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ORIGINAL ARTICLE

Food insecurity and self-reported markers of health across multiple body systems: associations with diet quality, mental well-being, gut symptoms, and immunity

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Abstract

Aim To explore the associations between food insecurity (FI) with dietary quality and markers of mental well-being, gastrointestinal symptoms, and immune status among United Kingdom (UK)-based adults.

Subject and methods An online questionnaire was administered to 953 UK-based adults, including 210 individuals living with FI, to evaluate FI status, diet quality, and a series of health outcomes. FI was measured using the six-item US Department of Agriculture (USDA) Household Food Security Survey. Diet quality was assessed using the Easy Diet Screener. Health outcomes included markers of mental well-being (Perceived Stress Scale and GAD-7 [generalised anxiety disorder seven-item scale]), gastrointestinal symptoms (Short Health Scale for gastrointestinal symptoms), and self-reported immune status (Immune Status Questionnaire, cumulative incidence of self-reported infections [CISRI] score, and antibiotic use). Cross-sectional associations were explored using logistic regression, with data presented as odds ratios (OR) with 95% confidence intervals (CIs).

Results Participants living with FI had almost threefold greater odds of following a Western dietary pattern (OR = 2.67, 95% CI [1.85, 3.91], $p < 0.001$). FI was associated with multiple negative health outcomes including greater odds of high perceived stress (OR = 3.12, 95% CI [2.10, 4.63], $p < 0.001$), reduced self-reported immune status (OR = 1.91, 95% CI [1.31, 2.77], $p < 0.001$), and gastrointestinal symptoms (OR = 2.30, 95% CI [1.39, 3.75], $p < 0.001$).

Conclusion These findings support the accumulating body of evidence that FI is linked with multiple adverse health outcomes and highlight it as a multi-system health risk factor. Tackling FI should be a major public health and policy priority.

Keywords Food insecurity · Diet quality · Mental health · Gastrointestinal health · Immune status

Introduction

Food insecurity (FI) is defined as limited or unreliable access to nutritionally adequate food, typically due to a lack of financial resources. FI is increasingly common in high-income countries, with ~11% of households in the United Kingdom (UK) living with FI (Food Foundation 2025). Certain population subgroups are particularly vulnerable to FI, with a higher prevalence in households with children (19%), single adult households (31%), those living with a disability (17–32% depending upon disability type/severity), and minority ethnic groups (21–32% depending upon ethnicity) (Food Foundation 2025). Rising food prices are a major contributor to the high rates of FI, and particularly impact households with limited financial resources (Francis-Devine 2024). FI has been associated with lower quality of life (Aljahdali et al. 2024b), reduced productivity (Weinstein et al. 2022), and increased risk of multiple non-communicable diseases (e.g., obesity, cardiometabolic diseases, depression, dementia) and all-cause mortality (Sun et al. 2020; Liu and Eicher-Miller 2021; Carvajal-Aldaz et al. 2022; McMichael et al. 2022; Qian et al. 2023). Combatting FI is therefore a major political, public health, and research priority.

Alterations in immune function and gastrointestinal (GI) function have both been proposed as mechanisms through which FI could negatively impact health (Gowda et al. 2012; Mohr et al. 2022). It is hypothesised that shifts in

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dietary behaviours and stress consequent to FI could induce an inflammatory state and alter immune function (Gowda et al. 2012). For example, a cross-sectional study in adults from the United States (USA) showed that FI was associated with 21% higher odds of greater inflammation (elevated C-reactive protein concentration) and 36% higher odds of elevated white blood cell count (Gowda et al. 2012). In a more recent US cohort study, FI was associated with greater inflammation and increased odds of impaired immune function as indicated by higher cytomegalovirus immunoglobulin G (IgG) antibody concentration, an indicator of impaired immune functioning previously linked with all-cause mortality, dementia, and cardiovascular disease risk (Aljahdali et al. 2024a).

Individuals experiencing FI typically consume less fibre and have a less diverse diet than individuals with food security (Shinwell et al. 2021), both of which could impact the gut microbiome and other markers of gut health (Heiman and Greenway 2016). Indeed, Mohr et al. (2022) showed differential relative abundance of key gut bacteria in US college students with/without FI. Specifically, those with FI had a higher relative abundance of *Enterobacteriaceae* and *Eisenbergiella*, and a lower relative abundance of *Megasphaera* and *Holdemanella*. The impact of this shift in the gut microbiome remains to be fully elucidated, but could influence processes including mucin degradation, short-chain fatty acid (SCFA) production, and inflammatory signalling (Mohr et al. 2022). FI is also characterised by irregular eating patterns (Shinwell et al. 2021), which have been associated with an increased risk of irritable bowel syndrome (IBS) and severe IBS symptoms (Bavani et al. 2022). Given the important role of the gut microbiome in human health, including immune function and immune education (Wu and Wu 2012; Zheng et al. 2020; Kimble et al. 2022), an altered gut microbiome and GI function could be one pathway through which FI impacts health.

Although prior research has established the association between FI and various adverse health outcomes, these investigations have typically focused on single health domains in isolation. Given that FI is a complex psychosocial and physiological stressor (Lee et al. 2012; Neal et al. 2025), a multi-system approach may offer greater insight into the links between FI and health by examining the associations between FI and different interconnected body systems in parallel. This could provide a more integrated understanding of the psychological and somatic burden of FI, highlighting patterns of risk which might not have been identified through single system assessments, and identify potential mechanisms through which it impacts health. Against this background, this study aimed to explore associations between FI status and key health-associated outcomes in a nationally representative UK cohort, including eating behaviours, stress and anxiety, self-reported immune status, and gut symptoms. We also aimed to establish a new cohort of free-living individuals who could be followed prospectively to explore changes in these parameters over time and evaluate the temporal and potentially causal interconnections between these systems (e.g., via causal mediation analyses). Here we report the characteristics of this cohort and results from cross-sectional analyses.

Methods

This study is a cross-sectional observational study. The study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures involving research study participants were approved by the Newcastle University Ethics Committee (REF 52648/2023). Written informed consent was obtained from all subjects/patients prior to data collection.

Questionnaire development and administration

The study questionnaire was created using an online survey tool (Online Surveys, Bristol). Briefly, the questionnaire comprised demographic questions to capture key participant characteristics (e.g., age, sex, living situation, education, exercise levels) alongside a suite of validated questionnaires (see below) for determining FI status, diet quality, stress and anxiety, immune status, and GI symptoms. The questionnaire was pilot-tested to ensure clarity and estimate completion time. A final version was then administered to a nationally representative sample, approximating the UK adult population in age, gender, and ethnicity, via an online participant recruitment platform (Prolific, see Peer et al. 2017). Participants were given modest remuneration for completing the questionnaire (~£9/h pro rata). The questionnaire design and analysis plan were pre-registered on the Open Science Framework (pre-registration at https://osf.io/mvj5a). Ethical approval was obtained from the Newcastle University Faculty of Medical Sciences Research Ethics Committee (REF: 52648/2023). We did not include data from one of our pre-planned questionnaires (Chrononutrition questionnaire, Veronda et al. 2020) in this analysis due to a high number of response errors by participants.

Demographics

Demographic characteristics included age, height, weight, sex at birth, ethnicity, number of adults in household, number of children in household, carers in household, bedrooms in household, exercise, smoking and vaping status, alcohol use, and marital status.

Food insecurity status

FI status was evaluated using the United States Department of Agriculture (USDA) Household Food Security Survey, a six-item short form screener validated to establish the presence and severity of FI (USDA Economic Research Services). Participants were dichotomised into food-secure/marginal food security (0–1 points) and low/very low food security (2–6 points) for the primary analyses. A priori secondary analyses differentiating between participants with low food security and very low food security were not undertaken due to low sample sizes in each group.

Diet quality

The Easy Diet Screener (EDS) (Malinowska 2022) was used to evaluate diet quality based on the frequency of consumption of key food groups broadly aligned with the components of the Eatwell Guide (UK government's recommendations for a healthy balanced diet) (Public Health England 2016). Total scores (range, 0–28) were dichotomised to define participants as having a healthy/intermediate (15–28 points) or unhealthy/Western (0–14 points) dietary pattern.

Stress and anxiety

Stress was measured using the Perceived Stress Scale (PSS) (Cohen et al. 1983), a 10-item validated questionnaire that evaluates participants' perceptions of stressful life events over the past month. A PSS lower than 14 indicates low perceived stress, while a score of 14–26 reflects moderate perceived stress, and a score above 26 reflects high perceived stress. Symptoms of generalised anxiety were evaluated using the GAD-7 (generalised anxiety disorder seven-item scale) questionnaire (Spitzer et al. 2006), a seven-item validated questionnaire that evaluates the severity of generalised anxiety symptoms in the past 2 weeks. Participants were classified as having "no anxiety" (GAD-7 score < 2), "minimal or mild anxiety" (GAD-7 score 2–9), or "moderate or severe anxiety" (GAD-7 score > 9). For consistency with other analyses, these results were then further dichotomised for the primary analysis. Accordingly, PSS scores were divided into low PSS (scores < 14) and high PSS (scores > 13), while GAD-7 results were subdivided into "no anxiety" (GAD-7 score < 2) and anxiety symptoms (GAD-7 scores of 2 and above). Secondary analyses using the original PSS cutoffs and three category GAD-7 cutoffs were also carried out and are reported in the supplementary materials. These analyses were considered supplementary given the smaller group sizes, which limit power to detect an effect.

Immune status

The Immune Status Questionnaire (ISQ) (Wilod Versprille et al. 2019) was used to assess participants' self-reported immune status. This questionnaire uses seven questions scored according to how often participants experienced specific immune status-related symptoms over the last 12 months. Answers were weighted and scored according to Appendix A in Wilod Versprille et al. (2019). An ISQ score below 6 was considered to indicate reduced immune status, while a score of 6 or above indicated normal immune status. We also assessed the cumulative incidence of self-reported infections (CISRI) (Minnetti et al. 2022) using scores compiled from standard questionnaires, as reported by Isidori et al. (2018). The questionnaire asks participants to rate the frequency of several infections over the last 12 months. "Never" responses were assigned a score of 0.5, while "1–2 times" was assigned a score of 2 and "3+ times" a score of 4. An answer of "not applicable" (N/A) was assigned when participants were unable to answer. In the absence of an established cutoff for this variable, the median was used to group the participants into "high CISRI" and "low CISRI" scores. The question regarding antibiotic use within the CISRI was analysed separately as per convention (Isidori et al. 2018). Here, self-reported antibiotic use was coded as a binary factor representing either "no antibiotic" or "any level of antibiotic" use over the last 12 months.

Gastrointestinal symptoms

The Short Health Scale for gastrointestinal symptoms (SHS-GI) (Walter et al. 2021) was used to assess GI symptoms. The SHS-GI is a four-item questionnaire which evaluates the presence and severity of GI symptoms, their impact on daily activities, worry associated with symptoms, and general well-being (Walter et al. 2021). The general well-being question was omitted from our analysis, as stress and anxiety were assessed using other measures; therefore, the SHS-GI consisted of the first three questions alone. Scores of 14 or less were considered to reflect normal GI function, while scores higher than 14 were considered to reflect impaired GI function.

Data processing

Due to the limited sample size of some ethnic groups, ethnicity was considered as a binary variable (White vs. other ethnicity). Only participants with body mass index (BMI) values between 15 and 50 were included in order to minimise the risk of under/over-reporting; 36 participants were excluded with BMI outside this range. The bedroom-to-person ratio was calculated as the sum of adults and children in the household divided by the number of bedrooms in the household. Exercise was coded as never, moderate (more

than once per month but less than four times a week), and frequent (four or more times per week). Smoking and vaping status was combined and grouped as never, past, and current smokers and vapers. Alcohol use was coded according to how many weekly portions of alcohol the participants consumed using portion definitions reported in the questionnaire (Malinowska 2022). Participants were assigned to none, low (1–2 portions), intermediate (3–4 portions), and high (five or more portions) alcohol consumption. In addition, marital status information was used to group participants into three categories: single, cohabiting or married, and widowed or divorced. Finally, all questionnaire outcome data was dichotomised. This was deemed necessary due to the nature of the data: although questionnaires were scored on a continuous scale, these scores had very small ranges and variation, violating homoscedasticity assumptions.

Statistical analysis

All statistical analyses were conducted in R (version 4.4.0). To assess the effect of FI on diet quality (EDS), we employed binary logistic regressions. According to our study's pre-registration, we included age, BMI, sex, and ethnicity as covariates in the fully adjusted model and used model performance (based on the Akaike information criterion [AIC]) to select the parsimonious model, which only included age, BMI, and sex as covariates. The null model and adjusted models were compared via the likelihood ratio test using analysis of variance (ANOVA) tests. The model including only age, BMI, and sex as covariates was selected as the final model for this analysis. For all remaining analyses, multivariable logistic regression models were fit using the binomial glm() function in base R and potential confounders included age, sex, ethnicity, BMI, bedroom-to-person ratio, adults in household, children in household, carers in household, exercise, smoking and vaping status, alcohol use, and marital status. Models were refined using the backward stepwise selection method using the step() function from the MASS package (version 7.3.60.2) (Venables and Ripley 2002), which selects the most parsimonious model based on the AIC.

For each model run in this study, model diagnostics included the following aspects. Multicollinearity was assessed using the variance inflation factor (VIF) from the *car* package. No predictors exceeded the conventional VIF threshold of 5. As per standard practice, influential outliers were identified using Cook's distance, leverage, and standardised residuals; when such observations were identified, models were run again removing the participants that appeared influential. The effect on the model estimates was then evaluated, and outliers were kept in final models if model estimates remained similar. All analyses were unaffected by outliers except the binary GAD-7 analysis, which showed some variation upon outlier exclusion; the ordinal GAD-7 analysis was unaffected by outliers. The linearity of continuous predictors (age and BMI) was assessed using the Box–Tidwell test, whereby interaction terms are included between each continuous predictor and its log transformation in an alternative model. Linearity assumptions were satisfied in all cases, as shown by non-significant interaction terms in these alternative models. Furthermore, goodness of fit was evaluated using the Hosmer–Lemeshow test, and McFadden's *R*-squared was calculated using the pscl package (Jackman 2024). Finally, the *pROC* (Robin et al. 2011) and *caret* (Kuhn 2008) packages were used for receiver operating characteristic (ROC) curve analysis and to establish the models' predictive accuracy. For all outcomes, results from the parsimonious models are reported in the results section. Final covariates included in each model are reported in Supplementary Fig. 1. Sensitivity analyses were conducted to evaluate whether our approach to categorisation impacted the observed associations, adjusting for the same set of covariates as the original analyses (Supplementary Fig. 1). We re-categorised the outcome variable ordinally (for EDS, anxiety, and stress) or continuously (for self-reported immune status markers and gut symptoms) depending upon the original scoring of the outcome variable. Linear regression was conducted using the lm() function in base R, and ordinal logistic regression was conducted using the polr() function from the MASS package.

Results

Cohort characteristics

A total of 953 participants completed the study questionnaire and were eligible for inclusion in this study (Table 1). The ethnicity of our cohort included 85.1% identifying as White, 7.9% as Asian, 3.4% as Black, 2.4% as mixed, and 1.1% as other or non-disclosed. There was a roughly even split between female (51.3%) and male (48.7%) participants, and 22.0% of the participants were living with FI. Compared with the food-secure participants, individuals living with FI tended to be younger, to be of a minority ethnic group, to have more children and carers in the household, to be former or current smokers, and to report a single relationship status.

Diet quality

FI was significantly associated with higher odds of following a Western diet (Fig. 1). Individuals with FI had 2.67 times greater odds of reporting a Western dietary pattern than individuals with food security (odds ratio [OR] = 2.67, 95% CI [1.85, 3.91], $p < 0.0001$).

Table 1 Participant demographics and questionnaire results, with participants categorised as per the analyses

	Food-secure ($N=743$)	Food-insecure ($N=210$)	Overall ($N=953$)
Age			
Mean (SD)	48.8 (15.1)	38.0 (13.9)	46.4 (15.5)
Sex			
Female	381 (51.3%)	108 (51.4%)	489 (51.3%)
Male	362 (48.7%)	102 (48.6%)	464 (48.7%)
BMI			
Mean (SD)	26.1 (5.56)	27.1 (6.71)	26.3 (5.85)
Ethnicity			
White	650 (87.5%)	165 (78.6%)	815 (85.5%)
Other	93 (12.5%)	45 (21.4%)	138 (14.5%)
Adults in household			
Mean (SD)	2.20 (0.889)	2.31 (1.29)	2.22 (0.990)
Bedroom ratio			
Mean (SD)	0.956 (0.458)	1.14 (0.588)	0.996 (0.495)
Children in household			
Mean (SD)	0.495 (0.861)	0.614 (0.987)	0.522 (0.891)
Carers in household			
Mean (SD)	0.225 (0.570)	0.319 (0.669)	0.246 (0.595)
Exercise			
Never	43 (5.8%)	14 (6.7%)	57 (6.0%)
Moderate	507 (68.2%)	156 (74.3%)	663 (69.6%)
Frequent	193 (26.0%)	40 (19.0%)	233 (24.4%)
Smoking and vaping			
Never	513 (69.0%)	119 (56.7%)	632 (66.3%)
Past	118 (15.9%)	34 (16.2%)	152 (15.9%)
Current	112 (15.1%)	57 (27.1%)	169 (17.7%)
Alcohol consumption			
None	326 (43.9%)	113 (53.8%)	439 (46.1%)
Low	181 (24.4%)	53 (25.2%)	234 (24.6%)
Intermediate	104 (14.0%)	22 (10.5%)	126 (13.2%)
High	132 (17.8%)	22 (10.5%)	154 (16.2%)
Marital status			
Single	167 (22.5%)	93 (44.3%)	260 (27.3%)
Married/cohabiting	515 (69.3%)	103 (49.0%)	618 (64.8%)
Widowed/divorced	61 (8.2%)	14 (6.7%)	75 (7.9%)
USDA Food Insecurity Score			
Mean (SD)	0.129 (0.336)	3.99 (1.58)	0.979 (1.79)
EDS			
Healthier diet	380 (51.1%)	47 (22.4%)	427 (44.8%)
Western diet	363 (48.9%)	163 (77.6%)	526 (55.2%)
ISQ			
Normal immune status	614 (82.6%)	137 (65.2%)	751 (78.8%)
Reduced immune status	129 (17.4%)	73 (34.8%)	202 (21.2%)
CISRI			
Low	516 (69.4%)	139 (66.2%)	655 (68.7%)
High	152 (20.5%)	40 (19.0%)	192 (20.1%)
Missing	75 (10.1%)	31 (14.8%)	106 (11.1%)
Antibiotic use			
None	709 (95.4%)	200 (95.2%)	909 (95.4%)
Use over last 12 months	21 (2.8%)	9 (4.3%)	30 (3.1%)
Not disclosed	13 (1.7%)	1 (0.5%)	14 (1.5%)
PSS			
Low perceived stress	360 (48.5%)	38 (18.1%)	398 (41.8%)
Perceived stress	354 (47.6%)	156 (74.3%)	510 (53.5%)
Not disclosed	29 (3.9%)	16 (7.6%)	45 (4.7%)
GAD-7			
No anxiety	91 (12.2%)	13 (6.2%)	104 (10.9%)
Anxiety	652 (87.8%)	197 (93.8%)	849 (89.1%)
GI symptoms			
Normal GI function	696 (93.7%)	179 (85.2%)	875 (91.8%)
Impaired GI function	47 (6.3%)	31 (14.8%)	78 (8.2%)

USDA United States Department of Agriculture, *EDS* Easy Diet Screener, *ISQ* Immune Status Questionnaire, *CISRI* cumulative incidence of self-reported infections, *PSS* Perceived Stress Scale, *GAD-7* generalised anxiety disorder seven-item scale

Anxiety and stress

FI was strongly associated with perceived stress (Fig. 1). Specifically, individuals with FI had 3.12 times greater odds of reporting perceived stress than food-secure individuals (OR = 3.12, 95% CI [2.10, 4.63], $p < 0.001$). Furthermore, FI was associated with a non-significant trend towards greater odds of generalised anxiety (OR = 1.77, 95% CI [0.95, 3.30], $p = 0.074$) (Fig. 1). As there was poor model fit (McFadden's $R^2 = 0.03$ and Hosmer–Lemeshow goodness-of-fit test $p < 0.00001$), we also investigated this outcome using an ordinal logistic regression model (see "Sensitivity analyses").

Self-reported immune status, infections, and antibiotic use

Participants living with FI had 1.91 times greater odds of having lower self-reported immune status, as measured by the ISQ, than food-secure individuals (OR = 1.91, 95% CI [1.31, 2.77], $p < 0.0001$). Conversely, FI was not significantly associated with CISRI scores (OR = 0.97, 95% CI [0.64, 1.44], $p = 0.89$) or self-reported antibiotic use (OR = 1.11, 95% CI [0.78, 1.59], $p = 0.56$; Fig. 1).

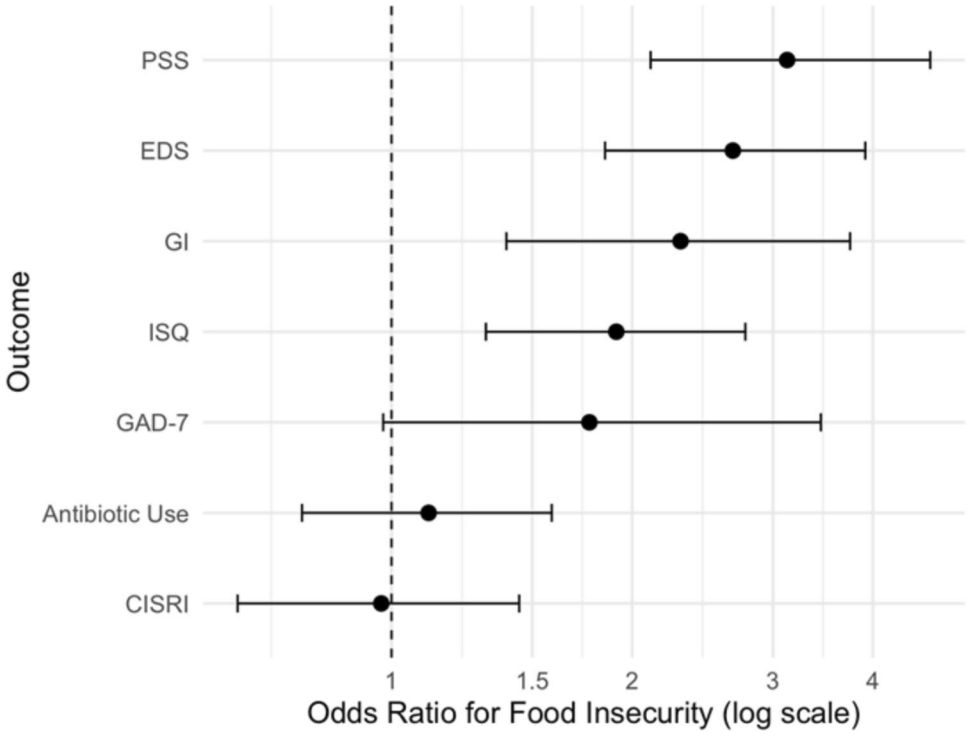

Fig. 1 Forest plot showing odds ratios (OR) and 95% confidence intervals (CI) for the fully adjusted models exploring associations between FI, diet quality, anxiety and stress, self-reported immune status, and GI outcomes. The dashed vertical line at OR = 1 represents the null value. *PSS* Perceived Stress Scale, *EDS* Easy Diet Screener, *GI* SHS-GI questionnaire, *ISQ* Immune Status Questionnaire, *GAD-7* generalised anxiety disorder seven-item scale, *CISRI* cumulative incidence of self-reported infections. The covariates included in each model and the odds ratios for model covariates are reported in Supplementary Fig. 1

GI function

Participants living with FI had 2.30 times greater odds of reporting altered GI symptoms, measured using the SHS-GI scale, than their food-secure counterparts (OR = 2.30, 95% CI [1.39, 3.75], $p < 0.001$; Fig. 1).

Sensitivity analyses

When diet quality was defined ordinally (Western diet, intermediate diet, and healthy diet), FI was associated with higher odds of following a Western dietary pattern (OR = 0.267, 95% CI [1.84, 3.87], $p < 0.001$).

When perceived stress was defined ordinally (low, moderate, and high perceived stress), there remained a strong association between FI and perceived stress (OR = 2.73, 95% CI [1.94, 3.87], $p < 0.001$). Meanwhile, when anxiety was defined ordinally (no anxiety, minimal-to-mild anxiety, and moderate-to-severe anxiety), there was now a significant association between FI and anxiety (OR = 2.70, 95% CI [1.93, 3.81], $p < 0.001$). In sensitivity analyses using linear regression, FI was associated with significantly lower ISQ scores (β = −0.58, 95% CI [−0.92, −0.24], standard error [SE] = 0.17, $p < 0.001$) and significantly higher CISRI scores (β = 0.63, 95% CI [0.26–1.00], SE = 0.19, $p < 0.001$) but not self-reported antibiotic use (β = 0.04, 95% CI [−0.08–0.17], SE = 0.06, $p = 0.50$). FI was associated with significantly higher GI symptoms (β = 1.58, 95% CI [0.80–2.36–0.17], SE = 0.40, $p < 0.001$). Overall, the results were consistent with the primary analyses for most outcomes, but with FI now significantly associated with anxiety scores (which trended towards significance in primary analyses) and CISRI scores (which were not significantly associated in the binary analyses).

Discussion

This cross-sectional study explored associations between FI and diet quality alongside a range of self-reported health outcomes. Our findings reveal that FI is associated with greater odds of adhering to a less healthy Western diet and poorer health across most measured outcomes, with particularly strong associations observed for perceived stress, self-reported immune status, and GI symptoms.

Food insecurity was associated with almost threefold greater odds of following a less healthy Western dietary pattern—typified by high consumption of red and processed meat, refined grains, confectionery, fried food, and high-fat dairy products. These findings align with investigations across various international settings demonstrating that FI is associated with lower diet quality across multiple settings. For example, in a cross-sectional analysis of approximately 800 Australian adults, FI was associated with lower diet quality, as measured by the Australian Recommended Food Score, in a dose-dependent manner (Kent

et al. 2024). Similarly, in a large Brazilian cohort (~30,000 individuals), FI was associated with 25% lower odds of adhering to a data-driven a posteriori-derived healthy dietary pattern rich in fruits, vegetables, and whole grains (Castro et al. 2022). Recent studies in US and UK cohorts have revealed more specific nutritional differences. In an analysis of National Health and Nutrition Examination Survey (NHANES) data by Nettle and Bateson (2019), women with FI consumed relatively more carbohydrates and less protein and fibre than their food-secure counterparts, but had similar total energy intake. A UK study by the same group including ~400 adults observed similar trends, though results were non-significant (Shinwell et al. 2021). Interestingly, both studies identified that FI was associated with lower diet diversity, suggesting reliance on a narrower range of foods and more irregular mealtimes (Nettle and Bateson 2019; Shinwell et al. 2021). We initially aimed to explore meal timing patterns in this study using a chrononutrition questionnaire, but data quality issues precluded this analysis. Further research into the associations between FI and meal timing, and subsequent effects on health, is therefore needed. Nevertheless, the consistent association between FI and low diet quality across international contexts, alongside the vast body of evidence linking low diet quality to negative health outcomes (discussed further below), suggests that this relationship could be a key pathway through which FI influences health-related parameters—something which requires substantiation in future prospective studies, for example, via causal mediation analysis.

FI was associated with poorer mental health outcomes in our sample. In particular, FI was associated with around threefold higher odds of experiencing high levels of perceived stress. Evidence for an association between FI and anxiety symptoms was also found, although this was only significant when categorising anxiety scores on a graded (as per usual scoring of the questionnaire) rather than binary scale. These data are broadly consistent with prior literature. For example, a systematic review and meta-analysis from 2020, including data from > 300,000 individual participants across 10 countries, reported that FI was significantly associated with risk of stress and depression, and was associated with greater anxiety in certain population subgroups (e.g., households in North America) (Pourmotabbed et al. 2020). The pathways linking FI to poor mental health outcomes are not fully understood and require causal verification, but could involve both biological and behavioural mechanisms. For example, FI is associated with lower diet quality, which could impact psychological well-being, given that diet quality is a known determinant of mental health via effects on metabolic health (Pan et al. 2012), inflammation (Lassale et al. 2019; Shannon et al. 2021), and the gut–brain axis (Cryan et al. 2019). Additionally, FI has been proposed to create psycho-emotional burden by impacting social relationships and leading to low self-efficacy and feelings of helplessness (Palar et al. 2015). Even when individuals have adequate total energy availability, FI could contribute to anxiety and stress when eating patterns deviate from culturally acceptable norms and because of uncertainty about the timing/availability of the next meal (Pourmotabbed et al. 2020).

We found robust associations between FI and both self-reported GI dysfunction and reduced self-reported immune status. Specifically, FI was associated with more than twice the odds of reporting altered GI symptoms and nearly twice the odds of reduced self-reported immune status. These results suggest that FI is associated with wide-ranging impacts across interconnected biological systems. These associations could be attributable, at least in part, to poor diet quality in these individuals (Severino et al. 2024). As noted above, participants living with FI were significantly more likely to follow a Western dietary pattern than their food-secure counterparts. Consumption of a Western diet has been demonstrated to negatively impact both gut symptoms and the immune system by altering the composition of the gut microbiome, negatively impacting gut barrier function, increasing intestinal permeability, and contributing to low-grade systemic inflammation via the leakage of harmful gut metabolites into the bloodstream (Severino et al. 2024). The lack of diet diversity and lower relative intake of fibre previously reported in individuals living with FI (and typical with a Western diet) may be especially relevant here, given that both are believed to be key contributors to a healthy and diverse gut microbiome and immune function (Heiman and Greenway 2016; So et al. 2018). However, as we did not measure the gut microbiome or inflammation levels in our participants, the impact of FI on health via these mechanistic pathways remains a hypothesis which requires direct exploration in the future. Additionally, the strong association between FI and perceived stress could contribute to both GI symptoms (Konturek et al. 2011) and lower immune status (Cohen et al. 1991).

Interestingly, we observed no significant associations in the primary analyses between FI and either CISRI scores (calculated according to the reported frequency of several infections over the last 12 months) or recent antibiotic use. When we conducted sensitivity analyses coding both outcomes on a continuous basis, CISRI scores were now significantly associated with FI, suggesting that treating this as a binary variable may have overlooked subtle differences in scores between individuals living with/without FI. Nevertheless, there remained no significant associations between FI and antibiotic use. It is possible that well-documented barriers to healthcare access among individuals living with FI (e.g., delaying care when needed, transportation difficulties, lack of social support; Kushel et al. 2006) could reduce the likelihood of seeking care or receiving prescriptions, leading to lower antibiotic use when needed.

Strengths and limitations

This study established a new cohort of individuals who matched the wider UK population in age, gender, and ethnicity. Interestingly, our cohort had a higher percentage of participants living with FI than the UK average (22% vs. ~11%), which could be a chance finding or related to our recruitment of participants via Prolific. A further strength is that we gathered comprehensive demographic information and insight into a range of health outcomes linked with FI. However, there are several limitations. Notably, our outcomes were all self-reported. Whilst we used validated questionnaires to assess outcomes, it is possible that some participants provided inaccurate responses due to social desirability or errors in reading/comprehension. Similarly, there may be a disconnect between perceived symptoms and direct biological measures (e.g., self-reported immune status may not fully reflect underlying physiological immune function), which requires exploration in future studies. In addition, our sample size is relatively small ($n < 1000$), which had implications for our analytical approach. Specifically, to maximise statistical power, we simplified our exposure variable to a binary classification (food-secure vs. food-insecure) rather than categorising participants based on level/severity of FI. We also used binary outcome measures. Whilst this approach has the benefit of maximising the sample size in each group, it may have obscured more nuanced dose–response relationships that could have emerged with larger sample sizes. Nevertheless, sensitivity analyses using alternative outcome classifications (e.g., dividing stress or anxiety scores into three rather than two groups) yielded broadly comparable results, suggesting our binary approach for the main analyses did not have a major effect on our overall findings. A further limitation is that several of our statistical models (e.g., for self-reported immune status, anxiety, and stress) showed low explanatory power (McFadden's $R^2 < 0.1$). Thus, despite achieving statistical significance, FI and the included covariates explained only a small proportion of variance in these outcomes. Consequently, the magnitude of the estimated effects should be interpreted with caution, and unmeasured factors may play a larger role in determining self-reported immune status, anxiety, and stress. Future research should explore additional biological, psychosocial, and environmental determinants to better understand the links between FI and these outcomes. Finally, our cross-sectional design presents two key limitations. Firstly, there is a risk of reverse causality. Secondly, we could not interrogate causal pathways between outcomes. This is particularly limiting given the potentially interconnected nature of diet quality, mental health outcomes, gut health, and immune status. For example, we could not determine whether FI affects immune status directly or indirectly through its impact on diet quality and subsequent gut health changes, or whether these systems influence each other bidirectionally. As we have obtained permission from this cohort to follow them up prospectively in the future, this would allow us to overcome some of these issues. Understanding the directionality of these relationships could have important implications for practice and the design of interventions aimed at improving food security status and health.

Conclusion

In this study, FI was associated with greater odds of adhering to a less healthy Western diet, having greater stress and anxiety, and having greater GI symptoms and lower immune status. These findings support the accumulating body of evidence that FI is linked with multiple adverse health outcomes and highlight it as a multi-system health risk factor. Tackling FI should be a major public health and policy priority. Given that this study was relatively small and cross-sectional in nature, larger prospective investigations are warranted to substantiate these findings and explore causal relationships.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10389-026-02700-8.

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Author contributions The study was conceived by CL, AA, SB, DD, EMLD, JM, MKR, NR, and OMS as part of a sandpit event. The online questionnaire was developed by the same authors, with further input from CN, EP, and ACW. Data were collected by CL and OMS. CL analysed the data, with statistical guidance provided by SG. CL and OMS drafted the manuscript, which was critically revised by AA, SB, DD, EMLD, SG, JM, MKM, CN, EP, NR, and ACW. All authors approved the final version of the manuscript.

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Data availability Data are available from the authors on reasonable request.

Code availability Analytic code is available from the authors on reasonable request.

Declarations

Ethics approval This study was conducted in accordance with the guidelines laid down in the Declaration of Helsinki, and all procedures

involving research study participants were approved by the Newcastle University Ethics Committee (REF 52648/2023).

Consent to participate Written informed consent was obtained from all subjects/patients prior to data collection.

Consent for publication Not applicable.

Conflicts of interest None.

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