron fortified crackers (eg. Vita wheat)									

Miscellaneous foods and snacks	**I never eat this food**	**Less than once a month**	**1 to 3 times a month**	**Once per week**	**2 to 3 times per week**	**4 to 6 times per week**	**Once per day**	**2 to 3 times per day**	**4 plus times per day**
Marmite									
Peanut butter									
Soup, vegetable based, homemade or canned									
Soup, meat based, homemade or canned									
Milk chocolate									
Dark chocolate									

Non – alcoholic beverages	**I never drink this**	**Less than once a month**	**1 to 3 times a month**	**Once per week**	**2 to 3 times per week**	**4 to 6 times per week**	**Once per day**	**2 to 3 times per day**	**4 plus times per day**
Complan, Sustagen (all varieties)									
Milo									
Coffee (all varieties)									
Black tea									
Herbal tea, fruit tea									
Fruit and vegetable juices (all varieties)									

106 food groups total.

A5) Food groupings from iron FFQ

Food groups from the food frequency questionnaire (FFQ)	
Food Group	**Foods Included**
Red meat	Beef, lamb, hogget, mutton, pork, veal, kidney, liver, other offal, ham, bacon, game meats, black pudding, beef jerky, corned beef.
Other meat	Chicken, turkey, duck, sausages, frankfurters, saveloys, luncheon, salami, brawn, pastrami, meat pies.
Fish & seafood	Fish, mussels, pipi, paua, cockles, oysters, scallops, crab sticks, crab, squid, crayfish, kina, prawns, shrimps.
Legumes, eggs, nuts & seeds	Eggs, peanuts, mixed nuts, macadamias, pecans, hazelnuts, brazil nuts, walnuts, cashews, pistachios, almonds, pumpkin seeds, sunflower seeds, pine nuts, sesame seeds, tahini, tofu, soybeans, tempeh, beans, lentils, peas, dahl, peanut butter.
Iron-fortified foods	Weetbix, cornflakes, rice bubbles, bran-based cereals, light and fruity cereals, chocolate-based cereals, sweetened cereals, breakfast drinks, breads fortified with iron, iron-fortified crackers, marmite, Complan, Sustagen, milo.
Fruits	Citrus fruits, kiwifruit, feijoas, persimmon, tamarillos, mango, pawpaw, melon, pineapple, fruit salad, strawberries, blackberries, cherries, blueberries, boysenberries, loganberries, cranberries, gooseberries, raspberries, sultanas, raisins, currants, figs, dried apricots, prunes, dates, mixed dried fruit.
Vegetables	Potato, kumara, green beans, broad beans, runner beans, asparagus, broccoli, cabbage, brussel sprouts, capsicum, cauliflower, courgette/zucchini, cucumber, gherkins, marrow, radishes, tomatoes, green peas, spinach, silverbeet, swiss chard, other green leafy vegetables, pumpkin, squash, yams, parsnip, taro leaves.
Breads & cereals	Porridge, rolled oats, oat bran, oatmeal, muesli, white rice, brown rice, instant noodles, white noodles or pasta, wholewheat noodles or pasta, couscous, polenta, bulghur wheat, wheat germ, wheat bran, white bread and rolls, brown bread and rolls, fruit bread, white flour muffins, wholemeal flour muffins, crackers.
Dairy & dairy alternatives	Cheese, cottage cheese, ricotta cheese, cream, sour cream, cream cheese, cow's milk as a drink, cow's milk added to drinks, cow's milk added to food, soy milk, coconut milk, yoghurt, ice cream.
Tea & coffee	Coffee, black tea, herbal tea, fruit tea.