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Research paper

Nutrient deficiency profiles and depression: A latent class analysis study of American population

Marcin Owczarek *, Joanna Jurek, Emma Nolan, Mark Shevlin

University of Ulster, Coleraine, United Kingdom

A R T I C L E I N F O

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A B S T R A C T

Background: Research into the effects of nutrition on depression is often performed by examining the effects of singular nutrients and dietary styles (e.g.: vegan, Mediterranean). The present study is the first one to establish the effects of patterns of nutritional deficiency within the American population and examines their effects on depression.

Methods: Data was drawn from National Health and Nutrition Examination Survey (NHANES). Latent class analysis was performed to identify homogeneous groups of nutrient deficiency. A 3-step analysis was performed to establish class-dependant differences in depression severity. BCH analysis revealed unique predictors of depression dependant on most probable class.

Results: Analysis revealed 4 classes of nutrient deficiency. Magnesium and dietary fibre were the least endorsed. 'Nutrient deprived' individuals showed the highest depression severity (Mean = 4.137, SD = 0.337). Profiles were predicted by different socioeconomic and anthropogenic predictors with meeting minimum calories showing the strongest odds of not being nutrient deprived (OR between 5.44 and 11.11). Overall, age ($\beta = -0.115$, $p \leq 0.01$) and income ($\beta = -0.147$, $p \leq 0.01$) were the strongest protecting factors while being female ($\beta = 0.128$, $p \leq 0.01$) and arthritis ($\beta = 0.130$, $p \leq 0.01$) were the strongest risk factors.

Limitations: The study involved binary variables based on minimum daily intakes and did not account for positive effects of exceeding minimum recommended doses.

Conclusions: The study supports the notion of a negative relationship between good nutrition and depression. Finding unique risk factors for depression symptoms supports the utility of nutrient deficiency profiling.

1. Introduction

The World Health Organization has acknowledged that depression is a leading cause of disability worldwide, with over 300 million people suffering from the disorder (World Health Organization, 2017). Different social, environmental, genetic and psychological determinants have been identified as increasing an individual's risk for depression (Vallance et al., 2011; Ford and Erlinger, 2004). One extant area of epidemiological research involves investigating the relationship between diet and depression. Evidence to date has indicated that consumption of traditional diets such as Mediterranean diet, rich in vegetables, fruits, nuts, whole cereals, legumes, and fish, with a moderate alcohol intake and limited intake of meat products and whole-fat dairy, may protect against depression (Sánchez-Villegas et al., 2009). Conversely, Western-style dietary habits, characterised by frequent consumption of red meats, refined grains and highly processed foods, high in sugars and fat, seem to have opposite effect and have been linked to higher risk of chronic illnesses, including depression (Quirk et al., 2013; Li et al., 2017a, 2017b). Associations between dietary patterns and depression may suggest that presence of certain nutrients within the diet may have a crucial role for maintaining good mental health, while nutritional deficiencies may negatively impact on mood and overall wellbeing (Rao et al., 2008). Frequent consumption of ultra-processed, often energy dense foods has been linked to poor mental and physical health (Marino et al., 2021). For instance, low intakes of whole foods (rich in health-promoting nutrients, including dietary fibres), such as fruits, vegetables and cereals have been associated with higher risk of depressive symptoms (Miki et al., 2016). Individuals who follow a high fibre diet, rich in vegetable fibre, appear to suffer from depression symptoms less often, when compared to those who have low fibre diet (Swann et al., 2021). Similarly, inadequate nutrition has been demonstrated to be a contributor to mental health problems (Sánchez-Villegas

* Corresponding author at: University of Ulster, Coleraine campus, Coleraine BT52 1SA, Northern Ireland, United Kingdom.
E-mail address: owczarek-m@ulster.ac.uk (M. Owczarek).

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et al., 2018) and suboptimal intakes of certain vitamins, such as vitamin B1 (Merete et al., 2008; Moorthy et al., 2012; Wu et al., 2021), vitamin B12 (Hintikka et al., 2003; Moorthy et al., 2012; Skarupski et al., 2010), as well as folate (Taylor et al., 2004) have been associated with higher depression scores and increase in depressive symptoms (Tolmunen et al., 2003; Taylor et al., 2004; Farah, 2009; Gilbody et al., 2007; Morris et al., 2008; Seppälä et al., 2013). Individuals in the lowest tertile of dietary folate intake, were shown to have a 67 % greater risk of depression, than those in the highest tertile, and were at increased risk of depression compared to deficiencies in other nutrients (Tolmunen et al., 2003). Similarly, patients diagnosed with depression appear to have on average 25 % lower blood folate concentrations than controls (Coppen and Bailey, 2000).

Although majority of investigations focused on the deficiencies of B vitamins (Vitamin B1, vitamin B12), owing to their roles implicated in many biological processes, such as metabolism and brain neurotransmitters synthesis (norepinephrine, serotonin and dopamine; Gougeon et al., 2016), there are also studies demonstrating that low intakes of certain minerals, may be associated with increased depression risk in the general population. A nutritional survey using data from the Furukawa Nutrition and Health Study found that intakes of magnesium, calcium, iron, and zinc were inversely associated with the prevalence of depressive symptoms (Miki et al., 2015). The protective role of magnesium is also supported by results of meta-analyses (Li et al., 2017a, 2017b; You et al., 2018). Magnesium itself has been previously suggested to reduce the risk of mental health issues when paired with calcium and zinc (Carroll et al., 2000). Calcium intake has also been inversely associated with depressive symptoms in cross-sectional analysis of middle-aged women and university students (Bae and Kim, 2012; Alkhatatbeh et al., 2021). Higher zinc and iron were also examined, and were associated with lower levels of depression (Li et al., 2017a, 2017b). Iron deficiency was suggested as contributor to depression pathogenesis, owing that individual with low iron level are more likely to suffer from apathy, fatigue and experience more depressive symptoms over lifetime (Lee et al., 2020). Low blood copper was previously suggested to be associated with depression (Thi Thu Nguyen et al., 2019). However, results obtained from another meta-analysis (Ni et al., 2018), suggested that high blood copper was more likely to be found in depressed individuals when compared to their non-depressed counterparts. High selenium intake was also associated with lower depression levels, after adjusting for sociodemographic covariates (de Almeida et al., 2021). Similarly, the results of a large study conducted in men (n = 9354), indicated that low daily selenium intake was associated with higher rates of depression (Czaderny, 2020).

The majority of studies in the field are focused on the relationship between diet and depression levels based on individual nutrients intakes (Rao et al., 2008) or presence of particular food groups within the overall diet, including meat, grains, dairy, fruit and vegetables based diets (Salehi-Abargouei et al., 2019; LaChance and Ramsey, 2018). However, previously identified 'dietary patterns' are not indicative of actual nutrient deficiencies as they appear in the population, rather these results are focused on dietary styles. To date, no study has empirically examined if there exist patterns of deficiencies in the population and whether these can inform mental health problems - including depression.

An identification of these groups of individuals with similar patterns of dietary risk or protective factors and an examination of sufficient or insufficient daily intake of nutrients, constitutes a person-centred analytic approach, with no a-priori assumptions beyond that the patterns of nutrition will emerge. Given the variability of the synergistic effects that individual nutrients have on mental health (Parletta et al., 2013), an exploration of the relationship between nutrient profile patterns as they appear in populations and depression might provide valuable insight into how nutrition gaps manifest in the general population. Furthermore, this approach might aid in establishing whether individual patterns reveal configurations of nutrient deficiency or sufficiency that exhibit similar outcomes of depression. Examining whether individuals exhibiting different patterns present unique predictors of depression may also highlight the need of differential clinical approaches and individual risks based on their dietary needs.

With many studies demonstrating correlations between certain individual nutrient deficiencies and mental health problems, it is clear that understanding differences in nutritional profiles within the population will be beneficial. Using structural equation modeling, this study aims to explore the possibility of profiling multiple insufficient nutrient intakes against sufficient nutrient intake levels based on the nutritional guidelines from the US Institute of Medicine. The secondary aim will explore if there are unique predictors of nutritional profiles to determine who may be at greater risk of nutritional deficiencies. Finally, this study will explore if these classifications of nutritional profiles are independently associated with a risk for depression.

2. Methods

2.1. Study population

The study uses data from The National Health and Nutrition Examination Surveys (NHANES) for the 2017–2018 years. NHANES surveys approximately 5000 individuals of all ages each year and the participants are interviewed in their homes. The NHANES study aims to estimate the prevalence of nutrition and health along with risk factors in a stratified, nationally representative probability sample of non-institutionalized US population. The interview involves dietary and health components. Initial participants numbered $N = 9254$ individuals, after removing those who did not fill the mental health component the sample was reduced to $N = 5090$. For the purposes of the present study only individuals who completed at least one (out of the two) dietary recall interviews and the mental health component of the NHANES were involved. After those removals, the sample was reduced to $N = 4791$ participants. Survey methodology involved in NHANES is available at https://wwwn.cdc.gov/nchs/nhanes/analyticguidelines.aspx.

2.2. Measures

2.2.1. Nutrition data

Data regarding nutrients was obtained from the 'Dietary Interview - Total Nutrient Intakes' part of the NHANES study. The data was gathered on two occasions (the first dietary recall interview is collected in-person in the Mobile Examination Center and the second interview is collected by telephone 3 to 10 days later) asking the participant about the participants' food intake during the previous 24-hour period. The dietary intake data was used to estimate daily totals for food energy, nutrients and other food components and supplements. Where possible (i.e. the participant completing both days of the interview) a mean value of daily intakes was calculated using data from both interviews. Data gathering procedures are described in: https://wwwn.cdc.gov/Nchs/Nhanes/2017-2018/DR1TOT_J.htm. The recommended dietary intake data was used to establish classes of nutritional deficiencies. Recommended daily intakes for calories, dietary fibre, folate, vitamin B1, vitamin B12, vitamin K, calcium, magnesium, iron, zinc, copper and selenium were established based on values provided by the US Institute of Medicine (Institute of Medicine (US) 1997; Institute of Medicine (US) 1998; Institute of Medicine (US) 2000; Institute of Medicine (US) 2001; Institute of Medicine (US) 2011). Based on these values, individuals were assigned a designation of (0) - does not meet the minimum dietary intake or (1) meets the minimum dietary intake for each of the listed nutrients. Those values were then used in establishing the latent profiles peasant within the sample.

2.2.2. Patient Health Questionnaire (PHQ-9)

Nine symptoms of depression were measured using the PHQ-9 (Kroenke et al., 2001). Participants are asked to indicate how often they have been bothered by each of the 9 presented symptoms during the last two weeks using a 4-point Likert scale. The answers ranged from 0 (Not bothered at all), to 3 (Nearly every day) with higher scores representing higher levels of depression. The possible scores ranged from 0 to 27. In the current sample, 90.9 % of the participants scored below a cut-off score of 10 which was previously suggested to possibly warrant moderate levels of depression which may require clinical help (Manea et al., 2012). The reliability in the sample was good (a = 0.83).

2.2.3. Covariates

Demographic data included age, gender, being married, obtaining a college degree, an individual's weight (kg), income (expressed in relation to the poverty line) and number of people in the household; was used in addition to NHANES medical data describing the participant: diagnoses of arthritis, diabetes, high blood pressure and whether the individuals smoked at least 100 cigarettes in their lifetime. This data was used as class-dependant covariates predicting depression in the BCH (Bolck–Croon–Hagenaars; Bolck et al., 2004) part of the present study (see Table 1).

2.3. Statistical analysis

After establishing descriptive values for the sample, the analytic process for the current study included four linked phases (appropriate sampling weights were included in the analyses):

(1) A latent class analysis (LCA) was performed to identify distinct homogeneous groups (latent classes), from categorical multivariate data- in the case of the present study, the LCA results would identify specific groups of malnutrition profiles present in the sample and the analysis will include data pertaining to meeting the minimum recommended daily amounts for (1) Folate, (2) Vitamin B12, (3) Vitamin B1, (4) Fibre, (5) Vitamin K, (6) Calcium, (7) Magnesium, (8) (9) Iron, (10) Zinc, (11) Copper and (12) Selenium. Five models with 2–5 classes were tested, and model selection was based on the results of a number of fit criteria. Low values for the Akaike Information Criterion (AIC; Akaike, 1987) and the Bayesian Information Criterion (BIC; Schwarz, 1978) indicate superior model fit among competing models – i.e. lower comparative values are considered superior. Additionally, the Lo-Mendell-Rubin adjusted likelihood ratio test (LMR-A) compares a k class solution to k-1 solution where k is the number of latent classes. If the probability value (p) of the comparison is <0.05, the k model is considered superior. Additional classes are added until the probability value exceeds 0.05 and the previous model is then considered superior (Lo et al., 2001). The entropy value indicates the distinctiveness of the latent classes when compared to one another and values closer to one suggest clear classification (Ramaswamy et al., 1993).

(2) Predictive validity of the established classes was provided by using a 3-step approach described in Asparouhov and Muthén (2012). PHQ-9 depression scores were specified as distal outcomes predicted by the latent classes using the DE3STEP method (with unequal means and equal variances across classes as an assumption; Asparouhov and Muthén, 2012). This method allows for testing for the equality of means across classes established with the LCA. A Wald test and subsequent pairwise comparisons inform about equality of means between the classes (Asparouhov and Muthén, 2012).

(3) To determine whether class membership was conditional on demographic and anthropogenic variables (i.e. Age, Weight, Income, Household size, Gender, College education, being married, arthritis, diabetes, smoking and high blood pressure), the BCH (Bolck et al., 2004) method was used. This method allows to evaluate unique associations between covariates and class membership. The process also allows for the effect of each covariate on class membership to be determined without any shift in the latent classes (Asparouhov and Muthén, 2014).

(4) To evaluate class-specific associations between demographic and anthropogenic variables with depression, manual BCH (Bolck et al., 2004) method was utilised (Asparouhov and Muthén, 2014). Latent class model of measurement was estimated and the BCH-specific class weights (which reflect the measurement error of the latent class variable) are saved. In the second step, the general auxiliary model is evaluated- i.e. conditional on latent class variable, the demographic and anthropogenic variables were regressed on the depression score. To highlight class specificity in relation to an overall approach, non-class-specific model was also estimated separately. This was performed to establish whether there are different risk/protective factors in relation to depression scores that are conditional on class membership.

Table 1
Descriptive statistics.

Variable	Mean	SD	Range
Age	49.51	18.37	18–80
Weight (kg)	83.19	22.95	36.20–219.60
Depression (PHQ-9)	3.30	4.58	0–27
Income (times above the poverty line)	2.55	1.61	0–5
Household size	3.14	1.63	1–7
Daily calories	2034.02	873.39	122.00–8356.50
	Frequency	% (percentage of the sample meeting the criterion)	
Gender (being female)	2442	51 %	0–1
College education	1109	23.1 %	0–1
Being married	2282	47.6 %	0–1
Arthritis diagnosis	1402	29.3 %	0–1
Diabetes diagnosis	722	15.1 %	0–1
Smoked at least 100 cigarettes	1978	41.3 %	0–1
High blood pressure	1745	36.4 %	0–1
		% (percentage of the sample meeting the minimum intake)	
Folate	2498	52.1 %	0–1
Vitamin B12	3875	80.9 %	0–1
Vitamin B1	3718	77.6 %	0–1
Fibre	668	13.9 %	0–1
Vitamin K	1183	24.7 %	0–1
Calcium	1852	38.7 %	0–1
Magnesium	1317	27.5 %	0–1
Iron	3343	69.8 %	0–1
Zinc	2895	60.4 %	0–1
Copper	3090	64.5 %	0–1
Selenium	4344	90.7 %	0–1

3. Results

3.1. LCA

The LCA model fit statistics are presented in Table 2. The AIC, BIC, LMR-LRT values supported a four-class model. The four-class solution was also characterised by sufficient Entropy (0.801). The class structure of the four-class solution is presented in Fig. 1. The largest class, Class 1 ($n = 1690$, 35.3 % of total sample) is characterised by low folates, fibre, vitamin K, magnesium and medium to high levels of other nutrients. For the purposes of this analysis it was designated as the 'Low nutrient' class. Class 2 ($n = 1322$, 27.6 % of total sample) was characterised by high

Table 2
Results of the LCA – fit statistics.

Model (Number of latent classes)	Loglikelihood	AIC	BIC	LMR-LRT	Entropy
1	−31,987.680	63,999.360	64,077.054	–	–
2	−27,261.952	54,573.904	54,735.766	9366.437**	0.835
3	−26,519.367	53,114.734	53,360.765	1471.810**	0.773
4	**−26,229.055**	**52,560.110**	**52,890.310**	**575.401****	**0.801**
5	−25,983.505	52,095.010	52,509.378	486.683	0.760

Note. AIC – Akaike Information Criterion; BIC – Bayesian Information Criterion; LMR-LRT- Lo–Mendel–Rubin likelihood ratio test; * - $p < .05$, ** $p < .01$; Solution chosen is shown in bold.

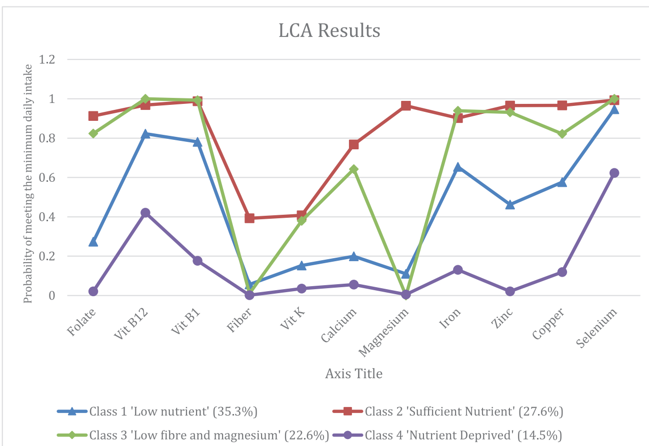

Fig. 1. Profile plot of the 4-class solution.
Note. Percentages of most likely class belonging provided in brackets.

comparative overall values with the exception of fibre and Vitamin K and was designated as 'Sufficient Nutrient' class. Class 3 (n = 1083, 22.6% of total sample) was characterised by values similar to the 'Sufficient Nutrient' class with the exception of fibre and magnesium and was designated as the 'Low fibre and magnesium' class. Members of class 4 (n = 694, 14.5 % of total sample) were characterised by lowest overall chances of meeting the minimum nutrient intakes and therefore the class was designated as the 'Nutrient deprived' class.

3.2. 3-Step analysis

The sum score of depression was modelled as a distal class-dependant outcome and the results of the tests of mean differences are presented in Table 3. Class 4 ('Nutrient Deprived') showed highest mean (M = 4.137) which showed significant effects when compared to classes 2 ('Sufficient Nutrient'; M = 2.798) and 3 ('Low magnesium and Fibre'; M = 2.937). Additionally, Class 1 ('Low Nutrient'; M = 3.324) showed a mean that was significantly higher when compared with the 'Sufficient Nutrient' class. These results suggest that there exist class specific differences between the classes when examining depression levels. The two classes showing highest odds of satisfying most nutrients – 'Sufficient Nutrient' and 'Low fibre and magnesium' classes showed no significant differences, however, the 'Low fibre and magnesium' class was not significantly different when compared with the 'Low nutrient class'.

Table 3
Mean depression scores across the four latent classes.

	Depression	
	Mean	Standard error
Class 1 (low nutrient)	3.324	0.193
Class 2 (sufficient nutrient)	2.798	0.150
Class 3 (low fibre and magnesium)	2.937	0.201
Class 4 (nutrient deprived)	4.137	0.337
Bivariate Wald test comparisons (significant differences)	4 > 2,3; 1 > 2	

Seeing as the mean depression scores were below the moderate 'caseness' cut-off of 10 (Kroenke et al., 2010). The analysis was extended to include caseness comparison between the classes. Only Class 4 was shown to exhibit significant differences in caseness compared to other classes with belonging to Classes 1 to 3 being suggested as showing lower probability of meeting at least the moderate depression criteria as measured by the PHQ-9. Results are presented in Table 4.

3.3. Unique associations between demographic and anthropogenic covariates and class membership

Table 5 presents the correlates of class membership. These results present unique associations between covariates and class membership in relation to class 4 (Nutrient Deprived). Meeting minimum daily calories was used as a categorical variable instead of total calorie intake as an increase in one daily calorie would be harder to interpret.

In the recent study, weight was a significant predictor of being allocated to class 3 when compared to class 4. Of note, class 3 In comparison to the 'Nutrient deprived' class, membership of 'Low nutrient' class was significantly associated with being female, meeting minimum daily calories, college education and being married. Membership of 'Sufficient Nutrient' class was associated with being female, meeting minimum daily calories, income, household size, college education, being married, being diagnosed with diabetes and past or present smoking habit. Finally, membership in the 'Low fibre and Magnesium' class was associated with being female, weight, meeting minimum daily calories and income. Strongest effects were observed for obtaining college education as being predictive of belonging to the 'Sufficient Nutrient' class (B = 2.725; SE = 0.459; OR = 15.26).

3.4. Class-specific associations between demographic and anthropogenic variables with depression

Table 6 presents the results of the BCH analysis and an overall regression model (Multiple linear regression). These results examine the associations between demographic and anthropogenic predictors and depression in a class specific (BCH) and overall sample manner.

When examining associations with depression, with the exception of Income, which showed significant effects across classes, and weight, which did not present any significant effects, the results suggest class specificity of predictors used. The differences between class-specific models and the overall model suggest validity of a class-specific approach. The results suggest that the nutrient deficiency profiles show qualitative differences with regards to depression risk factors. The R^2 ranged from 0.076 to 0.103 for the class specific models and was 0.109 for the overall models (entire sample) suggesting that the models explained approximately 7.6 % to 10 % of the depression score variance.

4. Discussion

The present study used NHANES 2017/2018 data to establish and explore the use of dietary profiles being predictive of depression in a

Table 4
Odds ratio comparison of probable depression (PHQ-9 score > 10) between the classes.

Class	Class 1 'low nutrient' (case % = 9.5)	Class 2 'sufficient nutrient' (case % = 6.7)	Class 3 'low fibre and magnesium' (case % = 6.6)	Class 4 'nutrient deprived' (case % = 14.1)
Class 1 'low nutrient'	x			
Class 2 'sufficient nutrient'	1.463 (0.793–2.133)	x		
Class 3 'low fibre and magnesium'	1.493 (0.760–2.226)	1.02 (0.475–1.565)	x	
Class 4 'nutrient deprived'	**0.642 (0.326–0.958)***	**0.439 (0.214–0.664)****	**0.43 (0.212–0.648)****	x

Note: The results are presented as odds ratios with 95 % confidence intervals shown in brackets; * - $p < .05$, ** $p < .01$.

Table 5
Correlates of class membership - multinomial logistic regression analysis.

	Class 1 (low nutrient) [n = 1690]	Class 2 (sufficient nutrient) [*n* = 1322]	Class 3 (low fibre and magnesium) [*n* = 1083]
Variable	**B (SE) [OR]**	**B (SE) [OR]**	**B (SE) [OR]**
Age	1.006 (0.005) [2.73]	1.008 (0.005) [2.74]	1.01 (0.005) [2.75]
Gender (being female)	**0.607 (0.084)** [2.73] ** [1.83]**	**0.436 (0.058)** [1.55]**	**0.171 (0.025)** [1.19]**
Weight (kg)	1.004 (0.003) [2.73]	1.001 (0.003) [2.72]	**1.007 (0.003)* [2.74]**
Meeting minimum daily calories	**1.859 (0.326) ** [6.42]**	**2.408 (0.496)** [11.11]**	**1.694 (0.341)* [5.44]**
Income (times above the poverty line)	1.074 (0.05) [2.93]	**1.163 (0.051)** [3.2]**	**1.166 (0.056)** [3.21]**
Household size	0.959 (0.04) [2.61]	**0.895 (0.039)** [2.45]**	0.955 (0.042) [2.6]
College education	**1.615 (0.295) * [5.03]**	**2.725 (0.459)** [15.26]**	1.238 (0.236) [3.45]
Being married	**1.535 (0.21)* [4.64]**	**1.665 (0.224)** [5.29]**	1.342 (0.193) [3.83]
Arthritis diagnosis	0.795 (0.124) [2.21]	1.01 (0.149) [2.75]	0.844 (0.133) [2.33]
Diabetes diagnosis	0.872 (0.08) [2.39]	**0.796 (0.071)** [2.22]**	0.867 (0.08) [2.38]
Smoked at least 100 cigarettes	0.889 (0.115) [2.43]	**0.785 (0.099)* [2.19]**	0.998 (0.135) [2.71]
High blood pressure diagnosis	0.859 (0.128) [2.36]	0.903 (0.128) [2.47]	1.124 (0.169) [3.08]

Note. Reference class is class 4 (nutrient deprived; $n = 694$); B unstandardized beta value, SE standard error, OR odds ratio; '*' – significant at the 0.05 level; '**' – significant at the 0.01 level.

sample of 4791 participants of general adult population (over 18 years of age) from the United States. To this end, binary deficiencies of nutrients, previously described as relating to mental health, were established using the recommended daily intake values provided by Institute of Medicine (US) (Institute of Medicine (US) 1997; Institute of Medicine (US) 1998; Institute of Medicine (US) 2000; Institute of Medicine (US) 2001; Institute of Medicine (US) 2011). These were then used to establish latent classes using the LCA. Results suggested that a four-class solution was the most optimal. Then, differences in depression scores were established using the 3-step procedure (Asparouhov and Muthén, 2012). The results of the 3-step analysis suggested that the classes showed heterogeneity in depression scores, with classes suggestive of better nutrition scoring significantly lower when compared to those suggestive of nutritional deficiencies. Finally, to establish whether different class-dependent demographic and anthropological factors influence depression, the BCH analysis was performed (Asparouhov and Muthén, 2014). BCH results further support qualitative distinctiveness of the established classes.

The results of the present study provide insights into the relationship between nutritional deficiencies and depression. Firstly, to the knowledge of the authors, the present study is the first one to establish profiles of nutritional deficiencies in a nationally representative population. The results suggest variability in achieving minimum daily recommended intakes with most of the sample (Classes 3 and 4) being at high risk for not meeting the values of vitamin B1, dietary fibre, vitamin K, Calcium, Magnesium, Iron, Zinc and Copper. In relation to depression, individuals assigned to classes satisfying most nutritional values showed lower depression scores. Following observations are consistent with other studies which demonstrated that low intakes of vitamins and minerals are associated with higher risk of experiencing psychiatric problems (Rao et al., 2008). For example, insufficient intake of magnesium may contribute to increased neuron damage (Kaner et al., 2015), whereas inadequate dietary zinc and iron status (Lehto et al., 2013; Kaner et al., 2015) were suggested to negatively impact overall brain function

Table 6
Class-specific associations between demographic and anthropogenic variables with depression.

	Class 1 'low nutrient' (35.3 %)	Class 2 'sufficient nutrient' (27.6 %)	Class 3 'low fibre and magnesium' (22.6 %)	Class 4 'nutrient deprived' (14.5 %)	Overall model (Entire sample)
Age	−0.079	−0.106**	−0.109*	−0.122*	−0.115**
Gender (being female)	0.129**	0.114**	0.084*	0.060	0.128**
Weight (kg)	0.026	0.005	0.051	0.020	0.017
Meeting minimum daily calories	0.030	0.050*	0.070	−0.085	0.009
Income (times above the poverty line)	−0.098**	−0.073*	−0.083*	−0.139*	−0.147**
Household size	−0.033	−0.044	−0.010	−0.051	−0.056*
College education	−0.050	−0.049*	−0.025	−0.039	−0.037
Being married	−0.093**	−0.070*	−0.059	−0.071	−0.061**
Arthritis diagnosis	0.104**	0.119**	0.150*	0.111	0.130**
Diabetes diagnosis	0.060	0.044	0.085	0.070	0.070**
Smoked at least 100 cigarettes	0.098**	0.106**	0.055	0.144**	0.116**
High blood pressure	0.077*	0.072**	0.049	0.042	0.059*
R^2	0.095**	0.080**	0.076**	0.103**	0.109**

Note. '*' – significant at the 0.05 level; '**' – significant at the 0.01 level; Overall model was estimated separately (non-BCH).

(Bodnar and Wisner, 2005). These effects have been supported by experimental studies, which also demonstrated the relationship between low intakes of zinc and selenium within diet and increased severity of depression-like symptoms (Grønli et al., 2013; Li et al., 2018).

In the current study, class 1 'Low Nutrient', class 2 'Sufficient Nutrient' and class 4 'Nutrient Deprived' (not the 'Sufficient nutrient' class) demonstrated endorsement of Magnesium and Fibre below 20 %, suggesting the two nutrients are the most likely to be deficient in the population. Magnesium was previously suggested to play a role in modulating the glutamate receptor (NMDA receptor) and gamma-aminobutyric acid receptors (GABA receptor) and to interact with the hypothalamus-pituitary-adrenal axis (HPA) (Serefko et al., 2013), all previously suggested to exhibit neuronal dysregulation in depressed individuals (Murck, 2002). In addition, class 4 ('Nutrient Deprived') has been reported to have higher depression score measured by PHQ-9 questionnaire when compared to scores in classes 2 ('Sufficient Nutrient') and 3 ('Low magnesium and Fibre'). No statistically significant difference was found in the reported depression score between class 2 and class 3. This finding may suggest that inadequate intakes of magnesium and dietary fibre have limited effect to contribute to the depression risk when not accompanied by other deficiencies. Of note, participants in class 2 and class 3, when compared to class 4 (and to a lesser extent – class 1) appear to have higher chances to achieve the minimal recommended intakes of vitamin B12, vitamin B1, vitamin K, iron, zinc and selenium, which adequate intakes have been previously shown to be protective against depressive symptoms (Skarupski et al., 2010; Kim et al., 2020; Wang et al., 2018, Wu et al., 2021). Nevertheless, the exact mechanism how dietary fibre can influence depression is still limited to few observational studies showing associations between dietary fibre intake/high fibre diets and prevalence of depressive symptoms (Miki et al., 2015; Xu et al., 2018; Lee et al., 2020; Swann et al., 2021). Research to date suggested that dietary fibre obtained from whole foods, such as fruits, vegetables and cereals may favourably impact on depressive symptoms through decreasing inflammation, that has been implicated in depression pathogenesis (Miller and Raison, 2016). The potential protective effects on dietary fibre on depression risk might be linked with adiposity, given a bidirectional link between depression and obesity (Mannan et al., 2016). Furthermore, the intake of magnesium and fibre has previously been reported to be highly correlated and showed similar anti-inflammatory effects which, while beyond the scope of this study, may point towards specific dietary choices (e.g.: grains; King et al., 2005).

Comparing the depression levels between the 'Sufficient' and the 'Low fibre and magnesium' classes, showed no significant differences when examined Depression (PHQ-9) scores continuously. While further research is needed, this may be due to previous studies mostly focusing on deficiencies in singular nutrients or not controlling for intake of other nutrients (see: Li et al., 2018; Woo et al., 2006; Othman et al., 2018; Tarleton and Littenberg, 2015). This reinforces the notion that when examining large-scale population studies, using one 'marker' of deficiency may be of limited utility. For example, low levels of magnesium or fibre, seen across three of the lower classes (not the 'sufficient nutrient' class) identified within this study, cut across around 77 % of the population, out of which many would have different depression outcomes based on synergistic and cumulative effects of the entire nutrition profile. The present study supports examining the interplay of nutrients within overall deficiency profiles when considering the effects of diet on depression.

Examining differences between the classes in terms of probable depression diagnosis (caseness) suggests that the profile of overall deficiency (Class 1 - 'Nutrient deprived') showed significantly worse outcomes compared to other classes with other classes showing no significant differences. These results suggest that, when using nutrient deprivation as a predictor, only severe deficiencies differentiate depression cases from other nutritional profiles. However, it is important to note that even subsyndromal increases in depression can be impairing to the quality of life of an individual (Goldney et al., 2004).

Examining correlates of class membership revealed qualitative demographic and anthropogenic differences between classes. Present results suggest that college education is a strong predictor of having a diet that provides sufficient depression-related nutrients. Higher weight was uniquely associated with belonging to class 3. While the present study did not examine body fat percentage, low magnesium and fibre intakes were previously associated with obesity (Luppino et al., 2010; Shamnani et al., 2018; Lu et al., 2020; Davis, 2018). Class 1 did not present any unique predictors (i.e. those which were not significant for any other class) potentially electing the class as being an 'intermediate' class between Class 4 and Classes 2 and 3. The results suggest that being female universally increases one's odds of not being in the 'nutrient deprived' class. This is consistent with previous findings suggesting that women choose foods that are healthier and are more conscious of recommended intakes (Fagerli and Wandel, 1999). Interestingly however, previous research also suggested higher differences in food consciousness between socioeconomic groups rather than between genders, the present findings do not support this notion when examining class 1 and 4 against income. This difference may be due to methodologies used – e.g. present study examines profiles of nutrient deprivation rather than food items consumed, which may provide a higher resolution description of the issue. Class 2 'Sufficient nutrient' showed the most unique predictors of belonging to it when compared to class 4 'Nutrient Deprived'. Diabetes, which was dubbed one of the 'diseases of modern civilisation' (Tuchman, 2009), was one of these predictors. Overall, this would be in-line with other significant predictors of belonging to this class – high education, large household size, being married and of high income. While body weight was not shown as being a high predictor of belonging to the class despite the disease being associated with obesity (Dunstan et al., 2002), the class could be best described as one that could reap the rewards along with the risks of living in higher echelons of a civilised society. While warranting further exploration, age and being diagnosed with high blood pressure were not significant predictors of class membership. These two factors are related in that it was previously suggested that blood pressure rises as an effect of both age-related structural changes of the arteries and lifestyle (Pinto, 2007). These results might suggest wide age ranges being present in each class and warrant future examination.

The BCH analysis provides insight into what specific predictors influence depression in each class. Meeting the minimal calorie intake values showed significant, albeit very low, effects in the 'Sufficient nutrition' class but not in the other classes. This highlights the effects of diet on depression - not all diets can provide a wide variety of nutrients that are needed to accommodate good mental health. Other results further highlight the importance of examining dietary profiles rather than individual risk factors. For example, that depression is more common in patients with rheumatoid arthritis has previously been well described (Dickens et al., 2002). However, this variable was not a significant predictor in the 'nutrient deprived' class. While more research is needed this may point to other issues resulting from nutrient deficiency taking primacy over this predictor. Similarly, the well-described effects of gender (Girgus and Yang, 2015) have not been observed in that class, possibly due to similar causes. In contrast, both effects were among the strongest when considering the overall sample, providing further insight into how well-described effects can be modular depending on nutrition. While both the 'Sufficient nutrition' and 'Low fibre and magnesium' classes did not exhibit significant differences in depression scores, college education showed a protective effect, high blood pressure and smoking habit showed negative effect for the 'Sufficient nutrition' members but lacked an effect in the 'Low fibre and magnesium' class. These results may point to other differences between these classes (e.g. habitual, genetic, synergistic between the risk factors and diet etc.) not captured by the present analysis. Nevertheless, these results support the notion that classifying the population based on their nutrient deficiencies reveals profiles of individuals with unique needs and risk factors for depression.

The two main strengths of the study are that it is the first one to consider patterns in dietary deficiencies when predicting mental health outcomes (also one of the few to include dietary supplements) and that it uses a nationally representative sample of adults. However, the study is not free of certain limitations. First, while vitamin D has been widely implicated in the pathophysiology of depression (Anglin et al., 2013), the study design did not allow for inclusion of Vitamin D levels as the data gathered was based on dietary interviews only and not blood levels. In the light of cutaneous vitamin D synthesis, these values would not be reliable (Gilchrest, 2008). It is also important to note that recent genomic studies question the role vitamin D plays in causing depressive symptoms (Milaneschi et al., 2019). Second, while most of the sample showed low chances of being in classes of high nutrient values, the study design involved minimum daily intake recommendations and therefore did not account for dose-response mechanisms of exceeding these doses. It should be recognised that this approach suffers from loss of information due to dichotomisation. Future studies could explore beneficial effects of exceeding the recommended values. Third, the 2017–2018 NHANES data only includes information about depression – further analyses could explore the utility of dietary profiles in other common mental health ailments (e.g. general anxiety disorder, PTSD, psychosis).

It is hoped that the present study will serve as a first-of-many to highlight the importance of examining dietary profiles rather than considering individual nutrients in a dose-response manner when examining mental health. Beyond simply suggesting that there is a negative relationship between good nutrition and depression, the study supports the notion that the US population may be classified into distinct profiles of nutrient deficiency. These may have utility when planning interventions (clinical, policymaking) as they reveal unique risk factors for depression.

CRediT authorship contribution statement

Marcin Owczarek: statistical analysis, writing, original draft, conception and design.

Joanna Jurek: review and editing, conception and design.

Emma Nolan: review and editing, original draft.

Mark Shevlin: review and editing, statistical analysis.

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Conflict of interest

The authors declare no conflict of interest.

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