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Bitterness as an indicator of diet quality: A secondary analysis of the Australian National Nutrition and Physical Activity Survey

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Bitter foods are linked to health benefits, but a comprehensive evaluation of dietary bitterness remains limited. This study quantified dietary bitterness and examined its relationship with nutritional quality. This secondary analysis of the 2011-12 National Nutrition and Physical Activity Survey (NNPAS) combined dietary data from 8975 Australian adults with an established sensory food database. The bitterness of foods consumed was calculated by multiplying the bitterness of each food by the grams consumed (bitterness intensity), then summing to estimate the total bitterness of an individual's diet. Tertiles of bitterness were created, and ANOVA with a Bonferroni post hoc test was used to compare individual characteristics and food and nutrient intakes between groups. We hypothesized that more bitter diets might exhibit a more favorable nutritional profile. Age was the strongest predictor of dietary bitterness ($\beta = 0.26$), with older adults consuming more bitter diets ($P < .001$). Compared to the least bitter diets, those with the most bitter diets had higher intakes of vegetables (+30%), fruits (+34%), wholegrain cereals (+36%), and low-fat dairy (+57.2%), and lower intake of refined cereal (-18.0%) $P < .001$. Beverages contributed more to dietary bitterness than solid foods (87% *vs* 13%; $P < .001$), particularly in the most bitter diets (94.6% *vs* 79.7%; $P < .001$). Higher intakes of tea/coffee (+285%) and milk (+6%), and lower soft drink (-16%) and juice (-10%) consumption characterized the most bitter diets ($P < .001$). Dietary bitterness may serve as an indicator of diet quality. Promoting bitter diets requires consideration of both individual characteristics and preferences for bitter foods and beverages.

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1. Introduction

Bitterness is one of the five basic tastes and has historically served as a warning signal of potentially toxic substances, such as plant-derived alkaloids, rancid fats, and certain toxins [1]. However, quantitative analysis reveals that fewer than 60% of bitter compounds are toxic, and only 56% of toxic substances taste bitter [2]. In modern diets, many bitter foods are widely accepted and enjoyed, indicating that bitterness is no longer a reliable indicator of toxicity [3].

Many bitter-tasting foods offer potential health benefits. Meta-analyses of observational studies demonstrate that higher consumption of coffee, tea, and brassica vegetables is associated with lower risk of obesity and type 2 diabetes mellitus (T2DM) [4–9]. One explanation for these health outcomes could be the bioactive bitter compounds found in these foods (e.g., caffeine in coffee, catechin in tea, and sinigrin in brassica vegetables), which drive their bitter taste, and have been shown to regulate postprandial glycemia and energy intake in humans [10,11]. Additionally, these health-promoting properties of bitter foods may be attributed to their nutritional characteristics (e.g., fiber and phytochemical content of brassica vegetables [12]), or the bitter compounds themselves [13,14]. Therefore, diets rich in bitter foods may provide a healthier profile. Cox et al. reported that higher-quality Australian diets are characterized by higher bitterness [15]. Bitter foods are also predominantly non-ultra-processed, indicating a healthier dietary profile [16,17].

Previous research has mainly focused on preferences for specific bitter foods and their consumption patterns, rather than quantifying bitterness at the whole-diet level [18–21]. Methods vary across studies; consequently, information on potential individual factors influencing dietary bitterness [18] and the nutritional profile of bitter diets is limited. Therefore, this study aimed to (i) quantify dietary bitterness and evaluate the impact of individual factors on it; (ii) characterize the more nutritional profile of more bitter diets; and (iii) identify the foods contributing most to the dietary bitterness. We hypothesized that individuals' dietary bitterness may be shaped by their characteristics. Moreover, the nutrient profile of diets may vary with bitterness level, with more bitter diets potentially reflecting healthier dietary patterns, suggesting that bitterness can serve as an indicator of diet quality.

2. Methods

The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guideline was followed to report this secondary analysis study [22].

2.1. *Data preparation*

Data from the 2011 to 12 National Nutrition and Physical Activity Survey (NNPAS) [23] and the Sensory Diet database [24] were used to perform this study. The NNPAS was conducted by the Australian Bureau of Statistics (ABS) as part of the nationwide Australian Health Survey (AHS). The sampling design and survey methodology are described in detail in the AHS Users' Guide, 2011-13 [23]. Briefly, the AHS design was a stratified, multistage area sample of about 25,000 private dwellings selected across Australia, excluding very remote areas. From the sampled households, approximately 32,000 people aged two years and over were selected (usually one adult and one child per household). It included data at the individual and diet levels, collected via a face-to-face interview using standardized tools, including a highly structured automated multiple–pass 24–hour dietary recall and a dedicated physical activity questionnaire [23]. Ethics approval for the NNPAS was granted under the Census and Statistics Act 1905, as detailed in the AHS User Guide [23,25].

The Sensory Diet database was developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) [24]. The database contains the taste profiles, including bitterness, of all the foods (over 5600 items) available in the Australian market and consumed in Australian diets [24]. The study protocol was reviewed and approved by both the ABS and the CSIRO prior to granting access to the datasets.

Supplementary Fig. 1 illustrates the integration of datasets used in this secondary analysis. Individual-level data (including sociodemographic characteristics, self-reported health, and selected dietary information) and food-level data (including nutrient composition and food groups) from the NNPAS were merged using participant identification (ID) codes. These were then linked to the Sensory Diet database via food codes, including 2-digit (major), 3-digit (sub-major), 5-digit (minor), and 8-digit levels, used in the Australian Food and Nutrient database (AUSNUT) [23,26]. The Sensory diet database components used in this study, the bitterness metrics, and the analytic code can be made available upon reasonable request.

2.2. *Participant characteristics*

This secondary analysis focused on adults aged 19 years or above, consistent with the Australian and New Zealand nutrient reference values [27] and ABS reports [23]. Pregnant and/or lactating participants were excluded, as this may have affected their weight and typical dietary intake.

The sociodemographic, health and dietary-related data (Table 1) were either used in the original classification of the NNPAS for sex (male/female), area of residence (major cities, inner regional, or outer regional/remote), socioeconomic status measured using socio-economic index of disadvantage for areas (SEIFA) quintiles [28]) or classified for the study as: age (19-30, 31-50, 51-70, and $\geq$70 years) [27], country of birth (Australia or overseas), education level (university degree, certificate/diploma, or school qualification), smoking status (yes/no), physical activity level (very low/sedentary, low, medium, or high) [29], body mass index (BMI; underweight, healthy weight, overweight, or obese [30]), central obesity based on waist circumference (WC; not at risk, at risk, or central obesity) [30], current diabetes status (yes/no), usual daily vegetable intake (low $<$2 serves, medium 2-4 serves, or high $>$4 serves per day), based on recommendations from obesity risk reduction reports suggesting health benefits from consuming approximately 1 to 4 serves of vegetables per day [31], current dieting status (yes/no), and salt added to food at the table (yes/no).

Table 1 – Bitter taste properties of Australian diets by sociodemographic characteristics, health, and dietary related factors. Data obtained from the National Nutrition and Physical Activity Survey, combined with the Sensory diet dataset, included 9118 (8975 unweighted) Australian adults.

Characteristic/ category	N	c (%)	Energy intake (kJ)		Bitter score		Bitter density	
			Mean	SD	Mean	SD	Mean	SD
	9118	100.0	8734	3655	37719	26008	4.9	3.7
Sociodemographic								
Gender								
Male	4633	50.8	10002*a	3889	36824	26135	4.1*a	3.3
Female	4485	49.2	7424 b	2857	38644	25848	5.7 b	4.0
Age								
19-30	2070	22.7	9522*a	4082	23920*a	18517	2.9*a	2.6
31-50	3374	37.0	8956 b	3719	39304 b	25862	5.0 b	3.7
51-70	2667	29.2	8363 c	3324	44952 c	28230	5.9 c	3.9
70+	1008	11.1	7352 d	2724	41612 c	22731	6.2 c	3.8
Country of birth								
Australia	6273	68.8	8797	3666	37911	26340	4.9	3.8
Overseas	2845	31.2	8594	3628	37296	25260	4.9	3.6
Education[£]								
University degree	2294	25.2	8998*a	3634	38648	25045	4.8*	3.5
Certificate/Diploma	3195	35.0	8936 a	3678	37673	26109	4.7 a	3.6
School qualification	3491	38.3	8367 b	3636	37038	26637	5.1 b	4.0
Area of residency								
Major cities	6533	71.7	8701	3675	36487*a	25209	4.8*a	3.7
Inner regional	1737	19.1	8829	3603	39879 b	26814	5.0 b	3.6
Outer regional/Remote area	847	9.3	8792	3608	42789 b	29323	5.5	4.2
SEIFA quintile								
1st (most disadvantaged)	1646	18.1	8520	3736	36302	27259	4.9	4.0
2nd	1818	19.9	8576	3716	36825	25013	4.9	3.7
3rd	1886	20.7	8857	3653	39680	26896	5.1	3.8
4th	1726	18.9	8828	3822	37072	24509	4.8	3.6
5th	2043	22.4	8853	3371	38392	26138	4.9	3.6
Health factors								
Currently smoking								
Yes	1618	17.7	8949	3786	39939*a	30016	5.1*a	4.1
No	7499	82.3	8687	3625	37240 b	25036	4.9 b	3.7
Physical activity level[£]								
High	1382	15.2	9687*a	4230	36513	25683	4.4*a	3.5
Moderate	2541	27.9	8629 b	3420	38559	25832	5.0 b	3.6
Low	3149	34.5	8521 b	3485	36852	26120	4.9 b	3.8
Very low/Sedentary	1933	21.2	8487 b	3678	38909	26221	5.3 b	3.9
Weight status								
Underweight	142	1.6	9229*	4793	27725*a	21578	3.8*a	3.3
Healthy weight	2797	30.7	9106 a	3784	35438 b	25215	4.5 b	3.6
Overweight	2899	31.8	9048 a	3508	40049 c	26348	5.0 c	3.7
Obese	3279	36.0	8117 b	3532	38038 c	26295	5.3 c	3.9
Central obesity status[£]								
Not at risk	2945	32.3	9394 a	3933	34538*a	25235	4.2*a	3.5
At risk	1792	19.6	8917 b	3483	39268 b	25881	4.9 b	3.5
Central obesity	3103	34.0	8440 c	3437	40662 b	27067	5.4 c	3.9
Currently diabetic[££]								
Yes	513	5.6	7843 *a	3314	40413	26312	5.7	3.9
No	8561	93.9	8795 b	3670	37512	25991	4.9	3.7
Dietary factors								
Usual daily vegetable intake								
<2 serve	2290	25.1	8751	3641	34162*a	25934	4.5*a	3.8

(continued on next page)

Table 1 (*continued*)

Characteristic/ category	N	c (%)	Energy intake (kJ)		Bitter score		Bitter density	
			Mean	SD	Mean	SD	Mean	SD
2-4 serves	4602	50.5	8653	3642	38168 b	24904	5.0 b	3.7
>4 serves	2226	24.4	8883	3693	40450 c	27865	5.2 b	3.8
Currently following a diet[£]								
Yes	1273	14.0	7671*a	3171	39370	24603	5.7	3.8
No	7836	85.9	8907 b	3699	37449	26226	4.8	3.7
Salt is added to food [£]								
yes	4465	49.0	8935	3621	40064*a	27065	5.1	3.8
no	4642	50.9	8543	3678	35495 b	24761	4.8	3.7

Abbreviations: c, proportion of the contribution of population within subgroups; n, proportion of population within subgroups; SD, standard deviation; SEIFA, socio-economic index of disadvantage for areas.

* Mean value is significantly different by characteristic category (Independent T-Test or one-way ANOVA: $P < .001$). [Alphabets] There are differences within subgroups, if letters are not same (Bonferroni post hoc: adjusted $P < .001$).

[£] Data were not available for some of respondents.

[££] There is a group of respondents with less than 1% of population.

2.3. *Nutrition characteristics of diet*

Nutritional characteristics included: energy and selected nutrients intake (g), including protein, fat, carbohydrate, dietary fiber, calcium, sodium, alcohol, caffeine and sugars [32,33]; percentage contribution of nutrients to total energy intake (%) for protein, fat, carbohydrate, dietary fiber, alcohol, and sugars [32]; and core food groups and subgroups (serves) including grains and cereals (whole grains/ high-fiber cereals and refined grains/ low-fiber cereals), vegetables (green/ brassica, orange, starchy, whole, other, legumes and vegetable juice), fruits (fresh/canned, dried, and fruit juice), dairy and alternatives (high-fat, medium-fat, and low-fat dairy), and meat and alternatives [34,35]. Discretionary foods and beverages, energy-dense and nutrient-poor items usually high in saturated fat, added sugars, or salt, and low in fiber and essential micronutrients [32], were identified using the NNPAS classification [36].

Foods were also re-classified into solid foods or beverages (liquids). Beverages were then subcategorized (g) into drinking water (tap and bottled water), tea/coffee, juices (fruit and vegetable juice), milk and milk substitutes (plain milk, flavored milk, plain milk substitutes, flavored milk substitutes), soft drinks and others (soft drink, electrolyte, energy and sport drinks, cordial, other prepared beverages, and foods consumed as beverages), and alcoholic beverages [37].

2.4. *Dietary Guideline Index for Adults (DGI-AD)*

To evaluate how the Australian diet complies with the dietary guidelines, the CSIRO Dietary Guideline Index for Adults (DGI-AD) was used [38]. The overall DGI-AD score comprises eleven scoring components: fruit, vegetables, cereals, whole grains and breads/cereals, meat and alternatives, dairy and alternatives, reduced fat dairy, water intake, healthy fats/oils, discretionary foods, and variety of diet. DGI-AD scores ranged from 0 to 100 where the higher scores reflected diets that were more consistent with the Australian dietary guidelines, therefore reflected a higher quality of diet [39]. More details of DGI-AD components and scoring methods are provided in Supplementary Table 2.

2.5. *Bitterness properties of diet*

To describe dietary bitterness, the total bitterness of foods and beverages consumed was calculated per individual on the day of recall (“bitter score”). The bitter score is related to the amount of food consumed and, therefore, to energy intake. Thus, a “bitter density” value was also calculated to control for energy intake. The following steps were taken to compute bitter score and bitter density values of the diet for each individual:

- Bitter score: for each food item consumed, the bitter score was calculated by multiplying the bitter taste intensity of the food (from Sensory Diet database, scored 0-100) by the amount consumed in grams (from NNPAS). Individual bitter scores were then summed across all foods consumed to estimate an individual’s overall (’total’) dietary bitter score.
- Bitter density: the bitter density was calculated by dividing the total dietary bitter score by total energy intake consumed (kJ).

2.6. *Foods driving the dietary bitterness*

To identify food items contributing to the overall dietary bitterness, the 3-digit codes of foods tested in the Sensory Diet database (n = 725) were filtered to include only those consumed by ≥2% of the sample, reflecting the acceptability of the food to Australians. The characteristics of these 3-digit groups were then summarized for consumers (who consumed that food, and not the population average), using the mean bitter score, portion size (the average amount of consumption [g]), and mean bitter taste intensity. Following this, the 3-digit groups were ranked by the bitter score and the top twenty 3-digit groups were selected as the items that contribute most to the dietary bitterness.

2.7. Statistical analysis

Statistical analyses were performed using IBM SPSS statistical software package (Version 28.0, Armonk, NY: IBM Corp). The significance threshold was set at $P < .001$ to reduce Type I error, given the large sample size (n > 300) and multiple comparisons.

Normality of total energy intake, bitter score, and bitter density was assessed using absolute skewness (<2) and absolute kurtosis (<7) criteria. All variables met these thresholds, and given the large sample size (n = 8975), their distributions were considered approximately normal in accordance with established guidelines [40], supporting the use of parametric statistics. Descriptive statistics (mean ± standard deviation [SD]) were then used for all variables across the overall sample and subgroups. Outliers were excluded using the outer fence method: values beyond the 25th percentile minus 3×interquartile range (IQR) or the 75th percentile plus 3×IQR were removed. All data were weighted for age, gender, and area of residency to reflect the demographic structure of the Australian population, using a variable provided in the NNPAS individual-level dataset.

Because the Sensory Diet database lacks taste profile data for alcoholic beverages, a sensitivity analysis was performed by removing energy from alcohol and recalculating the bitterness properties of diets to decide whether to retain or exclude energy from alcohol in the main analysis.

Diets were ranked by bitter score and divided into tertiles (lowest tertile = least bitter, middle = medium, highest tertile = most bitter) to assess differences in nutritional characteristics. The use of tertiles balances sufficient contrast in exposure with adequate sample size within each category, while avoiding arbitrary cut–points. Differences in the bitterness properties of diets and comparisons between the most and least bitter diets were tested using an independent samples t-test and one-way analysis of variance (ANOVA) with a Bonferroni post hoc test.

A multivariable linear regression model was fitted to examine the independent associations between sociodemographic, health, and dietary factors and dietary bitterness. All explanatory variables were entered simultaneously into the regression model based on prior theoretical considerations and evidence, rather than statistical significance in univariate analyses.

To ensure both statistical and practical relevance, only differences exceeding 10% that were statistically significant were considered meaningful and highlighted in the discussion of results.

3. Results

3.1. Characteristics of respondents included in this study

A total of 9341 Australian adults participated in the first phase of NNPAS, of whom 9115 were not pregnant or lactating. After removing outliers, a total of 8975 respondents were included in the analytical sample. To account for the complex AHS sampling design, analyses incorporated ABS survey weights. Weighted estimates represent the corresponding population distribution, as defined by Census data [41]. Therefore, the final (weighted) sample size of 9118 adults differed numerically from the unweighted sample size of 8975 (Fig. 1).

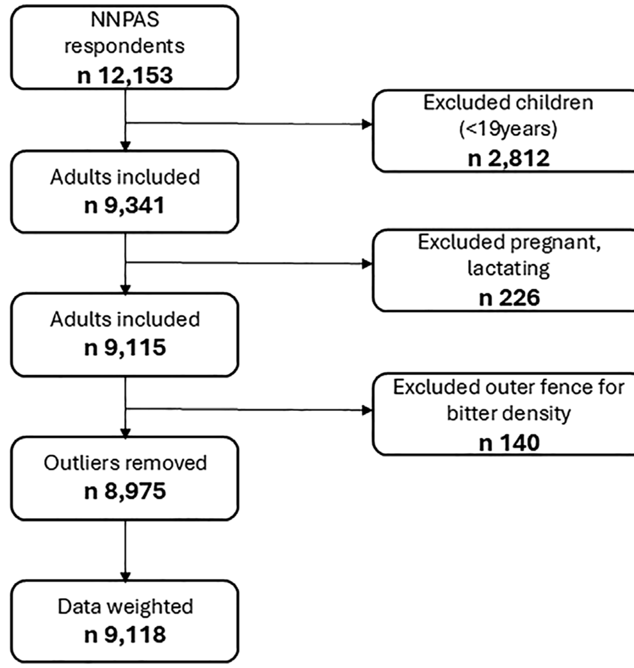

Fig. 1 – Participant selection for the secondary analysis of Australian adults from the 2011–2012 NNPAS. Of 9341 adults who completed the dietary component, pregnant or lactating participants and those with missing or implausible dietary intake data were excluded. After removing dietary outliers, the sample was weighted to reflect the corresponding population distribution. The final sample size of 9118 (weighted), derived from 8975 (unweighted), was included in the analysis; NNPAS: National Nutrition and Physical Activity Survey.

3.2. Characteristics associated with dietary bitterness

Sociodemographic, health, and dietary characteristics of the final sample are presented in Table 1. The total bitter score of diets ranged from 377 to 270,403, with a mean of 37,719 ± 26,008. Bitter density (bitter score per unit of energy intake) ranged from 1 to 22 (mean 5 ± 4).

Bitter scores differed significantly across sociodemographic, health, and dietary factors ($P < .001$). Bitter scores increased with age, with adults aged 50+ consuming diets with nearly double the bitter scores of those aged 19 to 30 (44,953 ± 28,231 *vs* 23,920 ± 18,516). Residents of regional and remote areas had bitter scores approximately 15% higher than those in major cities. No significant differences in bitter scores were found by physical activity level, diabetic status, or current dieting status ($P > .001$). Conversely, higher bitter scores (~ 7-15%) were observed among current smokers, overweight/obese individuals, and those with or at risk of central obesity. Higher vegetable intake was associated with higher bitter scores (40,450 ± 27,865 *vs* 34,162 ± 25,934 for>4 *vs* <2 serves/day). Similarly, individuals who added salt to food had higher bitter scores than those who did not (40,450 ± 27,865 *vs* 35,495 ± 24,761).

The bitter density metric, derived from both bitter score and energy intake, was influenced by either or both components. For age, weight, and central obesity status, higher bitter density resulted from lower energy intake and higher bitter scores. In contrast, for smoking status, regional residency, and vegetable intake, higher bitter density was primarily driven by higher bitter scores. Among females, individuals with lower education and lower physical activity levels had higher bitter density, mainly due to lower energy intake.

Overall, patterns in bitter score and bitter density were largely consistent across sociodemographic, health, and dietary factors. Therefore, the bitter score was used as the primary measure of the dietary bitterness in subsequent analyses.

When alcohol energy was removed, the results indicated no change in the patterns or significance of group differences in the bitterness properties of diets (Supplementary Table 1). Therefore, it was decided to retain the alcohol-derived energy in the main analysis.

3.3. *Characteristics of participants with the least and most bitter diets*

Diets were categorized into tertiles based on bitter score: least bitter (<23,098), medium (23,098 to 44,166), and most bitter (44,166<).

The demographic characteristics of individuals in the tertile groups differed; the most bitter diet group had a greater proportion of older adults aged 50+ (51.9% *vs* 28.6%), residents outside major cities (32.6% *vs* 26.5%), overweight individuals (35.1% *vs* 27.5%), and those with or at risk of central obesity (67.5% *vs* 56.3%) than those in the least bitter group (Table 3). This group also had more respondents consuming more than two serves of vegetables daily (79.0% *vs* 69.7%) and adding salt to food (53.4% *vs* 43.6%).

3.4. *Predictors of dietary bitterness*

Table 2 presents the association between population characteristics and dietary bitterness. The regression model was statistically significant, explaining 9% of the variance in dietary bitterness (F [14, 9102] = 62.57, $P < .001$), indicating that dietary bitterness is influenced by multiple population-level factors rather than a single dominant determinant. Age emerged as the strongest predictor ($\beta = 0.26$), suggesting that dietary bitterness increases markedly with age. Several other factors were also associated with dietary bitterness, though with smaller effect sizes; higher bitterness was associated with residing outside major cities, higher socioeconomic position, and higher usual vegetable intake, while lower bitterness was observed among current smokers and those with central obesity. Education level, gender, and salt addition to food showed modest but statistically significant associations. The Regression coefficients were interpreted in the context of the full multivariable model, with emphasis on overall patterns of association rather than isolated effect estimates. Collectively, these results indicate that dietary bitterness reflects a complex interplay of sociodemographic, health, and dietary factors, providing context for the subsequent exploration of diet quality.

Table 2 – The association between population characteristics and dietary bitterness. Data obtained from the National Nutrition and Physical Activity Survey, combined with the Sensory diet dataset, included 9118 (8975 unweighted) Australian adults.

Characteristic (reference)	B	SE	β
Sociodemographic			
Gender (male)	1703.4	532.3	0.03*
Age (19-30)	7193.9	293.7	0.26*
Country of birth (Australia)	491.3	585.6	0.01
Education (University degree)	−930.5	232.4	−0.04*
Area of residency (major cities)	2563.2	427.7	0.06*
SEIFA quintile (1st)	962.8	192.9	0.05*
Health factors			
Currently smoking (smoker)	−1300.1	174.9	−0.08*
Physical activity level (high)	−633.8	223.7	−0.03
Weight status (underweight)	1074.9	388.1	0.04
Central obesity status (no risk)	−629.4	128.1	−0.06*
Currently diabetic (yes)	771.1	486.6	0.02
Dietary factors			
Usual daily vegetable intake (low)	1964.2	375.6	0.05*
Currently following a diet (yes)	−750.5	640.4	−0.01
Salt is added to food (yes)	3097.6	471.3	0.07*
Adjusted R^2	0.09		

Abbreviations: SE, standard error; SEIFA, socio-economic index of disadvantage for areas.
All the factors were included in a multivariable linear regression model. No evidence of problematic multicollinearity was detected (all variance inflation factors [VIFs] < 5).
* Coefficient value is significantly different by characteristic category ($P < .001$).

3.5. *Nutritional profile of the most versus the least bitter diets*

Nutritional characteristics of the most and least bitter diet groups are presented in Table 4. When macronutrients were expressed as a percentage of total energy intake, the most bitter diets had a lower proportion of energy from carbohydrates (44.3 ± 11.5 *vs* 42.7 ± 10.3 percentage of energy; −3.8%) and a higher proportion from fat (30.2 ± 9.3 *vs* 31.6 ± 8.6 percentage of energy; +4.6%) and sugar (18.6 ± 9.4 *vs* 19.6 ± 8.3 percentage of energy; +5.8%) ($P < .001$ for all). Dietary fiber was also higher in the most bitter diets (2.1 ± 1.1 *vs* 2.4 ± 1.0 percentage of energy; +12.1) (Supplementary Fig. 2).

The most bitter diet group reported significantly higher absolute energy intake (9162 ± 3616 *vs* 8311 ± 3659 kJ; +10.2%, $P < .001$), and greater consumption of macronutrients: protein (+10.3%), fat (+14.6%), carbohydrate (+6.7%), sugar (+6.7%), and fiber (+20.3%) ($P < .001$ for all; Supplementary Fig. 3).

Calcium and sodium intakes were significantly higher in the most bitter diet group (+21.9% and +6.2%, respectively; $P < .001$). Caffeine intake was markedly higher (over five times greater) in the most bitter diet group (278.0 ± 180.5 *vs* 52.3 ± 68.1 mg; +431.5%, $P < .001$; Supplementary Fig. 2). No significant differences were observed in the intake of free/added sugars or alcohol. However, individuals in the most

Table 3 – Number of adults in different bitter diets included in this study. Data obtained from the National Nutrition and Physical Activity Survey, combined with the Sensory diet dataset, included 9118 (8975 unweighted) Australian adults.

Characteristic/category	Bitter diet							
	Least		Medium		Most		Whole sample	
	n	c (%)	n	c (%)	n	c (%)	n	c (%)
	3038	100.0	3041	100.0	3039	100.0	9118	100.0
Sociodemographic								
Gender								
Male	1628	53.6	1541	50.7	1463	48.1	4633	50.8
Female	1409	46.4	1499	49.3	1576	51.9	4485	49.2
Age								
19-30	1193	39.3	601	19.7	276	9.1	2070	22.7
31-50	975	32.1	1213	39.9	1186	39.0	3374	37.0
51-70	628	20.7	874	28.7	1164	38.3	2667	29.2
70+	241	7.9	354	11.6	413	13.6	1008	11.1
Country of birth								
Australia	2100	69.1	2041	67.1	2132	70.1	6273	68.8
Overseas	938	30.9	999	32.9	907	29.9	2845	31.2
Education[£]								
University degree	711	23.7	772	25.8	810	27.1	2294	25.2
Certificate/Diploma	1033	34.5	1117	37.3	1045	34.9	3195	35.0
School qualification	1252	41.8	1104	36.9	1135	38.0	3491	38.3
Area of residency								
Major cities	2246	74.0	2238	73.6	2049	67.4	6533	71.7
Inner regional	543	17.9	560	18.4	634	20.9	1737	19.1
Outer regional/Remote area	248	8.2	243	8.0	356	11.7	847	9.3
SEIFA quintile								
1st (most disadvantaged)	639	21.0	511	16.8	496	16.3	1646	18.1
2nd	621	20.4	591	19.4	606	19.9	1818	19.9
3rd	554	18.2	659	21.7	672	22.1	1886	20.7
4th	584	19.2	569	18.7	573	18.9	1726	18.9
5th	640	21.1	711	23.4	691	22.8	2043	22.4
Health factors								
Currently smoking								
Yes	523	17.2	546	18.0	549	18.1	1618	17.7
No	2515	82.8	2495	82.0	2490	81.9	7499	82.2
Physical activity level[£]								
High	463	15.4	481	16.0	438	14.6	1382	15.2
Moderate	791	26.4	859	28.6	891	29.7	2541	27.9
Low	1122	37.4	1022	34.0	1004	33.5	3149	34.5
Very low/Sedentary	622	20.7	644	21.4	667	22.2	1933	21.2
Weight status								
Underweight	65	2.1	48	1.6	29	1.0	142	1.6
Healthy weight	1039	34.2	892	29.3	867	28.5	2797	30.7
Overweight	835	27.5	998	32.8	1066	35.1	2899	31.8
Obese	1098	36.1	1104	36.3	1078	35.5	3279	36.0
Central obesity status[£]								
Not at risk	1126	43.7	959	36.7	860	32.5	2945	32.3
at risk	540	20.9	600	23.0	652	24.6	1792	19.6
Central obesity	912	35.4	1054	40.3	1137	42.9	3103	34.0
Currently diabetic[££]								
Yes	148	4.9	173	5.7	192	6.3	513	5.6
No	2886	95.1	2850	94.3	2825	93.7	8561	93.9
Dietary factors								
Usual daily vegetable intake								
<2 serve	922	30.4	731	24.0	637	21.0	2290	25.1
2-4 serves	1433	47.2	1576	51.8	1593	52.4	4602	50.5
>4 serves	683	22.5	734	24.1	809	26.6	2226	24.4

(continued on next page)

Table 3 (*continued*)

Characteristic/category	Bitter diet							
	Least		Medium		Most		Whole sample	
	n	c (%)	n	c (%)	n	c (%)	n	c (%)
Currently following a diet[£]								
Yes	357	11.8	467	15.4	449	14.8	1273	14.0
No	2678	88.2	2572	84.6	2586	85.2	7836	85.9
Salt is added to food[£]								
Yes	1321	43.6	1522	50.1	1622	53.4	4465	49.0
No	1711	56.4	1515	49.9	1416	46.6	4642	50.9

Abbreviations: c, proportion of the contribution of population within subgroups; n, proportion of population within subgroups; SD, standard deviation; SEIFA, socio-economic index of disadvantage for areas.
[£] Data were not available for some of respondents.
[££] There is a group of respondents with less than 1% of population.

Table 4 – Nutritional characteristics of the most versus the least bitter diets among Australian adults. Data obtained from the National Nutrition and Physical Activity Survey combined with Sensory diet dataset and included 9118 (8975 unweighted) Australian adults in whole sample and ~ 3039 in each tertile of diet by bitterness.

Characteristics	Bitter diet								
	Least		Medium		Most		Whole sample		%dif (%)
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Energy and nutrients intake (absolute)									
Energy (kj)	8311	3659	8728	3640	9162	3616	87334*	3655	**10.2****
Protein (g)	87.3	43.5	91.7	45.8	96.3	43.7	91.8*	44.5	**10.3****
Fat (g)	69.4	40.8	74	42.0	79.6	41.6	74.3*	41.7	**14.6****
Carbohydrate (g)	220.7	111.4	224.5	104.6	235.4	108.6	226.9*	108.4	**6.7**
Sugars (g)	95.4	65.2	102	63.3	102.3	67.9	99.9*	65.8	**6.7**
Free sugars[1] (g)	57	56.6	56.7	54.7	60.7	55.7	58.1	55.7	**6.5**
Added sugars[2] (g)	49.3	54.2	49.7	51.3	53.9	52.8	51.0	52.8	**9.3**
Dietary fibre (g)	20.7	12.1	23.3	12.0	25.0	12.3	23.0*	12.3	**20.3****
Alcohol (g)	13.4	30.4	16.4	33.1	14.8	29.3	14.9	31.0	**10.3**
Discretionary F&Bs (g)	1358.6	1432.0	1291.2	1297.4	1187.5	1157.0	1279.1*	1302.0	**−12.6****
Calcium (mg)	728	481	798	447	888	467	805*	470	**21.9****
Sodium (mg)	2378	1428	2450	1403	2524	1415	2451*	1417	**6.2**
Caffeine (mg)	52.3	68.1	144.2	101.2	278.0	180.5	158.2*	156.2	**431.5****
Contribution to total energy intake (percentage contribution to total energy intake)									
Protein	18.6	6.8	18.3	6.0	18.4	5.8	**18.4**	6.2	**−1.0**
Fat	30.2	9.3	30.8	8.7	31.6	8.6	**30.9***	8.9	**4.6**
Carbohydrate	44.3	11.5	43.1	11.0	42.7	10.3	**43.4***	11.0	**−3.8**
Sugars	18.6	9.4	19.1	9.3	19.6	8.3	19.1*	9.1	**5.8**
Free sugars[1]	10.7	8.8	10.2	8.5	10.2	7.5	10.3	8.3	**−4.8**
Added sugars[2]	9.2	8.4	8.9	8.0	9	7.2	9.0	7.9	**−2.1**
Dietary fibre	2.1	1.1	2.3	1.0	2.4	1.0	2.3*	1.0	**12.1****
Alcohol	4.2	9.0	4.9	8.9	4.4	8.1	4.5	8.7	**4.9**

Abbreviations: %dif, the percentage difference between the mean values of most versus least bitter diet groups; SD, standard deviation.
[1] Free sugars (WHO).
[2] Added sugars (FSANZ).
* Mean value is significantly different between the most bitter diet and the least bitter diet (ANOVA with Bonferroni correction: $P < .001$).
** Statistically significant difference greater than 10% is considered meaningful.

bitter diet group consumed fewer discretionary foods and beverages (1187.5 ± 1157.0 *vs* 1358.6 ± 1432.0 g; –12.6%).

3.6. *Beverage contribution to dietary bitterness*

Table 5 summarizes the contribution of solid foods and beverages to both energy intake and dietary bitterness. Solid foods contributed significantly more to total energy intake than beverages (83.2% *vs* 16.8%, $P < .001$); however, beverages contributed disproportionately to overall dietary bitterness, accounting for 91.4% compared to 8.6% from solid foods. This pattern was consistent across all tertiles of dietary bitterness, with the most bitter diet group showing an even greater contribution from beverages (94.6%) compared

Table 5 – Contribution of solid foods and beverages (liquid) in the bitterness and total energy intake by bitterness of diets among Australian adults. Data obtained from the National Nutrition and Physical Activity Survey combined with Sensory diet dataset and included 9118 (8975 unweighted) Australian adults in whole sample and ~ 3039 in each tertile of diet by bitterness.

	Bitter diet											
	Least			Medium			Most			Whole sample		
	Mean	SD	c (%)	Mean	SD	c (%)	Mean	SD	c (%)	Mean	SD	c (%)
Bitterness of diet												
Foods	2680.6	2063.4	20.3	3401.6	2405.2	10.3	3634.2	2479.3	5.4	3238.9*	2358.0	8.6
Beverages	10512.7	5752.2	79.7	29585.9	6525.3	89.7	63331.5	21890.2	94.6	34480.1*	25725.5	91.4
Food & Beverages	13193.3	5819.0	100.0	32987.5	6137.9	100.0	66965.7	21880.7	100.0	37719.0*	26008.4	100.0
Total energy intake												
Foods	6944.2	3169.6	83.6	7260.7	3169.2	83.2	7603.3	3174.7	83.0	7269.5*	3182.2	83.2
Beverages	1366.6	1522.4	16.4	1467.7	1437.6	16.8	1558.4	1384.7	17.0	1464.2*	1451.3	16.8
Food & Beverages	8310.7	3659.3	100.0	8728.4	3640.4	100.0	9161.7	3616.4	100.0	8733.7*	3654.9	100.0

Abbreviations: c, proportion of the contribution of foods or beverages in the bitterness/total energy of diet; SD, standard deviation.

* Mean value is significantly different between the most bitter diet and the least bitter diet (ANOVA with Bonferroni correction: $P < \cdot 001$).

Table 6 – Beverage consumption in the most versus the least bitter diets among Australian adults. Data obtained from the National Nutrition and Physical Activity Survey combined with Sensory diet dataset and included 9118 (8975 unweighted) Australian adults in whole sample and ~ 3039 in each tertile of diet by bitterness.

Beverage	Bitter diet								
	Least		Medium		Most		Whole sample		%dif (%)
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Drinking water	2167.5	1860.1	2337.6	1931.0	2151.7	2007.0	2218.9	1935.2	**2.4**
Tea/coffee	192.8	274.0	672.3	392.1	1363.4	656.2	742.9*	671.3	**285.4****
Juice (fruit/vegetable)	218.5	366.8	192.1	347.3	176.1	349.5	195.6*	355.0	**−10.5****
Milk and milk substitutes	253.0	404.4	258.9	424.2	289.9	386.5	267.2*	405.6	**5.6**
Soft drinks and others	515.5	762.0	430.6	672.9	350.5	594.4	432.2*	683.1	**−16.2****
Alcoholic beverages	399.4	942.4	413.6	868.7	361.6	742.4	391.5	855.3	**−2.0**

Abbreviations: %dif, the percent of difference between the mean values of most bitter diet compared to the least bitter diet; SD, standard deviation.

* Mean value of total bitter score is significantly different between the most bitter diet and the least bitter diet (ANOVA with Bonferroni correction: $P < \cdot 001$).

** Statistically significant difference greater than 10% is considered meaningful.

to the least bitter group (79.7%, $P < .001$; Supplementary Fig. 4).

Table 6 and Supplementary Fig. 4 present the types of beverages consumed and their contribution to dietary bitterness. The most bitter diet group consumed significantly more tea and coffee; over seven times more than those in the least bitter group (1363.4 ± 656.2 *vs* 192.8 ± 274.0 g; +285.4%, $P < .001$). Milk and milk substitute intake was also higher in the most bitter group (289.9 ± 386.5 *vs* 253.0 ± 404.4 g; +5.6%, $P < .001$), aligning with the higher calcium and caffeine intakes observed in this group.

Conversely, the most bitter diet group reported lower consumption of fruit/vegetable juices (–10.5%) and soft drinks/other beverages (–16.2%) compared to the least bitter group ($P < .001$ for both). No significant differences were found in the intake of drinking water or alcoholic beverages between groups.

3.7. *Core food group intake in the most versus the least bitter diets*

Table 7 and Supplementary Fig. 6 present the intake of core food groups among individuals in the most and least bitter diet groups.

No significant differences were observed in total grain and cereal consumption. However, the most bitter diet group reported higher intake of whole grains/high-fiber cereals (+36.2%) and lower intake of refined grains/low-fiber cereals (–18.0%) compared to the least bitter group ($P < .001$ for both).

Table 7 – Core food groups (and subgroups) consumption (serves) in the most versus the least bitter diets among Australian adults. Data obtained from the National Nutrition and Physical Activity Survey combined with sensory dataset and included 9118 (8975 unweighted) Australian adults in whole sample and ~ 3039 in each tertile of diet by bitterness.

Characteristics	Bitter diet								
	Least		Medium		Most		Whole sample		%dif (%)
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Grains and cereals[#]	4.6	3.4	4.6	3.1	4.5	2.9	4.5	3.1	**−1.8**
Whole grains/ high-fibre cereals	1.4	1.9	1.7	1.9	1.9	2.0	1.6*	2.0	**36.2******
Refined grains/ low-fibre cereals	3.2	3.0	2.9	2.8	2.6	2.6	2.9*	2.8	**−18.0******
Vegetables and legumes[#]	2.6	2.6	3.1	2.9	3.4	3.0	3.0*	2.9	**30.2******
Green/brassica vegetables	0.6	0.8	0.7	0.9	0.7	0.9	0.6*	0.9	**26.9******
Orange vegetables	0.3	0.7	0.4	0.7	0.4	0.8	0.4*	0.7	**34.9******
Starchy vegetables	0.5	1.1	0.6	1.3	0.8	1.4	0.6*	1.3	**53.6******
Whole vegetable	1.1	1.3	1.2	1.4	1.3	1.4	1.2*	1.4	**16.6******
Other vegetables	1.0	1.3	1.2	1.6	1.3	1.6	1.2*	1.5	**21.5******
Legumes as vegetables	0.2	0.8	0.2	0.8	0.2	0.9	0.2	0.9	**16.1**
Vegetable juice	0.7	0.3	0.7	0.3	0.8	0.4	0.7*	0.3	**18.0******
Fruits[#]	1.4	1.8	1.5	1.9	1.6	1.8	1.5*	1.8	**16.0******
Fresh/canned fruit	0.8	1.2	1.0	1.3	1.1	1.3	0.9*	1.3	**33.9******
Dried fruit	0.1	0.4	0.2	0.7	0.2	0.7	0.2*	0.6	**104.9******
Fruit juice	0.5	1.2	0.4	1.1	0.3	0.9	0.4*	1.1	**−34.6******
Dairy and alternatives[#]	1.2	1.3	1.4	1.2	1.7	1.3	1.4*	1.3	**33.7******
High-fat dairy	0.4	0.6	0.4	0.7	0.4	0.7	0.4	0.7	**10.9**
Medium-fat dairy	0.5	0.9	0.5	0.8	0.7	1.0	0.6*	0.9	**34.1******
Low-fat dairy	0.4	0.8	0.4	0.7	0.6	0.8	0.5*	0.8	**57.2******
Meat, poultry, and alternatives[#]	2.2	1.9	2.3	2.0	2.3	2.0	2.2	2.0	**7.1**

[#] According to Australian Dietary Guidelines, the recommended average number of standard serves per day for Australian adults is: 3-6 for grains and cereals, 5-6 for vegetables and legumes, 2 for fruits, 2.5-4 for dairy and alternatives, and 2-3 for meats, poultries, and alternatives.SD, standard deviation; %dif, the percent of difference between the mean values of most bitter diet compared to the least bitter diet.

* Mean value of total bitter score is significantly different between the most bitter diet and the least bitter diet (ANOVA with Bonferroni correction: $P < \cdot 001$).

** Statistically significant difference greater than 10% is considered meaningful.

The most bitter diet group consumed significantly more vegetables and legumes (3.4 ± 3.0 *vs* 2.6 ± 2.3 serves; +30.2%, $P < .001$), with greater consumption across all vegetable subgroups except legumes. Notable differences included green/brassica vegetables (+26.9%), orange vegetables (+34.9%), starchy vegetables (+53.6%), whole vegetables (+16.1%), other vegetables (+21.5%), and vegetable juice (+18.0%) ($P < .001$ for all).

Fruit intake was also higher in the most bitter diet group (1.6 ± 1.8 *vs* 1.4 ± 1.8 serves; +16.0%, $P < .001$), particularly for fresh/canned fruits (+33.9%) and dried fruits (+104.9%).

Dairy and dairy alternative intake was greater in the most bitter diet group (1.7 ± 1.3 *vs* 1.2 ± 1.3 serves; +33.7%, $P < .001$), driven by higher consumption of medium-fat (+34.1%) and lower-fat (+57.2%) dairy products, with no difference in high-fat dairy intake.

No significant differences were found in meat, poultry, and alternative consumption between the groups (2.2 ± 1.9 *vs* 2.3 ± 2.0 serves; $P > .05$).

3.8. *The ADG-AD scores for the most versus the least bitter diets*

Overall, the ADG-AD score for Australian adults was 43.4 ± 17.7. The most bitter diet group had a higher score than the least bitter diet group (44.3 ± 17.2 versus 41.4 ± 17.9, $P < .001$). While this difference of ~ 3 points (out of 100) is statistically significant, it would not be considered meaningful (Supplementary Fig. 7).

3.9. *Foods contributing to dietary bitterness*

Coffee and coffee substitutes, and tea were the largest contributors to dietary bitterness, with their impact more pronounced in the most bitter diet group (Supplementary Tables 4 & 5).

Other notable contributors included municipal and bottled unflavored water, soft drinks and flavored mineral waters, fruit and vegetable juices, and brassica vegetables such as cabbage and cauliflower. These items were not only inherently bitter but also consumed in large quantities.

Some items, while not highly bitter themselves, contributed to overall bitterness due to high consumption volumes. Examples include unflavored dairy milk substitutes, pome fruits, vegetable-based dishes, and cake-type desserts in the most and least bitter tertiles; citrus fruits in the most bitter group; and mixed meat dishes in the least bitter group.

Conversely, some bitter items, such as pickles, chutneys, and relishes, chocolate and chocolate-based confectionery, and nuts and seeds, contributed less to dietary bitterness due to their relatively low consumption.

4. Discussion

This study examined dietary bitterness among Australian adults, with some variation across sociodemographic, health, and dietary factors observed. Older adults consumed significantly more bitter diets. The most bitter diets were nearly five times as bitter as the least bitter diets and were linked to higher nutritional quality (e.g., higher dietary fiber and vegetable intake and lower soft drink consumption), thereby confirming our hypothesis. Highly bitter foods consumed in large quantities (e.g., coffee, tea, and vegetable dishes) were the main contributors to overall dietary bitterness. In contrast, intensely bitter foods (e.g., pickles and olives) contributed less because smaller portions were consumed.

Research on dietary bitterness and its links to diet quality and health has been limited and inconsistent due to methodological variation. Most studies identify clusters of highly bitter foods and assess their intake patterns (variety, frequency, or energy contribution) [18–21], overlooking moderately bitter foods consumed in larger quantities. Teo et al. broadened this approach by examining bitterness intensity across all foods, though they did not account for consumption quantity [16]. The current study addressed these limitations by calculating a total bitter score (grams consumed × bitterness intensity) [42,43]. This approach provides a more comprehensive quantification of dietary bitterness and offers advantages over intensity-only measures.

Age emerged as the strongest predictor of dietary bitterness, suggesting that exposure to bitter–tasting foods increases across adulthood. Older adults, aged 50+, reported bitterness scores nearly twice as high as those aged 19-30. This may be associated with age-related declines in bitter taste sensitivity that may increase tolerance and preference for bitter foods [44]. Previous research among Australian adults has similarly reported higher tea and coffee consumption in older individuals [37]. Age has been suggested to influence the bitter taste sensitivity phenotype determined by the bitter taste receptor genotype, with younger individuals more likely to carry the sensitive allele and older individuals less likely to do so [44,45]. Additionally, ageing is linked to reduced taste perception due to a decline in taste receptors and sensory cell function, affecting both taste detection and neurotransmission [46]. It should be noted that the regression findings suggest that dietary bitterness reflects a complex interplay among sociodemographic, health, and dietary factors, with age playing a prominent but not exclusive role. This highlights that bitter taste exposure is a composite dietary behavior rather than a single indicator of health.

Despite evidence that women have greater bitter taste sensitivity [47,48], no gender differences in dietary bitterness were observed. Reports of higher consumption of bitter foods such as coffee among women [49,50] suggest that taste sensitivity does not necessarily limit intake, and that learned preferences and repeated exposure may override innate sensitivity.

Given Australia's ethnic diversity [51], this study explored potential ethnic differences by using the "country of birth" reported in NNPAS. Although sensory studies show that bitter taste sensitivity is higher in Asians [52] and lower in Africans [53], compared to Caucasians, no significant differences in dietary bitterness were observed between Australian-born and overseas-born participants. This may reflect cultural acquisition [54] or limitations in using the birthplace to represent household dietary patterns.

Socio-economic status is often associated with dietary habits, with more socioeconomically disadvantaged groups generally having less healthy patterns [55], and a higher household income being linked to increased bitter food intake [56]. However, this study found no difference in diet bitterness based on socio-economic position, as measured by SEIFA, an area-level indicator of disadvantage. This aligns with previous Australian findings showing no clear association between vegetable intake and socio-economic status [57]. Additionally, while higher education is often associated with a greater preference for bitter tastes [56,58], no such link was found in this study. Interestingly, residents in regional and remote areas tended to have more bitter diets than those in major cities, possibly due to the older average age in these regions [59].

Individuals with obesity and central obesity had more bitter diets than those with a healthy weight or WC, possibly due to reduced bitter taste sensitivity associated with obesity [60,61]. This may lead to compensatory increases in bitter food consumption. For example, replacing sugary drinks with coffee or tea has been linked to modest improvements in BMI (-0.1 kg/m^2) and WC (-0.3 cm) [62]. Current smokers also had more bitter diets, consistent with evidence of reduced bitter taste sensitivity from smoking-induced changes in the fungiform papillae [63–65]. No significant difference in dietary bitterness was observed between those with and without diabetes, despite taste impairments being common in diabetes [66]. This may be because diabetes-related taste changes primarily affect sweet, salty, and sour tastes, not bitter [67,68]. Importantly, individuals may simultaneously engage in both health–promoting dietary behaviors and adverse lifestyle behaviors, underscoring the complexity of interpreting dietary bitterness as a singular marker of health.

Australians consuming two or more serves of vegetables each day reported greater diet bitterness, probably reflecting not only vegetable consumption but also higher intake of other bitter foods, such as coffee and tea. Repeated exposure to bitter tastes can boost preference for bitter foods, regardless of individual sensitivity [69].

A surprising finding was that sodium intake did not differ between the most and least bitter diet groups, despite individuals in the more bitter diet group being more likely to add salt at the table. This discrepancy may stem from the sodium data reflecting pre-consumption food content, while salt-use habits were captured separately in this study. Since salt is traditionally used to mask bitterness [70], those who season their food may perceive bitter foods as less intense, enabling greater consumption. However, most research on salt's masking effects focuses on taste perception, with limited understanding of its impact on post-ingestion detection of bitter compounds. Given that individuals in the most bitter diet group were more likely to add salt to food and had a higher risk of central obesity, behaviors linked to cardiometabolic disease, future research should examine whether bitter taste is independently associated with chronic disease outcomes after adjusting for overall dietary quality.

In this study, although individuals with the most bitter diets consumed more total energy, protein, and fat, their macronutrient distribution as a percentage of energy fell within the recommended ranges [34]. Higher consumption of vegetables was associated with higher dietary bitterness, reflecting the bitterness of vegetables as well as higher consumption of coffee, tea and other bitter foods in this group [69]. The most bitter diets also had higher levels of calcium intake, likely due to greater consumption of lower-fat dairy products. This finding aligns with sensory research indicating that calcium, found in dairy foods and vegetables, contributes to bitterness [71,72], and evidence linking higher calcium intake to healthier dietary patterns among Australians [73]. Fiber intake was also higher in the most bitter diet group, primarily from whole grains and high-fiber cereals [74], which are known to impart bitterness [75]. Increased fiber intake is associated with significant health benefits, including a reduced risk of T2DM and obesity [76].

Individuals with the most bitter diets reported higher intakes of whole grains/high-fiber cereals, vegetables, fresh/canned fruits, and low-fat dairy and dairy alternatives, which are key components of a healthy diet [35,77,78]. Notably, vegetable intake was nearly one serve higher (3.4 *vs* 2.6), which is linked to better weight outcomes [31,79]. Higher intake of wholegrain/ high-fiber cereals [80–82] and dairy content [83,84] also reflects better diet quality and closer adherence to dietary guidelines. However, the most bitter diets only scored slightly higher on the DGI-AD than the least bitter diets. This may be attributed to the way the DGI-AD evaluates compliance with the Australian dietary guideline, in which vegetable, fruit, grain, and dairy product consumption are only four of eleven components [39]. Additionally, although the most bitter diets were closer to the recommended amounts than the least bitter diets, these differences may not have been sufficient to produce a substantial difference in DGI-AD score. Increasing dietary bitterness may therefore support healthier eating patterns, especially important given that most Australians fall short of recommended serves for major food groups [34].

Beverages (liquids) made a greater contribution to dietary bitterness than solid foods (91.4% *vs* 8.6%), which was more pronounced in the most bitter diets. This may be because liquids are consumed more quickly, reducing oral exposure time and taste intensity, which makes bitter drinks more palatable [85,86]. Additionally, beverages tend to produce weaker satiety signals compared to solid foods, leading to higher consumption [85]. It should be noted that higher consumption of bitter solid foods, such as brassica vegetables, also contributed to the dietary bitterness, albeit slightly.

Beverage choices varied significantly, with the most bitter diet group consuming seven times as much tea and coffee, less fruit and vegetable juice and fewer soft drinks [35]. Caffeine intake was five times higher in the most bitter diets. Caffeine is the primary source of bitterness in coffee and tea [87] and serves as the benchmark for bitterness in sensory studies [88]. This is consistent with findings by Teo et al., who demonstrated that removing coffee and tea markedly reduced overall dietary bitterness [16]. Furthermore, extensive research links coffee [89–90] and tea [91] consumption with various health benefits, including anti-cancer, anti-obesity, anti-atherosclerotic, and anti-diabetic effects.

Given the healthier nutritional profile of the most bitter diets, encouraging the consumption of more bitter foods may benefit Australian adults. However, practical guidance is needed on how to achieve this. Previous research has focused primarily on bitterness intensity [18–21], whereas this study highlights the combined importance of intensity and consumption volume. Foods that are highly bitter but consumed in small amounts (e.g., olives, nuts, seeds) contributed little to overall dietary bitterness, while moderately bitter foods consumed in larger quantities (e.g., pome fruits, vegetable dishes) had a greater impact. The main contributors were foods that are both highly bitter and consumed in substantial amounts, such as coffee, tea, mineral water, and brassica vegetables. This is the first study to demonstrate that both bitterness intensity and quantity shape dietary bitterness, which might help inform advice for those with a preference for moderately bitter foods rather than intensely bitter options.

A key strength of this study was the use of nationally representative data from the NNPAS, combined with the CSIRO Sensory Diet database, which provides objective bitterness ratings from a trained sensory panel, considered the gold standard in sensory science [24]. This allowed for a comprehensive and generalizable assessment of dietary bitterness across a large sample of the Australian population. The study also examined a wide range of social, health, and nutritional factors using multiple statistical approaches, with consistent findings that strengthen confidence in the results.

Several limitations should be acknowledged. The cross–sectional design precludes causal inference, and the observed associations likely reflect complex, multifactorial relationships shaped by demographic, behavioral, and metabolic factors. Accordingly, exposure to bitter taste may represent overlapping dietary and lifestyle pathways rather than a single marker of health, and the findings should be interpreted as exploratory. This study relied on a single 24–hour dietary recall, which does not capture usual intake and is subject to recall bias, despite the use of standardized protocols and trained interviewers. As such, findings are most applicable at the group level and should be interpreted with caution. While misreporting was statistically managed by removing outliers, this still represents a limitation. Data on the bitterness of alcoholic beverages were unavailable and therefore were not included in the overall bitterness estimates. Although a sensitivity analysis was performed excluding energy from alcohol, this limitation should be considered when interpreting results. A key limitation of this study is the use of data from the 2011 to 2012 NNPAS, which was the most recent version at the time of analysis. Recently, the newer 2023-2024 data have become available. Given changes in the food environment over time, including the increased availability and consumption of ultra-processed foods, contemporary diet quality may have shifted. Although the fundamental relationships between taste perception, demographics, and food preferences are unlikely to have changed substantially, the generalizability of our findings to current dietary behaviors should be interpreted with caution. Therefore, replication of this study using more recent nationally representative dietary datasets and further investigation of the relationship between ultra-processed food consumption and diet bitterness are required to explore the potential influence of ongoing changes in the food system.

5. Conclusion

This study demonstrated that dietary bitterness varied with individual characteristics and was linked to certain markers of healthier eating patterns among Australian adults. Beverages (particularly coffee and tea) were the main contributors to dietary bitterness. More bitter diets contained more vegetables, whole grains, and low-fat dairy, and lower consumption of refined cereals, juices, and discretionary foods.

These findings suggest that promoting bitter diets aligns with healthy eating messages. The concept of "bitter is better" may resonate with consumers and serve as a simple guide to healthier food choices. However, given the concurrent associations between diet bitterness with smoking and obesity, such patterns should be interpreted within a broader behavioral and health context when formulating public health recommendations. These recommendations should also be tailored to individual characteristics and focus on accessible bitter foods consumed in meaningful amounts, rather than only on intensely bitter foods that are rarely consumed. The findings describe overall dietary patterns rather than endorsing the consumption of commercial products, particularly alcoholic beverages, which were excluded from this analysis. Future research should examine whether interventions that increase dietary bitterness can improve long-term diet quality and health outcomes.

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During the preparation of this work, the author(s) used Grammarly for grammar checking. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the published article.

Author declarations

None.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.nutres.2026.07.001.

CRediT authorship contribution statement

Zinat Mohammadpour: Writing – original draft, Visualization, Validation, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Paige G. Brooker:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization. **Gilly A. Hendrie:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization. **Leonie K. Heilbronn:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Amanda J. Page:** Writing – review & editing, Supervision, Methodology, Conceptualization.

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