Determining the relative validity of a Food Frequency Questionnaire (FFQ) for assessing nutrient intakes against Four-Day Food Diaries (4DFDs) of New Zealand adults following a vegan diet.

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Abstract

Background: In recent years, veganism has gained traction in developed countries. A vegan diet eliminates animal products and animal by-products including milk, yoghurt, cheese, eggs, honey and gelatine. It is often adopted for animal welfare, environmental concern and associated health benefits. As the vegan diet becomes increasingly more common, a validated food frequency questionnaire (FFQ) is needed for future research regarding the health benefits and risks of the vegan diet. To our knowledge the only validated FFQ for the vegan adult population was developed in the USA. This FFQ is unsuitable for use in New Zealand (NZ) due to cultural, ethnic and food supply differences.

Aim: This study assesses the relative validity of a semi-quantitative FFQ for assessing nutrients against a four-day diet recall in vegan adults living in Auckland, New Zealand.

Methods: As a part of The Vegan Health Research Programme, a convenience sample of adults aged >18 years whom had adopted a vegan diet for a minimum of two years, were recruited for a cross-sectional observational study. Participants (n=167) completed both a four-day food diary (4DFD) and FFQ, which were compared for the relative validity of 31 nutrients. Relative validity was assessed using correlation coefficients, paired t-tests or Wilcoxon signed rank test, cross classification and weighted kappa statistic, linear regression and Bland-Altman plots. All 31 nutrients underwent energy adjustment.

Results: Correlation coefficients improved after energy adjustment with values ranging from 0.116 – 0.661. Out of the 31 nutrients, 25 showed improvement in correlation after energy adjustment. Following this, 12 energy-adjusted nutrients were correctly classified (i.e. >50% correctly classified). After energy adjustment, weighted kappa analysis moderately improved the outcomes with values ranging from lowest value 0.149 (caffeine) to highest value 1.10 (vitamin B6 and vitamin E). Of the 31 nutrients assessed, 24 had higher mean intakes in the 4DFD compared to the FFQ. In Bland-Altman and linear regression, the slope of bias was statistically significant (p-value <0.05) for most unadjusted nutrients (n=23). At the same time, energy, protein, total fat, saturated fat, carbohydrate, thiamine, vitamin C, vitamin A, and zinc showed non-significant results (p-value >0.05). For energy adjusted nutrients (n=17), saturated fat (SFA), poly-unsaturated fat (PUFAS), sugars, riboflavin, phosphorus,

and iron were non-significant, indicating that the measurement differences between FFQ and 4DFD were not significantly dependent on mean nutrient intakes.

Conclusion: Despite nutrients iodine, vitamin B6, total folate, niacin equivalents and niacin showing poor correlations, the FFQ was reasonably accurate at measuring relative validity of the remaining 26 nutrients. However, it is noteworthy the FFQ tended to underreported on most nutrients compared to the 4DFD. This FFQ could be used in future research to assess the relative intake of nutrients of adult vegans living in NZ. However, it should not be used to assess absolute nutrient intakes.

Keywords: vegan; nutrients; benefits; risks; validation; food frequency questionnaire; food diary

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Abbreviation List

4DFD	Four-Day Food Diary
FFQ	Food Frequency Questionnaire
FR	Food Record
USA	United States of America
USD	United States Dollar
UK	United Kingdom
MDPI	Multidisciplinary Digital Publishing Institute
BMI	Body Mass Index
DRI	Dietary Reference Intake
DAL	Dietary Aid Load
CI	Confidence Intervals
LOA	Limits of Agreement
SFA	Saturated Fatty Acids
MUFA	Monounsaturated Fatty Acid
PUFA	Polyunsaturated Fatty Acid
N-3 fatty acids	Omega 3 Fatty acids
ALA	Alpha Linolenic Acid
DHA	Docosahexaenoic Acid
EPA	Eicosapentaenoic Acid
CVD	Cardiovascular Disease
T2D	Type 2 Diabetes
HTN	Hypertension
LDL-C	Low Density Lipoprotein Cholesterol
TG	Triglycerides
NZ	New Zealand
SD	Standard Deviation
κ	Kappa Statistics
r	Correlation Coefficients
<	Less than
>	Greater than
n	Number
β	Beta
AI	Artificial Intelligence
ID	Identification
SPSS	Statistical Package for the Social Sciences

Chapter One: Introduction

1.1 Background

In recent years, veganism has gained traction in developed countries, with evidence suggesting increasing numbers of consumers are choosing to omit animal products from their diet (Sexton et al., 2022). A vegan diet involves the elimination of animal products and all animal by-products including milk, yoghurt, cheese, eggs, honey and gelatine (North et al., 2021). Veganism is adopted for many reasons including concern regarding associated ethical conflicts/animal welfare, environmental concerns and health benefits (Sullivan et al., 2021).

A longitudinal investigation on New Zealand (NZ) consumers' attitudes surrounding meat and plant-based diets identified that 1.1% of New Zealanders followed a vegan diet (Milfont et al., 2021). Research undertaken by Price Waterhouse Coopers in 2020 revealed that 35% of the NZ adult population was either 'likely' or 'most likely' to adopt and vegetarian or vegan diet within the next twelve months (Skinner, 2019). Furthermore, there are an increasing number of vegan products available for purchase. There has been exponential growth in the vegan food market in Europe and North America, with a record high turnover of USD$3.3 billion in 2022 (Sexton et al., 2022). In 2020, USA raised a record high of USD$3.1 billion for the engineering of alternative proteins (Keerie, 2021). With the expected increase in the vegan population both outside and within NZ, there is an increasing need for dietary analysis of nutrient intakes to better assess the associated health outcomes.

The Academy of Nutrition and Dietetics concluded that a well-planned vegan diet is appropriate for all stages of life, including pregnancy and breastfeeding if planned carefully (Melina et al., 2016). Vegan diets are healthful, nutritionally adequate and may provide health benefits for the treatment and prevention of certain non-communicable diseases such as type two diabetes mellitus, hypertension, obesity, stroke and cancer (Melina et al., 2016). However, vegan diets may be associated with increased risk of developing deficiencies including vitamin B12, vitamin D, iron, iodine, zinc, and calcium, due to the exclusion of dairy and red meat (Menzel et al., 2021). Most of the current research regarding health outcomes associated with vegan diets has been undertaken in European populations (Elorinne et al., 2016; Pollakova et al., 2021; Waldmann et al., 2006; Waldmann et al., 2004). However, results are somewhat conflicting, and more research is required particularly in

other countries where the food supply and nutrient requirements differ. There is a wide variety of food consumed in the vegan diet. Common foods in the vegan diet are beans, soy products, legumes, lentils, rice, grains, oats, breads, root and cruciferous vegetables, fruits, non-dairy milks, nuts and seeds (Müller et al., 2021). However, with the recent evolution of veganism, there has been a surge in the food development space, offering vegan friendly ice cream, lollies, desserts, meat and dairy analogues, condiments, sauces and snacks (Gallagher et al., 2022).

Accurate and validated dietary assessment tools are vital to assess the unique characteristics of the vegan diet and support research exploring the associated health outcomes in this field. Multiple dietary assessment methods are available, each with their strengths and limitations. A weighed food record is the most accurate measurement of dietary intake. However, as participants need to undergo training to accurately record all food consumed including details such as weights, brands, products and cooking descriptions. Therefore, this method is generally more labour intensive, time, and financially consuming (Willett, 2012). Twenty-four hour food recalls assess meals, snacks and beverages consumed within the last 24 hours and are usually conducted by trained personnel. They are less labour, time and financially intense; however, they rely on memory and are not entirely reflective of usual intake. Food Frequency Questionnaires (FFQ) can reduce participant and researcher burden and involve participants selecting the foods they consume and how often from a list provided (Willett, 2012). Previous research has used validated FFQs designed for the general population and made adaptations specific to the vegan diet (Bruns et al., 2022; Gallagher et al., 2022), These adaptations have not been validated. Currently, only one validated FFQ has been developed in the USA specifically for vegans (Dyett et al., 2014). However, due to differences in eating patterns and the food supply, an FFQ needs to be developed specifically validated for the NZ vegan population to ensure an accurate measurement of dietary intake.

1.2 Purpose of the Study

With increasing adoption of veganism, more information/support is required to assess the dietary intake of this growing population. This study aims to assess the validity of a semi-quantitative FFQ developed to measure the relative intake of significant nutrients in vegan diets amount adults aged >18 years in NZ. If validated, this FFQ could be used in further research to explore dietary intake and health outcomes of vegan populations.

1.3 Aim

This study aims to assess the relative validity of a semi-quantitative FFQ for assessing nutrients against a four-day food record in vegan adults living in Auckland, New Zealand.

1.4 Hypothesis

The semi-quantitative food frequency questionnaire is a valid dietary assessment tool for assessing relative nutrient intake in adults living in New Zealand consuming a vegan diet.

1.5 Thesis Structure

The first chapter of the thesis provides a brief background, introduces the reader to veganism, the purpose of the study, researchers' contributions and introduces the aim of the research. The second chapter is a literature review that explores the health benefits and concerns associated with a vegan diet. The literature review covers a critical review of international studies conducted in populations where people choose to follow a vegan diet, the only validated FFQ for the vegan population conducted in USA, and reviews of validation studies conducted in the NZ population. A critique of statistical tools utilised in validation studies is also covered. Chapter three is a research manuscript that provides an introduction, methods, results and discussion to the study. Chapter four comprises the conclusion, future recommendations as well as a strengths and limitations section.

1.6 Researchers Contributions

Table 1: Contribution of Researchers to the Study

Researcher	Contributions to thesis
Catherine Hassall	Main researcher and author. Data entry of 4DFD. Participant recruitment. Contributor to creation of vegan FoodWorks10 database. Writing, editing and statistical analysis and final composition of the thesis.
Associate Professor Kathryn Beck	Primary supervisor of the FFQ validation study. Co-investigator in The Vegan Health Research Programme. Development of the Vegan FFQ. Assistance with data collection, development of the vegan FoodWorks10 database, guidance statistical analysis and interpretation.
Professor Cathryn Conlon	Co-supervisor of the FFQ validation study. Co-investigator in The Vegan Health Research Programme. Assistance with development of the Vegan FFQ, data collection, and statistical interpretation.
Professor Pamela Von Hurst	Primary investigator of The Vegan Health Research Programme. Application for research ethics. Assistance with participant recruitment, data collection and management.
Fellow MSc students Abril Clark, Amelia Dunnett, Aimee Czirfa, Chelsea Corkindale, Fiona Lee, Lucie Hill, Rebecca Pearce	Assistance with data entry and vegan FoodWorks10 database creation.
Dr Karen Mumme	Assistance with 4DFD entry and editing. Oversaw data management for The Vegan Health Research Programme.
Owen Mugridge	Project co-ordinator of The Vegan Health Research Programme. Participant recruitment and data collection.
Dr Hajar Mazahery	Development of the Vegan FFQ. Assistance with the 4DFD entry, development of the Vegan FoodWorks10 database. Participant recruitment and data collection.
Rebecca Paul	Project co-ordinator of The Vegan Health Research Programme. Participant recruitment and data collection. Assistance with the 4DFD entry, development and review of the Vegan FoodWorks10 database.

Abbreviations: FFQ, Food Frequency Questionnaire; 4DFD, 4-day food diary.

Chapter Two: Literature review

2.1 Introduction

The literature review will cover potential health benefits and concerns related to a vegan diet and aspects related to nutrient intake assessment in research. This literature review will assess all the dietary intake assessment methods utilised in research, particularly the FFQ, discussing all strengths and limitations. Furthermore, it will include the purpose behind the statistical analysis tests used to validate FFQs used in nutrition research. .

Relevant literature and references were searched in the Massey University Library Database, Scopus, Google Scholar, PubMed, Taylor & Francis Online and Multidisciplinary Digital Publishing Institute (MDPI). The searched keywords included food frequency questionnaire OR FFQ, Vegan, validated, validation studies, statistical analysis in validation studies, vegan nutrients of concern and health benefits of veganism and New Zealand. A Boolean search technique was used to narrow down the search results. Search included dates from 1993 – 2023 in order to include research within the scope of relevance.

2.2 Introduction to Veganism

The vegan diet is defined as the exclusion of all animal products and animal by-products including meat, chicken, fish, seafood, eggs, milk and milk products, cheese, yoghurt, honey and gelatine (Sexton et al., 2022; Sullivan et al., 2021). Vegan diets are adopted for reasons including but not limited to; environmental concerns, ethical conflicts/animal welfare concerns, religious beliefs and health benefits (Selinger et al., 2022). A longitudinal investigation on NZ consumers attitudes surrounding meat and plant-based diets identified that 1.1% of New Zealanders followed a vegan diet (Milfont et al., 2021). In 2020, 35% of New Zealanders revealed they are ‘likely’ or ‘more than likely’ to adopt a vegetarian or vegan diet within the next 12 months (Skinner, 2019). With this expected growth in a diet which eliminates several food groups, nutritional research and evidence to form dietary guidelines are needed.

2.3 Health Benefits of the Vegan Diet

Vegan diets have the potential to combat the negative health implications of typical Western diets. These diets are typically high in processed foods, saturated fats, cholesterol, and refined carbohydrates and low in dietary fibre, mono-unsaturated fatty acids (MUFAS), poly-unsaturated fatty acids (PUFAS), whole grains, legumes, pulses and essential vitamins and minerals (Bakaloudi et al., 2021; Schüpbach et al., 2017; Weikert et al., 2020). A higher intake of unrefined carbohydrates, dietary fibre and unsaturated fatty acids (often seen in the vegan diet) may decrease the risk of developing non-communicable diseases and can even be implemented in their treatment (Marrone et al., 2021; Melina et al., 2016). As these diseases continue to increase exponentially both globally and in NZ (Lal et al., 2012), the assessment of the benefits of a vegan diet would be highly beneficial. Evidence shows that vegan diets are associated with improved lipid biomarkers, greater control of blood glucose levels, and superior antioxidant protection against free radical damage (Müller et al., 2021). All of these significantly decrease an individual's risk of cardiovascular disease (CVD), type two diabetes (T2D) (Barnard et al., 2009), hypertension (HTN) (Alexander et al., 2017), cancer (Cory et al., 2018), stroke and neurodegenerative diseases (Bakaloudi et al., 2021; Ferguson et al., 2022)

Cardiovascular disease, type two diabetes mellitus, obesity, and hypertension are common non-communicable diseases that are highly prevalent worldwide, particularly in Western countries (Selinger et al., 2022). Such diseases are heavily linked to lifestyle factors such as dietary intake (Tuso et al., 2013). Currently an estimated one in three adults can be classified as overweight or obese worldwide (Chooi et al., 2019). A study by Ferguson et al (2022) found that following a plant-based diet led to lower body weight, BMI, and waist circumference of their participants (Ferguson et al., 2022). Furthermore an estimated 90% of T2D is attributed to excessive weight and associated underlying metabolic syndromes (Hossain et al., 2007). Vegan diets have been shown to lower the risk of T2D, decrease blood glucose values and provide better glycaemic control in T2D individuals (Barnard et al., 2009; Pollakova et al., 2021). Further research into T2D suggests that people following vegan diets have increased glycaemic control compared with those following traditional hypocaloric diets (Pollakova et al., 2021). Adding dietary fibre assists glycaemic regulation through lowering the rate of gastric emptying. Dietary fibre decreases the rate of glucose absorption, resulting in a more sustained energy response (Barnard et al., 2009; Lee et al., 2016). Along with

dietary fibre, vegan diets have high amounts of the polyphenols, a powerful antioxidant which protects against certain cancers, CVD, T2D, and neurodegenerative diseases. Furthermore, vegan diets, which are higher in fruit and vegetable intake, combat the high dietary acid load (DAL) and potential renal acid load (PRAL) in standard Western diets which are typically high in meats and cheese consumption. A low DAL and PRAL is associated with combating numerous health risks, especially CVD and T2D (Müller et al., 2021).

Obesity and T2D are two common underlying conditions that contribute to atherosclerosis, HTN and CVD (Hossain et al., 2007). Hypertension is the leading cause of CVD and premature death, with 1.39 billion adults worldwide diagnosed with hypertension in 2010 (Mills et al., 2020). In a retrospective European study of 11,004 participants of varying dietary groups (omnivore, pescetarian, vegetarian and vegan), vegans had the lowest incidence of HTN (Alexander et al., 2017). A vegan diet has been used in the treatment of hypertension, resulting in reduced medication and a decrease in significant biomarkers, low density lipoprotein cholesterol (LDL-C) and triglycerides (TG) (Lindahl et al., 1984; McLean et al., 2013). Currently 32% of NZ adults are obese (Norman et al., 2021). In 2006, healthcare costs attributed to obesity were $624 million, with this value expected to increase (Norman et al., 2021). Furthermore, the prevalence of obesity in NZ children ranges from 8.4 to 28.8%, primarily influenced by socioeconomic factors (Gibb et al., 2019). Nearly 40% of NZ adolescents are overweight, obese, or severely obese with a particular prevalence of serve obesity in Polynesian adolescents (Utter et al., 2015). Current research on the vegan diet provides insights into combating obesity-related health issues, such as having improved healthy weight management (Ferguson et al., 2022), lower fasting glucose and better glycaemic regulation (Barnard et al., 2009; Pollakova et al., 2021) and lower incidence of CVD and HTN (Alexander et al., 2017). Further research, including longitudinal studies and trials in diverse populations, would be valuable in understanding the potential long-term impacts, and feasibility of implementing a vegan diet within different demographics. As everyday dietary habits in a vegan diet are linked to decreasing the prevalence and progression of the previously mentioned diseases, a validated FFQ for the vegan populations is vital to unveiling additional information between the two.

2.4 Health Concerns of the Vegan Diet

Although a vegan diet has many health benefits, excluding meat, poultry, and dairy does give rise to some health concerns. Vegans have various nutritional risks with conflicting research findings regarding vitamin B12, vitamin D, iron, iodine, protein, zinc, and calcium (Craig, 2009). Deficiencies in these nutrients can lead to health conditions including but not limited to iron deficiency anaemia, neurodegenerative diseases, sarcopenia and osteoporosis. Based on European studies in adults, vegan diets are not deficient in vitamins A, C, and E, B1, B6, folate, magnesium, phosphorous, and copper (Bakaloudi et al., 2021; Waldmann et al., 2004). A study undertaken in Germany among female vegans aged 50 years revealed that 42% had an iron intake of >18mg/d. This sits above the mean daily iron intake recommended by the German Nutrition Society (Waldmann et al., 2004). However, 40% of the young German women on a vegan diet were classified as iron-deficient, based on serum ferritin concentrations. Several European studies have shown that the iron status between vegan and non-vegan groups shows little difference (Bakaloudi et al., 2021; Larsson & Johansson, 2002; Schüpbach et al., 2017). More research is required to unveil how much of a risk iron deficiency poses to vegans, along with what dietary recommendations should be made for vegan diets.

The status of cobalamin (vitamin B12) has more evidence to indicate a nutritional inadequacy in the vegan population (Bakaloudi et al., 2021; Pawlak et al., 2014; Schüpbach et al., 2017). Vitamin B12 is found in lean meats, poultry, eggs, and seafood. Vitamin B12 is not found in foods of plant origin and is subsequently added to products such as non-dairy milk, through a manufactured fortification process. The liver stores several milligrams of digested vitamin B12 and recycles 75% of it. Therefore, vitamin B12 deficiency can take 5 to 10 years to appear (Obersby et al., 2013). Obersby, (2013) also identified that vegans had the lowest mean serum concentrations of vitamin B12 (172pmol/L) compared to, vegetarians (209pmol/L) and omnivores (303pmol/L) (Pawlak et al., 2014). Deficits in vitamin B12 trigger a cascade of effects on reducing bone mineral density through increasing osteoclast function and reducing blood flow to bone tissue (Obersby et al., 2013; Pawlak, 2021).

Iodine has been a documented deficiency in the vegan population of Norway, which had the lowest iodine intake compared to vegetarian and pescetarian groups (Groufh-Jacobsen et al., 2020). Iodine is found mainly in dairy and seafood which are excluded from a vegan diet.

The first study to assess iodine intake in vegans in the USA, indicated that the median intake of iodine was lower in vegans than the average iodine intake of the American population (Leung et al., 2011). The literature needs more information regarding iodine intake in vegans. Iodine is essential for healthy foetal development and growth (Skeaff, 2011). Since most of those who adopt a vegan diet are women (Oliver, 2023), a iodine deficiency would have more severe impact on a poorly planned vegan diet.

Essential nutrients in maintaining bone mineralisation are calcium, vitamin D, phosphorous and magnesium. These are usually consumed through dairy products and fatty fish which are excluded in a vegan diet (Menzel et al., 2021). Peak mineral bone density occurs at approximately 25 years of age. From this point forward, bone health shifts into a more catabolic state slowly progressing over the following decades. Bone mineralisation is of particular importance for women, who have an increased risk of fractures, sarcopenia and osteoporosis due to the sudden drop in oestrogen peri and post-menopause (Stevenson et al., 1989). It is further exacerbated when peak bone mineral density is not achieved by age 25 (Stevenson et al., 1989). This is of particular concern for vegans, as most are female (Paslakis et al., 2020). Psychological research reflects that approximately 79% of vegans are women (Oliver, 2023).

In Germany, vegans aged 30-60 displayed significantly lower urinary calcium than the omnivore group (Menzel et al., 2021). With calcium being a notable nutrient of concern in vegans (Menzel et al., 2021), the implications on bone health, particularly in women, could be seen in decades to come (Bakaloudi et al., 2021; Schüpbach et al., 2017; Thorpe et al., 2021). Further evidence is required to review the risk a dietary-induced calcium deficiency poses to a vegan diet.

Currently, the literature requires more research surrounding vitamin D intake in a vegan diet. Vitamin D is a significant nutrient of concern for Finnish vegans aged 18-50, where lower serum 25-hydroxyvitamin D3 was reported (Elorinne et al., 2016). It is unclear whether this risk extends to vegans in other regions worldwide. Studies have shown in European populations that vegans are at a higher risk of fractures than other dietary groups that include animal products (Menzel et al., 2021; Pawlak, 2021; Tong et al., 2020).

Protein is typically a first thought for nutrients of concern when adopting a vegan diet. Plant proteins include soy milk, tofu, tempeh, textured soy protein, nuts, seeds, grains, and legumes (Messina & Reed Mangels, 2001). Plant proteins tend to have a less favourable amino acid profile than their meat counterparts (Reid-McCann et al., 2022). Therefore, it is generally recommended that protein requirements be increased for those following a vegan diet (Reid-McCann et al., 2022). A systematic review of 48 studies conducted in European vegan populations, revealed that total protein intake was the lowest compared to other dietary groups in three papers (Bakaloudi et al., 2021). In addition, approximately 64.5% of vegans met their dietary protein requirements, with only 8.1% achieving above their protein requirements (Bakaloudi et al., 2021). Furthermore, a study conducted by Waldmann et al., (2003) found that 72.2% of vegans were below the minimum recommendation of 0.8g/kg per day. Alternatively, some European studies have shown that vegan diets achieve protein requirements (Allès et al., 2017; Mariotti & Gardner, 2019).

Lastly, n-3 omega fatty acids are of concern for those following vegan diets (Craig, 2009). Long chain n-3 fatty acids are essential in the human diet. Familiar sources of n-3 fatty acids include fish, eggs, nuts and seaweed, with vegans only being able to eat nuts and seaweed. Docosahexaenoic acid (DHA) is a n-3 fatty acid commonly found in cold water fatty fish like salmon and mackerel. Around 50% of the fatty acids found in the human brain are DHA (Kaur et al., 2014). Eicosapentaenoic acid (EPA), a n-3 fatty acid similarly found in fish, is the parent of series three eicosanoid hormones (Kaur et al., 2014). Alpha-linolenic acid (ALA), found in nuts and walnuts, is an n-3 fatty acid that can convert to DHA and EPA in the body. This conversion rate differs from person to person (Burns-Whitmore et al., 2019). Therefore, it is recommended that vegans supplement with algae-derived n-3 fatty acids to meet their nutritional requirements (Burns-Whitmore et al., 2019; Craig, 2009). Deficiencies in n-3 fatty acids can contribute to CVD and neurodegenerative conditions (Craig, 2009). With all of these said, most of this research has been conducted in Europe, where the food supply, availability, nutrient requirements, and vegan products vastly differ from those in NZ. More research should be conducted in different regions worldwide, as countries have varying food access and nutrient requirements.

2.5 Dietary Assessment Methods

In order to assess the vegan diet in the NZ population, new dietary assessment tools need to be considered in terms of their strengths and weaknesses. More research is needed on the vegan population in NZ, and with the vegan diet expected to increase exponentially, the nutritional adequacy of the diet must be assessed. Food frequency questionnaires, food records, 24h-recalls, and diet histories are the four main methods used in dietary assessments. With strengths and limitations to all methods, the chosen method should be utilised dependant on the aims of the study, the study population, and the sample size required.

Food Frequency Questionnaire

The FFQ is a retrospective questionnaire, asking participants the frequency of foods consumed from a list of foods. The time period can range from within the last few weeks to years. FFQs can either be qualitative or semi-quantitative. They can assess frequency alone or with food portion estimations (Willett, 2012).

Several studies have utilised FFQs as a retrospective dietary assessment tool, which captures long term dietary intake (Cade et al., 2002; Gibson, 2005; Willett, 2012). They have been used in epidemiological studies since the 1990s for their ability to measure long-term dietary intake (Shim et al., 2014). Food Frequency Questionnaires are far less burdensome (including financially) compared to 24h-recalls and 4DFDs. They take less time to complete and do not require as much detail as is required for 24h-recalls and 4DFD. Because of this, they have a high respondent rate compared to other dietary assessment tools (Watson et al., 2009; Willett, 2012),

One limitation of FFQs is their specific questions regarding food groups. Food groups are highly influenced by food availability, accessibility, culture and the economy of the study population. Food systems have a variety of internal and external factors impacting the dietary patterns of each population. FFQs either need to be culturally diverse or only replicated for similar populations. For example, an FFQ developed to assess the intake of vegans in the USA will be based on the available foods, which likely differ in the food items required to assess the dietary intake of vegans living in other countries. Therefore, using it in countries

such as NZ would not be appropriate. Using it in countries such as Canada would be more appropriate due to being geographically close and likely have similar food type and brand offerings. The FFQ relies on participant memory, and there is potential for error with participants estimates regarding frequency and estimated portion sizes (Willett, 2012).

Food Record

Food records have been considered the "Gold Standard" of dietary assessment tools due to their ability to capture accurate dietary information over several days. Food records, also known as food diaries, involve the recording of food and beverages consumed over a 3 to 7-day period. They can capture precise food amounts without relying on memory (Willett, 2012). Food records include cooking methods, weighed food items, brands, food item descriptions, and times of foods and drinks consumed. Weighed food records involve the meticulous weighing of all food, while in estimated food records, household items, food models or other descriptors, e.g. palm size, are used to estimate the amounts consumed (Cade et al., 2002; Cheng et al., 2013; Rankin et al., 2010; Willett, 2012). In the literature, weighed and estimated food records have been preferred for many reasons. Estimated food records have a high response rate in specific study populations, i.e. children. (Rankin et al., 2010). Estimated food records sacrifice a degree of accuracy for ease of administration. Weighed food records are more accurate than estimated food records (Thompson & Subar, 2017). Due to their highly regarded accuracy, weighed food records are often utilised as a reference method in validating other dietary assessments (Rankin et al., 2010). The main issue with food records is the participants' tendency to change their dietary patterns once their dietary intake is recorded (Willett, 2012). The burden of weighing foods for several days can be laborious for the participants, increasing the risk of atypical consumption and decreasing time and energy recording (Thompson & Byers, 1994).

24-Hour Recall

24h-recalls are typically utilised in large scale studies with a large-study population, where dietary assessments longer than 24 hours are not feasible to administer, collect, and process (Thompson & Byers, 1994; Thompson & Subar, 2017; Willett, 2012). All food and drinks consumed within the last 24 hours (or the previous day) are recorded and are therefore dependent on memory for accuracy. A trained researcher can undertake the 24h-recall or can

be self-administered. Furthermore, 24h-recalls are much less time-consuming and burdensome for participants than food records (Cade et al., 2002; Willett, 2012). Although 24h-recalls provide some context on dietary intake and patterns, one day is not reflective on an entire year's worth of dietary intake and patterns (Thompson & Subar, 2017; Willett, 2012). Multiple 24h-recalls are often used in research and they provide useful insight for large-scale studies.

Diet History

The original diet history was developed by Bertha Burke in 1947 which involves elements of a food record and FFQ. Participants must complete a 24-hour or three-day food diary and a questionnaire on food frequently consumed within the last 1-3 months (National Research Council Committee on & Health, 1989). A nutritionist or a dietitian interviews each participant for approximately 90 minutes. Due to the length and complexities of this method, it is seldom utilised in research (Shim et al., 2014). This method can be diluted to include an interview covering the usual intake and portion sizes for meals and snacks. Then, to improve accuracy, the interviewer covers a tailored list of foods often consumed by the participant to gather any omitted information (Ramsden et al., 2010). Although a diet history interview reveals pertinent information regarding participants' intake, meal patterns, portion sizes and long-term dietary intake, it heavily depends on a skilled dietitian or nutritionist to extract all the relevant information. Additionally, the interviewee must remain free from bias so not to skew the results in favour of the hypothesis (Willett, 2012). In summary, this method can be highly accurate; however, due to its requirements, there are more practical methods to use as a dietary assessment tool in research. This method would be more useful in small-scale study populations or clinical settings (Shim et al., 2014).

Table 2: Advantages and Disadvantages of the Four Main Dietary Assessment Methods

Dietary Assessment Method	Advantages		Disadvantages	
FFQ	1.	Assesses ones' typical dietary intake and patterns.	6.	Needs to be validated for the study population to be considered an accurate dietary assessment tool.
	2.	Able to capture up to the last 12 months' worth of dietary intake, which can be more reflective for diseases/conditions which are progressive in nature.	7.	Self-administered FFQs do require literacy and numeracy skills to complete.
	3.	Is a retrospective analysis meaning participants do not need to conduct this over the following days/weeks.	8.	Relies on accurate estimations of portion sizes which can be burdensome.
	4.	Cost effective and less burdensome/time consuming for both researcher and participant.	9.	Relies on the accuracy of the participants memory.
			10.	Is a complied list of preselected food items which may not capture all foods consumed in participant's diet.
	5.	Can be designed and modified for specific nutrients or dietary patterns.	11.	FFQs are population specific, with each population having a variety of factors impacting nutrient requirements and food choice.
Food Record	1.	Is a prospective assessment method and is therefore not reliant on participants memory.	5.	Involves training and follow up communication, therefore can become burdensome for both researcher and participant.
	2.	A weighed food record provides a highly detailed description of participants recent dietary intake and patterns.	6.	Due to this, there is an increased risk of low respondent/completion rate.
	3.	Estimated food diaries contain relatively accurate portion sizes of food consumed.	7.	Requires good literacy and numeracy skills.
			8.	Relies on the honesty of the participant to record all information truthfully.
	4.	If standardised protocols with instructions and guides included, inaccuracies can be minimised.	9.	Food records generally include a follow up with a trained researcher to gather missed intel.

Dietary Assessment Method	Advantages		Disadvantages	
24H-Recall	1.	Fast, cost effective and less labour required for the participant.	6.	A singular 24h-recall is not always accurately reflective of typical dietary intake/meal patterns.
	2.	Includes a detailed account of the previous 24h dietary intake.	7.	A detailed account of intake is largely reliant on the skill of the interviewer.
	3.	Additionally, multiple spread out 24h-recalls can be more reflective of long term intake and patterns.	8.	Conducting and processing 24h-recalls can be expensive as well as time consuming.
	4.	Can provide context regarding dietary intake (times and locations food was made/cooked/eaten).	9.	Due to this, 24h-recalls can be a high burden to researchers.
	5.	Does not require good literacy skills to complete.		
Diet History	1.	Able to assess in depth long-term and recent dietary intake, habits and patterns.	4.	Expensive as well as time consuming for participants and especially researchers.
	2.	Participant literacy skills are not required.	5.	Not a feasible method for a medium for large scale study.
	3.	A trained dietitian or nutritionist is usually the interviewer, therefore estimated food portions are more likely accurate.	6.	The in-depth information gathered relies on the interviewer's skill and lack of bias.

Abbreviations: FFQ: Food Frequency Questionnaire, 4DFD; four-day food diary, 24h; 24 hours

2.6 Dietary Assessment Challenges in Vegan Studies

Assessing the dietary intake of vegan populations living in NZ requires several considerations, which are challenging for researchers and participants. These challenges are listed as follows.

Dietary Variation

Veganism can be a polarising diet with dietary variation expanding from the diversity of reasons for people being vegan. Vegans may be categorised as ‘healthy’, ‘ethical’ or ‘environmental’ (Stahler, 2005),. This impacts the types of food consumed. For example, if individuals adopt a vegan diet for reasons unrelated to animal welfare, they may still consume honey (Kirsten et al., 2020; Stahler, 2005). According to Stahler et al (2005), in a survey of youth dietary patterns in the USA, it was found that approximately 5% of vegans consume honey. ‘Healthy’ vegans may consume honey for its anti-inflammatory and antimicrobial health benefits, citing no ethical violation/animal exploitation.

There is an increasing amount of ultra-processed and processed vegan food is on the market, which could benefit from further nutritional fortification (Gallagher et al., 2022). ‘Ethical’ vegans could consume food and drink in a manner that preserves their ethos but could negatively impact health outcomes (Greenebaum, 2012). Future research on the vegan population may have to distinguish ‘healthy’ vegans from ‘ethical’ vegans to obtain a more accurate understanding of what the vegan population is eating. No current literature has made such distinctions among the vegan population while assessing health benefits or concerns. However, this may be required in future research.

Lastly, dietary variation may occur in the data recording of vegan-specific foods. As the vegan food market is a vast and rapidly growing area of development, dietary assessment databases have yet to catch up with all available options on the market (Sexton et al., 2022). Therefore, dietary variation may occur due to to inaccurate recording of vegan niche foods in the 4DFD. For these reasons, variation can occur between participants and researchers. Synergistically, if the FFQ captures only some of the vegan foods available on the market, this data will also need to be included.

Under and/or Over Reporting

With any population, the risk of under-reporting and over-reporting is a common occurrence (Thompson & Byers, 1994; Willett, 2012). Furthermore, recording dietary intake of food and drink consumed for four days is not a habit most participants would already be conducting (Thompson & Byers, 1994). Therefore, it is highly foreseeable that participants may unconsciously or intentionally omit information in their food records. Underreporting appears to be more common among women and overweight/obese individuals (Hirvonen et al., 1997; Macdiarmid & Blundell, 1998). Macdiarmid and Blundell (1998) discuss how underreporting is a multidimensional issue with factors such as participants' weight, gender, education level, motivation, social class, and level of dietary restraint all contributing to the risk factors. These factors are potentially due to self-image or constraints related to boredom recording every detail of food/drink consumed (Poppitt et al., 1998). There appears to be a pattern of food types being under/overreported. Research has shown that energy consumed from snacks between meals was significantly higher than recorded (Poppitt et al., 1998). Under-reporting likely occurs due to the participants inaccurate estimations of portion sizes, which can be due to the participants having varied knowledge on measurements of non-weighed food (Bazelmans et al., 2007). Bazelmans (2007) study discovered that participants who underreported total energy intake synergistically underreported cheese and candies and overreported bread, fruit and vegetable intakes (Bazelmans et al., 2007). Lastly, research has shown that carbohydrates and fats are generally underreported and proteins overreported (Macdiarmid & Blundell, 1998). However, this is a more complex issue as it is vital to distinguish between people who undereat and people who underreport foods such as cakes and chips due to negative association with weight and body image (Macdiarmid & Blundell, 1998).

The vegan population, a predominantly female and health-orientated population (Oliver, 2023; Paslakis et al., 2020), may be more likely to encounter assessment errors related to under/over-reporting. To limit mis-reporting, emphasis should be placed on providing extensive training to participants before completing dietary assessment tools (Bazelmans et al., 2007; Cade et al., 2002).Theoretically, an antagonistic argument can be made as vegans

are generally more passionate about their lifestyle. Thus, they may be more inclined to provide accurate information to aid research, currently lacking in this space.

2.7 Analysis of Dietary Intake

A standardised food composition database specific to its regional population is typically used to analyse dietary assessment tools. Food databases comprise of foods significant to their region of consumption, and are collated and analysed (Margetts, 1997; Willett, 2012). Across the different databases, foods, nutrients, and dishes will vary. To maximise the accuracy of assessing dietary information, utilising the most modern database for the population is recommended (Margetts, 1997). Additionally, different countries have food policies that may involve the fortification of foods. This is done to help specific sub-populations meet nutrient requirements and decrease the risk of associated health implications. This practice contributes to differences in the nutrient content of foods. For example, NZ soil has a low iodine content. In the previous two decades, mild iodine deficiency has been found in NZ adults and children (Thomson, 2004). In 2009, the NZ government moved to make the iodine fortification of bread compulsory, and table salt has been fortified with iodine in NZ since 1924 (Edmonds et al., 2016). Additionally, with the rise of alternative meat, dairy, and egg products in the vegan food market, alternative meats in NZ will differ from those in Europe and America.

FOODFiles is the central food composition database available in New Zealand; it contains reliable nutrient values from frequently consumed foods in NZ (Sivakumaran et al., 2018). Unfortunately, there are some limitations to using food databases. Dietary information can be inaccurate or missing, especially with the rapid growth in processed vegan food products (Gallagher et al., 2022). To ensure the accuracy of the recorded information, standardised protocols need to be utilised. The recording of nutrition information panels from food packages or analysis of foods not currently in the database must be explored. FOODFiles could be updated to include more composite foods in the NZ marketplace. An updated database would benefit both vegan and non-vegan dietary research in NZ. However, this could potentially be achieved through the recent explosion of artificial intelligence (AI).

2.8 Selecting a Dietary Assessment Method

The appropriate dietary assessment tool to select depends on factors related to the study design, sample population, timeframe, and budget. For studies with a large sample size, an FFQ is optimal compared to 24h-recalls or food records, as an FFQ is less time-consuming to complete (Thompson & Subar, 2017; Willett, 2012). A self-administered FFQ retrospectively assesses the long-term intake of participants, requiring little financial need or training to conduct. Furthermore, Willet (2012), advises that an FFQ is advantageous to researchers as FFQs have a higher completion rate than 24h-recalls.

FFQs are contraindicated when participants are cognitively impaired (e.g. older adults) (Thompson & Subar, 2017). Since the vegan diet is typically adopted by the millennial and younger generations (Brunton, 2019), an FFQ may be a more appropriate fit. However, since FFQs are specific to their region, ethnic foods may be missed by the FFQ (Grainger et al., 2022). This is also a concern for vegan foods in NZ. As veganism is still a niche diet in countries such as NZ, vegan food products could unintentionally be excluded from a vegan FFQ, similar to niche ethnic foods.

The gold standard of dietary assessment is given to food records/diaries for their ability to capture detailed intake. Although a weighed food record is relatively accurate, four days of dietary intake still needs to be entirely representative of a person's regular intake. As health outcomes associated with dietary intake typically occur over a significant period, assessing intake over an extended period through an FFQ may be more appropriate (Willett, 2012).

2.9 Assessing the Validity of a Food Frequency Questionnaire

An FFQ is highly region/population specific, with close-ended questions probing the frequently consumed foods that are commonly consumed in the population. Therefore, FFQs need to be validated for accuracy in the region or population in which they are intended to be used before being used in scientific research. Assessing the validity of a questionnaire is to assess whether or not the questionnaire measures what it is intended to and by how much (Tsang et al., 2017). Although many methods exist to assess validity, comparing FFQs to weighed food records is optimal (Willett, 2012). Most FFQ validation studies, compare the

questionnaire to a weighed food record or several 24h-recalls (Cade et al., 2002). On the other hand, food records and 24h-recalls are not the only dietary assessment tools used in validation studies. Biochemistry and isotope techniques have been used to assess recent dietary intake. Biomarkers are void of memory-related challenges related, under, mis, or over-reporting. Biomarkers are assessed through blood, urinary and tissue samples avoiding the challenge of training participants' and relying on participants honesty and accuracy (Willett, 2012). They are, however, often invasive and expensive.

Biomarkers hold promise for both direct and objective measurement of food intake. The number of comprehensively validated biomarkers of food intake is limited. However, this is a growing area of research (Dragsted et al., 2018). Although biomarkers do not encompass errors that food records or 24h-recalls do, they have complications related to the wide variability in measurement. Variation of metabolic efficiency is the primary complication for measuring biomarkers in general populations (Dragsted et al., 2018). The digestion and absorption of nutrients vary, making the measurement difficult to control or validate as effective. For example, urinary analysis can assess caffeine metabolites but not the source of the caffeine. The caffeine metabolism rate varies among the population due to the CYP1A2 gene (Carswell et al., 2020). Lastly, the procedure for biomarker analysis is more invasive than food records. Due to their more invasive nature, the number of participants willing to participate may decrease due to personal and cultural beliefs (Margetts, 1997).

2.10 Study Population for Validation Studies

Food frequency questionnaires were initially designed to be used for general population research. Approximately one-third of FFQs have been created and validated for specific diseases and conditions (Cade et al., 2002). Previously validated FFQs have been modified to suit another region or population better. However, this may run the risk of inaccuracy. Multiple studies have adapted validated FFQs or alternative dietary questionnaires to assess the dietary intake of the vegan population (Bruns et al., 2022; Gallagher et al., 2022). However, these still need to be validated. Since the foods differ significantly in the vegan diet, a previously existing validated questionnaire will need to encapsulate the vegan diet accurately. Therefore, newly developed or modified FFQ/questionnaires must be validated in order to achieve the same aims for a different region/population (Cade et al., 2002).

One of the significant factors which impact the validity of FFQs is ethnicity. A prevalent concern associated with FFQs pertains to the extent of their validity and reliability across diverse cultural and ethnic assessments (El Sayed Ahmad et al., 2020). The variety of culturally diverse foods and FFQs should correspond to various cultures and ethnicities within the study population. Currently, there are no statistics on the ethnic diversity of vegans in the NZ population. Internationally, vegans typically comprise white middle-class women (Wrenn, 2017). The results of The Vegan Health Research Programme also reflect this (see Appendix Table 4).

2.11 Sample Size Requirements for Validation Studies

According to Willett (2012), the appropriate sample size for an FFQ validation study should be between 100 to 200 participants to ensure the detection of statistically significant data correlations (Willett, 2012). Furthermore, Willett (2012) suggested that validation studies involving correlation coefficients would benefit from having a minimum of 150 participants to improve statistical significance. However, this suggestion was made from a study comparing a dietary assessment tool to a 12+ day food record. If the study uses a short-term dietary assessment tool (e.g. 24h-recall), a sample size larger than 150 participants is required to maintain the accuracy of the correlation coefficients (Cade et al., 2002). There is a universal understanding that validation studies have no reason to obtain over 200 participants (Willett, 2017).

2.12 Reference Methods and Recorded Days Required for Validation Studies

Validation studies require the use of reference methods in order to obtain accuracy and precision of dietary estimates without impeding the participants' habitual patterns (Hosbas Coskun et al., 2021; Margetts, 1997). Reference methods have measurement errors that are independent of the dietary assessment tool. When the errors are independent, any lack of agreement between the two assessment tools will come down to individual dietary variations. Furthermore, since FFQs partially assess long-term habitual dietary patterns, utilising another assessment, such as a 24h food-recall (shorter but more precise), may result in poor correlations regardless of the accuracy of both tools (Margetts, 1997). Ultimately, the validity needs to be revised because the two assessment tools need to be comparable.

Food records can obtain greater range of information relating to dietary intake and habitual patterns than a 24h-recall. Although several 24h-recalls can be used to obtain information similar to that of a food record, the main limitation of validity for 24h-recalls is dependent on the strength of participants' memory. For populations with low health literacy or studies with a significantly large study population, a 24h-recall may be the most suitable option. Although there are errors with any dietary assessment tool, choosing the most optimal tool for the study design and aim will inevitably decrease instances of errors (Cade et al., 2002).

Employing food records across all four seasons enables researchers to conduct comparative analyses to ascertain the suitability and robustness of food records in relation to other dietary assessment methodologies (Yang et al., 2010). One standard food record does not account for seasonal changes in food availability and dietary patterns. A comparison of a 3-7 day food record in each season of the year can account for variability that a standard one-off food record cannot. However, because food records are time-consuming and expensive to obtain, conducting four food records throughout the year will only magnify the financial burden. Additionally, completing four food records throughout one year will require consistent high motivation from all participants. Motivation is required to maintain participant involvement in the study and the accuracy of the recorded information (Yang et al., 2010). Alternatively, increasing the number of recorded days may additionally increase the precision of the recorded information. Including more recorded days allows a more valid estimate of nutrient intakes to be obtained. This will make comparing to an FFQ more accurate (Cade et al., 2002). However, the exact number of days required to record to obtain a more accurate value of each nutrient will vary with the study population. For example Basiotis (1987), found that it took only three days to obtain the true average energy intake, and it took approximately 42 days for vitamin A. Although this study had a small sample size, it still reiterates the debate on how many recorded days are required to maximise the precision and accuracy of dietary intake and habitual patterns. Ultimately, it has been concluded that for most study designs, food records can be at most 4 to 5 days long (Stram et al., 1995). The longer the food records are, the heavier the burden is placed on the participant, meaning accuracy may be sacrificed.

2.13 Sequence of Administration of Dietary Assessment and Reference Methods

Optimally, the tool being assessed (test method) for validity should be administered before the reference tool is compared. Participants may become more aware of their diet and mimic their responses in the reference method if the test method is not administered first (Margetts, 1997). Administering the testing method after the reference method may increase participants' focus on their diet, disproving the actual precision and accuracy of the validated tool (Black, 2000; Poslusna et al., 2009). Moreover, FFQs and 4DFDs must be administered at the same time period to account of changes in intake over the year (Cade et al., 2002).

Because the two assessment methods show a good correlation, this does not reflect good validity. If there are errors with the reference method, there will be errors with the test method. Therefore, the selection and application of the reference method is even more vital (Gibson, 2005).

2.14 Validated FFQs for the Assessment of Vegan and Vegetarian Diets and the New Zealand Population

Currently, only one validated FFQ has been developed specifically for the vegan population (Dyett et al., 2014). The FFQ contained 396 single food items, which were consumed regularly, > 2 a month. A modified version of the block method was utilised in the FFQ to create a vegan food list. Of these, 180 foods contributed 80% of each nutrient of interest in a vegan diet. Alterations were made with the input of dietitians and public health professionals (Dyett et al., 2014). The final FFQ included closed and open questions, portion size options, frequency, and support questions. The food groups in the FFQ included: (1) Peas and beans, (2) nuts, seeds, and nut-butter, (3) vegetarian meat analogues including cheese and egg alternatives, (4) fats, oils and salad dressings, (5) breads, (6) cooked cereals and grains, (7) ready to eat cereals, (8) leafy vegetables, (9) non-leafy vegetables, (10) fruits and fruit juices, (11) milk substitutes including teas, coffees, alcohol beverages, (12) salty snack (potato chips, popcorn), (13) desserts, sweets and sweetener. One hundred vegans (24 males and 76 females) from 19 different states in the US submitted a completed mailed FFQ. These were further compared to 24h-recalls done via unannounced telephone calls. Protein, n-3 fatty

acids, calcium, iron, zinc, vitamin D and B12 were the nutrients assessed. The results showed that FFQ nutritional intakes were higher than the recalls.

The data was validated through Pearson's correlation coefficient, analysing the linear relationship between values derived from the FFQ and 24h-recall values. Standardised correlations were used to ensure the data would be analysed in a uniform measurement. Results ranged from 0.191 (calcium) – to 0.600 (*n*-3 fatty acids). Only calcium had a p-value >0.05 at 0.758. Single-ranked tests, quartile ranking and cross-tabulation of participant intakes were used to assess if the two assessment methods were consistently aligned. From the signed-rank tests, the FFQ intakes significantly exceeded the 24h-recall for 60 of the participants. However, for approximately 50 participants, there were no significant differences in vitamin B12. One sample t-tests were used to capture the differences between the two assessment methods and the DRI (Dietary Reference Intake) for the sex and age of the participants. Adjustments were made for energy using residual regression method, with nutrient intakes as the dependent variable, and energy intake as the independent variable (Kipnis et al., 1997).

Other studies have examined the diet intake of vegans using generic FFQs validated for the general population. Others have adapted FFQs developed for the general population for use in the vegan population. These have not been validated in vegan populations. Examples of these are described below.

Bruns created a Healthy Eating Index (HEI-flex) to assess the dietary intake of German adult vegans, omnivores and 'flexitarians' aged 25-45. It was based on a previously validated FFQ with amendments to accommodate the vegan participants (vegan milks, yoghurt, cheese, cream cheese, pate, sausages and meats) (Bruns et al., 2022). The FFQ was initially validated for the German population for National Health and Nutrition monitoring and utilised two 24-recalls as a reference method (Haftenberger et al., 2010).

Gallagher (2022), used the EPIC-Norfolk FFQ in conjunction with the validated vegan FFQ from the USA (Dyett et al., 2014) to assess dietary patterns in vegan adults living in the UK. In a European study an FFQ was used, which was validated for Polish females aged 13-21 years, to assess nutritional habits among vegans, lacto/ovo vegetarians, pescatarians and omnivores (Kwiatkowska et al., 2022). Meanwhile, an FFQ was validated for South Asian

women in NZ aged 18-50, to assess vitamin B12 intake in Australian women of reproductive age (Benham et al., 2021). This study included a large number of vegan women (72%). Using validated tools is appropriate in countries with similar food supplies and shared food composition databases.

A vegetarian and omnivore semi-quantitative FFQ for Harbin, China, was assessed for validity and reproducibility in 2022. Participants included 36 vegetarians and 64 omnivores aged 25-40 who completed a 116-item questionnaire based on Chinese residents' dietary guidelines. The reference method for this study was three consecutive 24h-recalls. Instead of specific nutrient intakes, food groups and energy macronutrients were assessed, i.e., mushrooms, rice, porridge, protein, and fat. The study mentions how there are FFQs available for the vegetarian monk population in China, however these are not identified.

Nevertheless, this is the FFQ for 'ordinary vegetarians' in China (Sun et al., 2022). In Taiwan, the validation and reproducibility of a vegetarian and omnivore FFQ was conducted. The FFQ contained 64 items and food groups, with separate sections on cooking methods, dietary habits, and supplement use. Approximately 103 participants were recruited, and 53% of participants were omnivores. Dietary records and biomarkers (serum folate and vitamin B12) were used as a reference method (Chiu et al., 2014).

Several FFQs have been validated for adult populations in NZ. A 59-item semi-quantitative FFQ aimed at residents in Dunedin adults aged 30-59 was conducted in 2020 (Sam et al., 2020). The reference method was an eight-day weighed food record and biomarkers for vitamin C, β-carotene and vitamin E. A total of 132 participants completed both the test and reference method. Of these 81% were NZ European, and 51% were female. Aside from dietary lifestyle, this demographic is eerily similar to the demographic of the participants in The Vegan Health Research Programme. A total of 29 nutrients were assessed in this FFQ. Similarly, Sam (2014), administered an FFQ to Dunedin adults in 2014. This 154-item FFQ had a similar demographic to its descendant FFQ and aimed to assess habitual intake across multiple nutrients in NZ adults (Sam et al., 2014). Furthermore, a thesis presented in 2019 assessed the validity of a 220-item FFQ among 287 premenopausal women aged 18-45 (Sam et al., 2014). A total of 161 NZ European and 126 Pacific women. Similar to the validation of

the FFQ for The Vegan Health Research Programme, Drury (2019), assessed 31 nutrients against four-day weighted food records as a reference method.

Only validated FFQ utilised for the USA would not apply to European populations. This is due to the significant differences in food supply, accessibility, marketplace and nutritional requirements across the two continents. Despite the wealth of literature on European vegans, a validated FFQ for the vegan population in Europe could not be found. The food availability and marketplace for vegan options vastly differ between the USA and regions across the globe, including Australia and NZ. Although there are tools available that can be adapted to the vegan population in NZ, having a statistically validated FFQ for the NZ population ensures better accuracy. This would be the first step in providing a tool to assess vegans' dietary intake across NZ and Australia accurately.

2.15 Statistical Analysis for the Validation of Dietary Assessment Tools

There needs to be concurrence on the optimal statistical approach to validate a dietary assessment tool. An FFQ, should use a combination of statistical tools to assess validity (Cade et al., 2002). Statistical tools to assess validity include the following:

Correlation Coefficients

Correlation coefficients are the most frequently utilised statistical tool in validation studies to examine the relationship between two assessment methods. Tools such as the Pearson, Spearman, and Interclass correlation coefficients are used in 83-90% of validation studies (Cade et al., 2002). However, correlation coefficients are flawed by their dependent nature on the range of values produced by the study population. Consequently, this can be influenced further by the sample size of the study population (Cade et al., 2002). Coefficients range from -1 to +1, with zero indicating no relationship between the two methods (Lombard et al., 2015). Correlations below 0.3-0.4 indicate a poor relationship between the two dietary assessment methods (Cade et al., 2002; Willett, 2012). Values between 0.6-0.7 indicate a strong likeness between dietary assessment methods. Values that are above 0.8-0.9 are statistically improbable. However, correlation coefficients do not measure the exact alignment between the two assessment methods, only the magnitude of the relationship. Thus, high correlation coefficients do not necessarily indicate a strong level of agreement

between the two assessment methods (Bland & Altman, 2010; Lombard et al., 2015; Willett, 2017). Therefore, correlation coefficients should not be used as a singular measurement of validity (Lombard et al., 2015; Masson et al., 2003).

Paired T-test and Wilcoxon Singed-Rank Test

The paired t-test or Wilcoxon signed-rank test compares two assessment methods' group means (or the mean difference). When the absolute value of a dietary intake is measured, the group means of each nutrient should be assessed to determine how each method compares against the other (Cade et al., 2002). However, this comparison only constitutes a partial validation. This method does not rank the individual values for each nutrient across the distribution. It does not reveal how the tests can bring forth information regarding the correct classification of the participant's nutrient values (Matos et al., 2012).

Cross Classification and Weighed Kappa Statistic

Cross-classification categorises the nutrient intakes from the assessment methods and analysing how well the dietary assessment methods classify them into different classes. Cross-classification involves categorising (ranking) the participant's nutrient intakes into either tertiles (thirds), quartiles (fourths), or quintiles (fifths) (Masson et al., 2003). Placing the participant's nutrient intakes into categories shows whether the two dietary assessment methods fit the same category. Participants in the same category for both dietary assessment methods, are 'correctly classified'. Participants whose nutrient values are in opposite categories are 'grossly misclassified' (Cade et al., 2002). Typically, at least 50% of participants should be correctly classified, while no more than 10% should be misclassified into the antagonist categories (Gibson, 2005).

Weighed kappa statistic functions to summarise inter-rater agreement in categorical data, analysing the agreement of the value inside a category (Sim & Wright, 2005). This helps to account for variances of misclassification due to chance in cross-classification.

Bland-Altman Analysis

The Bland-Altman analysis is a simplified method to evaluate bias between the mean differences, and measure limits of agreement (LOA), from which 95% of differences fall

within (Giavarina, 2015). The analysis shows a visual representation of agreement for nutrient values from the test (e.g. FFQ) and the reference method (e.g. food diary). Assessing the mean differences between the nutrient values rather than the mean nutrient value, apparent outliers and trends become more visible (Bland & Altman, 1999; Bland & Altman, 2010). The LOA is calculated by the mean difference in nutrient intake ±1.96 standard deviation. The narrower the LOA are from the mean difference, the stronger the level of agreement is. While the wider the LOA are from the mean differences, the weaker the level of agreement is between the two dietary assessment methods. The Bland-Altman analysis does not state whether LOAs are acceptable limits or not (Bland & Altman, 1999; Cade et al., 2002; Giavarina, 2015).

Linear Regression Analysis and Bland-Altman Plots

Linear regression is used in conjunction with the Bland-Altman plots to validate the measurement of agreement. In a review of validated FFQs, only 4% of the reviewed studies utilised linear regression models (Cade et al., 2002). Linear regression can only be calculated if a correlation exists (Giavarina, 2015). The results should not be statistically significant. A p-value <0.05 indicates a statistically significant result, assuming proportional bias among variables and that any differences between the two methods are conditional on the mean intakes (Bland & Altman, 1999). Linear regression provides a clear account of any issues of agreement within assessment methods, with a remarkable change in the slope of the regression line (Giavarina, 2015). Linear regression models can show if changes in the dependent variable (nutrient values) are associated with changes in the independent variable (assessment method), thereby revealing the strength of agreement (Giavarina, 2015).

Energy Adjustment of Nutrient Intakes

Energy adjustment is often utilised where self-reporting of dietary intake takes place. It acts to intercept inaccurate data from participants who may have under, over, or misreported. The Women's Health Trial Vanguard Study revealed considerable shrinkage in outliers, enhancing the statistical power while preserving the results following energy adjustment (Kipnis et al., 1997). Willet (2012), stated that energy adjustment can substantially reduce measurement error due to the extraneous variation of nutrient intake related to body size,

physical activity and metabolic health. Furthermore, energy adjustments can decrease potential bias while increasing the strength of the correlation coefficients between the reference and test methods (Willett, 2012). Cade (2002), further highlights that energy adjustments are relevant for the dietary intake connected to health and disease. However, it is essential to know when to conduct energy adjustments and which methods should be utilised (Cade et al., 2002). In recent literature on validation studies, energy adjustment has improved correlations for most nutrient values (Dyett et al., 2014; Sam et al., 2020; Sam et al., 2014)

2.16 Summary

In summary of the reviewed literature, there is a need for population-specific FFQs for the growing vegan population. Currently, there is only one validated FFQ for the vegan population, developed in the USA in 2014 (Dyett et al., 2014). This study assessed the validity of seven nutrients (protein, iron, calcium, zinc, n-3 fatty acids, vitamin D and vitamin B12) from the FFQ against 24h-recalls from 100 participants. As FFQs are population-specific, FFQs should be developed and validated for the populations in which they are intended to be used (Willett, 2012). Correlation coefficients are the most used statistical test conducted in FFQ validation studies due to their ability to assess the strength of a relationship between two methods (Lombard et al., 2015). However, due to their limitations, correlation-coefficients should be used with other statistical validation tests. Cross-classification, weighted kappa and Bland-Altman should be used alongside correlation coefficients to assess validity (Cade et al., 2002). Furthermore, the ideal study population size for validation studies is 150-200 participants (Willett, 2012).

Moving forward, currently, there are no validated FFQs for the vegan population in NZ or a similar region. As the number of people adopting a vegan diet grows in Western countries like NZ, the need to assess potential health outcomes becomes more prevalent (Milfont et al., 2021). A validated FFQ would be a valuable tool for future research.

Chapter Three: Research Manuscript: Determining the Relative Validity of a Food Frequency Questionnaire to Assess Nutrient Intakes in New Zealand Vegans.

Abstract

Background: In recent years, veganism has gained traction in developed countries. A vegan diet eliminates of animal products and all animal by-products, including milk, yoghurt, cheese, eggs, honey and gelatine. It is adopted for reasons including animal welfare, environmental concerns and associated health benefits. As the vegan diet becomes increasingly common, a validated food frequency questionnaire (FFQ) is needed for future research regarding the health benefits and risks of a vegan diet. The only validated FFQ for the vegan adult population was developed in the USA. However, this FFQ may not be suitable for use in New Zealand (NZ) due to cultural and food supply differences.

Aim: This study assesses the relative validity of a semi-quantitative FFQ for assessing nutrients against a four-day diet recall in vegan adults living in Auckland, New Zealand.

Methods: As part of The Vegan Health Research Programme, a convenience sample of adults aged >18 who had adopted a vegan diet for at least two years were recruited for a cross-sectional observational study. Participants (n=166) completed a four-day food diary (4DFD) and FFQ, which were compared for the relative validity of 31 nutrients. Relative validity was assessed using correlation coefficients, paired t-tests, or Wilcoxon signed rank test, cross-classification, and weighted kappa statistic, linear regression, and Bland-Altman plots. All 31 nutrients underwent energy adjustment.

Results: Correlation coefficients improved after energy adjustment with values ranging from 0.116 – 0.661. Out of the 31 nutrients, 25 showed improvement in correlation after energy-adjustment. Following this, 12 energy adjusted nutrients were correctly classified (i.e. >50% correctly classified). After energy adjustment, weighted kappa analysis moderately improved the outcomes with values ranging from the lowest value of 0.149 (caffeine) to the highest value of 1.10 (vitamin B6 and vitamin E). Of the 31 nutrients assessed, 24 had higher mean intakes in the 4DFD than the FFQ (see Table 4). In Bland-Altman and linear regression, the slope of bias was statistically significant (p- <0.05) for most unadjusted nutrients (n=23). At

the same time, energy, protein, total fat, saturated fat, carbohydrate, thiamine, vitamin C, vitamin A, and zinc showed non-significant results ($p > 0.05$). For energy-adjusted nutrients (n=17), SFA, PUFAS, sugars, riboflavin, phosphorus, and iron were non-significant, indicating that the measurement differences between FFQ and 4DFD were not significantly dependent on mean nutrient intakes.

Conclusion: Despite the poor correlations between iodine, vitamin B6, total folate, and niacin, the FFQ was reasonably accurate at measuring the relative validity of the remaining 27 nutrients. However, it is noteworthy that the FFQ tended to underreport on most nutrients compared to the 4DFD. This FFQ could be used in future research to assess the relative intake of nutrients of adult vegans living in NZ. However, it should not be used to assess absolute nutrient intakes.

3.1 Introduction

The vegan diet omits all animal products and animal-derived products, including meat, seafood, milk, yoghurt, eggs, cheese, honey and gelatine (North et al., 2021). Following a vegan diet has been a growing trend in recent years, particularly in developed countries, with research showing a steady rise (Brunton, 2019). In 2020, a record high of USD$3.1 billion was fundraised to develop meat alternative proteins (Keerie, 2021). Furthermore, Europe and North America peaked with USD$3.3 billion in 2022 spent in the vegan food market (Sexton et al., 2022). Health Navigator NZ (2022), estimates that 300,000 New Zealanders are vegetarian or vegan. A longitudinal investigation of NZ consumer's attitudes surrounding meat and plant-based diets identified that 1.1% of New Zealanders followed a vegan diet (Milfont et al., 2021).

As the vegan diet involves the exclusion of many food groups, concerns have been raised regarding the extent of the health benefits and risks associated with following a vegan diet. The diet consists of low volumes of refined carbohydrates, salt, cholesterol and saturated fats. Dietary factors which are implicated in the development and proliferation of non-communicable diseases (NCDs) such as hypertension (HTN), cardiovascular disease (CVD), type two diabetes (T2D) and obesity (Bakaloudi et al., 2021; Marrone et al., 2021; Müller et al., 2021). However, the vegan diet continues evolving with the expansion of vegan

alternatives and vegan composite meals, leaving the benefits and risks of the diet uncertain. The vegan diet typically includes high quantities of wholegrains, vegetables, fruits, nuts, and legumes, which contain immuno-protective nutrients such as antioxidants, MUFA's, PUFA's, fibre, phytochemicals, vitamins and minerals (Bakaloudi et al., 2021; Schüpbach et al., 2017; Weikert et al., 2020).

Following a vegan diet has been associated with a lower body mass index (BMI), waist circumference, and body weight (Ferguson et al., 2022). Factors which are directly implicated in the onset and progression of CVD and T2D (Hossain et al., 2007). However, a vegan diet has significant nutrient deficiency risks, including protein, iron, bone minerals (vitamin D, calcium, phosphate, magnesium), iodine, vitamin B12 and zinc. Deficiencies in these nutrients can lead to health consequences, including but not limited to, iron deficiency anaemia, neurodegenerative diseases, sarcopenia, osteoporosis and more (Craig, 2009; Elorinne et al., 2016; Schüpbach et al., 2017). Studies have shown that vegan populations have low intakes of vitamin B12 and iron (Pawlak et al., 2014; Waldmann et al., 2004). However, some studies have indicated little to no difference in iron intake between vegan versus non-vegan dietary groups (Bakaloudi et al., 2021; Larsson & Johansson, 2002; Schüpbach et al., 2017). European studies have identified that those who follow a vegan diet have an increased risk of bone fractures. likely related to low intakes of vitamin D, calcium, and phosphate (Bakaloudi et al., 2021; Elorinne et al., 2016; Stevenson et al., 1989; Tong et al., 2020). Overtime, the manifestation of health concerns with a vegan diet may become increasingly evident.

In order to assess the dietary intake and associated health outcomes of vegans in NZ, an accurate dietary assessment must be conducted. The most utilised dietary assessment method is the food diary or food record. Participants must include accurate descriptions (e.g., cooking methods and brands) and quantities of all foods and drinks consumed over several days, including at least one weekend day. However, this method involves more time and training for the researchers and participants and relies quite heavily on the accuracy and honesty of the participants (Willett, 2012). This method also fails to capture long-term habitual dietary intake, which provides information more reflective of the progressive nature of NDCs. A food frequency questionnaire (FFQ) can capture habitual dietary intake more effectively. FFQs are region-specific with a selection of closed and open-ended questions about the frequency of foods consumed within the population. They take up less time for participants

and researchers, do not require a skilled interviewer to administer, and are less of a financial burden.

Nevertheless, for an FFQ to be an accurate dietary assessment tool, it must be statistically validated for the study population. This is especially important if this study population is a minority compared to the general population, e.g. chronic illness, specific culture or religion, or a specific diet (Cade et al., 2002; Willett, 2017). Currently, there is only one statistically validated FFQ for the vegan population worldwide. Conducted in the USA, the FFQ was validated by comparisons to 24h-recalls (Dyett et al., 2014). However, there are likely to be differences between vegan diets in the USA and NZ due to differences in food availability and accessibility, varied religious and cultural values and practices, a differing social and economic climate, as well as the differences in nutrients found in certain foods (Gibson, 2005). Therefore, the steady increase in the vegan population in NZ, coupled with the undiscovered extent of the health implications of the vegan diet, calls for an increased need for a validated dietary assessment tool to aid further research in NZ.

3.2 Materials and Methods

The vegan FFQ, designed for NZ, was validated at Massey University, Auckland, New Zealand, as a part of The Vegan Health Research Programme. The Vegan Health Research Programme uses a cross-sectional design to assess the health benefits, risks, and motivators associated with a vegan diet. A total of 212 adults >18 years who have been following a strict vegan diet for two or more years were recruited. Participants completed an FFQ (test method) developed specifically for the NZ vegan population, followed by a four-day-food-diary (4DFD) (reference method). Ethical approval was obtained from the Health and Disability Ethics Committee, reference 2022 EXP 12312. Written informed consent was obtained from each participant.

3.3 Participants and Recruitment

Participants were excluded if they were planning on pregnancy and/or breastfeeding or had any known NDCs. Participant recruitment and data collection took place between May 2022 and January 2023.

Participants that matched the inclusion criteria were recruited from the Auckland region via word of mouth, advertisement at Massey University Albany campus, vegan stores/cafes/restaurants, gyms and social media platforms/groups. The successful applicants were invited to the Human Nutrition Research Unit (HNRU) at Massey University, Auckland, NZ, for data collection.

3.4 Data Collection

Once potential participants contacted the research team, online/telephone screening was used to check eligibility. Upon determining eligibility, successful participants visited Massey University Albany Campus for blood pressure, body composition, nutrient biomarkers and bone density measurements. A self-administered questionnaire collected demographic data related to age, gender, education level, and ethnicity. Body composition was assessed using weight (Inbody) and height (Rod Stadiometer), and BMI was calculated. All participants were given unique ID numbers for analysis throughout the study to retain anonymity. Trained interviewers followed a standardised protocol, providing assistance where required with the questionnaire and FFQ.

The self-administered FFQ was conducted during this initial appointment. The researcher checked each response to ensure the data collected was accurate and complete.

Following this appointment, each participant was asked to complete a four-day food diary (4DFD) at home. The four-day food diary obtained from each participant involved brand names of foods, amounts in metric or commercial format and photos of the meals/snacks/supplements used. Participants were assigned four consecutive days to complete their food diary, which included one weekend day. An instruction video was shown to each participant with details on how to enter foods into the diary, which included cooking methods, estimating food portions, brands, types of foods, and times recorded. Any recipes

participants' made were recorded with ingredient specifications, cooking methods, and portions consumed. All participants filled out a follow-up form where any discrepancies (missing volumes or brands) in their food dairies were amended. Furthermore, each participant was required to complete the vegan FFQ and a 4DFD.

3.5 Development of the FFQ

The semi-quantitative FFQ was adapted from the recently validated FFQ from the NZ REACH (Researching Eating, Activity and Cognitive Health) study (Yu, 2019). Changes were made to the FFQ, including adding of meats and dairy analogues. Anything on the FFQ that was not vegan was removed (meat, chicken, fish, dairy, eggs, honey and gelatine-containing products). Brand names were omitted, and similar foods were grouped. For example, vegan butter substitutes were categorised into shea-based butter, coconut-based butter/spreads, olive or rapeseed oil-based spreads/butter and other vegetable oil-based butter. The FFQ conducted in the USA was used as a reference (Dyett et al., 2014). Changes were made to the FFQ following an audit of vegan foods in NZ supermarkets and the first five food diaries completed by participants. The foods that make a significant contribution to typical vegan diets were as follows:

1. Vegan meat, chicken, fish and egg substitutes
2. Nuts and seeds
3. Fruits and vegetables
4. Beans, lentils, legumes
5. Cereals, grains, breads
6. Vegan milk and cream substitutes
7. Miscellaneous foods and snacks

The final FFQ contained 196 food items covering alternative meats, dairy products, breads, grains, fruits, vegetables, drinks, confectionary items, and food groups more prevalently consumed in a vegan diet (nuts, seeds, beans, and legumes).

The final FFQ contained ten frequency questions ranging from “I never eat this food” to “6 plus times per day”. At the beginning of the FFQ, there are three example questions and descriptions of how to answer the FFQ.

3.6 Data Entry and Management

Dietary analysis assessed nutrient intakes using FoodWorks10 software, manually entering all 4DFDs. Trained researchers on The Vegan Health Research Programme team entered ~30 participants’ recorded diaries each, following a standardised protocol for vegan alternative foods not currently available on the NZ food composition database. The food diaries were manually entered into FoodWorks10 (Xyris Software, Australia Pty Ltd). The standardised protocol was a Vegan Codebook developed by internal researchers, which contained substitutions and suggestions for food and drink items recorded in the food diaries, that were not available in the database.

Foods were selected from the NZ FOODFiles 2018 (NZ Plant and Food Research 2019) or the Australian database (AusFoods 2019 or AusBrands 2019).
When a food item was unavailable, either a new recipe or new food was created manually, following the ingredients and nutritional profile of the food. Assumptions were made with the guidance of existing foods if information was scarce. Regular team meetings were held to discuss vegan foods added to the database to ensure consistency. This database was reviewed by trained researchers in The Vegan Health Research Programme before data analysis. The nutrition panel of vegan composite foods was made to match the nutritional profile of the newly created foods in the database.

The FoodWorks10 database calculates the mean daily intakes for energy, macro and micronutrients. The nutrients analysed from the vegan FFQ were energy, protein, carbohydrates, sugar, total fat, saturated fats, polyunsaturated and monounsaturated fats, dietary fibre, alcohol, thiamine, riboflavin, niacin, niacin equivalents, vitamin C, vitamin E, vitamin B6, vitamin B12, total folate, vitamin A, β-Carotene, sodium, potassium, magnesium, calcium, phosphorus, iron, zinc, selenium, iodine, and caffeine.

The FFQ was mapped in FoodWorks10 alongside a copy of the vegan FoodWorks10 database created from the 4DFD entry. Vegan foods created in the 4DFD database were used

to represent categories in the FFQ, (i.e. Sunfed chicken represents chicken strips). Participant responses to all 196 food items from the FFQ were then calculated into gram amounts. Nutrients from a sample participant's 4DFD entry was compared to with nutrients from their as a quality control measure to check if the values were relatively similar, before merging the nutrient results from each assessment method into one database.

3.7 Statistical Analysis

Statistical analysis used the Statistical Package for the Social Sciences (SPSS) software version 25. Data was cleaned and edited prior to use. The data was checked for normality with the following tests: Q-Q plots, histograms, Kolmogorov-Smirnov and Shapiro-Wilk tests.

Various of statistical methods were selected to assess the validity of the FFQ against the 4DFD. Correlation coefficients such as Pearson's and Spearman's coefficients were utilised to compare energy, macro, and micronutrients from the FFQ and the 4DFD. A magnitude of 0 to +1 was used to indicate the strength of the relationship between the two assessment methods. Mean energy, macro, and micronutrient differences across the two assessment methods were assessed using the paired t-test or Wilcoxon signed ranks. Cross-classification categorised the energy, macro, and micronutrient intakes into tertiles from both dietary assessment methods (Cade et al., 2002). Ideally, at least 50% of the participants should be in the correct classification, with the opposite tertiles occupying less than 10% of the participants (Masson et al., 2003). The weighted kappa statistic was employed to assess the level of agreement between the two assessment methods alongside cross-classifications. The weighed kappa statistic was derived from the expected and observed value of agreement in the cross-classification table. Kappa values greater than 0.80 reflected excellent agreement, 0.61-0.8 good agreement, 0.41-0.60 moderate agreement, 0.21-0.40 fair agreement, while <0.20 was considered poor agreement (Masson et al., 2003). Bland-Altman scatterplots were utilised to gauge a visual agreement between the two assessment methods. The means of each nutrient being assessed were plotted on the horizontal axis, and the differences were plotted on the vertical axis. This included calculations of Limits of Agreement (LOA = mean differences + two standard deviations) (Bland & Altman, 2010). Lastly, the linear regression model was implemented, with the independent variable's mean nutrient intake for each nutrient assessed. In contrast, the dependent variable illustrated the difference in nutrient

intakes across the two assessment methods. Thus, revealing the level of agreement for each nutrient.

3.8 Results

A total of 212 participants were recruited to The Vegan Health Research Programme, 168 of whom completed both the 4DFD and the FFQ. One participant was excluded for not meeting the energy cut-off criteria of 500kcal (2,100kJ) – 5000kcal (21,000kJ) per day (Chacko George et al., 2004) (see Figure 3.1).

The majority of the participants recruited for this study were NZ European (84.9%) and 74.1% of the participants identified as female. The mean ± standard deviation age was 40.8±12.49 years. Sixty eight percent of participants had an education level greater than high school (NCEA level 3 or equivalent). Most participants (66.3%) had a normal BMI of 18.5-24.99kg/m^2, and only 4.8% had a BMI of >30kg/m^2 (Table 4).

Table 3: Demographics and Characteristics of Study Participants (n=167)

Characteristics	**Mean ± SD or N (%)**
Age (y)	40.8 ± 12.49
Gender	
Male	41 (24.7)
Female	123 (74.1)
Gender diverse	2 (1.2)
Ethnicity	
European	141 (84.9)
Māori	8 (4.8)
Pacific people	1 (0.6)
Asian	10 (6)
Middle Eastern/Latin American/African	5 (3)
Education	
Lower than high school	2 (1.2)
High school	13 (7.8)
Diploma/Certificate	37 (22.3)
Bachelor's degree	76 (45.8)
Master's degree	33 (19.9)
Doctoral level	5 (3)
Anthropometry	
Weight	69.27 ± 12.49
Height	169.77 ± 9.02
BMI (kg/m^2)	23.93 ± 3.14
Underweight BMI <18.49kg/m^2	3 (1.8)
Normal BMI 18.5-24.99kg/m^2	110 (66.3)
Overweight BMI 25 – 29.99kg/m^2	45 (27.1)
Obese BMI >30kg/m^2	8 (4.8)

Note: Table includes participants who completed 4DFD and/or FFQ. European includes New Zealand European and European from other countries. Abbreviations; BMI, Body Mass Index.

3.9 Relative Validity of the FFQ

Mean Comparisons and Correlation Coefficients

Looking at the mean intakes of all the nutrients, the FFQ underestimated most nutrients compared to the 4DFD. A total of 24 nutrients were recorded in higher mean values in the 4DFDs compared to the mean FFQ intakes. The most notable nutrients include sodium (56%), caffeine (65.5%), and iodine (70%). Unadjusted correlations for mean nutrient intake ranged from 0.227 for iodine to 0.608 for caffeine (see Table 4). After energy adjustments, 25 nutrients showed improvement, with values ranging from 0.116 (vitamin E) to 0.661 (caffeine). Most nutrients fell between 0.40 – 0.60. All correlation coefficients except iodine, total folate, and niacin were statistically significant ($p < 0.05$). Fifteen nutrients showed energy-adjusted correlations above 0.40 and below 0.60, indicating a fair degree of agreement. Five nutrients showed energy-adjusted correlations above 0.60, indicating a strong agreement.

Table 4: Mean + SD and Correlation Coefficients between FFQ and 4DFD (n=167)

Nutrient	FFQ mean ± SD	4DFD mean ± SD	Mean difference ± SD	Percentage difference (%)	P-value	Effect size	Correlation coefficients Raw	Correlation coefficient Adjusted
Energy	6863.8 ± 2949.5	8965 ± 2543.3	2101.2 ± 406.2	23.4	<.001	0.63	0.275	-
Protein	55.3 ± 26.9	75.1 ± 25.5	19.8 ± 1.4	26.4	<.001	0.66	0.337	0.437
Total fat	66.7 ± 32.2	85.5 ± 33	18.8 ± 0.8	22.0	<.001	0.56	0.473	0.626
SFA	17 ± 10	21.5 ± 10.5	4.5 ± 0.5	21.0	<.001	0.41	0.418	0.370
PUFA	20.8 ± 10.6	22.4 ± 8.66	1.6 ± 1.94	7.1	<.001	0.15	0.421	0.372
MUFA	24.4 ± 12.7	35 ± 15.2	10.6 ± 2.5	30.2	<.001	0.71	0.441	0.642
Carbohydrates	177.7 ± 83.5	240.5 ± 80.3	62.8 ± 3.2	26.1	.004	0.60	0.224	0.610
Sugars	87.4 ± 54.4	85.7 ± 36.6	3.2 ± 17.8	3.7	.001	-0.22	0.367	0.560
Dietary fibre	45.1 ± 23.7	46.3 ± 15.1	1.2 ± 8.6	2.6	.001	0.59	0.360	0.601
Alcohol	4 ± 6.2	6 ± 11	2 ± 4.8	33.3	.001	0.21	0.523	0.560
Thiamine	1.44 ± 0.76	1.82 ± 0.77	0.38 ± 0.01	20.9	.001	0.41	0.292	0.311
Riboflavin	2.1 ± 1.3	1.6 ± 0.73	0.5 ± 0.57	31.3	.001	-0.40	0.412	0.516
Niacin*	15.9 ± 11	19.5 ± 8	3.6 ± 3	18.5	.192	-5.5	0.102	0.420
Niacin equ*	25.5 ± 14.2	32.8 ±10.2	7.3 ± 4	22.3	0.04	-6.85	0.163	0.313
Vitamin C	126.5 ± 94	146.2 ± 100.6	19.7 ± 6.6	13.5	.001	0.17	0.319	0.522
Vitamin E	13.5 ± 6.07	10.6 ± 6.06	2.9 ± 0.01	27.4	.001	0.70	0.355	0.116
Vitamin B6	4.12 ± 3.42	2.60 ± 1.64	1.52 ± 1.78	58.5	.003	-0.43	0.230	0.359
Vitamin B12	1.9 ± 1.8	2.1 ± 3.62	0.2 ± 1.82	10.5	.001	0.66	0.431	0.473
Total folate	593.1 ± 321.1	634.6 ± 238.4	41.5 ± 82.7	6.6	.065	-2.6	0.143	0.232
Vitamin A	1052.6 ± 654.2	1072.4 ± 757.8	19.8 ± 103.6	1.8	.001	0.38	0.350	0.557
β-Carotene	4034.8 ± 3038.2	4339.6 ± 3567	304.8 ± 528.8	7.6	.001	0.85	0.421	0.549
Sodium*	1214.8 ± 537.5	2759.8 ± 1075.6	1545 ± 538	56.0	.005	1.41	0.214	0.354
Potassium	4396.8 ± 2043.6	3909.8 ± 1155.2	487 ± 888.4	12.5	.001	-0.23	0.343	0.515
Magnesium	520 ± 244.9	569.9 ± 182.3	49.9 ± 62.6	8.8	.001	0.21	0.425	0.534
Calcium	1089.7 ± 591.8	901.7 ± 328.4	188 ± 263.4	20.9	.001	-0.35	0.473	0.444
Phosphorus	1340.2 ± 613.2	1455.1 ± 450.7	114.9 ± 162.5	7.9	.001	0.19	0.367	0.527

Iron	16.5 ± 7.4	18.4 ± 5.7	1.9 ± 1.7	10.3	.001	0.25	0.317	0.462
Zinc	8.5 ± 3.9	10.4 ± 4.1	1.9 ± 0.2	18.3	.003	0.38	0.226	0.309
Selenium	47.8 ± 61.3	53.2 ± 33	5.4 ± 28.3	10.2	.001	0.97	0.401	0.521
Iodine*	45.6 ± 22.7	152 ± 284.2	106.4 ± 261.5	70.0	.945	-10.8	0.227	0.208
Caffeine	307.4 ± 226.3	185.7 ± 125.7	121.7 ± 100.6	65.5	.001	-0.67	0.608	0.661

*Spearman's correlation coefficients and Wilcoxon signed rank test conducted for non-normally distributed data. Abbreviations; Adjusted, energy adjusted data, SFA, Saturated fatty acids; Niacin equ, niacin equivalents from tryptophan conversion; MUFA, Mono-unsaturated fatty acids; PUFA, poly-unsaturated fatty acids.

Cross Classification and Weighted Kappa Statistic

Participants ranged from 57.5% (caffeine) to 34.7% (vitamin B6 and vitamin E), correctly classified into the same tertiles, with a mean of 47.6%. 25% nutrients were correctly classified at >40% and twelve at >50%. Participants ranged from 3% (caffeine) to 21% (vitamin E) for grossly misclassified. Grossly misclassified exceeded 10% for sixteen nutrients, with three nutrients at >15%. After energy adjustment, 20 nutrients were correctly classified between 40%- 50%, and grossly misclassified only exceeded 15% for four nutrients, with twelve nutrients sitting below 10%.

Weighted kappa statistics showed poor agreement (κ <0.20) for alcohol and caffeine. Fair agreement (κ = 0.21-0.40) was shown for vitamin C, B12, and sugars. Good agreement (κ = 0.61-0.80) was seen with nine nutrients. After energy adjustment, poor agreement for caffeine was observed with a value of 0.149. The majority of nutrients (n=16) showed fair agreement and good agreement was observed for five nutrients (niacin, vitamin B6, vitamin E, total folate and iodine) (Table 5).

Table 5: Cross-Classification and Weighted Kappa Statistics

Nutrient	Correctly classified into the same tertiles (%)		Grossly misclassified into opposite tertiles (%)		Weighted kappa statistic (κ)	
	Raw	Adjusted	Raw	Adjusted	Raw	Adjusted
Energy	41.9	-	16.2	-	0.68	-
Protein	45.4	49.1	12.6	11.4	0.53	0.40
Carbohydrates	45.0	51.0	15.6	9.60	0.55	0.33
Sugars	51.5	49.1	10.2	9.00	0.32	0.40
Alcohol	55.7	53.3	6.00	7.20	0.20	0.27
Dietary fibre	45.5	54.5	10.2	6.00	0.53	0.23
Total fat	46.1	53.3	14.4	9.60	0.50	0.26
SFA	45.4	43.7	10.8	13.2	0.53	0.60
MUFA	45.5	55.1	13.8	7.80	0.53	0.21
PUFA	45.5	46.1	12.6	12.0	0.53	0.50
Thiamine	43.1	43.7	15.0	10.8	0.63	0.40
Riboflavin	44.3	43.7	13.8	13.2	0.57	0.40
Niacin	37.8	39.0	19.2	14.4	0.90	0.80
Niacin equ	41.9	44.3	15.0	13.8	0.68	0.57
Vitamin B6	37.1	34.7	17.4	19.8	0.93	1.10
Total folate	40.2	37.1	15.6	15.0	0.76	0.92
Vitamin B12	50.0	50.3	9.60	9.00	0.36	0.35
β-Carotene	48.0	49.7	11.4	10.8	0.43	0.37
Vitamin A	44.3	48.0	15.0	12.6	0.57	0.43
Vitamin C	51.0	50.3	10.2	11.4	0.33	0.35
Vitamin E	42.0	34.7	18.6	21.0	0.68	1.10
Sodium	42.0	44.9	10.2	12.0	0.68	0.55
Potassium	44.3	53.3	11.0	12.0	0.57	0.26
Magnesium	45.0	55.1	10.8	10.2	0.55	0.21
Calcium	46.1	52.7	13.2	9.00	0.50	0.28
Phosphorus	41.0	52.1	11.4	9.60	0.72	0.30
Iron	45.0	48.0	13.2	9.00	0.55	0.43
Zinc	42.0	46.7	13.8	10.2	0.68	0.48
Selenium	46.7	49.7	15.0	8.40	0.48	0.37
Iodine	41.3	40.1	15.6	18.0	0.71	0.77
Caffeine	61.7	57.5	4.80	3.00	0.05	0.15

Abbreviations; Adjusted, energy adjusted data, SFA, Saturated fatty acids; Niacin equ, niacin equivalents from tryptophan conversion; MUFA, Mono-unsaturated fatty acids; PUFA, poly-unsaturated fatty acids.

3.10 Bland-Altman Analysis and Linear Regression between FFQ and 4DFD

Bland-Altman analyses was conducted to measure the level of agreement between the FFQ and the 4DFD and identify outliers. Bland-Altman plots illustrate the range of limits of agreement and the consistency of variance across the mean intakes. Examples of raw and energy-adjusted Bland-Altman plots for vitamin B12 are shown below in Figure 1. The difference in adjusted vitamin B12 intakes spreads further across the mean difference (midline) as the mean intake increases. LOA are smaller in unadjusted vitamin B12 intakes than energy-adjusted (see Table 3.4).

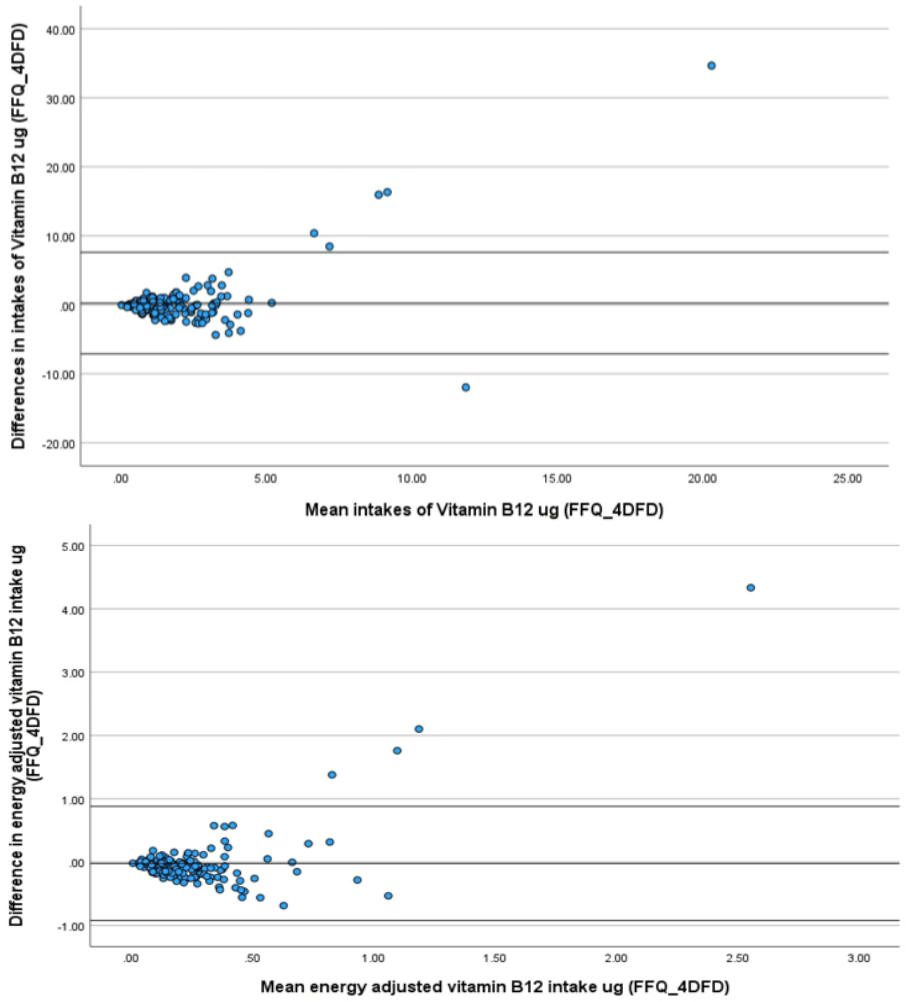


Figure 1: Bland-Altman Plots - Vitamin B12
An example of the Bland-Altman plot of the agreement for vitamin B12 intake (raw and energy-adjusted intake) between FFQ and 4DFD. The midline represents the mean difference between the two dietary assessment methods. The top and bottom lines represent the limits of agreement (LOA = mean difference ± 1.96 standard deviations).

Bland-Altman and Linear Regression

The slope of bias was statistically significant (p-value <0.05) for most unadjusted nutrients (n=23). While energy, protein total fat, saturated fat, carbohydrates, thiamine, vitamin A, vitamin C, and zinc showed non-significant results (p-value >0.05). For energy-adjusted nutrients (n=17), SFA, PUFAS, sugars, riboflavin, phosphorus, and iron were non-significant. This indicates that the measurement difference between the FFQ and 4DFD was not significantly dependent on mean nutrient intakes. The mean unstandardised coefficient (β) was nearly zero for most nutrients. Values ranged from -0.797 (potassium) and 1.976 (iodine) in unadjusted nutrients. Mean unstandardised coefficients (β) for energy-adjusted nutrients ranged from -0.926 (vitamin B6) to 1.963 (iodine).

Table 6: Linear Regression Analysis of Nutrient Intakes in the FFQ and 4DFR

Nutrient	Raw				Adjusted			
	Significance value (p value)	Unstandardised coefficients (β)	SE	LOA (95% confidence intervals)	Significance (p value)	Unstandardised coefficients (β)	SE	LOA (95% confidence interval)
Energy	0.063	-0.219	0.117	-0.450, 00.012	-	-	-	-
Protein	0.832	-0.023	0.110	6.226, 36.07	<0.001	0.526	0.093	0.343, 0.708
Total fat	0.773	0.027	0.093	-0.157, -0.211	0.044	0.151	0.074	0.004, 0.298
SFA	0.454	0.075	0.100	-0.122, -0.272	0.192	-0.138	0.105	-0.346, 0.070
PUFAS	0.004	-0.286	0.098	-0.479, -0.093	0.201	-0.135	0.105	-0.342, 0.073
MUFAS	0.010	0.250	0.096	0.061, -0.440	<0.001	0.283	0.072	0.142, 0.424
Carbohydrates	0.617	-0.062	0.124	-0.307, -0.182	0.004	0.220	0.076	0.070, 0.370
Sugars	<0.001	-0.565	0.100	-0.762, -0.367	0.072	-0.144	0.079	-0.301, 0.013
Dietary fibre	<0.001	-0.638	0.099	-0.833, -0.442	<0.001	-0.377	0.075	-0.526, -0.228
Alcohol	<0.001	0.709	0.709	0.554, 0.864	<0.001	0.341	0.081	0.182, 0.501
Thiamine	0.860	0.200	0.115	-0.207, -0.248	<0.001	0.787	0.101	0.588, 0.987
Riboflavin	<0.001	0.774	0.090	-0.951, -0.597	0.056	-0.168	0.087	-0.341, 0.005
Niacin	<0.001	-0.553	0.135	-0.818, -0.287	0.017	-0.238	0.099	-0.432, -0.433
Niacin equivalents	<0.001	-0.563	0.128	-0.816, -0.310	0.006	-0.288	0.103	-0.492, -0.084
Vitamin C	0.359	0.103	0.112	-0.118, -0.323	0.009	0.228	0.086	0.057, 0.398
Vitamin E	<0.001	0.781	0.096	0.592, 0.971	<0.001	1.477	0.088	1.302, 1.651
Vitamin B6	<0.001	-1.067	0.100	-1.264, -0.870	<0.001	-0.926	0.091	-1.105, -0.747
Vitamin B12	<0.001	1.088	0.106	0.877, 1.298	<0.001	1.170	0.098	0.978, 1.363
Total folate	<0.001	-0.509	0.130	-0.765, -0.253	0.036	-0.265	0.126	-0.513, -0.017
Vitamin A	0.045	0.217	0.107	0.005, 0.429	<0.001	0.398	0.081	0.239, 0.557
β-carotene	0.024	0.225	0.098	0.030, 0.419	<0.001	0.338	0.082	0.176, 0.500
Sodium	<0.001	1.025	0.104	0.820, 1.230	<0.001	1.376	0.071	1.236, 1.517

Potassium	<0.001	-0.797	0.097	-0.988, -0.606	<0.001	-0.395	0.085	-0.564, -0.227
Magnesium	<0.001	-0.408	0.096	-0.598, -0.219	0.028	0.189	0.085	0.020, 0.357
Calcium	<0.001	-0.755	0.083	-0.919, -0.591	<0.001	-0.497	0.097	-0.688, -0.206
Phosphorus	<0.001	-0.442	0.102	-0.644, -0.240	0.772	0.027	0.091	-0.154, 0.207
Iron	<0.001	-0.395	0.109	-0.611, -0.180	0.513	0.064	0.097	-0.128, 0.255
Zinc	0.617	0.062	0.124	-0.182, -0.306	<0.001	0.601	0.106	0.391, 0.811
Selenium	<0.001	0.824	0.089	-1.00, -0.642	<0.001	-0.649	0.080	-0.807, -0.490
Iodine	<0.001	1.976	0.025	1.927, 2.025	<0.001	1.963	0.029	1.905, 2.020
Caffeine	<0.001	-0.697	0.069	-0.834, -0.561	<0.001	1.002	0.060	0.883, 1.122

Abbreviations; Adjusted, energy adjusted data, SFA, Saturated fatty acids; Niacin equ, niacin equivalents from tryptophan conversion; MUFA, Mono-unsaturated fatty acids; PUFA, poly-unsaturated fatty acids.

3.11 Discussion

Only one validated FFQ for the vegan population is available for use in the USA (Dyett et al., 2014). This study presents the second validated FFQ for the global vegan population, and is the only validated FFQ that can be utilised for future research within and around NZ. Each completed FFQ was compared against the completed 4DFD to determine the relative validity of the created FFQ for assessing nutrient intake.

3.12 Validity of the FFQ

The vegan FFQ developed in the USA had similar results in energy-adjusted correlation coefficients for protein (0.374), iron (0.449), zinc (0.506), and vitamin B12 (0.464) (Dyett et al., 2014). Compared to the Vegan Health Research Programme, energy-adjusted correlation coefficients were protein (0.437), iron (0.462), zinc (0.309), and vitamin B12 (0.473). Other validation studies conducted in N concluded similar correlation coefficient ranges, 0.11-0.50 (Sam et al., 2014) and 0.17-0.73 (Drury, 2019). Chiu et al (2014), developed an FFQ for the vegetarian population of Taiwan, whose raw correlation coefficients ranged from 0.31 – 0.67. Following energy adjustment, the correlation coefficients moderately improved for 25 nutrients in Chiu's study. However, the FFQ intakes were standardly higher than recalls, which was the opposite direction to the present study. The mean intakes for n=24 nutrients in The Vegan Health Research Programme were higher in the 4DFD than the FFQ responses. Lastly, in a validation of an omnivore and vegetarian FFQ in China, the Pearson correlation coefficients in unadjusted nutrients ranged from 0.46 – 0.83. This study showed no improvements after energy adjustment (Sun et al., 2022).

As correlation coefficients only measure the strength of a relationship, further statistical tests are required to determine relative validity (Cade et al., 2002). In general, the FFQ underestimated amounts of 24 of 31 nutrients when compared to the 4DFD, with a significant percentage difference in iodine (70%), caffeine (65.5%), and vitamin B6 (58.5%). In Chiu's (2014) validation of a vegetarian FFQ, median percentage differences ranged from -1.6 to 78.6%. Fifteen nutrients showed energy-adjusted correlations above 0.40 and below 0.60, indicating a fair degree of agreement. Five nutrients showed energy-adjusted correlations above 0.60, indicating a strong agreement.

In the energy-adjusted data, approximately 25 nutrients had a value of at least 40% correctly classified. Among these, 12 were >50% correctly classified. The lowest percentage of correctly classified nutrients were vitamin E and B6 at 34.7%. After the nutrients had been adjusted for energy, 19 nutrients became correctly classified (>50%). Gross misclassification raw values ranged from 4.8% (caffeine) to 19.2% (niacin). Twenty-six of the nutrients were >10% grossly misclassified. After energy adjustment, this value dropped to 15 nutrients. Masson (2003), stated that correct classification should occur with at least 50%, while gross misclassification should occur no greater than 10%. In Drury et al.'s (2019) validation study, NZ European women had a higher percentage of correctly classified nutrients than Pasifika women (carbohydrates 51.6% and 40.4%; total fat 47.9% and 27.6%). In Sam et al's (2020) FFQ validation study, an average of 76.2% of participants were correctly classified into the same or adjacent fourths, with 5.7% grossly misclassified.

Weighted kappa statistics were undertaken to account for chance agreement and the degree of disagreement that may have occurred during the cross-classification process (Masson et al., 2003). Weighted kappa statistic energy-adjusted values ranged from 0.149 (caffeine) to 1.10 (vitamin B6 and vitamin E). Similar ranges were seen in other validation studies where weighted kappa statistics were used (0.05-0.29) (Drury, 2019).

The linear regression analysis revealed that 23 nutrients were statistically significant with a p-value <0.05, except for energy, protein, total fat, saturated fat, carbohydrates, thiamine, vitamin C, vitamin A, and zinc. After energy-adjustment, 17 nutrients showed a significant result. The Bland-Altman plots showed that with the mean intakes increasing, the mean difference between FFQ and 4DFD also increased (see Appendix C). Similarly to the previous statistical tests after energy adjustment, the LOA moderately improved for most nutrients (Bland and Altman, 1999), especially for protein, total fat, SFA, MUFAS, carbohydrates, thiamine, vitamin C, vitamin A, β-Carotene, and zinc.

The Vegan Health Research Programme FFQ shows reasonable relative validity compared to the 4DFDs. The notable outliers in correlation coefficients were iodine, niacin, and total folate. In the FFQ, vegan sources of these foods were limited to seaweed, strawberries, dark leafy greens, green beans, and potatoes.

3.13 Strengths and Limitations in Assessing the Relative Validity on an FFQ

One notable strength of the Vegan Health Research Programme lies in its recruitment of 212 participants, demonstrating robustness in accordance with the recommended range of 150-200 participants for validation studies (Willett, 2017). The final number of participants who completed both the FFQ and 4DFD was 167, which is within this ideal range. Most of The Vegan Health Research Programme participants had education levels greater than a Bachelor's degree (n=144). Contemporary literature suggests a correlation between under-reporting and lower educational attainment. Thus, the high proportion (68%) of the participants have advanced education levels in the study lends support to its representation of dietary accuracy (Ballard-Barbash et al., 1996; Briefel et al., 1997; Macdiarmid & Blundell, 1998). The FoodWorks10 database had strengths and limitations in itself. The FoodWorks10 database had few of the composite vegan foods available in Australasia. For example, the database did not have vegan pizzas, burgers, or alternative meat and dairy products. These foods were created in the database using the new recipe/new foods function and overriding the nutrition information panel to reflect the true amount of nutrients. This ensured the ability to enter accurate nutritional information regarding vegan products and obtain more accurate dietary data. To capture the relative validity, a wide variety of statistical tests were conducted. Correlation coefficients were initially conducted to assess the strength of the relationship between the two assessment methods. Correlation coefficients have become the most utilised statistical tool in validation studies (Lombard et al., 2015). To further establish the relative validity of the FFQ, paired t-tests, Wilcoxon tests, cross-classification with weighted kappa statistics, and Bland-Altman plots with linear regression analyses were conducted. Furthermore, energy adjustment was utilised to adjust for confounding factors that impact finding the true value to increase the accuracy of the data. Several studies have exemplified how energy adjustment improves the validity of FFQs (Cade et al., 2002; Willett, 2012).

In contrast, there were several limitations to the research. As mentioned, the FoodWorks10 database with FOODFiles2018 contains only a few vegan alternative products currently available in NZ. To counter this each student involved in The Vegan Health Research Programme had to create new composite vegan foods on the database as the food diaries were

being entered. Although this database was vetted by several researchers, with the number of people involved in creating the database, there is an increased risk of protocol disparity across the research team entering the food diaries. On that note, a potential limitation is misreporting. The literature identifies that women are more likely to misreport dietary intake (Macdiarmid & Blundell, 1998). Since 74.1% of the participants in this study are female, it poses a potential limitation to the accuracy of the recorded information (Macdiarmid & Blundell, 1998; Poppitt et al., 1998). Additionally, food items such as fruits, vegetables and protein tend to be over-reported meanwhile, foods such as lollies, snacks had in-between meals, and condiments tend to be underreported (Bazelmans et al., 2007; Macdiarmid & Blundell, 1998) as those who adopt vegan diets are generally regarded as 'health conscious' individuals, a degree of misreporting may have likely taken place in assessing this population. Furthermore, this sample population may differ from New Zealand's vegan population. Due to the nature of a convenience sample, assessing blood biomarkers and bone density, we could only recruit vegan participants residing in the Auckland region with the ability to travel to the Albany Campus on the North Shore. This is illustrated in the ethnic breakdown of the participants, mainly identifying as NZ European. Due to the magnitude of Auckland, vegans in areas such as south, east or west Auckland (all areas with different ethnic proportions) may not have been able to commute to the North Shore campus. New Zealand has numerous regions where food retailers access differs based on socioeconomic status (Wiki et al., 2019). Therefore, what vegans on the North Shore, Auckland, consume may differ from what vegans in Taranaki consume. Lastly, the length of the FFQ could have impacted the accuracy of the responses received. The vegan FFQ has 196 questions, including an 'other foods' section where descriptions must be included -theoretically, the longer the questionnaire is, the higher the risk associated with inaccurate reporting.

3.14 Conclusion

In conclusion, the semi-quantitative 196-item FFQ was reasonably accurate at measuring dietary intake among the vegan population in Auckland, New Zealand, compared to 4DFDs. The FFQ showed relative validity in assessing 31 nutrients with less accuracy in assessing iodine, vitamin B6, total folate, and niacin. FFQs are valuable tools for estimating of relative rather than absolute dietary intake. This FFQ could be used for future research conducted on vegans within NZ. Further recommendations for future FFQ validation studies in vegans should aim to have updated, vegan-specific dietary databases available for the reference method chosen.

Chapter Four: Conclusions and Future Recommendations

This is the first validation of a vegan FFQ completed for the NZ population. The only validated FFQ for vegan population was conducted in the USA and only assessed seven nutrients (iron, protein, vitamin D, vitamin B12, zinc, *n*-3s, and calcium) (Dyett et al., 2014). As the vegan populations grow in developed countries, the need for a vegan-specific validated nutrition assessment tool grows (Milfont et al., 2021). It is challenging to create and validate an FFQ that accurately captures intake estimates for a population and does not pose high risks to underreporting or misreporting.

The Vegan Health Research Programme aimed to assess the benefits and risks of New Zealand adults following a vegan diet. This thesis aimed to assess the relative validity of the semi-quantitative FFQ in determining nutrient intake in adult NZ vegans. A validated FFQ will aid future research looking into health benefits and risks associated with a vegan diet in Australasia. In order to assess validity, the 196-item FFQ was compared to each participant's 4DFD. A total of 31 nutrients were assessed and adjusted for energy intake was conducted, as recommended in validation studies (Kipnis et al., 1997). Correlation coefficients improved after energy adjustment with values ranging from 0.116 – 0.661. Of the 31 nutrients, 25 showed improvement in correlation after energy adjustment. Similar results were seen in the validated FFQ created for the vegetarian population of Taiwan (Chiu et al., 2014) and in the validation of the vegan FFQ in the USA (Dyett et al., 2014). Following this, 25 energy-adjusted nutrients were correctly classified, with >40% in cross-classification, and 12 of these >50% correctly classified. When accounting for any chance agreement that may have occurred, weighted kappa statistics moderately improved the outcomes with energy-adjusted values ranging from 0.149 (caffeine) to 1.10 (vitamin B6 and vitamin E). Similar but improved outcomes were seen in validation studies done in NZ adults (Drury, 2019; Sam et al., 2020; Sam et al., 2014). The FFQ showed moderate validity, with key outlier nutrients being iodine, vitamin B6, total folate and niacin. The FFQ tended to underreport most nutrients compared to the 4DFD.

4.1 Strengths and Limitations

The Vegan Health Research Programme obtained 212 participants, 167 of whom completed the FFQ and the 4DFD. Validation studies should have a population of approximately 200 participants to assess validity accurately (Cade et al., 2002; Willett, 2012). Correlation coefficients have been used in almost all validation studies, to assess the relationship strength between the test and reference method (Lombard et al., 2015). To further increase the accuracy of the validation, paired t-tests, Wilcoxon signed rank tests, correlation coefficients, weighted kappa statistic, linear regression models, and Bland-Altman tests were conducted. Conducting these tests aims to show validity beyond correlation. Lastly, energy adjustment was conducted to account for confounding factors in energy intake, which may affect the true outcome. The vegan FoodWorks10 database had both strengths and limitations. The FOODFiles18 database on the FoodWorks10 software had few vegan composite foods and meals available to enter. Due to this, protocols for entering the new foods and recipes had to be established and continuously reviewed by the research team. After entering of all the 4DFDs, the research team reviewed and checked all the data before any of the data was extrapolated. Although this process was vetted by many researchers involved in the study, having numerous people involved in entering the 4DFD increased the risk of protocol disparity among the data.

4.2 Significance of the Study

This is the first study in the Southern Hemisphere to statistically validate an FFQ for the vegan population. The only validated FFQ for the vegan population was conducted in the USA in 2014 and investigated seven nutrients (protein, iron, zinc, vitamin D, vitamin B12 and *n*-3 fatty acids) (Dyett et al., 2014). This FFQ appears reasonably accurate for measuring the relative nutrient intake of adult vegans living in NZ. With some adaptation, this FFQ could be used for future research In vegan populations. This study has wider implications for further research in the vegan population in Australasia.

4.3 Recommendations for Future Validation Studies.

Following this research, numerous recommendations can be implemented for future FFQ validation studies and to improve the vegan FFQ. These adjustments could enhance validation outcomes and more effectively capture dietary intake when assessing the vegan population.

1. Use a range of statistical tests to prove validity. When assessing a wide range of nutrients or a specific population, conducting a range of statistical tests will help determine the relative validity of the FFQ. Energy adjustment can aid in improving statistical outcomes.
2. An alternative to FoodWorks10, a more vegan-specific database, could be utilised to improve the accuracy of data entry. Potentially FoodWorks10 could be updated to contain more vegan inclusive food options.
3. Future FFQs in the vegan population should include more fermented foods in the FFQ, such as sauerkraut, kimchi, and kombucha, under the 'other foods' section as these foods were consumed regularly.
4. The length of the FFQ should be taken into consideration during administering. Our FFQ is 196 items long, which may negatively impact the accuracy of the answers. Some categories, such as vegan cheeses, nuts and seeds, cereals, and grains that share similar nutritional profiles, could be merged into one question. Further validity may be required for nutrients that showed poor validity in this study (niacin, niacin equivalents, vitamin B6, iodine, and vitamin E).

In conclusion, this semi-quantitative FFQ is a reasonably accurate and cost-effective dietary assessment tool for measuring dietary intake among adult vegans in NZ. Despite the nutrients iodine, vitamin B6, total folate niacin equivalents, and niacin showing poor correlation, the FFQ was reasonably accurate at measuring relative validity for the remaining 26 nutrients. This FFQ could be used in future research in vegan populations in Australasia to assess the relative intake of nutrients but should not be used to assess absolute nutrient intakes.

Chapter Five: Appendices

Appendix A: Food Frequency Questionnaire (FFQ)

VEGAN Study – Vegan Food Frequency Questionnaire

Please ask one of the researchers to enter your participant ID 880178

When answering this questionnaire consider your intake of food over the past month. Consider whether you have had that food on a monthly, weekly or daily basis. To help you do this, please think of an event in your life that happened one month ago and think about your eating patterns since that date. Don't spend too long thinking about each food.

Please answer by ticking the box which best describes how often you ate or drank a particular food or drink in the past month.

Example

In the past month I have had this food… (bananas)

If you eat 1 medium banana 3 days per week this represents three servings per week so select **'2 to 3 times per week'**

Food item	Serving size	I never eat this food	Not this month but I have sometimes	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 to 5 times per day	6 plus times per day
Bananas	1 medium					r					

Example

In the past month I have had this food… (Sugar (all varieties) added by you to food / drinks)

If you drink 2 cups of coffee with 1 tsp sugar in each and 4 cups of tea with 1 tsp sugar in each and one bowl of cereal with 1 tsp sugar choose the category **'6 Plus times per day'**.

Food item	Serving size	I never eat this food	Not this month but I have sometimes	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 to 5 times per day	6 plus times per day
Sugar (all varieties) added by you to food / drinks	1 tsp										r

Example

In the past month I have had this food… (White bread and rolls (including sliced and specialty breads such as foccacia, panini, pita, naan, chapatti, ciabatta, Turkish, English muffin, crumpets, pizza bases, wraps, tortilla's, burrito, roti), rewena bread)

E.g. If eating 2 medium slices of bread two times per week this represents four servings per week so select **"4 to 6 times per week".**

Food item	Serving size	I never eat this food	Not this month but I have sometimes	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 to 5 times per day	6 plus times per day
White bread and rolls (including sliced and specialty breads such as foccacia, panini, pita, naan, chapatti, ciabatta, Turkish, English muffin, crumpets, pizza bases, wraps, tortilla's, burrito, roti, rewena bread, French bread)	1 medium slice or 1/2 medium roll						r				

The questionnaire starts here

In the past month I have had this food….

Fruit	Serving size	I never eat this food	Not this month but I have sometimes	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 to 5 times per day	6 plus times per day
Apples, pears, nashi pears	1 medium										
Bananas	1 medium										
Citrus fruits (e.g., orange, tangelo, tangerine, mandarin, grapefruit, lemon, lime)	1 medium or 2 small										
Stone fruit (e.g., apricots, nectarines, peaches, plums, lychees)	1 medium or 2 small										
Avocado	¼ avocado										
Olives	4 olives										
Strawberries, blackberries, cherries, blueberries, boysenberries, loganberries, cranberries, gooseberries, raspberries (fresh, frozen, canned)	½ cup										
Dried fruit - sultanas, raisins, currants, figs, apricots, prunes, dates	2 Tbsp										
All other fruit (e.g., feijoa, persimmon, tamarillo, kiwifruit, grapes, mango, melon, watermelon, pawpaw (papaya), pineapple, rhubarb)	1 medium or ½ cup										

In the past month I have had this food….

Vegetables	Serving size	I never eat this food	Not this month but I have sometimes	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 to 5 times per day	6 plus times per day
Potato (e.g., boiled, mashed, baked, jacket, instant, roasted)	1 medium or ½ cup										
Hot potato chips, French fries, wedges, hash brown	½ cup hot potato chips, French fries or wedges or 2 hash browns										
Kumara, taro, green banana, cassava (e.g., boiled, mashed, baked, roasted)	1 medium or ½ cup										
Carrots	1 medium or ½ cup										
Other root vegetables (e.g., yams, parsnip, swedes, beetroot, turnips)	1 medium or ½ cup										
Peas, green	½ cup										
Green beans, broad beans, runner beans	½ cup										
Broccoli, cauliflower, brussel sprouts, cabbage (all varieties)	½ cup										
Salad vegetables (e.g., lettuce, cucumber, celery, sprouts)	½ cup										
Green leafy vegetables (e.g., spinach, silver beet, swiss chard watercress, puha, Whitloof, chicory, kale, chard, collards, Chinese kale, Bok Choy, taro leaves (palusami))	½ cup										
Tomatoes (all varieties)	1 medium or ½ cup										
All other vegetables (e.g., corn, pumpkin, mushrooms, capsicum, peppers, courgette, zucchini, gerkins, marrow, squash, asparagus, radish, eggplant, artichoke)	½ cup										
Onions, leeks, garlic	1 Tbsp										

In the past month I have had this food....

VEGAN meat (e.g., beef, lamb, pork and goose), chicken, fish, and egg substitutes	Serving size	I never eat this food	Not this month but I have sometimes	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 to 5 times per day	6 plus times per day
Vegan meat substitute											
Soy based meat substitutes (including beef mince, beef meat balls)	Palm size or ½ cup										
Other meat substitutes (e.g., Bean supreme, Sanitarium beef mince, pea based meat)	Palm size or ½ cup										
Soy based burgers	1 patty										
Other burger substitutes (e.g., mushroom, cauliflower, sweet potato/kumara, chickpeas, beetroot, or quinoa-based burgers)	1 patty										
Vegan chicken substitutes											
Chicken substitute strips	½ cup										
Other chicken substitutes (e.g., nuggets, tender, burgers)	Palm size, ½ cup or 1 patty										
Vegan fish substitutes											
Fish substitutes	Palm size or 1/2 cup										
Vegan egg substitutes											
Egg replacer	1 tsp										
Easy egg	1 Tbsp										
Vegan sausage, bacon and pate substitutes											
Tofu based sausages	1 sausage										
Other type sausages (e.g., soy or pea based)	1 sausage										
Bacon substitutes	½ thin slice										
Pate substitutes	1 Tbsp										

In the past month I have had this food....

Nuts and seeds	Serving size	I never eat this food	Not this month but I have sometimes	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 to 5 times per day	6 plus times per day
Nuts											
Walnuts	1 Tbsp										
Cashew nuts	1 Tbsp										
Almonds	1 Tbsp										
Peanuts	1 Tbsp										
Pistachio	1 Tbsp										
Hazelnuts	1 Tbsp										
Macadamia	1 Tbsp										
Pecan	1 Tbsp										
Brazil nuts	1 Tbsp										
Pine nuts	1 Tbsp										
Coconut	1 Tbsp										
Nuts butters or spreads											
Cashew butter	1 tsp										
Almond butter	1 tsp										
Peanut butter	1 tsp										
Pesto prepared with nuts	1 tsp										
Seeds											
Pumpkin seeds	1 Tbsp										
Sunflower, sesame seeds	1 Tbsp										
Flaxseed, linseed	1 Tbsp										
Chia seeds	1 Tbsp										
Seeds butter											

Seeds butter (e.g., sesame seed butter (Tahini), sunflower seed butter, pumpkin seed butter)	1 tsp										

In the past month I have had this food....

Legumes and Soy	Serving size	I never eat this food	Not this month but I have sometimes	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 to 5 times per day	6 plus times per day
Beans											
Kidney beans, black beans, navy beans, adzuki beans	½ cup										
White beans, black eye beans	½ cup										
Lima beans, butter beans	½ cup										
Mung beans	½ cup										
Fava beans	½ cup										
Baked beans, refried beans, and chilli beans	½ cup										
Soybean											
Soya beans	½ cup										
Silken tofu	½ cup										
Firm and high protein tofu	½ cup										
Tempeh	½ cup										
Peas and Lentils											
Chickpeas or garbanzo beans (excluding falafels and hummus)	½ cup										
Split peas	½ cup										
Lentils (green and brown)	½ cup										
Dahl	½ cup										
Pigeon peas	½ cup										
Falafel	½ cup										
Hummus	1 Tbsp										
Protein Powders											
Bean or fava bean protein powder added to foods or drinks	2 Tbsps										
Soy protein powder added to foods or drinks	2 Tbsps										
Pea protein powder added to foods or drinks	2 Tbsps										

In the past month I have had this food....

Cereals and grains	Serving size	I never eat this food	Not this month but I have sometimes	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 to 5 times	6 plus times per day
Bran based cereals, muesli, porridges (e.g., rolled oats, oat bran, oat meal, All Bran, Sultana bran)	½ cup										
Weetbix, cornflakes or rice bubbles	2 weetbix or ½ cup										
Sweetened cereals (e.g., Nutrigrain, Froot Loops, Frosties, Milo cereal, CocoPops)	½ cup										
Other breakfast cereals (e.g., Special K, Light and tasty)	½ cup										
White rice	½ cup cooked										
Brown rice	½ cup cooked										
Red rice	½ cup cooked										
White pasta, noodles (e.g., spaghetti, canned spaghetti, vermicelli, rice noodles, instant noodles)	½ cup cooked										
Whole meal pasta, noodles	½ cup cooked										
Barley	½ cup cooked										
Couscous	½ cup cooked										
Cornmeal (Polenta)	½ cup cooked										
Congee	½ cup cooked										
Bulgur wheat	½ cup cooked										
Spelt	½ cup cooked										
Millet	½ cup cooked										
Quinoa	½ cup cooked										
Pancakes, waffles, sweet buns, scones, sweet muffins, fruit bread, doughnuts, brioche	1 serve										
White bread and rolls (including sliced and specialty breads such as foccacia, panini, pita, naan, chapatti, ciabatta, Turkish, English muffin,	1 medium slice or ½ medium roll										

crumpet, pizza base, wraps, tortillas, burrito, roti, rewena bread, French bread)											
Whole meal or **wheat meal** bread and rolls (including sliced and specialty breads)	1 medium slice or ½ medium roll										
Whole grain or multi grain bread and rolls (including sliced and specialty breads)	1 medium slice or ½ medium roll										
Rye bread and rolls (including sliced)	1 medium slice or ½ medium roll										
Sprouted bread (including sliced)	1 medium slice or ½ medium roll										
Bread crumbs	1 Tbsp										
Crackers (e.g., crisp bread, water crackers, rice cakes, cream crackers, Meal mates, vitawheat)	2 medium crackers										

In the past month I have had this food….

VEGAN dairy products substitutes	Serving size	I never eat this food	Not this month but I have sometimes	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 to 5 times per day	6 plus times per day
Vegan cheese substitutes											
Cheese not fortified with calcium (including mozzarella, tasty, cheddar, pizza blend)	2 slices or 1/3 cup										
Cheese fortified with calcium (e.g., Angel Food cheddar and mozzarella)	2 slices or 1/3 cup										
Parmesan	2 slices										
Cream cheese	1 Tbsp										
Vegan yoghurt substitutes											
Plain and non-flavoured Greek yoghurt	½ cup										
Flavoured yoghurt	½ cup										
Vegan cream substitutes											
Soy-based cream	1 Tbsp										
Cashew-based cream	1 Tbsp										
Coconut-based cream (regular)	1 Tbsp										
Coconut-based cream (light)	1 Tbsp										
Condensed and evaporated milk	1 Tbsp										
Sour cream	1 Tbsp										
Vegan milk substitutes											
Coconut milk (not fortified with calcium)	1 cup										
Coconut milk (fortified with calcium)	1 cup										
Tinned coconut milk (regular)	1 cup										
Tinned coconut milk (light)	1 cup										
Almond milk (not fortified with calcium)	1 cup										
Almond milk (fortified with calcium)	1 cup										
Almond milk (high protein)	1 cup										
Soy milk (regular)	1 cup										

Soy milk (lite)	1 cup										
Soy milk (unsweetened)	1 cup										
Oat milk (regular and unsweetened)	1 cup										
Rice milk	1 cup										
Cashew milk	1 cup										
Seeds milk	1 cup										
Peanut milk	1 cup										
Plant based milk smoothies, milkshakes, flavoured milk	1 cup										
Plant-based milk puddings (e.g., rice pudding, custard, semolina, instant puddings)	½ cup										
Ice cream											
Ice cream individual pack	1 ice cream										
Ice cream from tub	½ cup										

In the past month I have had this food….

Alcohol	Serving size	I never eat this food	Not this month but I have sometimes	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 to 5 times per day	6 plus times per day
Beer, lager, cider (all varieties)	1 can or bottle										
Red wine	1 small glass										
White wine	1 small glass										
Port, sherry, liqueur	1 small glass										
Spirits (e.g., gin, brandy, whiskey, vodka)	1 shot or 30ml										
Ready to drink alcoholic beverages (e.g., Canadian club, Smirnoff ice)	1 bottle or can										

In the past month I have had this food….

Non – alcoholic drinks	Serving size	I never eat this food	Not this month but I have sometimes	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 to 5 times per day	6 plus times per day
Vegan hot chocolate, drinking chocolate, Cocoa, Milo	1 cup										
Coffee (all varieties)	1 cup										
Tea	1 cup										
Herbal tea, fruit tea	1 cup										
Low calorie cordials	1 glass										
Cordials (including syrups, powders) (e.g., Raro)	1 glass										
Fruit or vegetable juice (calcium fortified)	1 glass										
Fruit and vegetable juices (all varieties)	1 glass										
Sports drinks (e.g., Powerade)	1 glass										
Energy drinks (e.g., Red Bull, V)	1 glass										
Diet soft/fizzy drinks (e.g., Sprite Zero, Diet Coke, Coke Zero)	1 glass										
Soft/fizzy drinks (e.g., Sprite, Coke)	1 glass										
Water (including tap, bottled or sparkling water)	1 glass										

In the past month I have had this food….

VEGAN butter substitutes, margarine, and oils	Serving size	I never eat this food	Not this month but I have sometimes	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 to 5 times per day	6 plus times per day
Vegan butter substitutes and margarines											
Shea-based butter substitute (e.g., Naturli vegan block)	1 tsp										
Coconut-based spreads/butter substitutes (Nuttelex coconut, Alpha one coconut, Vutter)	1 tsp										
Olive oil or rapeseed oil-based spreads/butter substitutes (e.g., Olivani including original, lite, avocado, Nuttelex Olive, Naturli vegan spreadable)	1 tsp										
Other vegetable oils-based spreads/butter substitute (e.g., Nuttelex reduced fat)	1 tsp										
Oils											
Olive oil, canola oil, rice bran oil, avocado oil, peanut oil	1 tsp										
Other vegetable oils (e.g., sunflower oil, soybean oil, corn oil and sesame oil)	1 tsp										
Coconut oil	1 tsp										

In the past month I have had this food....

Miscellaneous VEGAN foods and snacks	Serving size	I never eat this food	Not this month but I have sometimes	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 to 5 times per day	6 plus times per day
Cakes, slices, chocolate brownie, pastries	1 medium serve										
Cheesecake	1 medium slice										
Pies, puddings	1 medium serve										
Cookies (e.g., chocolate chunk, choc chip cookies)	½ big cookie or 3 small cookies										
Plain biscuits	2 biscuits										
Chocolate or cream filled biscuits	2 biscuits										
Chocolate (all varieties)	A row (4 squares)										
Muesli bars	1 bar										
Nuts and seeds snack bars (contain nuts, seeds and fruits - e.g., cashew salted caramel, hazelnut sesame chocolate, linseed sunflower almond, Nograin-ola bars)	1 bar										
Nuts and seeds snack pieces (contain nuts and fruits - e.g., munchme pistachio cranberry)	4 pieces										
Fruit filled bars (contain only fruit - e.g., triple berries bar)	1 bar										
Coconut cocoa bar	1 bar										
Protein and energy bar (contain both pea pro and nuts - e.g., Protein and energy choc mint, protein choc fudge, protein almond butter cookie)	1 bar										
Sugar (all varieties) added by you to food / drinks	1 tsp										
Jam, marmalade, syrups, sweet spreads or preserves	1 tsp										
Marmite, vegemite	1 tsp										
Sweets, lollies	5-6 lollies										
Potato crisps	½ cup										
Corn/tortilla chips	½ cup										
Pretzels											
Popcorn											
Vegan mayonnaise substitutes, dressings, dips, and spices											
Vegan mayonnaise and aioli	1 Tbsp										
Vegan PeriPeri mayonnaise	1 Tbsp										
Light dressings (e.g., French and Italian dressing, balsamic vinegar)	1 Tbsp										
Vegan white sauce, cheese sauce, gravies	1 Tbsp										
Tomato sauce, tomato paste, barbeque sauce, sweet chilli sauce, salsa	1 Tbsp										
Worcestershire sauce, soy sauce	1 Tbsp										
Dips (all varieties)	1 Tbsp										
Pickles, chutney, mustard	1 Tbsp										
Spices (e.g., turmeric, ginger, cinnamon)	1 tsp										
Other foods											
Nutritional yeast	1 tsp										

Are there any other foods which you have eaten in the past month?

	Yes
	No

If yes, please state the food, the serving size and the frequency of consumption

Other foods	Serving size	I never eat this food	Not this month but I have sometimes	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 to 5 times per day	6 plus times per day

Appendix B: Four Day Food Diary (4DFD)

StudyID: _____

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

Health and Vegan Diet

4 Day Food Record

Thank you very much for taking part in this study. We are extremely grateful for your time, effort and commitment

If you have any questions, please contact Rebecca Paul on 022 1294112 (Email: veganstudy@massey.ac.nz)

All information in this diary will be treated with the strictest confidence. No one outside the study will have access to this.

Please bring the food diary with you when you come in for assessment at Massey University.

1

StudyID: _____

4 day food diary - what to do?

- Record all of the food that you eat and drink on the following dates.
- **Please complete the diary on consecutive days for 1 weekend day and 3 week days at your convenience. For example, Sunday, Monday, Tuesday and Wednesday OR Wednesday, Thursday, Friday and Saturday.**
- If possible record food at the time of eating or just after – try to avoid doing it from memory at the end of the day.
- Include all meals, snacks, and drinks, even tap water.
- Include anything you have added to foods such as sauces, gravies, spreads, dressings, etc.
- Write down any information that might indicate size or weight of the food to identify the portion size eaten.
- Use a new line for each food and drink. You can use more than one line for a food or drink. See the examples given.
- Use as many pages of the booklet as you need.
- You can also save any packets such as muesli bar wrappers and bring them in with your food diary

Describing Food and Drink

- Provide as much detail as possible about the type of food eaten. For example **brand names and varieties / types** of food.

General description	Food record description
Breakfast example – cereal, milk, sugar	2 Weetbix (Sanitarium) 1 cup So Good unsweetened almond milk 1 tsp Chelsea white sugar
Lunch – Meat Free Bacon Style Rashers sandwich and home-made fries	2 slices of wholegrain bread (Vogels) 2 slices Vegie Delights Meat Free Bacon Style Rashers 25g zenzo Dairy Free Vegan Cheddar Cheese Alternative 2 tsp Tablelands Dairy Free Buttery Spread ½ cup fries (home-made, deep fried in Pam's sunflower oil)

StudyID: _____

	1 cube dairy free cheddar cheese, match box size

- If you go out for meals, describe the food eaten in as much detail as possible.
- ***Please try to eat as normally as possible – e.g., Don't adjust what you normally eat just because you are keeping a diet record and be honest! This record will give us important information about your diet, and help us identify any possible deficiencies which we can then help you correct.***

Example day

Time food was eaten	Complete description of food (food and beverage name, brand, variety, preparation method)	Amount consumed (units, measures, weight)
Example 7:55am	Sanitarium Weetbix	2 weetbix
" "	So good unsweetened almond milk	150ml
" "	Chelsea white sugar	2 heaped teaspoons
" "	Orange juice (Citrus Tree with added calcium – nutrition label attached)	1 glass (275 ml)
10.00am	Raw Apple (gala)	Ate all of apple except the core, whole apple was 125g (core was ¼ of whole apple)
12.00pm	Home-made pizza (recipe attached)	1 slice (similar size to 1 slice of sandwich bread, 2 Tbsp tomato paste, 4 olives, 2 meat free bacon style rashers (zenzo), 1 Tbsp chopped spring onion, 3 Tbsp vegan mozzarella cheese)
1.00pm	Water	500ml plain tap water
3.00pm	Biscuits	2 x Lotus Biscoff biscuits
6.00pm	Lasagne	½ cup cooked Sunfed Bull free beef meat alternative mince, 1 cup cooked Budget lasagne shaped pasta, ½ cup homemade (recipe attached) vegan bechamel sauce made with soy milk (So Good, regular), ½ cup mixed vegetables (Pam's carrots, peas and corn), 4 Tbsp Veesey grated pizza blend cheese

StudyID: _____

Fried chicken alternative strips	100g chicken alternative strips (100g includes batter); fried in 3 Tbsp Nuttelex buttery margarine

General description	Food record description
Milo	I x cup Milo made with plant based Milo powder and 150mls So Good unsweetened almond milk, 100 ml hot water. No sugar

- **Record recipes** of home prepared dishes where possible and the proportion of the dish you ate. There are blank pages for you to add recipes or additional information.

Recording the amounts of food you eat

It is important to also record the quantity of each food and drink consumed. This can be done in several ways.

- By using household measures – for example, cups, teaspoons and tablespoons. Eg. 1 cup frozen peas, 1 heaped teaspoon of sugar.
- By weight marked on the packages – e.g. a 425g tin of baked beans, a 32g cereal bar.
- Weighing the food – this is an ideal way to get an accurate idea of the quantity of food eaten, in particular for foods such as meat alternatives, fruits, vegetables and cheese alternatives.
- For bread – describe the size of the slices of bread (e.g. sandwich, medium, toast) – also include brand and variety.
- Using comparisons – e.g. Meat alternative equal to the size of a pack of cards, a scoop of vegan chocolate ice cream equal to the size of a hen's egg.
- Use the food record instructions provided to help describe portion sizes.

General description	Food record description
Cheese alternatives	1 heaped tablespoon of grated dairy free cheddar cheese 1 slice dairy free cheddar cheese (8.5 x 2.5 x 2mm)

StudyID: ________

	½ Tbs vegan aioli (Heinz Mayonnaise Vegan Aioli) Water 1 cup to drink
Dinner – Vegan lentils spaghetti Bolognese	½ cup lentil sauce (see attached recipe) 1 cup spaghetti pasta (Home brand)
Snacks	Tam & Luke Snack Ball Salted Caramel (2 balls, 28g) 1 small banana 2 Salada crackers with 1 tsp peanut butter 20g Doritos Spicy Sweet Chili Flavoured Tortilla Chips

- Give details of all the **cooking methods** used. For example, fried, grilled, baked, poached, boiled…

General description	Food record description
Potatoes	2 medium size potatoes cut in slices and fried in 2tbs canola oil 2 large potatoes with skin (boiled)
Black bean and kumara burger	85g black bean and kumara burger (recipe provided) pan-fried in 2tsp olive oil 85g black bean and kumara burger (recipe provided) oven baked

- When using foods that are cooked (eg. pasta, rice, vegetables, etc), please record the **cooked portion** of food.

General description	Food record description
Rice	1 cup cooked Jasmine rice (cooked on stove top)
Meat alternatives	1 cup of cooked lentil sauce or 5 oven baked chicken style strips (Fry's)
Vegetables	½ cup cooked mixed vegetables (Wattie's peas, corn, carrots)

- Please specify the **actual amount of food eaten** (eg. for leftovers, foods where there is waste)

General description	Food record description
Apple	1 x 120g Granny Smith Apple (peeled, core not eaten – core equated to ¼ of the apple)

StudyID: ________

Date______________________________ **DAY 1**

Time food was eaten	Complete description of food (food and beverage name, brand, variety, preparation method)	Amount consumed

StudyID: ________

Recipes (Day 1)

StudyID: _____

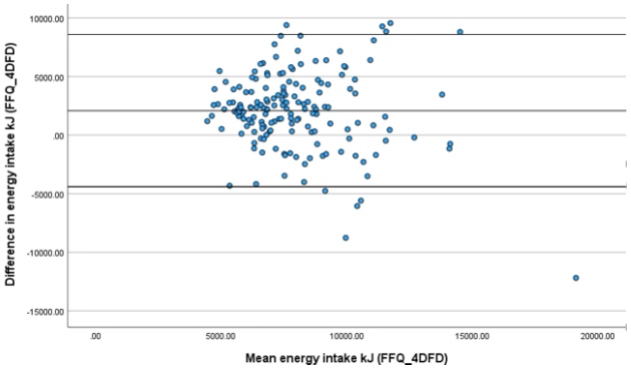
Date_____ DAY 2

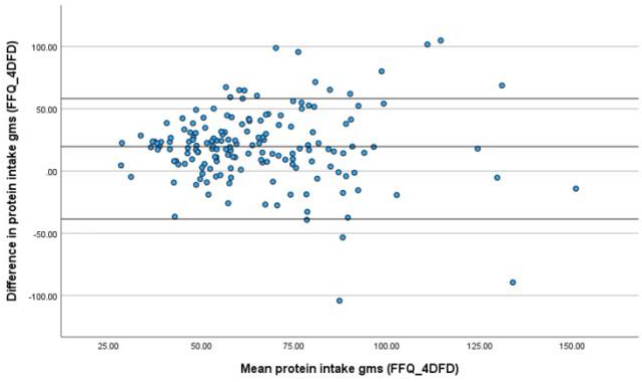
Time food was eaten	Complete description of food (food and beverage name, brand, variety, preparation method)	Amount consumed

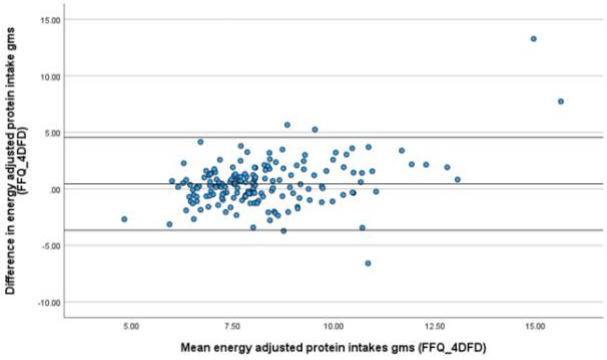
StudyID: _____

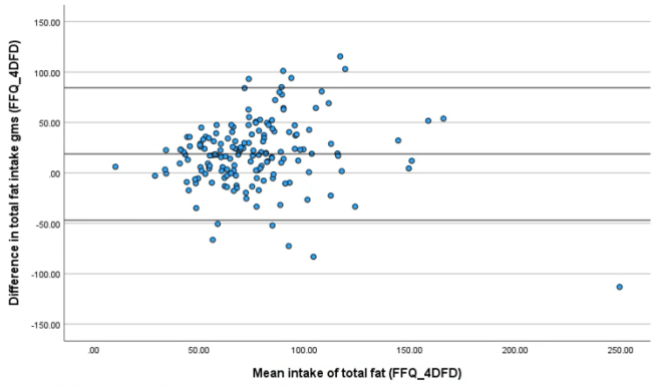
Recipes (Day 2)

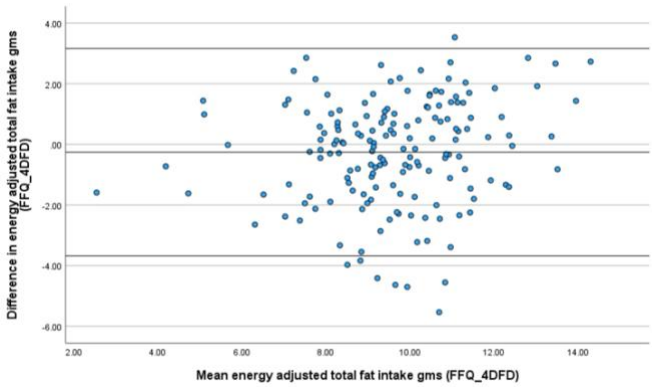
Appendix C: Bland-Altman plots

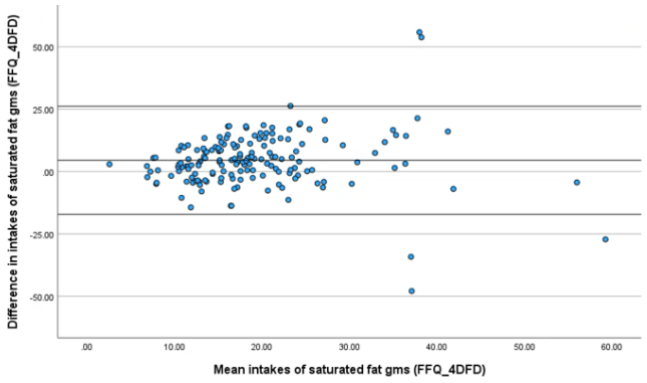








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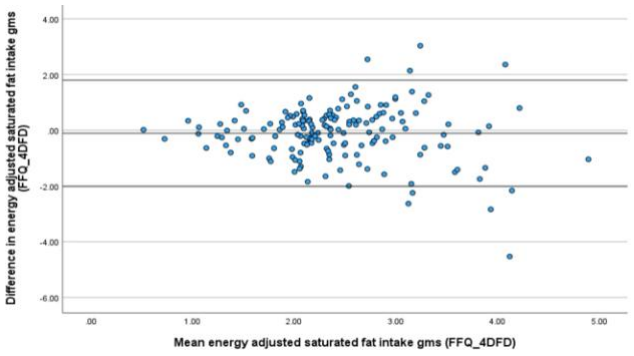
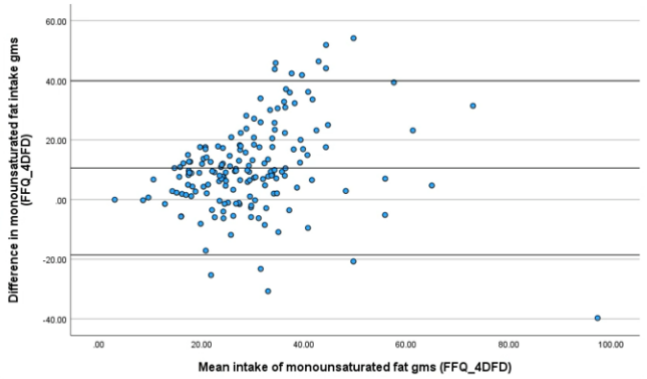
50.00
25.00
.00
-25.00
-50.00
.00
10.00
20.00
30.00
40.00
50.00
60.00
Mean intakes of saturated fat gms (FFQ_4DFD)


Difference in energy adjusted saturated fat intake gms (FFQ_4DFD)
4.00
2.00
.00
-2.00
-4.00
-6.00
.00
1.00
2.00
3.00
4.00
5.00
Mean energy adjusted saturated fat intake gms (FFQ_4DFD)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40.00
20.00
.00
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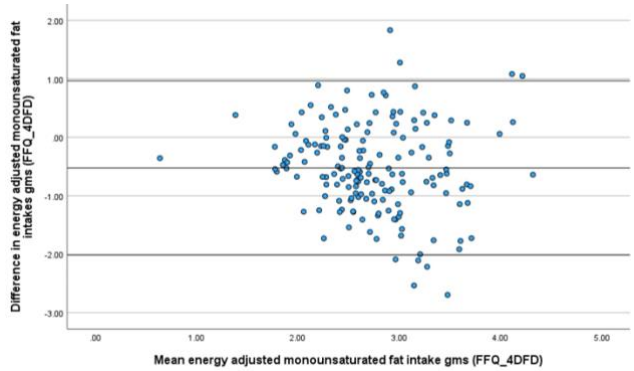
-40.00
.00
20.00
40.00
60.00
80.00
100.00
Mean intake of monounsaturated fat gms (FFQ_4DFD)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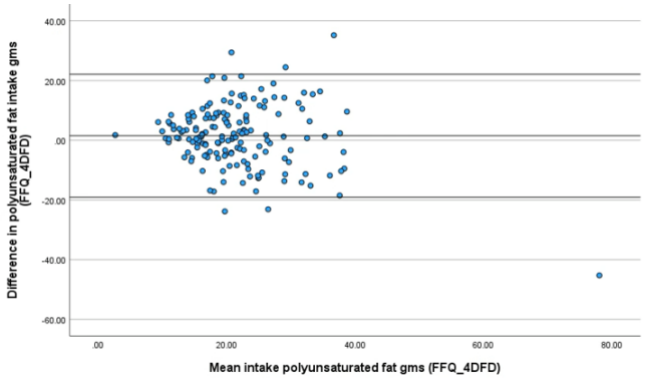
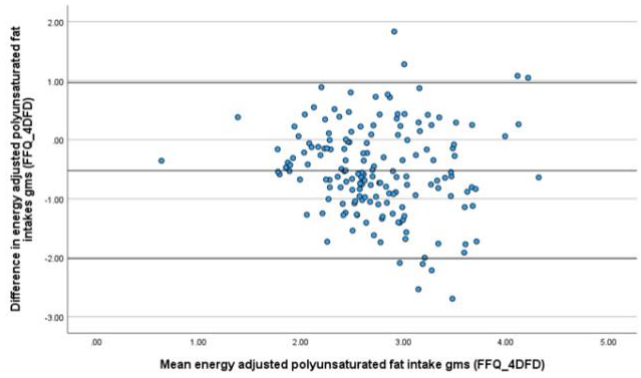
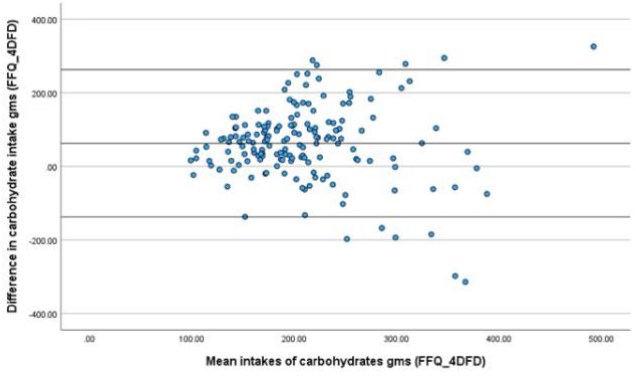
1.00
.00
-1.00
-2.00
-3.00
.00
1.00
2.00
3.00
4.00
5.00
Mean energy adjusted monounsaturated fat intake gms (FFQ_4DFD)


Difference in polyunsaturated fat intake gms (FFQ_4DFD)
40.00
20.00
.00
-20.00
-40.00
-60.00
.00
20.00
40.00
60.00
80.00
Mean intake polyunsaturated fat gms (FFQ_4DFD)


Difference in energy adjusted polyunsaturated fat intakes gms (FFQ_4DFD)
2.00
1.00
.00
-1.00
-2.00
-3.00
.00
1.00
2.00
3.00
4.00
5.00
Mean energy adjusted polyunsaturated fat intake gms (FFQ_4DFD)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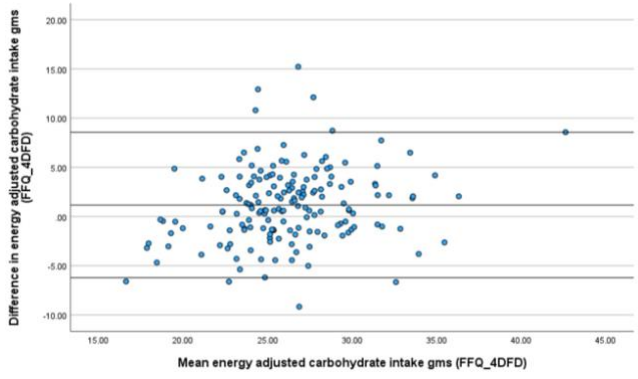
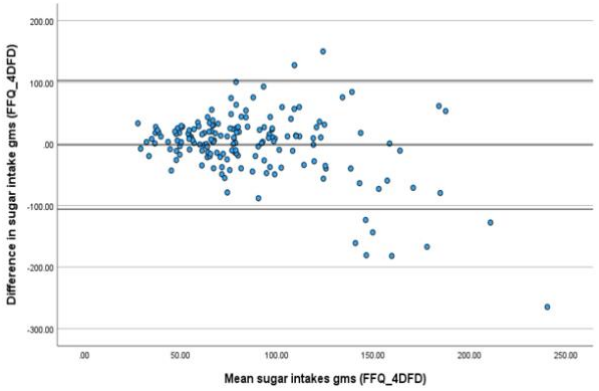
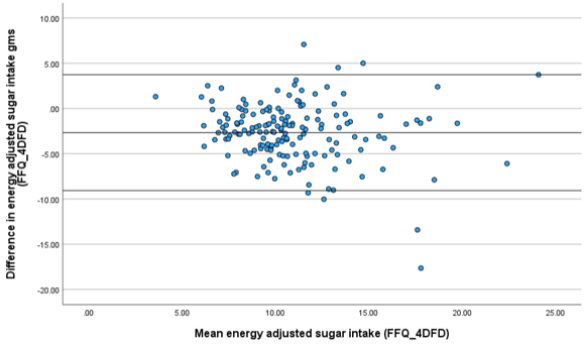
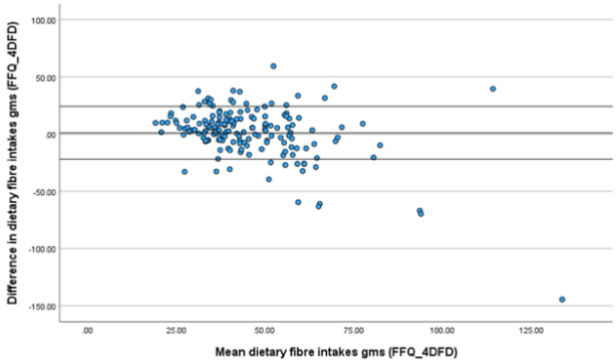
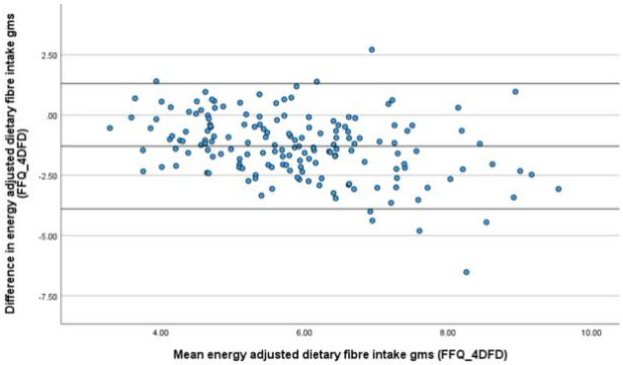
400.00
200.00
.00
-200.00
-400.00
.00
100.00
200.00
300.00
400.00
500.00
Mean intakes of carbohydrates gms (FFQ_4DFD)

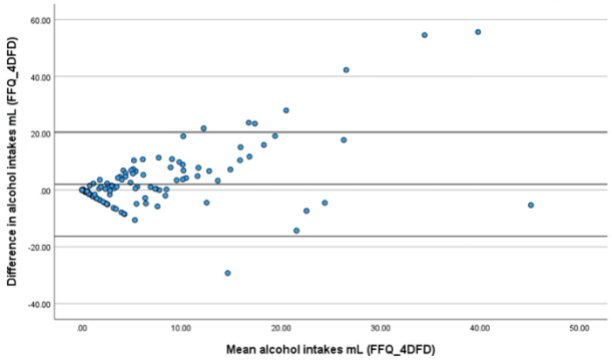

Difference in energy adjusted carbohydrate intake gms (FFQ_4DFD)
20.00
15.00
10.00
5.00
.00
-5.00
-10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
Mean energy adjusted carbohydrate intake gms (FFQ_4DFD)

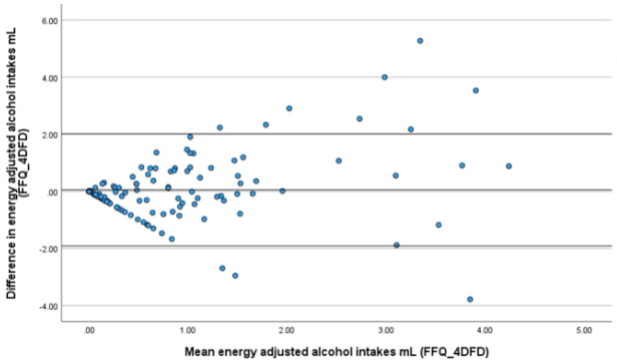

Difference in sugar intake gms (FFQ_4DFD)
Mean sugar intakes gms (FFQ_4DFD)

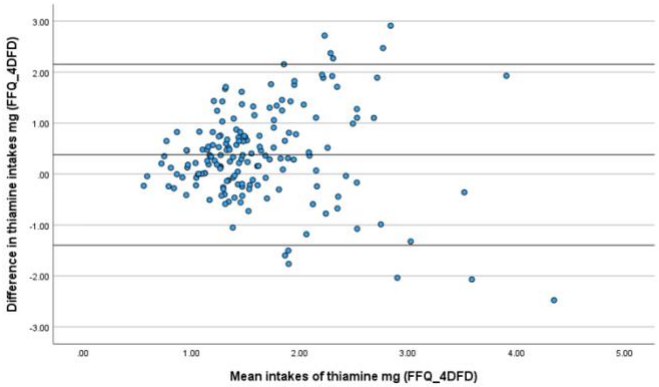

Difference in energy adjusted sugar intake gms (FFQ_4DFD)
Mean energy adjusted sugar intake (FFQ_4DFD)

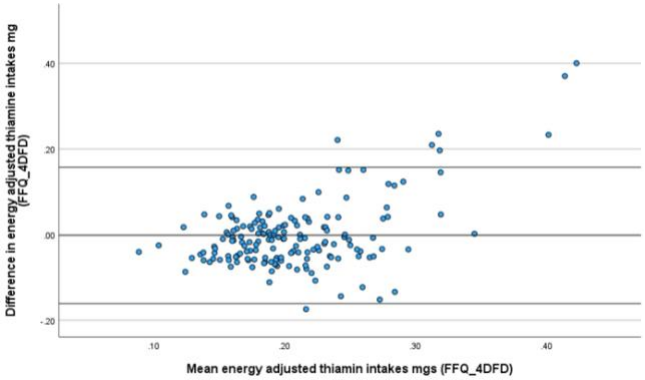

Difference in dietary fibre intakes gms (FFQ_4DFD)
Mean dietary fibre intakes gms (FFQ_4DFD)

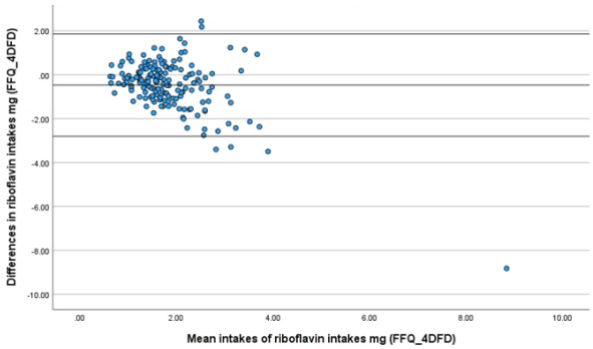

Difference in energy adjusted dietary fibre intake gms (FFQ_4DFD)
Mean energy adjusted dietary fibre intake gms (FFQ_4DFD)

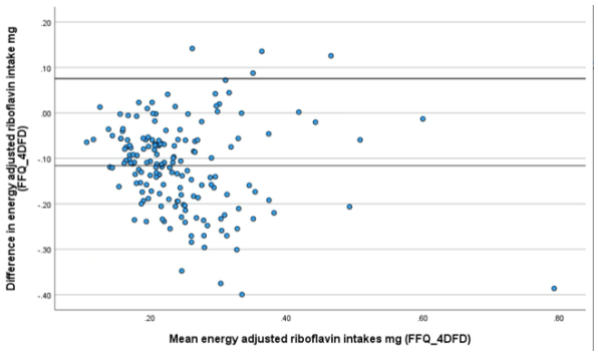

Difference in alcohol intakes mL (FFQ_4DFD)
Mean alcohol intakes mL (FFQ_4DFD)

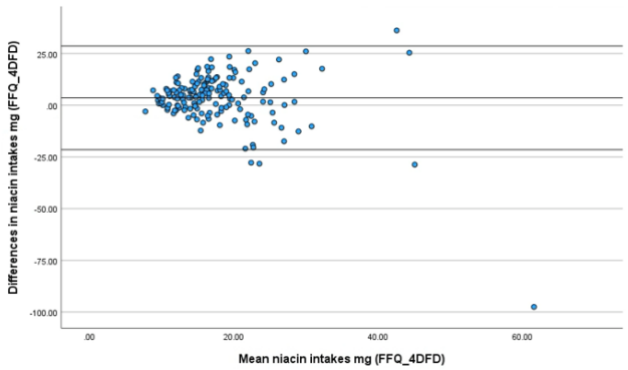

Difference in energy adjusted alcohol intakes mL (FFQ_4DFD)
Mean energy adjusted alcohol intakes mL (FFQ_4DFD)

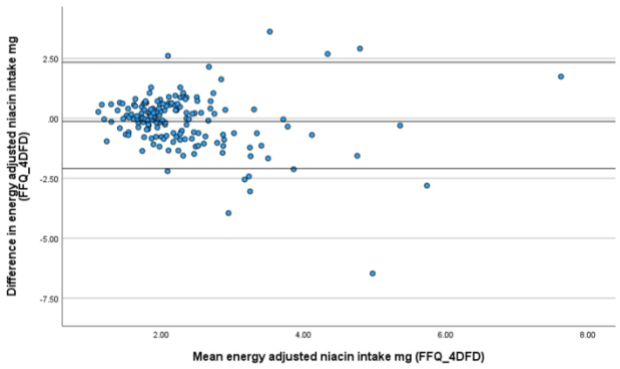

Difference in thiamine intakes mg (FFQ_4DFD)
Mean intakes of thiamine mg (FFQ_4DFD)

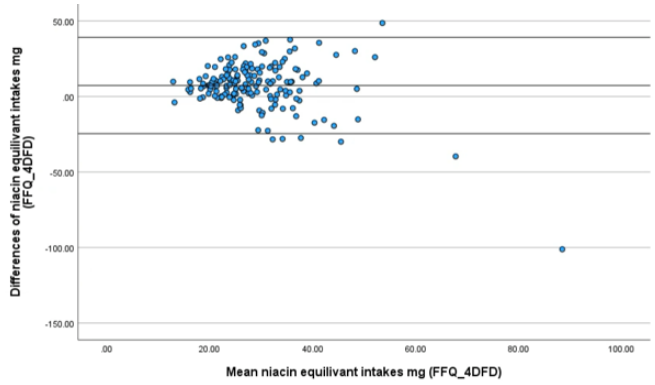

Difference in energy adjusted thiamine intakes mg (FFQ_4DFD)
Mean energy adjusted thiamin intakes mgs (FFQ_4DFD)

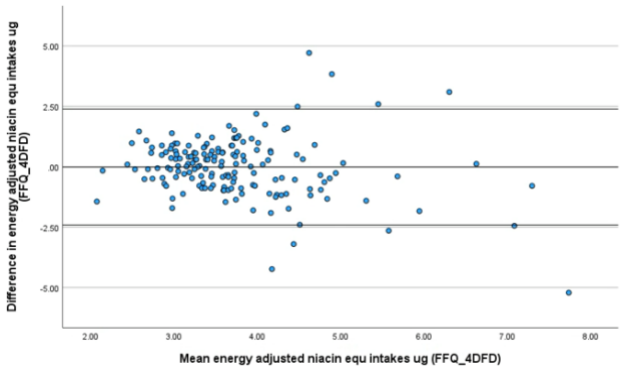

Differences in riboflavin intakes mg (FFQ_4DFD)
2.00
.00
-2.00
-4.00
-6.00
-8.00
-10.00
.00
2.00
4.00
6.00
8.00
10.00
Mean intakes of riboflavin intakes mg (FFQ_4DFD)

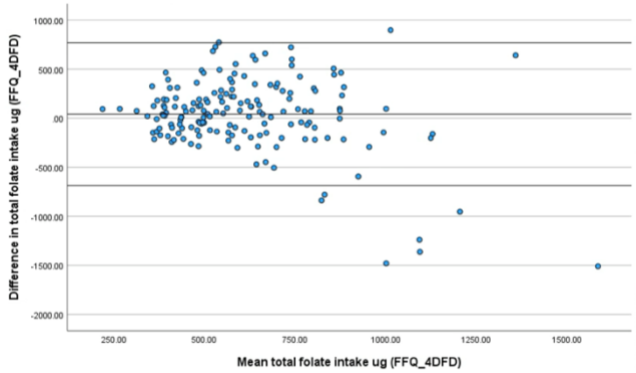

Difference in energy adjusted riboflavin intake mg (FFQ_4DFD)
.20
.10
.00
-.10
-.20
-.30
-.40
.20
.40
.60
.80
Mean energy adjusted riboflavin intakes mg (FFQ_4DFD)

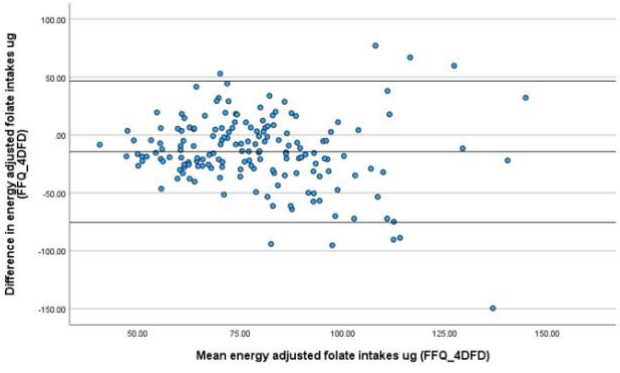

Differences in niacin intakes mg (FFQ_4DFD)
25.00
.00
-25.00
-50.00
-75.00
-100.00
.00
20.00
40.00
60.00
Mean niacin intakes mg (FFQ_4DFD)

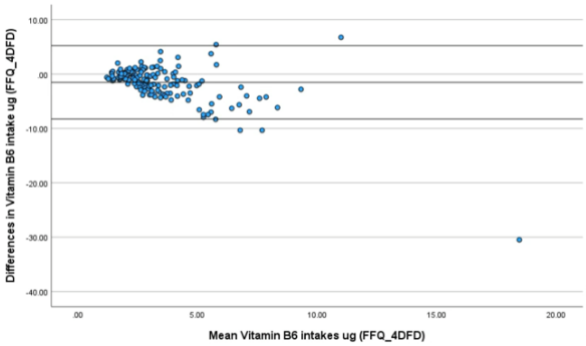

Difference in energy adjusted niacin intake mg (FFQ_4DFD)
2.50
.00
-2.50
-5.00
-7.50
2.00
4.00
6.00
8.00
Mean energy adjusted niacin intake mg (FFQ_4DFD)

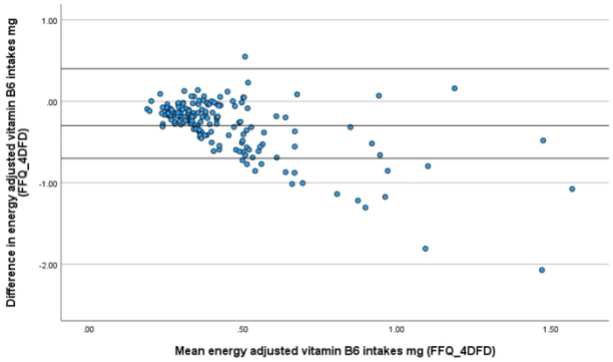

Differences of niacin equilivant intakes mg (FFQ_4DFD)
50.00
.00
-50.00
-100.00
-150.00
.00
20.00
40.00
60.00
80.00
100.00
Mean niacin equilivant intakes mg (FFQ_4DFD)

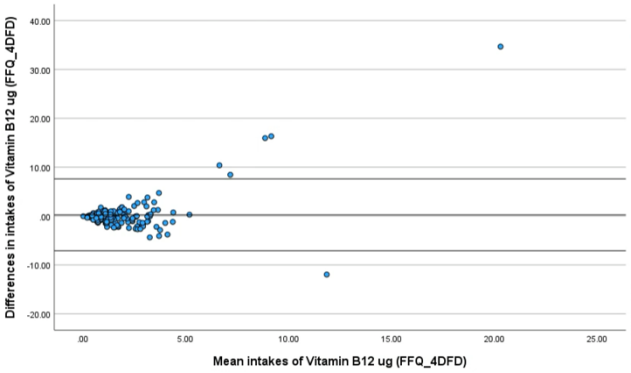

Difference in energy adjusted niacin equ intakes ug (FFQ_4DFD)
5.00
2.50
.00
-2.50
-5.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
Mean energy adjusted niacin equ intakes ug (FFQ_4DFD)

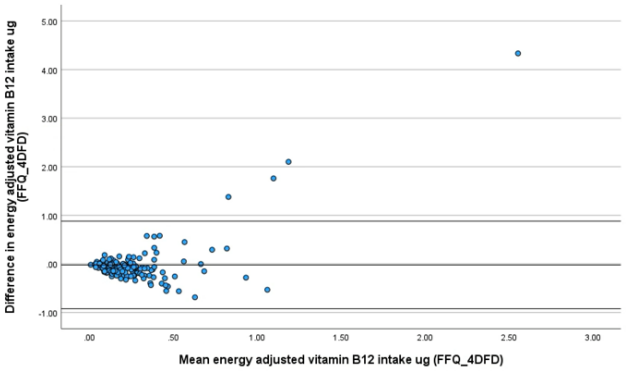

Difference in total folate intake ug (FFQ_4DFD)
1000.00
500.00
.00
-500.00
-1000.00
-1500.00
-2000.00
250.00
500.00
750.00
1000.00
1250.00
1500.00
Mean total folate intake ug (FFQ_4DFD)

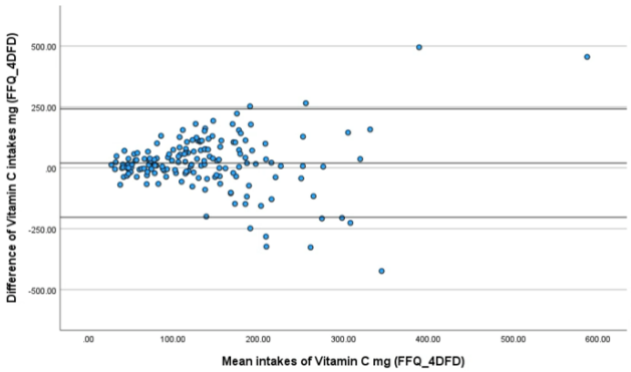

Difference in energy adjusted folate intakes ug (FFQ_4DFD)
100.00
50.00
.00
-50.00
-100.00
-150.00
50.00
75.00
100.00
125.00
150.00
Mean energy adjusted folate intakes ug (FFQ_4DFD)

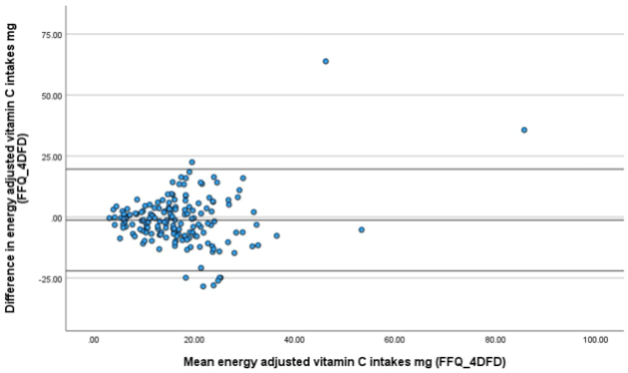

Differences in Vitamin B6 intake ug (FFQ_4DFD)
10.00
.00
-10.00
-20.00
-30.00
-40.00
.00
5.00
10.00
15.00
20.00
Mean Vitamin B6 intakes ug (FFQ_4DFD)

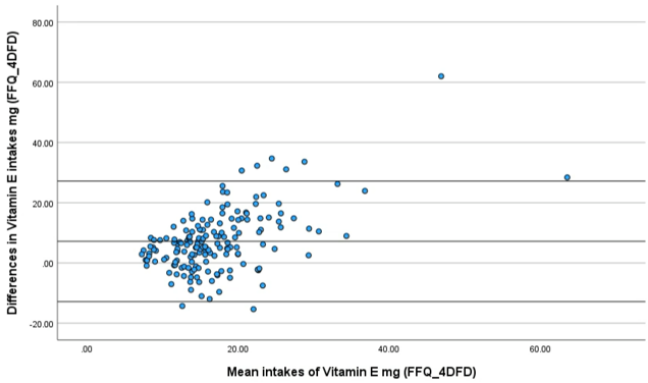

Difference in energy adjusted vitamin B6 intakes mg (FFQ_4DFD)
1.00
.00
-1.00
-2.00
.00
.50
1.00
1.50
Mean energy adjusted vitamin B6 intakes mg (FFQ_4DFD)

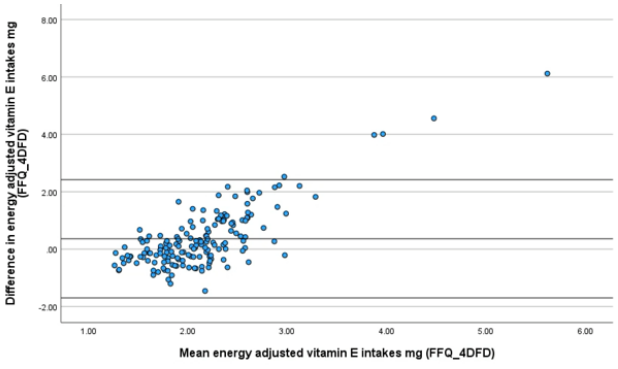

Differences in intakes of Vitamin B12 ug (FFQ_4DFD)
40.00
30.00
20.00
10.00
.00
-10.00
-20.00
.00
5.00
10.00
15.00
20.00
25.00
Mean intakes of Vitamin B12 ug (FFQ_4DFD)

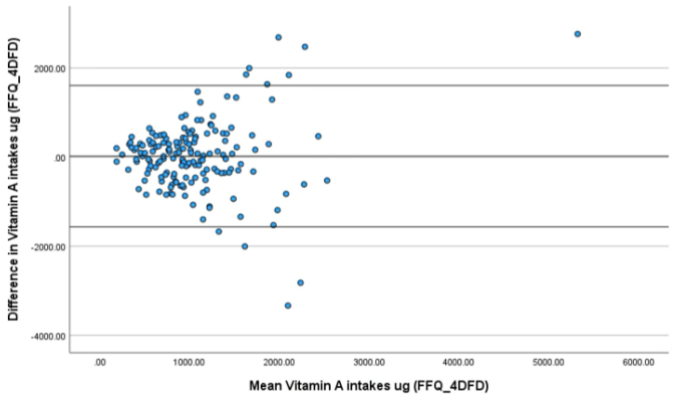

Difference in energy adjusted vitamin B12 intake ug (FFQ_4DFD)
5.00
4.00
3.00
2.00
1.00
.00
-1.00
.00
.50
1.00
1.50
2.00
2.50
3.00
Mean energy adjusted vitamin B12 intake ug (FFQ_4DFD)

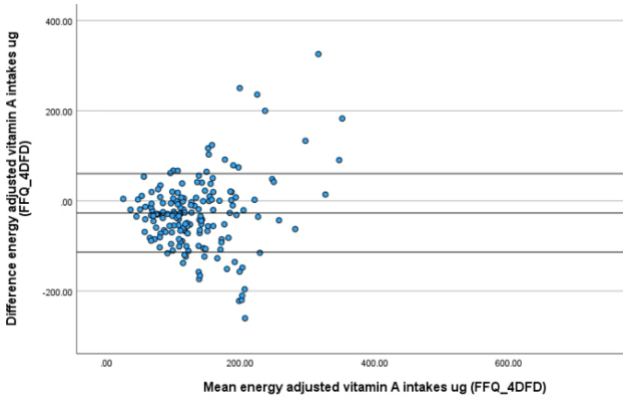

Difference of Vitamin C intakes mg (FFQ_4DFD)
500.00
250.00
.00
-250.00
-500.00
.00
100.00
200.00
300.00
400.00
500.00
600.00
Mean intakes of Vitamin C mg (FFQ_4DFD)

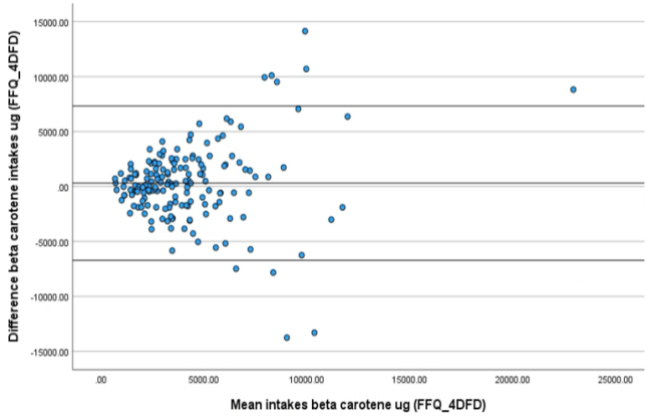

Difference in energy adjusted vitamin C intakes mg (FFQ_4DFD)
75.00
50.00
25.00
.00
-25.00
.00
20.00
40.00
60.00
80.00
100.00
Mean energy adjusted vitamin C intakes mg (FFQ_4DFD)

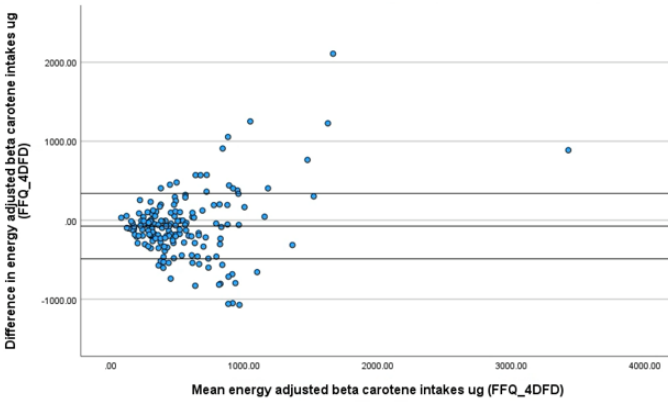

Differences in Vitamin E intakes mg (FFQ_4DFD)
80.00
60.00
40.00
20.00
.00
-20.00
.00
20.00
40.00
60.00
Mean intakes of Vitamin E mg (FFQ_4DFD)

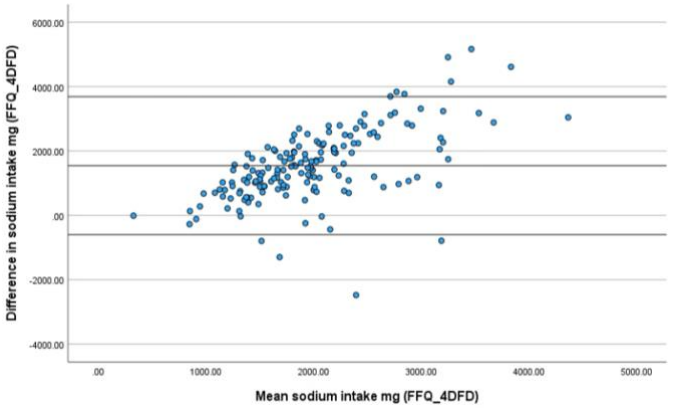

Difference in energy adjusted vitamin E intakes mg (FFQ_4DFD)
8.00
6.00
4.00
2.00
.00
-2.00
1.00
2.00
3.00
4.00
5.00
6.00
Mean energy adjusted vitamin E intakes mg (FFQ_4DFD)

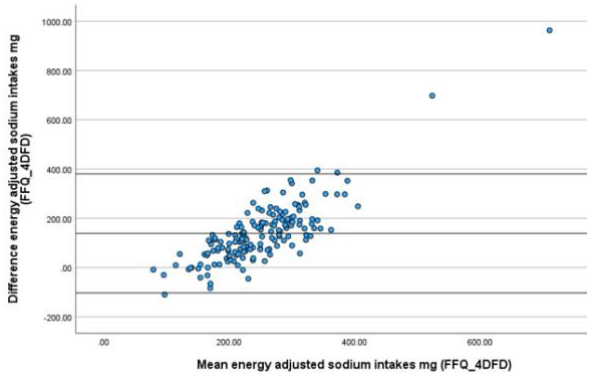

Difference in Vitamin A intakes ug (FFQ_4DFD)
2000.00
.00
-2000.00
-4000.00
.00
1000.00
2000.00
3000.00
4000.00
5000.00
6000.00
Mean Vitamin A intakes ug (FFQ_4DFD)

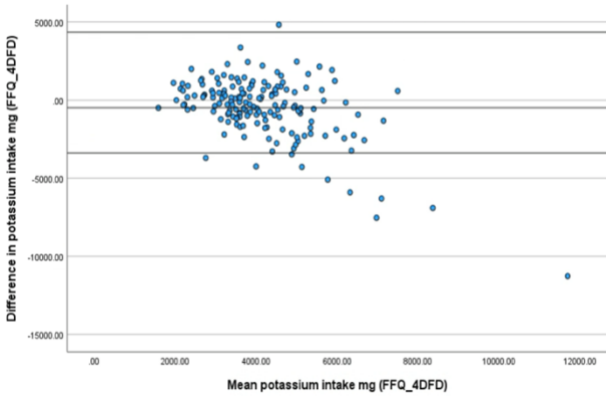

Difference energy adjusted vitamin A intakes ug (FFQ_4DFD)
400.00
200.00
.00
-200.00
.00
200.00
400.00
600.00
Mean energy adjusted vitamin A intakes ug (FFQ_4DFD)

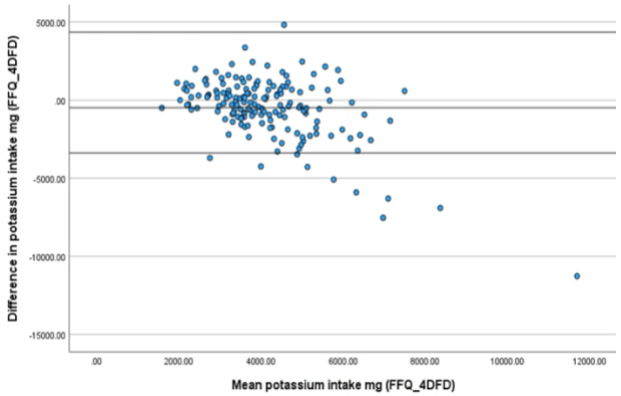

Difference beta carotene intakes ug (FFQ_4DFD)
15000.00
10000.00
5000.00
.00
-5000.00
-10000.00
-15000.00
.00
5000.00
10000.00
15000.00
20000.00
25000.00
Mean intakes beta carotene ug (FFQ_4DFD)

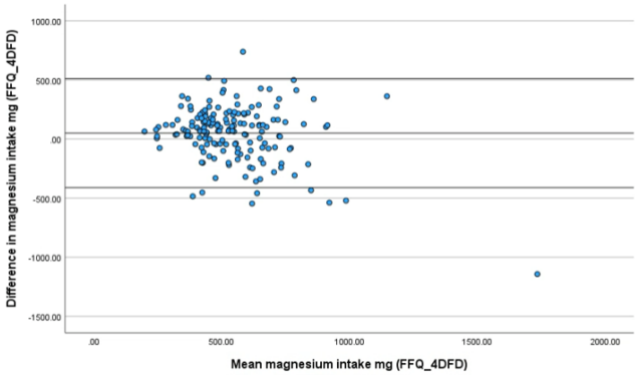

Difference in energy adjusted beta carotene intakes ug (FFQ_4DFD)
2000.00
1000.00
.00
-1000.00
.00
1000.00
2000.00
3000.00
4000.00
Mean energy adjusted beta carotene intakes ug (FFQ_4DFD)

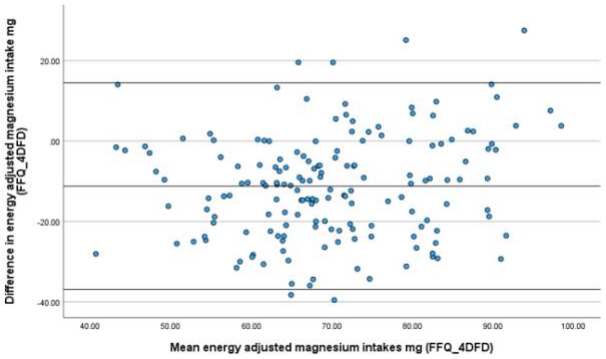

Difference in sodium intake mg (FFQ_4DFD)
6000.00
4000.00
2000.00
.00
-2000.00
-4000.00
.00
1000.00
2000.00
3000.00
4000.00
5000.00
Mean sodium intake mg (FFQ_4DFD)

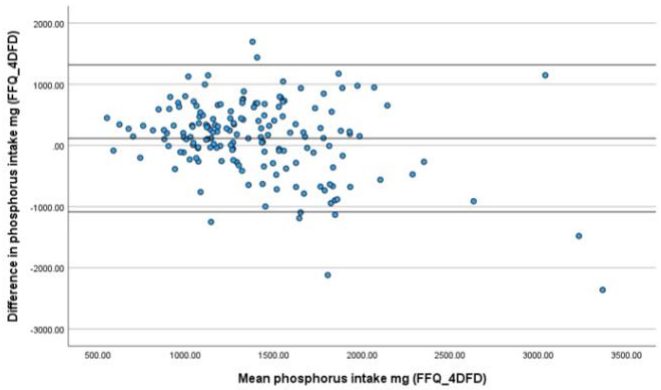

Difference energy adjusted sodium intakes mg (FFQ_4DFD)
1000.00
800.00
600.00
400.00
200.00
.00
-200.00
.00
200.00
400.00
600.00
Mean energy adjusted sodium intakes mg (FFQ_4DFD)

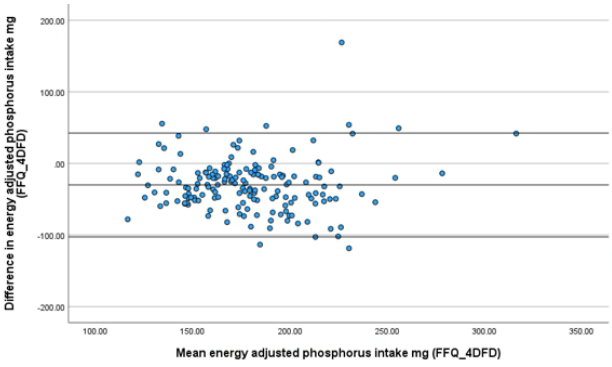

Difference in potassium intake mg (FFQ_4DFD)
5000.00
.00
-5000.00
-10000.00
-15000.00
.00
2000.00
4000.00
6000.00
8000.00
10000.00
12000.00
Mean potassium intake mg (FFQ_4DFD)

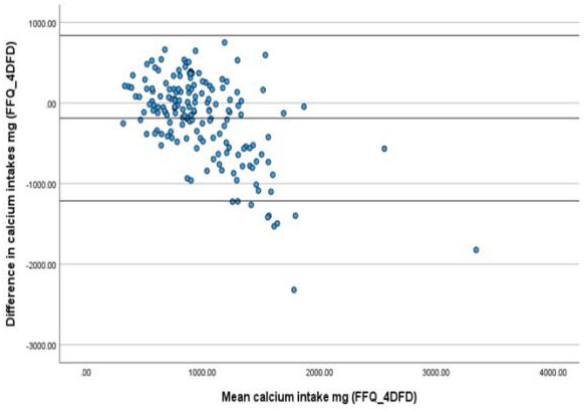

Difference in potassium intake mg (FFQ_4DFD)
5000.00
.00
-5000.00
-10000.00
-15000.00
.00
2000.00
4000.00
6000.00
8000.00
10000.00
12000.00
Mean potassium intake mg (FFQ_4DFD)

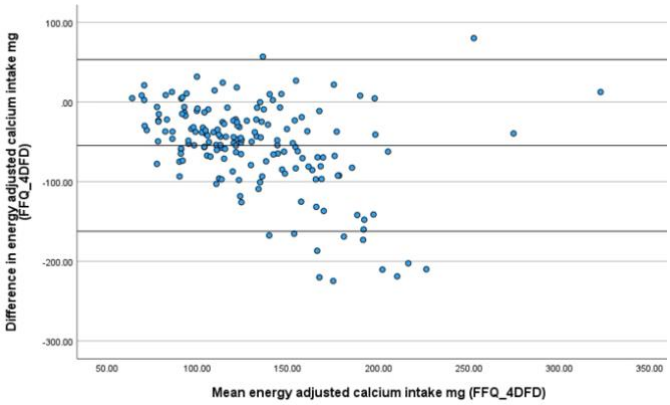

Difference in magnesium intake mg (FFQ_4DFD)
1000.00
500.00
.00
-500.00
-1000.00
-1500.00
.00
500.00
1000.00
1500.00
2000.00
Mean magnesium intake mg (FFQ_4DFD)

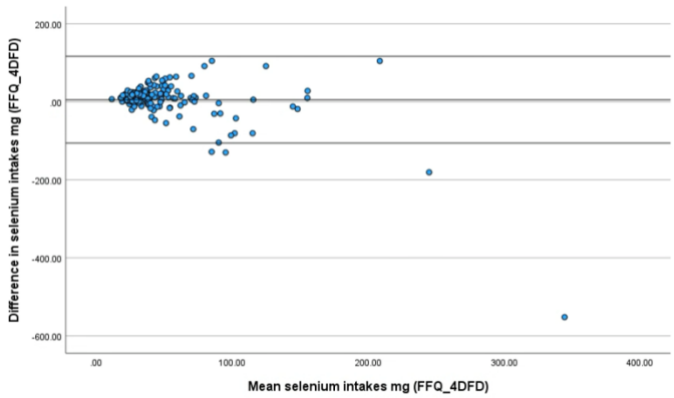

Difference in energy adjusted magnesium intake mg (FFQ_4DFD)
20.00
.00
-20.00
-40.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
Mean energy adjusted magnesium intakes mg (FFQ_4DFD)

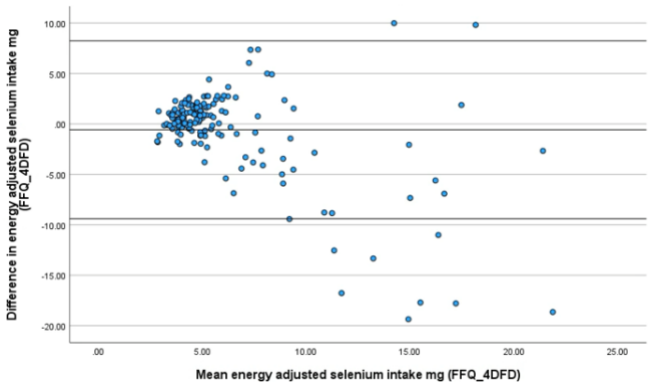

Difference in phosphorus intake mg (FFQ_4DFD)
2000.00
1000.00
.00
-1000.00
-2000.00
-3000.00
500.00
1000.00
1500.00
2000.00
2500.00
3000.00
3500.00
Mean phosphorus intake mg (FFQ_4DFD)

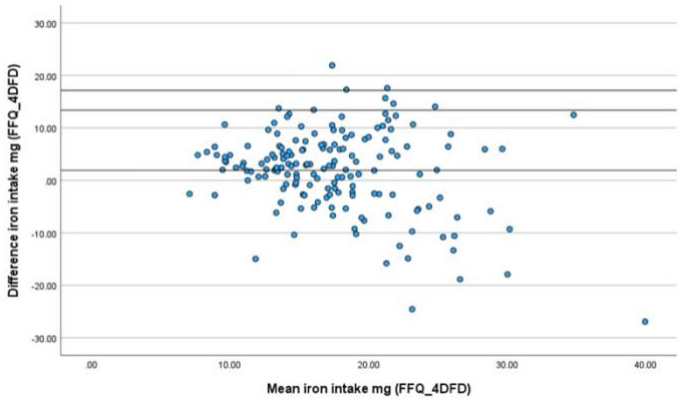

Difference in energy adjusted phosphorus intake mg (FFQ_4DFD)
200.00
100.00
.00
-100.00
-200.00
100.00
150.00
200.00
250.00
300.00
350.00
Mean energy adjusted phosphorus intake mg (FFQ_4DFD)

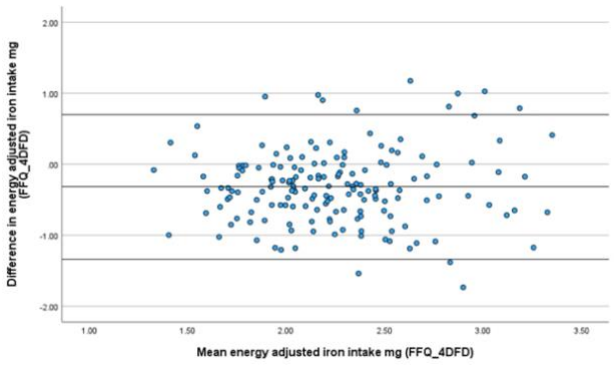

Difference in calcium intakes mg (FFQ_4DFD)
1000.00
.00
-1000.00
-2000.00
-3000.00
.00
1000.00
2000.00
3000.00
4000.00
Mean calcium intake mg (FFQ_4DFD)

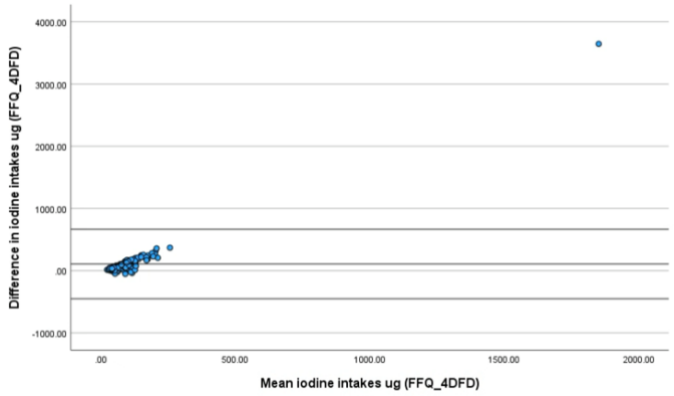

Difference in energy adjusted calcium intake mg (FFQ_4DFD)
100.00
.00
-100.00
-200.00
-300.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
Mean energy adjusted calcium intake mg (FFQ_4DFD)

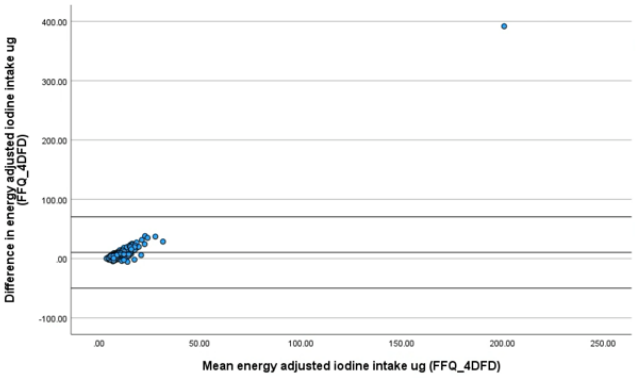

Difference in selenium intakes mg (FFQ_4DFD)
200.00
.00
-200.00
-400.00
-600.00
.00
100.00
200.00
300.00
400.00
Mean selenium intakes mg (FFQ_4DFD)

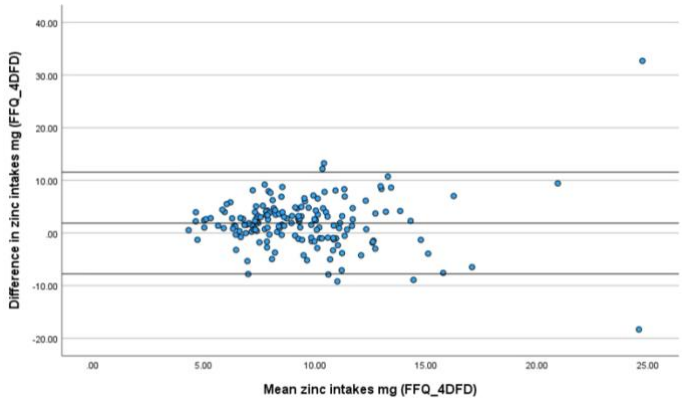

Difference in energy adjusted selenium intake mg (FFQ_4DFD)
10.00
5.00
.00
-5.00
-10.00
-15.00
-20.00
.00
5.00
10.00
15.00
20.00
25.00
Mean energy adjusted selenium intake mg (FFQ_4DFD)

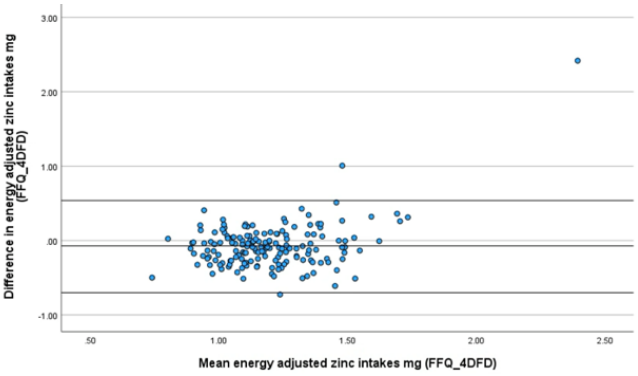

Difference iron intake mg (FFQ_4DFD)
30.00
20.00
10.00
.00
-10.00
-20.00
-30.00
.00
10.00
20.00
30.00
40.00
Mean iron intake mg (FFQ_4DFD)

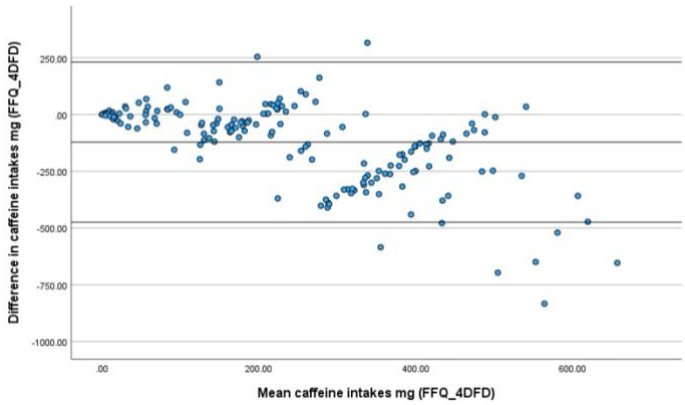

Difference in energy adjusted iron intake mg (FFQ_4DFD)
2.00
1.00
.00
-1.00
-2.00
1.00
1.50
2.00
2.50
3.00
3.50
Mean energy adjusted iron intake mg (FFQ_4DFD)

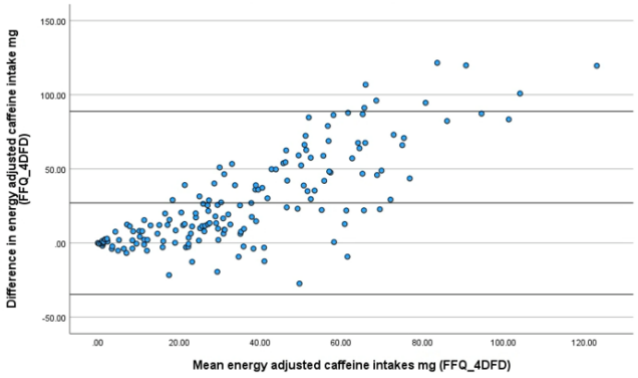

Difference in iodine intakes ug (FFQ_4DFD)
4000.00
3000.00
2000.00
1000.00
.00
-1000.00
.00
500.00
1000.00
1500.00
2000.00
Mean iodine intakes ug (FFQ_4DFD)


Difference in energy adjusted iodine intake ug (FFQ_4DFD)
400.00
300.00
200.00
100.00
.00
-100.00
.00
50.00
100.00
150.00
200.00
250.00
Mean energy adjusted iodine intake ug (FFQ_4DFD)


Difference in zinc intakes mg (FFQ_4DFD)
40.00
30.00
20.00
10.00
.00
-10.00
-20.00
.00
5.00
10.00
15.00
20.00
25.00
Mean zinc intakes mg (FFQ_4DFD)


Difference in energy adjusted zinc intakes mg (FFQ_4DFD)
3.00
2.00
1.00
.00
-1.00
.50
1.00
1.50
2.00
2.50
Mean energy adjusted zinc intakes mg (FFQ_4DFD)


Difference in caffeine intakes mg (FFQ_4DFD)
250.00
.00
-250.00
-500.00
-750.00
-1000.00
.00
200.00
400.00
600.00
Mean caffeine intakes mg (FFQ_4DFD)


Difference in energy adjusted caffeine intake mg (FFQ_4DFD)
150.00
100.00
50.00
.00
-50.00
.00
20.00
40.00
60.00
80.00
100.00
120.00
Mean energy adjusted caffeine intakes mg (FFQ_4DFD)

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