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# The Food Insecurity, Cardiometabolic Risk, and Microbiota (FIRM) Study: Protocol and Baseline Characteristics of Urban Low-Income Adults with Non-Communicable Diseases in Primary Care in Malaysia

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Tables 1 and 2 are available in the supplementary files section

# The Food Insecurity, Cardiometabolic Risk, and Microbiota (FIRM) Study: Protocol and Baseline Characteristics of Urban Low-Income Adults with Non-Communicable Diseases in Primary Care in Malaysia

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**Abstract**

The Food Insecurity, Cardiometabolic Risk, and Microbiota (FIRM) Study is a biopsychosocial-informed, integrated two-phase investigation conducted in Malaysian primary care. The study examines how food insecurity (FI), coping behaviours, dietary constraints, and biological pathways may contribute to cardiometabolic risk among urban low-income adults with non-communicable diseases (NCDs). This approach is designed to address a key evidence gap in primary care, where suboptimal cardiometabolic control among patients with established NCDs. This paper describes the FIRM Study protocol and reports baseline findings from Phase 1. Phase 1 involved 338 adults with NCDs recruited from primary care clinics. FI was assessed using the Food Insecurity Experience Scale (FIES), coping behaviours using the Malaysian Coping Strategy Instrument (MCSI), and 10-year cardiovascular disease (CVD) risk using the Framingham Risk Score, categorised as low (<10%), intermediate (10–20%), and high (>20%) risk. Cardiometabolic control was suboptimal: only 21.4% achieved glycemic control, 35.8% met lipid targets, and 65.1% achieved blood pressure control. Overall, 29% experienced FI. FIES-based FI did not differ across CVD risk categories ($p=0.709$). In contrast, MCSI tertiles showed a significant gradient across CVD risk categories ($p<0.001$), with coping-secure individuals predominantly observed in the low-risk group. These baseline findings suggest that coping behaviours may be more sensitive indicators of cardiometabolic vulnerability than FI exposure alone. They also provide a basis for subsequent FIRM components, including linear programming to develop cost-effective dietary strategies and gut microbiota analysis to explore biological pathways linking dietary constraints and metabolic risk.

**Keywords:** Food insecurity; Coping strategies; Cardiometabolic risk; Primary care; Type 2 diabetes; Gut microbiota; Linear programming; Biopsychosocial model

## 1.0 Introduction

Urbanisation in low- and middle-income countries (LMICs) has intensified the burden of non-communicable diseases (NCDs), particularly among low-income urban populations (1). Globally, over 75% of NCD-related deaths occur in LMICs, where rising living costs, limited access to nutritious foods, and reliance on low-cost, energy-dense diets contribute to adverse cardiometabolic outcomes (1,2). In Malaysia, type 2 diabetes (T2D) prevalence is higher in urban areas (19.8%) compared to rural settings (15.6%), and disease control remains suboptimal among low-income households (3).

Although Malaysia provides highly subsidised primary healthcare services (4), many individuals with established NCDs continue to fail to achieve recommended cardiometabolic targets (5), suggesting that cardiometabolic risk in primary care may be shaped by interacting social, behavioural, and biological factors.

Within this primary care context, food insecurity (FI), defined as limited or uncertain access to adequate food, represents an under-recognised determinant of cardiometabolic risk (6,7). FI is associated with poor diet quality and increased cardiometabolic risk (8,9), and may coexist with obesity in urban low-income settings, reflecting the “hunger-obesity paradox” (10). However, FI is not routinely assessed in clinical practice, and its relationship with cardiometabolic outcomes is not consistently observed. This suggests that FI exposure alone may not fully capture vulnerability in primary care populations (6,11).

How FI is measured may therefore influence its observed relationship with health outcomes. Experience-based measures such as the Food Insecurity Experience Scale

(FIES) capture perceived deprivation (12), whereas coping-based measures such as the Malaysian Coping Strategy Instrument (MCSI) reflect behavioural adaptations to constrained food access (13). These coping behaviours may provide a more proximal indicator of cardiometabolic vulnerability yet remain underexplored among primary care patients with established NCDs (14).

The biopsychosocial (BPS) framework provides a useful lens to examine how social conditions, behavioural responses, and biological processes interact to shape cardiometabolic risk (15). Despite its relevance, the application of BPS-informed approaches to cardiometabolic risk, particularly in relation to FI and dietary behaviour, remains limited. Beyond behavioural pathways, biological mechanisms linking FI to metabolic risk remain insufficiently understood. Gut microbiota dysbiosis has been implicated in T2D, yet its relationship with FI in metabolically vulnerable populations remains unclear (16). At the same time, dietary advice in primary care often assumes that patients can access and afford recommended foods (11). Linear programming (LP) offers a practical approach to developing cost-effective, nutritionally adequate diets, but its application in FI and cardiometabolic risk management remains limited (17).

The Food Insecurity, Cardiometabolic Risk, and Microbiota (FIRM) Study is an integrated two-phase investigation conducted within primary care settings in Malaysia to address these gaps. Guided by the BPS framework, the study is designed to assess FI and coping behaviours, model cost-effective dietary strategies using LP, and examine biological pathways through gut microbiota within the same population (**Figure 1**). Presenting FIRM as a single protocol is important because its baseline,

dietary modelling, and microbiome components collectively examine the pathway from social constraint to behavioural adaptation, clinical risk, feasible intervention, and biological mechanism. This paper describes the FIRM Study protocol and reports baseline findings from Phase 1, characterising the sociodemographic, clinical, anthropometric, behavioural, FI, and CVD risk profiles of the study population.

**Figure 1. Conceptual framework.**

## 2.0 Materials and Methods

### 2.1 Study Design

Guided by the BPS framework (18), the FIRM Study is an integrated two-phase investigation conducted in primary care settings in Malaysia. The phases are designed as interrelated components of a single integrated study to capture interconnected behavioural, dietary, and biological pathways within the same population. Phase 1 involves baseline assessment of FI, coping behaviours, CVD risk, clinical parameters, and anthropometric characteristics. These data inform the development of cost-effective dietary strategies using LP. Phase 2 involves gut microbiota analysis in a sub-sample of individuals with T2D, stratified by FI status, to examine microbial composition and its association with metabolic risk. This paper describes the overall study protocol and reports baseline findings from Phase 1.

### 2.2 Study Setting and Participants

The study was conducted in government primary health clinics in Selangor, Malaysia. Malaysia's public primary healthcare system provides subsidised services for citizens (4). Selangor was selected as the study location because it is one of the most

urbanised states in Malaysia, with 95.8% of its population living in urban areas and the largest urban population among Malaysian states (19). Within this setting, government primary health clinics provide structured follow-up for patients with NCDs, including T2D, hypertension, and dyslipidemia, typically through scheduled clinic visits at three to six-month intervals. As part of routine care, biochemical investigations are commonly performed before scheduled consultations to support clinical review and medication adjustment.

Participants were Malaysian adults aged 18-64 years with at least one diagnosed NCD, including T2D, dyslipidemia, or hypertension, and residing in low-income households. Low-income status was defined as a monthly household income <RM6,960 (~USD1,729), reflecting the urban cost-of-living threshold in Selangor (20). Exclusion criteria included pregnancy, lactation, requirement for specialised nutrition support, and severe comorbid conditions such as chronic kidney failure requiring dialysis, stroke, liver failure, active cancer, chronic corticosteroid use, or inflammatory bowel disease.

The sample size for Phase 1 was determined based on the estimated prevalence of high CVD risk, as defined by the Framingham Risk Score (FRS), among low-income urban populations in Malaysia (21.4%) (21). Based on this estimate, the initial required sample size was 251 participants. After accounting for a 20% non-response rate, the minimum sample size was increased to 311 participants. A total of 338 participants were ultimately recruited.

Within each clinic, outpatient appointment lists were used as the sampling frame for systematic random sampling. A sampling interval (k = N/n) was applied, with approximately every third patient selected after a random starting point. A total of 887 patients were screened, and 338 eligible participants were enrolled. Eligible participants were identified through clinic records and approached during routine clinic visits. Written informed consent was obtained before enrolment and data collection.

## 2.3 Phase 1 Data Collection: Baseline Assessments

Baseline data were collected during routine clinic visits using structured questionnaires and standardised clinical assessments conducted by trained personnel.

***2.3.1 Sociodemographic characteristics.*** Sociodemographic data, including age, sex, education level, and household income, were obtained using interviewer-administered questionnaires.

***2.3.2 Lifestyle and behavioural characteristics.*** Physical activity, perceived stress, smoking, and sleep were assessed using validated instruments. Physical activity was measured using the International Physical Activity Questionnaire-Short Form (IPAQ-SF) and expressed as metabolic equivalent task (MET) minutes per week. Participants were categorised into low (<600 MET-minutes/week), moderate (600-2,999 MET-minutes/week), and high (≥3,000 MET-minutes/week or ≥1,500 MET-minutes/week with vigorous activity) according to standard IPAQ scoring protocols (22). Perceived stress was assessed using the 10-item Perceived Stress Scale (PSS-10), with total scores calculated and categorised into low, moderate, and high stress levels based

on established cut-offs (23). Smoking behaviour was assessed using the Global Adult Tobacco Survey (GATS), and participants were classified as current smokers or non-smokers (24). Among current and former smokers, additional information on duration of smoking and cessation (years) was obtained. Sleep was assessed using self-reported measures of average sleep duration (hours per night) and the presence of sleep difficulty (yes/no).

***2.3.3 Clinical and biochemical measurements.*** Glycated haemoglobin (HbA1c), fasting plasma glucose, and lipid profile (total cholesterol, HDL-cholesterol, LDL-cholesterol, and triglycerides) were obtained from routine laboratory investigations conducted at the study site. The most recent laboratory results within two weeks of the study visit were extracted from medical records. Plasma glucose was measured using the hexokinase method. Serum lipid parameters were analysed using enzymatic colourimetric assays on an automated clinical chemistry analyser (Roche Cobas c311, Roche Diagnostics, Germany). HbA1c was measured using high-performance liquid chromatography (HPLC) (Bio-Rad D-10 system, Bio-Rad Laboratories, USA) and standardised according to the National Glycohemoglobin Standardisation Program (NGSP). Blood pressure was measured using an automated digital sphygmomanometer (Omron HEM-7120, Omron Healthcare, Japan) after at least 5 minutes of seated rest. Two measurements were taken at 1–2 minute intervals, and the average was used for analysis.

***2.3.4 Anthropometric measurements.*** Body weight was measured to the nearest 0.1 kg using a calibrated digital weighing scale (SECA 813, SECA GmbH, Germany), with participants wearing light clothing and without shoes. Height was measured to the

nearest 0.1 cm using a portable stadiometer (SECA 213, SECA GmbH, Germany). Body mass index (BMI) was calculated as weight (kg)/height (m²). Waist circumference was measured using a non-stretchable measuring tape (SECA 201) at the midpoint between the lower rib margin and the iliac crest. BMI was classified according to the World Health Organization (WHO) Asian cut-offs as underweight (<18.5 kg/m²), normal weight (18.5–22.9 kg/m²), overweight (23.0–27.4 kg/m²), and obese (≥27.5 kg/m²), which are recommended for Asian populations due to higher cardiometabolic risk at lower BMI levels (25). Central obesity was defined using waist circumference cut-offs recommended for Asian populations, as ≥90 cm for men and ≥80 cm for women (26).

***2.3.5 Food insecurity and coping behaviours.*** FI was assessed using the FIES, an 8-item experience-based measure of access-related food deprivation over the previous 12 months (12). The FIES has been validated across diverse populations, including the Malaysian population (27), supporting its applicability in this study population. Total scores range from 0 to 8, with higher scores indicating greater severity of FI. The scores are interpreted as food secure (0), mild (1-3), moderate (4-6), and severe (7-8) FI (27).

Coping behaviours were assessed using the MCSI, which captures behavioural responses to food-related constraints, including dietary compromise, portion reduction, and other household coping practices. The instrument comprises multiple items scored on a Likert scale, with higher scores reflecting greater reliance on coping strategies. Participants were categorised into tertiles (e.g., coping-secure, moderate coping, and coping-insecure) for analysis. The MCSI has been validated for use in

Malaysian populations, demonstrating acceptable internal consistency and construct validity (28).

***2.3.6 Dietary intake.*** Dietary intake data were collected using a semi-quantitative Food Frequency Questionnaire (FFQ) adapted from the Malaysian Adult Nutrition Survey (MANS) and previously validated for Malaysian populations (29). FFQ data will be converted into daily food and nutrient intakes by applying standard portion sizes and frequency weights, based on Malaysian food composition databases (30). Dietary intake data are not presented in the current analysis and will be reported separately.

***2.3.7 Cardiovascular risk assessment.*** Ten-year cardiovascular disease (CVD) risk was estimated using the Framingham Risk Score (FRS) and categorised into low (<10%), intermediate (10–20%), and high (>20%) risk groups (31). The FRS has been validated in Malaysian populations (21,32). This model incorporates age, sex, total cholesterol, high-density lipoprotein (HDL) cholesterol, systolic blood pressure (treated or untreated), smoking status, and T2D status. Clinical and biochemical parameters were obtained from routine medical records, while smoking status was self-reported.

## 2.4 Dietary Modelling Using Linear Programming

Dietary modelling using LP is planned to develop cost-effective, nutritionally optimised meal plans tailored to low-income populations and has been applied across diverse Malaysian population groups (17). The LP model will utilise dietary intake data derived from the semi-quantitative FFQ, together with food price data and predefined nutrient requirements, consistent with established LP approaches for dietary optimisation (33).

All participants with complete dietary intake data will be included in the dietary modelling to ensure that the full variability of dietary patterns within the study population is represented.

The LP model will be constructed using Microsoft Excel Solver (Microsoft Corporation, Redmond, WA, USA) to minimise total dietary cost while satisfying a set of constraints (34). These constraints will include nutrient adequacy, energy requirements, and culturally acceptable consumption patterns derived from observed dietary intake. Nutrient targets will be based on Clinical Practice Guidelines: Management of Dyslipidemia (35). Food price data will be obtained from national sources to reflect real-world affordability. This modelling component is designed to translate observed dietary behaviours into feasible and affordable dietary strategies within the same study population. Results from the LP analysis are not included in the present study and will be reported separately.

### 2.5 Phase 2: Biological Assessments (Gut Microbiota and Metabolic Biomarkers)

Phase 2 analysis is designed to investigate biological pathways linking FI and CVD risk. A sub-sample of participants with T2D will be selected from the Phase 1 cohort and stratified according to FI status into food-secure and food-insecure groups. Sample size for Phase 2 will be based on feasibility considerations and the need to adequately characterise microbial diversity and relative abundance within the study population (36). A total of 60 participants (30 per group) will be selected, which is consistent with previous 16S rRNA-based microbiome studies. This sample size is considered sufficient to capture variability in microbial composition and to detect

meaningful differences between groups in exploratory analyses (37). Stool samples will be self-collected using a standardised collection kit and processed for DNA extraction according to manufacturer protocols.

Gut microbial composition will be characterised using 16S rRNA gene sequencing, a widely established method for profiling microbial communities (38). Microbial diversity will be assessed using alpha diversity (within-sample diversity) and beta diversity (between-sample dissimilarity) metrics, following standard ecological and microbiome analytical approaches (39,40). Differential abundance analysis will be performed to examine variations in microbial taxa between food-secure and food-insecure participants, with particular focus on selected taxa of interest, including Faecalibacterium prausnitzii. Taxonomic classification will be performed at the genus and species levels where feasible, using established bioinformatics pipelines (39). Given the use of 16S rRNA sequencing, resolution at the strain level will not be achievable, and species-level identification will be interpreted with caution.

In addition, fasting blood samples are being collected and will be analysed at an accredited external laboratory (Innoquest Diagnostics, Malaysia). Biochemical analyses will include high-sensitivity C-reactive protein (hs-CRP), fasting plasma glucose, HbA1c, uric acid, and lipid profile. Analyses will be performed using standardised automated clinical chemistry methods, including immunoturbidimetric assays for hs-CRP, hexokinase method for glucose, enzymatic colourimetric assays for lipid parameters and uric acid, and NGSP-standardised methods for HbA1c, in accordance with internationally recognised laboratory standards, including ISO 15189 quality assurance procedures.

## 2.6 Ethics and Data Management

Ethical approval was obtained from the Medical Research Ethics Committee, Ministry of Health Malaysia (NMRR ID-24-01878-P8T), and Universiti Putra Malaysia (JKEUPM-2024-329). All procedures were conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants.

Participant confidentiality was maintained by assigning unique identification codes, and all data were anonymised before analysis. Data were securely stored in password-protected systems accessible only to authorised research personnel. Biological samples were handled and stored in accordance with standard biosafety and laboratory protocols.

## 2.7 Statistical Analysis

Data were analysed using SPSS version 30.0 (IBM Corp., Armonk, NY, USA). A p-value of $<0.05$ was considered statistically significant.

**Phase 1 analysis.** Continuous variables were assessed for normality and are presented as mean ± standard deviation (SD), or median (interquartile range, IQR), as appropriate, while categorical variables are presented as frequencies and percentages. Differences across CVD risk categories were assessed using the chi-square test for categorical variables. For continuous variables, one-way analysis of variance (ANOVA) was used for normally distributed data, and the Kruskal-Wallis test was applied for non-normally distributed data. Associations between FI measures (FIES and MCSI) and CVD risk were explored using the Chi-square test. Multivariable

logistic regression analyses will be performed to examine the association between FI and CVD risk, adjusting for potential confounders such as socioeconomic status and relevant clinical factors.

**Phase 2 analysis (Planned).** For microbiota analyses, diversity indices and relative abundance data are being analysed to examine group differences and associations with clinical outcomes. Sequencing data will be processed using established bioinformatics pipelines (QIIME2) for quality control and taxonomic assignment (41). Differences between food-secure and food-insecure groups will be assessed using independent t-tests or Mann-Whitney U tests, depending on data distribution. Associations between gut microbiota features and clinical metabolic markers will be evaluated using Spearman correlation. Multivariate Analysis of Covariance (MANCOVA) will be performed to examine the relationship between FI and microbial features, adjusting for potential confounders, including age and sex.

## 3.0 Results

### 3.1 Screening, Recruitment, and Final Analytic Sample

A total of 887 participants were screened, of whom 531 (59.9%) were eligible. After exclusions and data cleaning, a total of 338 participants were included in the final analysis (**Figure 2**). The overall sociodemographic and clinical characteristics of participants are presented in Table 1.

**Figure 2. Screening and recruitment process.**

### 3.2 Participant Characteristics

Baseline characteristics of the 338 participants are presented in Table 1. The mean age was 53.8 ± 8.8 years, and 58% were female. The majority were Malay (77.8%), with most participants married (82%) and having completed at least secondary education (92.9%). The mean monthly household income was RM3,680 ± 1,787 (~USD830), and more than half of the participants (53%) reported receiving financial aid. The average household size was 3.9 ± 1.8 members.

### 3.3 Clinical, Biochemical, and Anthropometric Profile

Participants demonstrated a high burden of multimorbidity, with the most common number of NCDs being three. Dyslipidemia was the most prevalent condition (85.2%) (Table 2). Cardiometabolic control was suboptimal. The mean HbA1c was 7.9 ± 1.8%, and fasting plasma glucose was 7.7 ± 2.8 mmol/L. Only 21.4% of participants achieved glycemic control (HbA1c <6.5%), 35.8% met lipid targets, and 65.1% achieved blood pressure control.

### 3.4 Lifestyle and Behaviour

The mean sleep duration was 6.4 ± 1.4 hours, with 31.7% of participants reporting sleep difficulty (Table 1). Median physical activity levels were 346 MET-minutes/week [IQR: 33–1386], with the majority (62.2%) classified as having low physical activity. Only 11.2% of participants achieved high levels of physical activity. The mean perceived stress score was 9.0 ± 7.7, indicating an overall low level of perceived stress. Most participants were categorised as having low (66%) or moderate (33.1%) stress levels, with a small proportion (0.9%) classified as high stress.

### 3.5 Food Insecurity, Coping Strategies and CVD Risk

Overall, 29% of participants experienced FI, predominantly at mild levels (21.6%), with smaller proportions experiencing moderate (6.2%) and severe (1.2%) FI (Table 2). The median MCSI score was 9 [6–15]. When categorised into tertiles, 16.6% of participants were classified as coping-secure, 52.1% as moderately food-insecure, and 31.4% as severely food-insecure based on coping behaviours.

Based on the FRS, 25.2% of participants were classified as low risk, 35.2% as intermediate risk, and 39.6% as high risk for 10-year CVD. Experience-based FI did not differ significantly across CVD risk categories (p=0.709). In contrast, coping-based classification demonstrated increasing reliance on coping strategies across CVD risk categories (p<0.001), with coping-secure individuals predominantly observed in the low-risk group.

## 4.0 Discussion

The FIRM study demonstrates a substantial burden of cardiometabolic risk among low-income adults with NCDs attending primary care in an urban setting, characterised by high multimorbidity, central obesity, and suboptimal metabolic control. Despite ongoing clinical management, only a minority achieved recommended glycemic and lipid targets, highlighting persistent gaps in disease control in this population.

These findings are highly consistent with national data from Malaysia. Evidence from the National Diabetes Registry (NDR) and DiabCare studies has repeatedly shown suboptimal cardiometabolic control in primary care (42), with fewer than 40% of patients achieving key treatment targets for HbA1c, blood pressure, and lipids. More recent reports indicate that only approximately 35% of patients achieve HbA1c ≤6.5%,

441 despite widespread access to care. Similarly, primary care studies in Malaysia have
442 reported that only 15-27% of patients achieve optimal glycemic control, with the
443 majority remaining above recommended targets (5). These patterns mirror the present
444 findings, indicating persistent suboptimal control and systemic issues in Malaysian
445 primary care.
446
447 Importantly, these findings must be interpreted within the context of Malaysia's highly
448 subsidised healthcare system (4). While access to primary care services is relatively
449 good, the persistence of poor metabolic control suggests that access alone is
450 insufficient to ensure effective disease management (43). This reflects a broader
451 implementation gap in which clinical recommendations are not fully translated into
452 real-world outcomes. In low-income urban populations, this gap is likely driven by
453 competing socioeconomic priorities, limited food affordability, and environmental
454 exposures that shape daily behaviours (44). Thus, the observed burden of obesity and
455 poor metabolic control reflects not a lack of healthcare access, but a mismatch
456 between clinical care and the lived realities of patients (10).
457
458 Within this context, FI emerges as a critical factor shaping health outcomes (45).
459 However, its impact may not be adequately captured by exposure alone. While FI
460 measured using the FIES was not significantly associated with CVD risk, coping
461 behaviours assessed using the MCSI were. It indicates that the health consequences
462 of FI may be mediated through behavioural responses, rather than the condition itself
463 (46). Strategies such as dietary compromise, meal irregularity, and reliance on low-
464 cost foods likely represent more immediate pathways influencing energy balance and
465 metabolic control (6).

This is consistent with evidence suggesting that behavioural adaptations to socioeconomic constraints may be stronger predictors of health outcomes than structural exposure alone (47). In urban environments, where food availability is abundant but nutritional quality is uneven, individuals may navigate constraints through adaptive behaviours that inadvertently increase cardiometabolic risk (48). This may explain the coexistence of coping strategies to FI and CVD risk observed in this study and previous research, reflecting a paradox driven by economic and environmental pressures (49).

Taken together, these findings reinforce the importance of understanding cardiometabolic risk as a multidimensional construct shaped by interacting social, behavioural, and biological factors (15). In this study, social vulnerability (FI) influences behavioural adaptations (coping strategies), which in turn contribute to adverse biological outcomes (poor metabolic control and increased CVD risk) (**Figure 1**). This integrated pathway underscores the limitations of conventional disease management approaches that focus primarily on clinical care without addressing underlying contextual factors.

These findings have several implications. First, we highlight the need to incorporate FI screening into routine primary care to identify patients at higher risk of poor outcomes. Second, we suggest that interventions should extend beyond general dietary advice to address the practical constraints faced by low-income populations. Third, this study emphasises the importance of integrating behavioural insights into clinical management to improve adherence and sustainability.

Importantly, the present findings provide a strong rationale for the subsequent components of this study. The identification of coping behaviours as a key pathway linking FI to cardiometabolic risk underscores the need for feasible, cost-sensitive dietary solutions. The application of LP represents a critical translational step, enabling the development of nutritionally adequate meal plans that are aligned with both economic constraints and cultural context (50). In urban low-income populations, where affordability is a primary determinant of food choice, such approaches are essential to bridge the gap between dietary recommendations and real-world feasibility.

At the same time, the observed relationships between behavioural factors and metabolic outcomes highlight the need to better understand underlying biological mechanisms (18). The ongoing gut microbiota analysis is particularly relevant, as dietary patterns associated with FI may alter microbial composition and metabolic function. These changes may contribute to pathways related to inflammation, insulin resistance, and lipid metabolism.

This study has several strengths, including its focus on a well-characterised urban primary care population and the integration of behavioural, clinical, and socioeconomic data within the same cohort. However, the cross-sectional design limits causal inference, and the findings may not be generalisable beyond similar urban low-income populations. Additional analyses, including dietary modelling and microbiome assessment, are ongoing and will further enhance understanding of these pathways.

## 5.0 Conclusion

In conclusion, cardiometabolic risk among low-income urban populations with NCDs in Malaysia is shaped by the interaction of structural constraints, behavioural adaptations, and biological processes. While healthcare access is relatively well established, effective disease control remains limited due to the influence of socioeconomic and environmental factors. Addressing these interconnected determinants through integrated and context-sensitive strategies will be essential for improving outcomes in primary care.


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# Figures

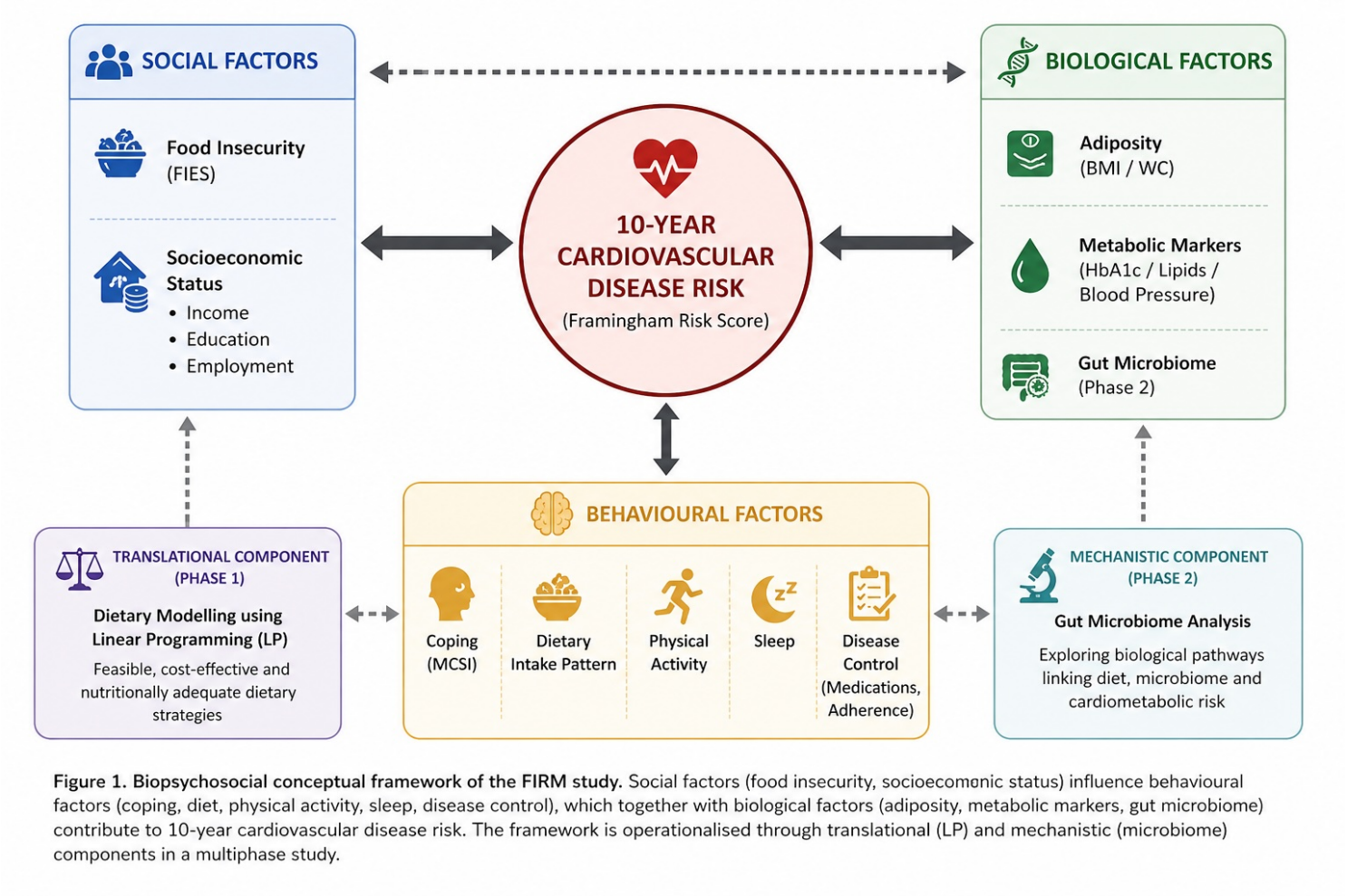
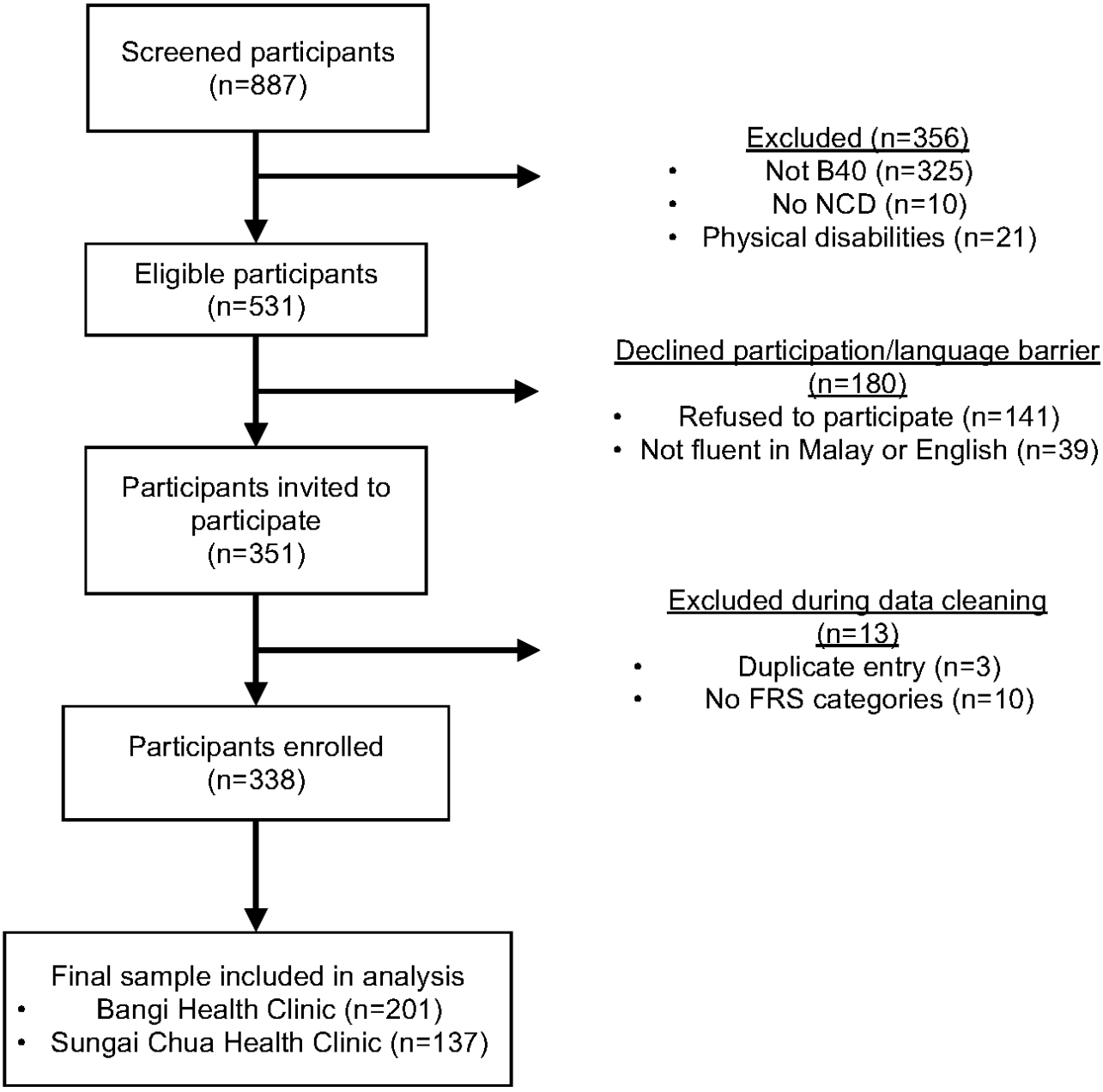



**Figure 1. Biopsychosocial conceptual framework of the FIRM study.** Social factors (food insecurity, socioeconomic status) influence behavioural factors (coping, diet, physical activity, sleep, disease control), which together with biological factors (adiposity, metabolic markers, gut microbiome) contribute to 10-year cardiovascular disease risk. The framework is operationalised through translational (LP) and mechanistic (microbiome) components in a multiphase study.

**Figure 1**

See image above for figure legend.




NCD: non-communicable disease; B40: bottom 40% of the household income population; FRS: Framingham risk score

**Figure 2**

Screening and recruitment process

## Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table1Sociodemographicandlifestyle.pdf
- Table2Clinicalnutritionalandfoodinsecurity.pdf