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Tree nut snack consumption is associated with better diet quality and cardiovascular disease risk in the UK adult population: National Diet and Nutrition Survey (NDNS) 2008-2014.

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Abbreviation

ANCOVA	Analysis of covariance
BMI	Body Mass Index
COMA	Committee on Medical Aspects of Food Policy
CRP	C-reactive protein
CVD	Cardiovascular disease
DBP	Diastolic blood pressure
DRV	Dietary Reference Value
EAR	Estimated Average Reference
ECI	Eating Choice Index
GLM	Generalised linear model
HDL-C	High density lipoprotein
HDS	Healthy diet score
IQR	Interquartile range
LDL-C	Low density lipoprotein
MDS	Mediterranean Diet Score
MUFA	Monounsaturated fatty acids
NDNS	National Diet and Nutrition Survey
NDNS-RP	National Diet and Nutrition Survey - Rolling Programme
NHANES	National Health and Nutrition Examination Survey
PUFA	Polyunsaturated fatty acids
RNI	Reference Nutrition Intake
SBP	Systolic blood pressure
SD	Standard deviation
SFA	Saturated fats
SI	Safe Intake
TAG	Triglycerides
TC	Total cholesterol
TNS	Tree nut snacks
TNS-A	Any amount of tree nut snacks
TNS-B	≥7.08 g tree nut snacks (equivalent to ¼ oz)
WC	Waist circumference

Abstract

Objectives: To examine associations of tree nut snack (TNS) consumption with diet quality and cardiovascular disease (CVD) risk in UK adults from National Diet and Nutrition Survey (NDNS) 2008-2014.

Design: Cross-sectional analysis using data from 4-d food diaries, blood samples and physical measurements for CVD risk markers. To estimate diet quality, modified Mediterranean Diet Score (MDS) and modified Healthy Diet Score (HDS) were applied. Associations of TNS consumption with diet quality and markers of CVD risk were investigated using survey-adjusted multivariable linear regression adjusted for sex, age, ethnicity, socio-economic and smoking status, region of residency and total energy and alcohol intake.

Setting: UK free-living population.

Subjects: 4,738 adults (≥19y).

Results: TNS consumers had higher modified MDS and HDS relative to non-consumers. TNS consumers also had lower BMI, WC, SBP and DBP and higher HDL compared to non-consumers, although a dose-related fully adjusted significant association between increasing nut intake (g per 1000 kcal energy intake) and lower marker of CVD risk was only observed for SBP. TNS consumption was also associated with higher intake of total fat, mono-, n-3 and n-6 polyunsaturated fatty acids, fibre, vitamin A, thiamin, folate, vitamin C, vitamin E, potassium, magnesium, phosphorus, selenium and iron; and lower intake of saturated fatty acids, *trans* fatty acids, total carbohydrate, starch, free sugar, sodium and chloride.

Conclusions: TNS consumers report better dietary quality and consumption was associated with lower CVD risk factors. Encouraging replacement of less healthy snacks with TNS should be encouraged as part of general dietary guidelines.

Keywords: nuts, cross-sectional analysis, diet quality, cardiovascular disease, nutrients

1. Introduction

An average of 2.55 snacks per day are consumed in the UK and Ireland, with over a third of these snacks being confectionary or crisps/popcorn/nuts(1). Nuts are a popular snack as shown by the growing trend for consuming tree nuts over the past ten years(2). North America was the region with the highest production; however, it was Europe that was the largest consumer in the world. Almonds (*Prunusdulcis*), walnuts (*Juglansregia*), pecans (*Caryaillinoinensis*), pine nuts (*Pinuspinea*), cashews (*Anacardiumoccidentale*), macadamia nuts (*Macadamia*), hazelnuts (*Corylusavelana*), pistachios (*Pistaciavera*), Brazil nuts (*Bertholletiaexcelsa*) and chestnuts (*Castanea*) are examples of edible tree nuts that are produced commercially(2).

Almonds, walnuts, pecans, pine nuts, cashews, macadamia nuts, hazelnuts, pistachios and Brazil nuts differ to some extent in their nutrient profiles. However, tree nuts are generally energy-dense, with a high proportion of fat made up of unsaturated fatty acids; low in sodium; and rich in plant-based protein, dietary fibre, and micronutrients, including niacin, vitamin B6, vitamin E, vitamin K, folic acid, calcium, magnesium, potassium, selenium, phosphorus and zinc. Tree nuts are also rich in phytosterols and (poly)phenols, which promote antioxidant and anti-inflammatory pathways(3-5). Because of these properties, tree nuts and health outcomes have been the focus of many human clinical trials and observational studies.

Previous dietary intervention studies showed that tree nut consumption resulted in lowered type-2 diabetes and cardiovascular disease risk factors. Walnut, almond, pistachio, macadamia, cashew and hazelnut consumption favourably modified blood lipid profile(6-15), mixed nuts improved insulin sensitivity(14), and walnuts lowered inflammatory markers(16) and improved endothelium-dependent vasodilation(17), all of which would be predicted to reduce the risk of CVD. Furthermore, contrary to popular perception, nut-enriched diets are not linked with increased risk of weight gain(18) and tree nut consumption has been shown to assist weight loss as part of an energy-restricted diet in obese or overweight subjects(19).

Cross-sectional analysis of tree nut consumption and indicators of diet quality and cardiovascular health have also been undertaken. In the US adult population (≥19 y), using the National Health and Nutrition Examination Survey (NHANES) 2005-2010 database (n=14,386) based on 24-h dietary recalls, it was reported that tree nut consumption was linked to lower body mass index (BMI), waist circumference (WC), systolic blood pressure (SBP),and insulin resistance index (HOMA-IR) and higher high-density lipoprotein (HDL-C) adjusted for age, sex, ethnicity, poverty index ratio, physical activity level, smoking status and alcohol intake(20). O'Neil *et al.* (2015) also showed that tree nut consumers, compared to non-consumers, had significantly higher diet quality scores (HEI-2005, a diet quality score widely used in the USA) and greater nutrient adequacy for dietary fibre, vitamin A, vitamin E, vitamin C, folate, calcium, iron, magnesium, zinc and potassium(21).

The purpose of the present study was to examine associations between tree nut snack (TNS) consumption and diet quality, dietary patterns, as well as CVD risk markers, in a nationally representative UK adult population, using data from the UK National Diet and Nutrition Survey (NDNS) rolling programme 2008-2014. Dietary data were derived from estimated 4-d food diaries in a population of 4,738 adults (≥19y)(22,23), which differs from the NHANES analysis 2005-2010, which was based on two multiple pass 24-h dietary recalls in a larger population of 14,386 adults(21). The hypothesis of this study was that greater tree nut snack (TNS) consumption would be associated with higher diet quality, healthier dietary patterns, greater nutrient adequacy, and lower prevalence of CVD risk markers in UK adults.

2. Materials and Methods

2.1. The National Diet and Nutrition Survey Rolling Programme (NDNS-RP) and study population

The NDNS-RP is a long-running government-funded scheme to assess diet, nutrient intake and nutritional status of the general population (>1.5y) living in private households in the UK (England, Scotland, Wales and North Ireland)(22,23). Random sampling was carried out on addresses throughout the UK. A single address could have multiple households and a household in an address was selected randomly. An adult in the household was also randomly selected. Selected participants were requested to complete a 4-d estimated food diary, interviewed to collect information, such as dietary habits, socio-demographic background and lifestyle as well as anthropometrically measured and blood sample taken(22,23).

The survey involves two stages: 1) interview visits to collect information on socio-demography, administer the 4-d food diaries, and carry out anthropometric measurements, and 2) a nurse visit to do further physical measurements and collect blood and 24-h urine samples(22,23). Following venepuncture, an EDTA and a serum gel monovette tube from each participant’s sample set were sent by post, to the Immunology and Biochemistry Laboratory at Addenbrooke’s Hospital in Cambridge for prompt analysis. The remaining samples (lithium heparin, serum or fluoride blood monovette tubes) were processed and stored below -40° C (or at a maximum of -20° C where -40° C facilities were not available), before being transported on dry ice to the Human Nutrition Research (HNR) facility for analysis. The cross-sectional analysis reported here included data from adult participants (≥19y, n=4,738), who completed a 4-d estimated food diary in the NDNS-RP 2008-2014 (Year 1-6)(22,23).

2.2. Cardiovascular disease risk markers

Body mass index (BMI; kg/m^2), waist circumference (WC; cm), systolic blood pressure (SBP; mmHg), diastolic blood pressure (DBP; mmHg), total cholesterol (TC; mmol/l), triglycerides (TAG; mmol/l), high density lipoprotein (HDL-C; mmol/l), low density lipoprotein (LDL-C; mmol/l), TC:HDL-C (the ratio of TC and HDL-C) and C-reactive protein (CRP; mg/l) were CVD risk markers included in the analysis. Interviewer measurement protocols and procedures for blood sample collection, processing, analysis and quality controls are detailed elsewhere(22,23). Body height and weight were measured using a portable stadiometer and a weight scale, and BMI was calculated by fieldworkers. Waist circumference measurement was taken using a tape measure. The discrepancy tolerances of repeat measurement readings were not detailed in the NDNS method protocols. Omron HEM907, an automated validated monitor, was used to measure blood pressure in a sitting position after a five-minute rest. Trained fieldworkers took blood pressure measurements three times and results were presented based on the mean value of second and third readings with one-minute intervals(22,23).

2.3. Diet quality indices

To estimate diet quality, two existing diet scores were used: the Mediterranean Diet Score (MDS)(24) and Healthy Diet Score (HDS)(25). Maynard *et al.* (2004) developed HDS based on Healthy Diet Indicator (HDI) and the UK guidelines at that point in time, as recommended by the Committee on Medical Aspects of Food Policy (COMA)(25). Modifications were applied to HDS for this study to reflect UK current recommendations(22,26-30), and nuts were removed from the MDS scoring system as appropriate for this study on diet and health associations with nut consumption. The potential top score of the modified MDS remained the same: 9, but the modified HDS had a potential top score of 14 while the original HDS scoring range was 0-12 (see Table A2 in Appendices). Table A1 and A2 in Appendices show original and modified items of MDS and HDS items respectively.

2.4. Statistical analysis

Prior to statistical analysis, TNS intake was defined and determined. TNS consumption was defined as: 1) any amount of consumption, or 2) ≥7.08 g (¼ oz) of TNS. The ≥7.08 g (¼ oz) cut-off was adopted to facilitate comparisons with previous cross-sectional analysis of associations between tree nut consumption and dietary scores/nutrient adequacy in a US adult population(21). Data on tree nut snack consumption were isolated from the database prior to statistical analysis and total tree nut snack intakes calculated. Tree nuts included were almonds, walnuts, pecans, pine nuts, cashews, macadamia nuts, hazelnuts, pistachios, Brazil nuts and chestnuts. Although the US Food and Drug Administration recognizes coconuts as a tree nut, they were excluded since they are fruits of palm trees and not commonly consumed whole as a snack food. Peanuts were also excluded since they are classified as legumes.

Statistical analysis was carried out using SPSS IBM 23 and a two-sided *P*-value of 0.05 was considered statistically significant. Data are presented as adjusted means (95% CI) for individual nutrient intakes, total diet quality scores as well as levels of CVD risk markers, and as medians (with IQRs) for the amount of TNS consumed and age. To examine whether there was a statistically significant association between tree nut consumption and alcohol and total energy intakes as well as demographic variables, i.e. age, sex, ethnicity, socio-economic and smoking status and region of residency, survey-adjusted GLM with a binary logistic link function was used. Survey-adjusted GLM with a linear link function (predictors: age, sex, ethnicity, socio-economic and smoking status, region of residency, total energy and alcohol intake) was used to examine whether there were significant differences between TNS consumers and non-consumers in their diet quality scores, nutrient intakes and CVD risk markers. To investigate dose-response associations between TNS consumption (g/1000 kcal energy intake) and diet quality and CVD risk markers, survey-adjusted multivariable linear regression models were used adjusting for the same covariates mentioned above. Normal residual distributions were checked by visual inspection of Q-Q plots; data with non-normally distributed residuals were log transformed using $\log_{10}$ for analysis of survey-adjusted generalised linear model (GLM) and multivariable linear regression. The results of analysis were back transformed into the geometric mean values. Homoscedasticity was checked by plotting the standardised residuals of dependent variables and predictors.

During the analysis, the weight factor provided by the NDNS database resource was applied to adjust for non-response and known socio-economic differences in the survey to ensure that the data was nationally representative for the UK population and reducing selection bias and non-response bias (31,32). The weight factor used are wti_Y14 (Weight for individual and diary-all ages, combined Y1-4) and wti_Y56 (Weight for individual and diary-all ages, combined Y5-6) for investigating differences in diet quality scores and nutrient intakes between TNS consumers and non-consumers, associations between tree nut consumption and demographic variables, and multivariable linear regression including diet quality scores. Weight factors wtn_Y14 (Weight for nurse-all ages, combined Y1-4) and wtn_Y56 (Weight for nurse-all ages, combined Y5-6) were used for GLM and multivariable linear regression including variables BMI, waist circumference and blood pressure; and wtb_Y14 (Weight for blood-all ages, combined Y1-4) and wtb_Y56 (Weight for blood-all ages, combined Y5-6) were used for GLM and multivariable linear regression for blood analyte variables including C-reactive protein and lipids(31,32).

3. Results

3.1. Demographic information

Table 1 shows background characteristics of TNS consumers and non-consumers. Median TNS-A (any amount of TNS intake) consumption (n = 484) contributed 0.8% of total energy intake while median consumption in the TNS-B group (including individuals who consumed ≥7.08 g TNS per day, equivalent to ¼ oz, n = 224) was 2.3% of total energy intake. On average TNS consumers were significantly older than non-consumers and were more likely to be female and non-smokers. TNS-A consumption was significantly associated with the demographic factors included, such as sex, ethnicity, socio-economic status, smoking status and region of residency. TNS-B consumption was also significantly associated with these demographic variables, except region of residency.

3.2. Diet quality scores

Geometric estimated marginal mean total scores of modified MDS were significantly higher in TNS-A consumers (5.9; 95% CI 5.2, 6.6) compared with non-consumers (4.9; 95% CI 4.4, 5.4; $P<0.001$). Similarly, geometric estimated marginal mean total scores for the modified HDS were significantly higher in TNS-A consumers (6.1; 95% CI 5.5, 6.8) compared with non-consumers (5.4; 95% CI 4.9, 6.0; $P<0.001$). Results for TNS-B consumers were almost identical (data not shown). To investigate dose-response associations between every gram increase in TNS consumption per 1000 kcal of adult's energy intake and diet quality scores, the survey-adjusted regression model was adjusted for age, sex, ethnicity, socio-economic and smoking status, alcohol and energy intakes. There was no dose response observed in the scores of modified MDS and modified HDS ($P = 0.726$ and $P = 0.971$ respectively).

3.3. Nutrient intake

TNS consumers had significantly higher total energy, food energy, fat, cis-monounsaturated fatty acids, cis n-6 fatty acids, cis n-3 fatty acids (TNS-A only), intrinsic milk sugars, and fibre intakes, as shown in **Table 2**. Saturated fatty acids, trans-fatty acids, total carbohydrate, starch, non-milk extrinsic sugars, intrinsic milk sugar and starch, and alcohol (TNS-B only) intakes were significantly lower in TNS consumers. For micronutrients, as shown in **Table 2**, fully adjusted analysis revealed that TNS consumers, relative to non-consumers, had significantly higher intakes of vitamin A (TNS-A only), vitamin E, thiamin, riboflavin (TNS-B only), folate, pantothenic acid, biotin, vitamin C, potassium, magnesium, phosphorus, iron, copper, zinc, manganese and selenium, and lower intakes of sodium and chloride. However, there were no differences between groups for vitamins D, riboflavin (TNS-A only), niacin equivalents, vitamin B6, vitamin B12, calcium and iodine.

3.4. Cardiovascular disease risk markers

Blood samples were not available from all participants, and anthropometric and blood pressure data were also missing. Associations between TNS consumption and CVD risk markers were analysed for the remaining participants. The estimated marginal mean (95% CI) values of CVD risk markers are shown in **Table 3**. For TNS-A consumers, BMI, WC, SBP and DBP were significantly lower and HDL was significantly higher compared to non-consumers. For those consuming >7.08 g TNS/d (TNS-B), only WC, SBP and DBP were significantly lower compared to non-consumers (data shown in Supplementary document). Survey-adjusted regression analysis showed that for every gram increase in TNS consumption per 1000 kcal of adults' energy intake (**Table 3**), SBP was significantly lower demonstrating a dose-response relationship ($P = 0.028$).

4. Discussion

Interventional and observational evidence suggests that replacing refined carbohydrate-based snacks with tree nut snacks may improve blood lipid profiles, management of body weight(33,34), and nutrient intakes. However, TNS intakes in the general UK population have not been fully investigated. Previous studies have been conducted in the NHANES US adult population(20,21) using multiple 24-h dietary recalls to collect food intake data. This cross-sectional analysis using a representative UK adult population revealed that just 10% of respondents reported consuming any amount of TNS during their 4-day food intake recording period, just less than 5% reported consuming more than 7.08 g (¼ oz) per day on average (around a handful over the 4-day period), and only 0.34% reported consuming the US Food and Drug Administration recommendation of 42.5 g per day(35). The relatively small sub-population of TNS consumers was more likely to be female, white, older and living in England and less likely to be current smokers relative to non-consumers.

Increments in TNS consumption (g per 1000 kcal of energy intake) were not associated with significantly greater modified MDS and HDS in consumers. This lack of dose-response relationship could be due to the low consumption of TNS in the population (for TNS-A consumers, median 0.8% of total energy intake, and 6.5 g/d in terms of total weight intake; for TNS-B consumers, 2.3% of total energy intake, and 14.0 g/d in terms of total weight intake). TNS consumption status may be an indicator of improved overall diet quality, but the actual amount consumed has very little practical impact.

Since TNS consumption status appears to act as a marker of healthy dietary patterns, it is not surprising that the overall nutrient intake profile of TNS consumers was more favourable compared to non-consumers. The contribution of non-milk extrinsic sugar intakes to energy was only marginally lower in TNS consumers (a difference of 1.0% of energy). Fibre (non-starch polysaccharides) intakes were 1.8 g higher in TNS consumers compared with non-consumers, but TNS intake is unlikely to contribute more than a third of this difference, with the remainder due to greater intakes of other fibre-rich foods.

The observations reported here and in the US population imply that TNS are usually eaten as a part of an overall healthier dietary pattern in industrialised countries(21), which would be predicted to translate to better cardiovascular health outcomes. UK TNS consumers had significantly reduced BMI, WC, SBP and DBP, and significantly higher HDL-C but the slightly lower mean CRP in TNS consumers did not reach statistical significance compared with non-consumers. O'Neil *et al.*(2015) previously reported that ≥7.08 g tree nut consumption was associated with lower BMI and WC, as well as SBP and higher HDL-C, in the US adult population adjusted for the same covariates as used in the present analysis, plus physical activity level(20). Feeding trials overall have reported that higher tree nut consumption did not result in weight gain(18,19), which may be related to their satiating/satiety-inducing properties(36), as well as limited lipid bioaccessibility(37). Since TNS consumers' median intake was low in the UK, observed differences in BMI and WC could be related to confounding factors such as physical activity levels, which was not considered in the present analysis due to lack of available data. Mean SBP was 4.3 mm Hg lower and mean DBP was 2.8 mmHg lower in TNS consumers compared to non-consumers, a clinically meaningful difference that would be predicted to reduce risk of CVD. The SUN prospective cohort study reported there was no association between tree nut consumption and blood pressure; the potential reasons could be an underestimated amount of nut consumption, no assessment on the change in nut consumption during follow-up, and no specific information on preparation method, e.g. salted, roasted or raw(38). The Physician's Health Study observed blood pressure reduction only in lean volunteers(39). A recent meta-analysis of 21 randomised control trials reported that total nut consumption lowered SBP in participants without type 2 diabetes, and mixed nuts also lowered DBP(40). Although plasma CRP concentrations were not significantly different in the NDNS cohort, a cross-sectional study using data from the Nurse's Health Study and Health Professional Follow-Up Study revealed that consumers eating tree nuts ≥5 times weekly based on Food Frequency Questionnaire (FFQ) had significantly lower CRP(41), suggesting larger differences in intake may be required to impact on systemic inflammatory markers. However, a meta-analysis of 20 randomised controlled trials suggested that tree nut consumption did not reduce CRP(42). In the current study, the amount of nuts consumed by consumers in the current UK cohort was low, and therefore the SBP and DBP differences observed are likely to be the sum effect of an overall healthier dietary pattern including TNS(43-46).

A significant difference was observed in HDL-C between TNS consumers and non-consumers. Cross-sectional analysis in the US adult population also reported higher HDL-C in TNS consumers(20). There were no significant differences observed in other blood lipids. A recent meta-analysis of 61 interventional clinical trials revealed that tree nut intake reduced TC, TAG and LDL-C and it was reported that the dosage of tree nut intake determined cholesterol lowering capacity rather than the nut types(47). A pooled analysis of 25 feeding trials conducted in seven countries demonstrated the reduction of TC, LDL-C and the ratio of TC to HDL-C but failed to report the increase of HDL-C in response to tree nut intake(48). These inconsistent associations of tree nut consumption and blood pressure, CRP and blood lipids between cross-sectional analysis and clinical trials could be due to different dosage and duration of consumption (duration of the study), residual confounding effects, characteristics such as baseline lipid profile, as well as study sample size relating to statistical power(41).

Strengths of this study include using a relatively large, nationally representative UK population, and the close agreement with results reported in a nationally representative US population suggest that findings may be generalisable to other industrialised countries with similar dietary profiles. The availability of estimated portion size food diary data over a 4-day period is considered to be one of the more accurate dietary assessment methods in large populations, although under-reporting of energy intake is a well-known problem with this methodology that limits the conclusions that can be drawn. Furthermore, the use of 4-d estimated food diaries means that significant nut intakes on other days may have been missed and a significant proportion of TNS consumers may have been wrongly classified as non-consumers; analysis based on frequency of tree nut consumption was not possible. Available information on physical activity was incomplete so statistical analysis models could not be adjusted for this potentially confounding factor. Different types of tree nuts have differing nutrient profiles and potentially nutrient bioaccessibility, and therefore it may be misleading to group them altogether in terms of associations with cardiovascular disease risk factors. In addition to that, missing data for cardiovascular disease risk factors resulted in lower sample sizes.

In conclusion, the prevalence of TNS consumers in the UK adult population is estimated to be approximately 10%, and median intakes were low in the group classified as TNS consumers. TNS consumption was associated with higher diet quality scores and a more favourable nutrient intake profile. TNS consumption may be a marker of a healthy dietary pattern and is associated with lower adiposity, and blood pressure. It is recommended that tree nuts should replace high refined carbohydrate-based snacks as part of a healthy diet. To determine the relative contribution of tree nuts to the sum impact of a healthier dietary pattern on risk of CVD, future randomized controlled trials should investigate the effect of replacing usual refined carbohydrate snacks with tree nuts on markers of cardiometabolic disease risk.

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Table 1. Background characteristics of tree nut snack (TNS) consumers compared to non-consumers in the UK adult population (≥19 y) based on NDNS 2008-2014, n = 4,738.

		TNS-A			TNS-B		
		Consumer, n = 484	Non-consumer, n = 4,254	p-value	Consumer, n = 224	Non-consumer, n = 4,514	p-value
Amount of tree nuts consumed (Median (IQR))	Gram	6.5 (10.8)			14.0 (10.6)		
	% total energy intake	0.8 (2.2)			2.3 (5.1)		
Age (median (IQR))		51 (24)	48 (27)	<0.001*	53 (24)	48 (27)	<0.001*
Sex	Male (%)	31.1	41.6	<0.001*	32.8	40.8	<0.001*
	Female (%)	68.9	58.4		67.2	59.2	
Ethnicity	White (%)	87.8	93.8	0.003*	88.9	93.4	0.016*
	Mixed ethnic group (%)	1.7	0.9		0.9	1.0	
	Black or Black British (%)	1.6	2.0		1.7	1.9	
	Asian or Asian British (%)	5.9	2.2		5.4	2.4	
	Any other group (%)	3.1	1.2		3.0	1.3	
Region	England (%)	68.1	54.8	0.003*	64.8	55.8	0.131
	Scotland (%)	11.9	17.9		11.9	17.5	
	Wales (%)	12.5	14.8		16.7	14.4	
	Northern Ireland (%)	7.5	12.6		6.6	12.3	
Socio-	Higher managerial and	27.2	13.7	<0.001*	25.9	14.6	<0.001*

economic status	professional occupations (%)						
	Lower managerial and professional occupations (%)	31.2	23.1		26.4	23.9	
	Intermediate occupations (%)	8.2	10.5		9.7	10.3	
	Small employers and own account workers (%)	11.0	10.4		11.1	10.4	
	Lower supervisory and technical occupations (%)	6.5	9.5		7.0	9.3	
	Semi-routine occupations (%)	9.4	15.1		13.2	14.6	
	Routine occupations (%)	3.4	12.9		4.5	12.2	
	Never worked (%)	1.3	3.1		0.7	3.0	
	Other (%)	1.9	1.7		1.5	1.8	
	Current smoker (%)	11.7	25.0		12.5	24.2	
Smoking status	Ex-Regular smoker (%)	25.7	23.6	<0.001*	27.3	23.7	<0.001*
	Never regular smoker (%)	62.6	51.4		60.2	52.2	
Alcohol intake (g/d) (median (IQR))		6.0 (18.4)	0.7 (16.7)	0.012*	4.4 (17.0)	1.8 (16.9)	0.002*
Energy intake (kcal/d) (unadjusted mean ± SD))		1900.3 ± 483.7	1750.8 ± 565.1	<0.001*	1952.4 ± 498.8	1756.8 ± 560.4	<0.001*

This is a descriptive table. Survey-adjusted GLM with a linear binary logistic function was used to investigate the association between TNS consumption and demographic variables.

*p was <0.05 indicating a significant association.

Table 2. Energy, macro- and micronutrient intake of tree nut snack consumers defined by any amount of daily consumption or ≥ 7.08 gram consumption per day, in the UK adult population (≥19 y) based on NDNS 2008-2014, n=4,738

Macronutrient (diet only, % food energy)[a]	Estimated marginal mean (95% CI)					
	TNS-A		*P*-value	TNS-B		*P*-value
	Consumers, n = 484	Non-consumers, n = 4,254		Consumers, n = 224	Non-consumers, n = 4,514	
Total energy (kcal)	1760.3 (1514.3, 2006.2)*	1565.0 (1322.3, 1807.6)	<0.001	1823.2 (1573.0, 2073.5)*	1621.1 (1379.5, 1862.7)	<0.001
Food energy (kcal)	1703.4 (1471.3, 1935.6)*	1523.4 (1294.3, 1752.4)	<0.001	1772.9 (1536.8, 2008.9)*	1572.7 (1344.8, 1800.5)	<0.001
Protein	17.4 (15.5, 19.2)	17.3 (15.5, 19.2)	0.827	17.5 (15.7, 19.4)	17.3 (15.5, 19.1)	0.384
Fat	37.1 (34.2, 40.0)*	35.1 (32.2, 38.0)	<0.001	37.6 (34.7, 40.5)*	35.2 (32.3, 38.0)	<0.001
Saturated fatty acids	12.2 (10.6, 13.7)*	12.5 (11.0, 14.0)	0.035	11.8 (10.2, 13.3)*	12.3 (10.8, 13.9)	0.008
cis-Monounsaturated fatty acids	14.3 (13.0, 15.6)*	13.0 (11.8, 14.3)	<0.001	15.0 (13.6, 16.3)*	13.1 (11.8, 14.4)	<0.001
cis n-6 fatty acids	6.2 (5.5, 6.9)*	5.3 (4.6, 6.0)	<0.001	6.6 (5.8, 7.3) *	5.4 (4.7, 6.1)	<0.001
cis n-3 fatty acids[θ]	1.1 (0.9, 1.3)*	1.0 (0.8, 1.2)	<0.001	1.0 (0.8, 1.1)	1.0 (0.9, 1.1)	0.469
Trans fatty acids	0.5 (0.4, 0.7)*	0.6 (0.5, 0.7)	<0.001	0.5 (0.3, 0.6)*	0.6 (0.4, 0.7)	<0.001
Carbohydrate	45.6 (42.4, 48.8)*	47.6 (44.4, 50.8)	<0.001	44.9 (41.7, 48.2)*	47.6 (44.4, 50.7)	<0.001
Total sugars	17.7 (14.5, 20.9)	17.2 (14.1, 20.4)	0.139	18.1 (14.9, 21.4)	17.8 (14.6, 20.9)	0.399
Starch	27.9 (25.1, 30.6)*	30.3 (27.6, 33.0)	<0.001	26.7 (24.0, 29.5)*	29.8 (27.1, 32.4)	<0.001

Non-milk extrinsic sugars	7.7 (4.7, 10.7)*	8.7 (5.8, 11.7)	0.001	7.5 (4.4, 10.5)*	9.0 (6.1, 11.9)	<0.001
Intrinsic milk sugars and starch	37.8 (34.8, 40.9)*	38.8 (35.8, 41.9)	0.001	34.3 (32.5, 36.2)*	35.9 (34.4, 37.6)	0.003
Intrinsic milk$^{\theta}$ sugars$^{\theta}$	10.0 (8.2, 11.8)*	8.5 (6.8, 10.3)	<0.001	9.9 (8.1, 12.1)*	7.9 (6.5, 9.6)	<0.001
Non-starch polysaccharides (Englyst Fibre, g)	15.1 (13.2, 16.9)*	13.3 (11.4, 15.1)	<0.001	15.8 (13.9, 17.7)*	13.7 (11.9, 15.5)	<0.001
Alcohol (g)$^{\dagger, \theta}$	12.1 (8.8, 16.5)	12.9 (9.6, 17.5)	0.290	10.0 (7.1, 14.0)*	12.7 (9.6, 16.9)	0.013
Micronutrients^{b}						
Vitamin A (retinol equivalents) (µg)$^{\dagger, \theta}$	904.9 (753.4, 1086.9)*	828.9 (696.5, 986.5)	0.024	966.1 (794.0, 1175.2)	885.5 (750.9, 1044.2)	0.128
Vitamin D (µg)$^{\dagger, \theta}$	2.5 (2.1, 3.0)	2.4 (2.0, 2.8)	0.213	2.4 (2.0, 2.9)	2.4 (2.0, 2.8)	0.912
Vitamin E (mg)$^{\theta}$	11.6 (10.1, 13.0)*	9.8 (8.4, 11.2)	<0.001	11.6 (10.6, 12.7)*	9.3 (8.6, 10.1)	<0.001
Thiamin (mg)	1.4 (1.2, 1.6)*	1.3 (1.1, 1.5)	0.001	1.5 (1.3, 1.7)*	1.3 (1.1, 1.5)	<0.001
Riboflavin (mg)	1.5 (1.2, 1.7)	1.4 (1.2, 1.7)	0.196	1.5 (1.3, 1.8)*	1.4 (1.2, 1.7)	0.003
Niacin equivalent (mg)	33.5 (28.7, 38.3)	33.8 (29.1, 38.6)	0.486	34.4 (29.5, 39.3)	33.8 (29.1, 38.5)	0.382
Vitamin B6 (mg)$^{\theta}$	1.9 (1.5, 2.3)	1.9 (1.5, 2.3)	0.992	1.9 (1.7, 2.1)	1.9 (1.8, 2.1)	0.530
Vitamin B12 (µg)$^{\dagger, \theta}$	4.6 (3.6, 6.0)	4.7 (3.7, 6.0)	0.777	4.5 (3.9, 5.2)	4.8 (4.3, 5.5)	0.154
Folate (µg)	242.3 (201.9, 282.6)*	229.4 (189.5, 269.2)	0.001	255.7 (214.7, 296.6)*	237.0 (197.5, 276.6)	0.001
Pantothenic acid (mg)	5.6 (4.6, 6.5)	5.3 (4.4, 6.3)	0.007	5.9 (4.9, 6.8)*	5.3 (4.4, 6.2)	<0.001
Biotin (µg)	36.4 (30.1, 42.7)*	30.0 (23.8, 36.3)	<0.001	41.3 (34.9, 47.6)*	31.7 (25.5, 37.9)	<0.001

Vitamin C (mg)[†, θ]	79.1 (58.4, 107.3)*	62.1 (46.0, 83.8)	<0.001	90.4 (75.3, 108.6)*	79.0 (67.8, 92.3)	0.012
Sodium (mg)	1854.8 (1596.0, 2113.6)*	2053.9 (1798.5, 2309.3)	<0.001	1732.2 (1469.6, 1994.8)*	2006.2 (1752.6, 2259.8)	<0.001
Potassium (mg)	2866.7 (2595.1, 3138.2)*	2645.3 (2377.3, 2913.3)	<0.001	3021.3 (2746.0, 3296.6)*	2694.8 (2428.8, 2960.5)	<0.001
Calcium (mg)	696.6 (591.3, 801.8)	702.8 (599.0, 806.7)	0.541	717.4 (610.8, 824.0)	709.6 (606.7, 812.6)	0.599
Magnesium (mg)	276.9 (251.0, 302.8)*	237.8 (212.3, 263.4)	<0.001	301.5 (275.3, 327.8)*	245.3 (219.9, 270.6)	<0.001
Phosphorus (mg)	1165.8 (1056.1, 1275.6)*	1125.4 (1017.1, 1233.7)	<0.001	1191.5 (1080.3, 1302.6)*	1126.2 (1018.9, 1233.5)	<0.001
Iron (mg)	11.1 (9.9, 12.4)*	10.4 (9.1, 11.6)	<0.001	11.2 (9.9, 12.4)*	10.5 (9.3, 11.7)	<0.001
Copper (mg)[†, θ]	1.2 (1.0, 1.4)*	1.0 (0.9, 1.2)	<0.001	1.4 (1.3, 1.6)*	1.2 (1.1, 1.3)	<0.001
Zinc (mg)	9.0 (7.9, 10.0)*	8.8 (7.7, 9.8)	0.044	9.3 (8.2, 10.3)*	8.8 (7.8, 9.8)	0.002
Chloride (mg)	3017.1 (2631.3, 3402.9)*	3286.7 (2906.0, 3667.5)	<0.001	2877.8 (2486.4, 3269.1)*	3242.2 (2864.3, 3620.1)	<0.001
Manganese (mg)	3.3 (2.8, 3.8)*	2.8 (2.3, 3.3)	<0.001	3.5 (3.0, 4.0)*	2.9 (2.4, 3.4)	<0.001
Iodine (µg)	161.9 (131.1, 192.7)	158.7 (128.3, 189.1)	0.282	158.2 (127.0, 189.4)	158.6 (128.5, 188.8)	0.914
Selenium (µg)[θ]	56.9 (48.3, 65.4)*	51.9 (43.4, 60.3)	<0.001	54.9 (49.8, 60.5)*	50.5 (46.6, 54.8)	0.004

The actual sample size in the computation for vitamin A and vitamin D, for TNS-A consumers was 314 and for TNS-A non-consumers was 2,172, whereas for TNS-B consumers was 138 and for TNS-B non-consumers was 2,348. The actual sample size in the computation for alcohol, cis-n3 fatty acids, intrinsic milk sugars and starch, vitamin E, vitamin B6, vitamin B12, vitamin C, copper and selenium for TNS-B consumers was 138 and for TNS-B non-consumers was 2,348. There were no missing values in the computation for other nutrients as outcomes.

* $p<0.05$ showed a significant difference

[†]Geometric marginal means were presented due to non-normally distributed residual data in TNS-A population.

[θ]Geometric marginal means were presented due to non-normally distributed residual data in TNS-B population.

a Survey-adjusted GLM with a linear link function and predictors: age, sex, ethnicity, region of residency, socio-economic and smoking status was used for energy intake as an outcome for TNS-A; Survey-adjusted GLM with a linear link function and predictors: age, sex, ethnicity, region of residency, socio-economic and smoking status, alcohol and energy intakes was used for other macronutrient intake outcomes for TNS-A; Survey-adjusted GLM with a linear link function and predictors: age, sex, ethnicity, region of residency, socio-economic and smoking status, and energy intake was used for alcohol intake as an outcome for TNS-A. The same statistical analysis was conducted for TNS-B but region of residency was excluded from predictors.

b Survey-adjusted GLM with a linear link function and predictors: age, sex, ethnicity, region of residency, socio-economic and smoking status, alcohol and energy intakes was used for TNS-A. The same statistical analysis was conducted for TNS-B but region of residency was excluded from predictors.

Table 3. Cardiovascular disease risk marker values in UK adults (≥19 y) based on NDNS 2008-2014, in consumers of any amount of tree nut snack and non-consumers, and the association of tree nut snack consumption and risk markers.

CVD risk marker	Value[a] (Estimated marginal mean (95% CI))		*P*-value	Associations between tree nut consumption and CVD risk markers[b]		
	Consumers	Non-consumer		β (95% CI)	*P*-value	R^2
BMI (kg/m^2)[c, †]	25.4 (24.0, 26.8)	26.3 (25.0, 27.8)	0.002*	1.035 (0.991, 1.081)	0.128	0.121
WC (cm)[d]	91.5 (88.5, 94.6)	94.2 (91.5, 97.0)	<0.001*	0.094 (-0.080, 0.268)	0.289	0.293
SBP (mmHg)[e]	119.7 (116.2, 123.2)	124.0 (120.8, 127.1)	<0.001*	-0.242 (-0.458, -0.026)	0.028*	0.286
DBP (mmHg)[e]	69.2 (66.8, 71.7)	72.0 (69.7, 74.2)	<0.001*	-0.034 (-0.196, 0.127)	0.677	0.033
TC (mmol/l)[f]	4.9 (4.5, 5.3)	4.9 (4.5, 5.3)	0.627	0.011 (-0.007, 0.029)	0.218	0.109
TAG (mmol/l)[g, †]	1.1 (0.9, 1.3)	1.1 (0.9, 1.4)	0.220	0.972 (0.813, 1.164)	0.757	0.084
HDL-C (mmol/l)[f]	1.5 (1.4, 1.7)	1.4 (1.3, 1.6)	0.008*	-0.001 (-0.009, 0.007)	0.754	0.277
LDL-C (mmol/l)[h]	2.9 (2.6, 3.3)	2.9 (2.6, 3.2)	0.980	0.011 (-0.006, 0.028)	0.204	0.046
TC:HDL-C[f]	3.5 (3.1, 4.0)	3.6 (3.2, 4.0)	0.412	0.016 (-0.005, 0.037)	0.143	0.163
CRP (mg/l)[i, †]	1.9 (1.3, 2.6)	2.1 (1.5, 2.9)	0.062	1.194 (0.933, 1.528)	0.157	0.095

a Survey-adjusted GLM with a linear link function and predictors: age, sex, ethnicity, region of residency, socio-economic and smoking status, alcohol and energy intakes was used.

b Survey-adjusted multivariable linear regression was used, adjusted for age, sex, ethnicity, region of residency, socio-economic and smoking status and alcohol intake.

*$p<0.05$ showed a significant difference.

[†]Geometric marginal means and geometric β (95% CI) values were presented due to non-normally distributed residual data. Geometric β values were interpreted as ratios of geometric means.

Due to missing data, sample sizes were as follows: TNS-A consumers 241[c], 384[d], 326[e], 274[f], 176[g,i], and 273[h]; non-consumers 1,616[c], 3,110[d], 2,456[e], 2,132[f], 1,161[g], 2,096[h], and 1,164[i].

Appendix A: Diet quality scores

Table A1. Original and modified Mediterranean Diet Score (MDS) and its scoring system(24)

Food group		Scoring*	
Original MDS	Modified MDS		
Cereals	Cereals	>median	1 (else: 0)
Vegetables	Vegetables	>median	1 (else: 0)
Fruits and Nuts	**Fruits**	>median	1 (else: 0)
Legumes	Legumes	>median	1 (else: 0)
Fish	Fish	>median	1 (else: 0)
Meat	Meat	<median	1 (else: 0)
Dairy products	Dairy products	<median	1 (else: 0)
Ratio of unsaturated to saturated fats	Ratio of unsaturated to saturated fats	>median	1 (else: 0)
Alcohol	Alcohol	10-50 g/d for men	1 (else: 0)
		5-25 g/d for women	1 (else: 0)

*Except alcohol, scoring of each food group is based on population and sex-specific median.

Table A2. Original and modified Healthy Diet Score (HDS) and the cut-off values for scoring(25)

HDS			HDS – modified based on current UK recommendations		
Index item	Cut-off values		Index item	Cut-off values	
	Score 1	Score 0		Score 1	Score 0
Saturated fatty acids (% energy intake)	0-10	>10	Saturated fatty acids (% energy intake)	0-11[a]	>11
Polyunsaturated fatty acids (% energy intake)*	6-10	<6 or >10	Polyunsaturated fatty acids (% energy intake)	6[b]-10	<6 or >10
Protein (% energy intake)	10-15	<10 or >15	Protein (% energy intake)	9[c]-15	<9 or >15
Total carbohydrate (% energy intake)*	50-70	<50 or >70	Total carbohydrate (% energy intake)	50[d]-70	<50 or >70
Dietary fibre (g)*	18-32	<18 or >32	Dietary fibre (g)	18[d]-32	<18 or >32
Fruits and vegetables (g)	≥400	<400	Fruits and vegetables (g)	≥400[e]	<400

Pulses and nuts (g)*	≥ 30	<30	Pulses (g)	≥ 30	<30
Total non-milk extrinsic sugar (% total energy intake)*	0-10	>10	Total non-milk extrinsic sugar (% total energy intake)	$0\text{-}5^{d}$	>5
Cholesterol (mg)*	0-245	>245	Trans-fatty acids (% energy intake)	$\leq 2^{e}$	>2
Fish (g)*	≥ 32	<32	Fish (g)	$\geq 40^{e}$	<40
Red meat and meat processed products (g)*	≤ 90	>90	Oily fish (g)	$\geq 20^{e}$	<20
Calcium (mg)*	≥ 700	<700	Red meat and meat processed products (g)	$\leq 70^{i}$	>70
			Calcium (mg)	$\geq 700^{c}$	<700
			Sodium (mg)	$\leq 2400^{c}$	>2400

* Items based on advice on healthy eating as recommended by the UK Committee on Medical Aspects of Food Policy (COMA)(25)

a Based on NDNS Results from Years 5 and 6 (combined) of the Rolling Programme (2012/2013 – 2013/2014)(22,23), UK Government Dietary Recommendations by Public Health England (2016)(26), Cardiovascular Disease Outcomes Strategy by UK Department of Health (2013)(27) and Draft report: Saturated fats and health by Scientific Advisory Committee on Nutrition (SACN) 2018(29)

b Based on UK Government Dietary Recommendations by Public Health England (2016)(26)

c Based on UK Government Dietary Recommendations by Public Health England (2016)(26)

d Based on UK Government Dietary Recommendations by Public Health England (2016)(26) and Scientific Advisory Committee on Nutrition (SACN) Report 2015 on Carbohydrates and Health(30)

e Based on NDNS Results from Years 5 and 6 (combined) of the Rolling Programme (2012/2013 – 2013/2014)(22,23) and The Eatwell Guide by Public Health England (2016)(28)

Appendix B: Associations between tree nut consumption (≥7.08 g) and CVD risk markers

Table B1. Cardiovascular disease risk marker values in UK adults (≥19 y) based on NDNS 2008-2014, n = 4,738, in consumers of ≥7.08 g of tree nut snack and non-consumers.

CVD risk marker	Value[a] (Estimated marginal mean (95% CI)) Consumers, n=224	Value[a] (Estimated marginal mean (95% CI)) Non-consumer, n=4,514	*P*-value
BMI (kg/m^2)[b, †]	26.0 (24.4, 27.6)	26.1 (24.8, 27.5)	0.705
WC (cm)[c]	91.6 (88.3, 94.9)	94.0 (91.2, 96.8)	0.015*
SBP (mmHg)[d]	118.3 (114.5, 122.2)	123.7 (120.5, 126.9)	<0.001*
DBP (mmHg)[d]	69.3 (66.5, 72.0)	71.7 (69.4, 74.0)	0.005*
TC (mmol/l)[e]	5.0 (4.6, 5.4)	4.9 (4.5, 5.3)	0.299
TAG (mmol/l)[f, †]	1.1 (0.8, 1.4)	1.1 (0.9, 1.4)	0.424
HDL-C (mmol/l)[e]	1.5 (1.4, 1.7)	1.5 (1.3, 1.6)	0.053
LDL-C (mmol/l)[g]	2.9 (2.6, 3.3)	2.9 (2.6, 3.2)	0.531
TC:HDL-C[e]	3.6 (3.1, 4.0)	3.6 (3.2, 4.0)	0.924
CRP (mg/l)[h, †]	2.0 (1.4, 2.8)	2.0 (1.5, 2.8)	0.685

a Survey-adjusted GLM with a linear link function and predictors: age, sex, ethnicity, socio-economic and smoking status, alcohol and energy intakes was used.

[†]Geometric marginal means were presented due to non-normally distributed residual data.

Due to missing data, sample sizes were as follows: TNS-B consumer 110[b], 186[c], 162[d], and 138[e,g], 86[f,h], non-consumers 1,747[a], 3,308[c], 2,620[d], 2,268[e], 1,251[f], 2,231[g], and 1,254[h].