British Journal of Nutrition (2024), 131, 1883–1891 doi:10.1017/S0007114524000412

Association of green tea consumption with prediabetes, diabetes and markers of glucose metabolism in rural Vietnam: a cross-sectional study

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(Submitted 15 September 2023 – Final revision received 18 January 2024 – Accepted 7 February 2024 – First published online 16 February 2024)

Abstract

The literature on green tea consumption and glucose metabolism has reported conflicting findings. This cross-sectional study examined the association of green tea consumption with abnormal glucose metabolism among 3000 rural residents aged 40–60 years in Khánh Hòa province in Vietnam. Multinomial logistic regression analysis was conducted to examine the association of green tea consumption (0, < 200, 200–< 400, 400–< 600 or ≥ 600 ml/d) with prediabetes and diabetes (based on the American Diabetes Association criteria). Linear regression analysis was performed to examine the association between green tea consumption and the log-transformed homeostatic model assessment of insulin resistance (HOMA-IR) (a marker of insulin resistance) and the log-transformed homeostatic model assessment of β-cell function (HOMA-β) (a marker of insulin secretion). The OR for prediabetes and diabetes among participants who consumed ≥ 600 ml/d *v.* those who did not consume green tea were 1·61 (95 % CI = 1·07, 2·42) and 2·04 (95 % CI = 1·07, 3·89), respectively. Higher green tea consumption was associated with a higher level of log-transformed HOMA-IR ($P_{\text{for trend}} = 0{\cdot}04$) but not with a lower level of log-transformed HOMA-β ($P_{\text{for trend}} = 0{\cdot}75$). Higher green tea consumption was positively associated with the prevalence of prediabetes, diabetes and insulin resistance in rural Vietnam. The findings of this study indicated prompting the need for further research considering context in understanding the link between green tea consumption and glucose metabolism, especially in rural settings in low- and middle-income countries.

Keywords: Diabetes: Prediabetes: Green tea: Insulin resistance: Insulin secretion

Diabetes has been on an increasing trend worldwide[1]. More importantly, the disease burden associated with diabetes has been shifting from high-income countries to low- and middle-income countries (LMICs)[1]. The number of adults with diabetes in LMICs was estimated to be 368 million in 2019 and is estimated to increase up to 588 million by 2045[2]. To curb such burden in LMICs, modifiable lifestyle-related factors of diabetes should be investigated in LMIC settings[3].

Tea is among the most popular and consumed beverages worldwide. Given its widespread consumption and rich antioxidant content, including essential compounds, such as catechin and epigallocatechin gallate[4], tea consumption has been studied extensively as a potential protective factor for diabetes. In a meta-analysis of 14 cohort studies conducted in high-income countries by Yang *et al.*[5], an inverse association was reported between tea consumption and diabetes (relative

Abbreviations: ADA, American Diabetes Association; BMI, body mass index; CDC, center for epidemiologic studies depression scale; CI, confidence interval; FPG, fasting plasma glucose; HbA1c, hemoglobin A1c; HOMA-β, homeostatic model assessment of β-cell function; HOMA-IR, homeostatic model assessment of insulin resistance; KHCS, Khánh Hòa Cardiovascular Study; LMICs, low- and middle-income countries; MET, metabolic equivalent; OR, odds ratio; SD, standard deviation; VND, Vietnamese Dong.

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https://doi.org/10.1017/S0007114524000412 Published online by Cambridge University Press

risk = 0·85 for those consuming 6 cups/d *v.* non-tea drinkers). However, the evidence was inconsistent when they examined specific associations in relation to different types of tea[5]; a significant inverse association was observed for black tea and oolong tea, but no strong evidence was available for green tea[5].

The present study was designed to extend the findings of previous studies in the following manner. First, evidence is limited and inconsistent on the association between green tea consumption and diabetes[6–12]. To our knowledge, only one Japanese study documented an inverse association between green tea consumption and diabetes,[9] while others reported a null association[6–8,10] or rather a positive association in Iran[12] and China[11]. Second, little is known about the association between green tea consumption and prediabetes[8,13]. Prediabetes is a state with higher levels of plasma glucose than normal but not high enough to be categorised as diabetes[14], and it has been linked with an elevated risk of diabetes and other negative health outcomes such as cardiovascular disease (CVD)[15–17]. Investigating the association between green tea consumption and prediabetes is important to mitigate the disease burden associated with prediabetes. Third, evidence on this subject from other LMICs is lacking, despite the positive association reported in the two above-mentioned studies conducted in LMICs, which had been interpreted in connection with the possible role of pesticide residue in tea leaves. For example, evidence is scarce in Vietnam, where tea drinking is a part of a traditional culture, and green tea is one of the most common types of tea consumed in the population[18]. Fourth, evidence is limited and inconsistent on the association between green tea consumption and markers of glucose metabolism, i.e., insulin resistance and insulin secretion. Examining such associations may facilitate understanding of how green tea consumption contributes to the development of diabetes.

Therefore, this study aimed to examine the association of green tea consumption with prediabetes, diabetes and markers of glucose metabolism (insulin resistance and insulin secretion) in rural residents in Khánh Hòa province, Vietnam.

Methods

Data for this cross-sectional study were obtained from the baseline survey of the Khánh Hòa Cardiovascular Study (KHCS), an ongoing prospective cohort study investigating determinants of CVDs among rural residents in Vietnam. The baseline survey was conducted between June 2019 and June 2020 in 8 out of the 14 communes in one of the 7 districts in Khánh Hòa province, which was purposively selected as it was deemed to represent the average level of affluence in rural Vietnam. The inclusion criteria for the KHCS were the residents aged 40–59 years (at the time of recruitment) who had resided in the selected communes for at least 6 months. The exclusion criteria included those living in the study communes for < 6 months; institutionalised people; those who were unable to provide informed consent; those who planned to move out of the commune within 1 year; pregnant women and those who gave birth within 1 year and those who had CVD events in the past. Commune health centre staff created lists of eligible participants in each commune and recruited participants until a survey sample of 3000 (i.e. convenient sampling). Details of the KHCS have been described in previous papers[19,20].

The baseline survey consisted of anthropometric measurements, blood sampling for biochemical measurements and a questionnaire on health-related lifestyle factors administered via face-to-face interviews. Written informed consent was obtained from all participants.

Assessment of diabetes and prediabetes

In this study, the participants were requested to fast for more than 8 hours before collecting their blood samples. Fasting plasma glucose (FPG) level was measured using Cobas 8000 (Roche), and HbA1c level was quantified by high- performance liquid chromatography using the HLC-723 G8 (Tosoh Bioscience).

According to the American Diabetes Association (ADA) criteria[14], diabetes was defined as FPG ≥ 7·0 mmol/l (≥ 126 mg/dl) or HbA1c ≥ 6·5 %. In addition, those with the use of anti-diabetic treatment or prescribed insulin were also regarded as having diabetes. Prediabetes was defined as FPG 5·6–6·9 mmol/l (100–125 mg/dl) or HbA1c 5·7–6·4 % among those without diabetes and normoglycaemia as FPG < 5·6 mmol/l (< 100 mg/dl) and HbA1c < 5·7 %. The ADA criteria have been widely used in previous studies across different countries and have been also used among Vietnamese populations[21,22].

Assessment of insulin resistance and insulin secretion

Insulin resistance was assessed by using homeostatic model assessment of insulin resistance (HOMA-IR), while insulin secretion was assessed by using homeostatic model assessment of β-cell function (HOMA-β). The HOMA-IR and HOMA-β were computed using the following equations and incorporated into statistical models as continuous variables after log transformation to reduce skewness: HOMA IR = (fasting insulin (microUnit/l) × FPG (mmol/l)) /22·5; HOMA-β = (20 × fasting insulin (microUnit/l)) /(FPG (mmol/l)–3·5)[23]. A higher HOMA-IR indicated greater insulin resistance, while a lower HOMA-β indicated lower β-cell function (decreased insulin secretion).

Assessment of tea consumption

Data on green tea consumption were obtained by asking questions regarding the frequency and serving size of green tea consumption for a typical week in the past year. Those who consumed green tea less than once a week were considered to be non-green tea consumers. Those who reported consuming green tea at least once a week were further asked how many times per day they consumed green tea and the amount of green tea they consumed per occasion. The amount of tea consumed per occasion was reported in comparison with the standard serving size for Vietnamese tea cup (40 ml per cup) shown in a picture booklet (showcard), minimising measurement bias. They were asked to denote their usual serving size from the following response options: ‘less’ for 0–0·8 times the serving size in the picture, ‘equal’ for 0·8–< 1·3 times, ‘greater’ for 1·3–1·7 times and 'greater than 1·7' for serving sizes greater than 1·7 times that in the picture. The values of 0·5, 1·0 and 1·5 were assigned for less, equal and greater, respectively. Those who selected 'greater than 1·7' were asked to specify the number of serving size. Daily consumption of green tea was calculated by multiplying the consumption frequency by serving size and was then categorised into five groups (0, < 200, 200–< 400, 400–< 600 or ≥ 600 ml/d) (equivalent to 0, < 5, 5–< 10, 10–< 15 or ≥ 15 Vietnamese tea cups/d, respectively).

In this study, data on 'other tea' consumption were also collected without specifying tea types, but listing lotus tea, jasmine tea and oolong tea as examples of other teas in the questionnaire. The same set of questions for other tea consumption were also asked.

Covariates

The following data on socio-demographic factors were collected: age (in years), sex (male or female), marital status (married/cohabiting or not), education (less than primary school, primary school, junior high school or high school or higher), job (government employee, non-government employee, self-employed, farmer or fisherman, houseworker, others or not working) and household income (low, middle or high). Data on monthly household income (in Vietnamese Dong (VND), the currency of Vietnam) were obtained by asking household representatives to choose from eleven options ranging from ≤ 1 000 000 to > 20 000 000 VND (or do not know); the response was divided by the square root of the number of household members to compute equivalised income, which was then grouped into tertiles (low, middle or high).

The following data on lifestyle-related factors were also collected: smoking status (never, former, or current), alcohol consumption (0, < 1, 1–< 2, or ≥ 2 drinks/d), physical activity (< 600, 600–< 1200 or ≥ 1200 metabolic equivalent-min/week) (based on Global Physical Activity Questionnaire[24]), sleep duration (< 6, 6–< 7, 7–< 8, 8–< 9, or ≥ 9 h/d), fruit consumption (0, < 1, 1–< 2, or ≥ 2 servings/d), vegetable consumption (0, < 1, 1–< 2, 2–< 3 or ≥ 3 servings/d), red meat consumption (0, < 100, 100–< 200 or ≥ 200 g/d), rice consumption (< 2, 2–< 3, 3–< 4, 4–< 6, 6–< 8 or ≥ 8 bowls/d), rice noodle consumption (0, < 2, 2–< 4, 4–< 7 or ≥ 7 bowls/week), coffee consumption (0, <65, 65–< 130 or ≥ 130 ml/d) (equivalent to 0, < 1, 1–< 2, or ≥ 2 cups/d, respectively) and family history of diabetes (yes, no or unknown). Tea and coffee drinkers were asked if they add sugar or condensed milk to tea or coffee (yes or no).

Depressive symptoms were assessed using the Center for Epidemiologic Studies Depression Scale (CES-D)[25] eleven items and those with a CES-D score of ≥ 9 out of 33 were regarded as having depressive symptoms.

Body mass index (BMI) was calculated based on measured weight (kg) and height squared (m^2) and categorised into five groups (< 18·5, 18·5–< 23·0, 23·0–< 25·0, 25·0–< 30·0 or ≥ 30·0 kg/m^2)[26]. Hypertension was defined as systolic blood pressure ≥ 140 mmHg, diastolic blood pressure ≥ 90 mmHg or the use of anti-hypertensive medication. Dyslipidaemia was defined as having at least one of the following conditions: total cholesterol ≥ 240 mg/l, LDL-cholesterol ≥ 160 mg/l, HDL-cholesterol < 40 mg/l, TAG ≥ 200 mg/l or the use of anti-dyslipidaemia medication.

Statistical analysis

Multinomial logistic regression analysis was performed to estimate the odds ratio (OR) and 95 % confidence interval (CI) for prediabetes and diabetes in relation to green tea consumption categories. Additionally, OR (95 % CI) per 40 ml (1 cup)/d was estimated. In Model 1, age and sex were adjusted. In Model 2, the following factors were further adjusted: marital status, education, job, income, smoking status, alcohol consumption, physical activity, sleep duration, fruit consumption, vegetable consumption, red meat consumption, rice consumption, rice noodle consumption, family history of diabetes, other beverage consumption (coffee, other tea consumption), BMI categories, hypertension, dyslipidaemia and depressive symptoms. In Model 3, the use of additives to beverages (yes or no) was further adjusted, given that sweetened beverages have been studied in relation to diabetes,[27] and the use of additives for tea may be a risk factor for diabetes. These variables were selected based on the previous literature on the associations of green tea consumption with prediabetes, diabetes and markers of glucose metabolism.

To examine the association between green tea consumption and HOMA-IR and HOMA-β, linear regression analysis was performed using the same model building procedure as in the multinomial logistic regression analysis. HOMA-IR and HOMA-β values were log-transformed before analysis to reduce skewness, and the values were presented in terms of adjusted geometric means and 95 % CI. The beta coefficient was also calculated for HOMA-IR and HOMA-β per 40 ml/d.

A set of analyses was conducted to examine the association of other tea consumption with prediabetes, diabetes and HOMA-IR and HOMA-β.

All statistical analyses were performed using SAS version 9.4 (SAS Institute). The $P_{\text{for trend}}$ was estimated by treating the exposure as a continuous variable in the model for each analysis. The level of statistical significance was set at $P < 0·05$ (two-sided) for the analyses.

Results

Table 1 shows the characteristics of the participants according to the green tea consumption categories. In the present study, 25·5 % of participants reported consuming green tea daily. In comparison with non-green tea drinkers, those who consumed green tea more frequently tended to be men, farmers, fishermen, current smokers, alcohol consumers and individuals with higher red meat and rice consumption. A similar trend was also observed for other tea consumption (online Supplementary Table S1).

Table 2 shows the results of multinomial regression analysis examining the association between green tea consumption and prediabetes and diabetes. In Model 1, compared with the lowest category of green tea consumption (0 ml/d), the OR (95 % CI) of prediabetes and diabetes was 1·44 (0·98, 2·11) ($P_{\text{for trend}} = 0·03$) and 1·74 (0·99, 3·07) ($P_{\text{for trend}} = 0·06$) for the highest category

https://doi.org/10.1017/S0007114524000412 Published online by Cambridge University Press

Table 1. Characteristics of participants in the Khánh Hòa Cardiovascular Study, Vietnam according to green tea consumption categories

	Green tea consumption categories									
	0 ml/d (*n* 2235)		< 200 ml/d (*n* 419)		200–< 400 ml/d (*n* 131)		400–< 600 ml/d (*n* 74)		≥ 600 ml/d (*n* 141)	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%
Age										
Mean	49·8		49·5		50·5		50·4		50·8	
SD	5·5		5·6		5·7		5·3		5·4	
Sex (female)	1563	69·9	160	38·2	27	20·6	26	35·1	64	45·4
Marital status (married/cohabitating)	1989	90·0	379	90·5	125	95·4	67	90·5	131	92·9
Education										
Less than primary school	283	12·7	37	8·8	13	9·9	11	14·9	8	5·7
Primary school	670	30·0	104	24·8	36	27·5	17	23·0	36	25·5
Secondary school	795	35·5	151	36·0	44	33·6	21	28·4	57	40·4
High school or higher	487	21·8	127	30·3	38	29·0	25	33·8	40	28·4
Job										
Government employee	192	8·6	58	13·8	16	12·2	6	8·1	23	16·3
Non-government employee	364	16·3	65	15·5	30	22·9	9	12·2	15	10·6
Self-employed	474	21·2	62	14·8	14	10·7	19	25·7	26	18·4
Farmer or fisherman	605	27·1	146	34·8	51	38·9	22	29·7	46	32·6
Houseworker	461	20·6	41	9·8	2	1·5	6	8·1	17	12·1
Other	72	3·2	27	6·4	5	3·8	4	5·4	3	2·1
Not working (retired or unemployed)	67	3·0	20	4·8	13	9·9	8	10·8	11	7·8
Household income										
Low	778	34·8	134	32·0	33	25·2	24	32·4	33	23·4
Middle	769	34·4	152	36·3	43	32·8	31	41·9	50	35·5
High	659	29·5	131	31·3	54	41·2	18	24·3	58	41·1
Missing	29	1·3	2	0·5	1	0·8	1	1·4	0	0·0
Smoking status										
Never	1689	75·6	198	47·3	41	31·3	31	41·9	77	54·6
Former	210	9·4	71	17·0	28	21·4	15	20·3	26	18·4
Current	336	15·0	150	35·8	62	47·3	28	37·8	38	27·0
Alcohol consumption										
0 drink/d	1732	77·5	225	53·7	49	37·4	37	50·0	71	50·4
< 1 drink/d	229	10·3	104	24·8	36	27·5	13	17·6	34	24·1
1–< 2 drinks/d	132	5·9	33	7·9	19	14·5	8	10·8	9	6·4
≥ 2 drinks/d	142	6·4	57	13·6	27	20·6	16	21·6	27	19·2
Physical activity										
< 600 MET-min/week	203	9·1	29	6·9	7	5·3	8	10·8	5	3·6
600–< 1200 MET-min/week	86	3·9	23	5·5	2	1·5	2	2·7	7	5·0
≥ 1200 MET-min/week	1946	87·1	367	87·6	122	93·1	64	86·5	129	91·5
Sleep duration (< 6 h/d)	237	10·6	38	9·1	14	10·7	7	9·5	19	13·5
Fruit consumption (≥ 2 servings/d)	257	11·5	43	10·3	17	13·0	6	8·1	34	24·1
Vegetable consumption (≥ 3 servings/d)	274	12·3	38	9·1	24	18·3	16	21·6	32	22·5
Red meat consumption (≥ 200 g/d)	190	8·5	57	13·6	36	27·5	12	16·2	28	19·9
Rice consumption (≥ 8 bowls/d)	196	8·8	73	17·4	23	17·6	9	12·2	19	13·5
Rice noodle consumption (≥ 7 bowls/d)	363	16·2	55	13·1	23	17·6	10	13·5	24	17·0
Coffee consumption										
0 ml/d	1393	62·3	156	37·2	43	32·8	32	43·2	56	39·7
< 65 ml/d	377	16·9	113	27·0	31	23·7	18	24·3	38	27·0
65–< 130 ml/d	422	18·9	136	32·5	49	37·4	21	28·4	37	26·2
≥ 130 ml/d	43	1·9	14	3·3	8	6·1	3	4·1	10	7·1
Adding sugar or condensed milk to tea or coffee (yes)	704	31·5	208	49·6	74	56·5	29	39·2	73	51·8
BMI categories										
< 18·5 kg/m^2	108	4·8	16	3·8	5	3·8	3	4·1	7	5·0
18·5–< 23·0 kg/m^2	1015	45·4	185	44·2	56	42·8	28	37·8	60	42·6
23·0–< 25·0 kg/m^2	548	24·5	101	24·1	37	28·2	17	23·0	36	25·5
25·0–< 30·0 kg/m^2	529	23·7	110	26·3	32	24·4	24	32·4	33	23·4
≥ 30·0 kg/m^2	35	1·6	7	1·7	1	0·8	2	2·7	5	3·6
Family history of diabetes (yes)	274	12·3	59	14·1	16	12·3	10	13·5	14	9·9
Hypertension (yes)	861	38·5	195	46·5	54	41·2	32	43·2	47	33·3
Dyslipidemia (yes)	998	44·7	192	45·8	71	54·2	34	46·0	57	40·4
Depressive symptoms (yes)	266	11·9	38	9·1	22	16·8	4	5·4	11	7·8

MET, metabolic equivalent.

(≥ 600 ml/d), respectively. The trend of increased odds for prediabetes with increased consumption of green tea remained the same even after adjusting for additional covariates in Model 2 ($P_{for\ trend}$ = 0·02) and Model 3 ($P_{for\ trend}$ = 0·02). The same trend was also observed in relation to diabetes when adjusting for covariates in Model 2 ($P_{for\ trend}$ = 0·04) and Model 3

https://doi.org/10.1017/S0007114524000412 Published online by Cambridge University Press

Table 2. OR and 95 % CI of prediabetes and diabetes according to green tea consumption categories

		Green tea consumption categories										
		< 200 ml/d (*n* 419)		200–< 400 ml/d (*n* 131)		400–< 600 ml/d (*n* 74)		≥ 600 ml/d (*n* 141)			Per 40 ml/d†	
	0 ml/d (*n* 2235)	OR	95 % CI	OR	95 % CI	OR	95 % CI	OR	95 % CI	$P_{for\ trend}$*	OR	95 % CI
Prediabetes												
No. events	1026	202		60		38		75				
Model 1	1·00 (reference)	1·14	0·90, 1·43	1·02	0·69, 1·51	1·40	0·83, 2·36	1·44	0·98, 2·11	**0·03**	1·01	1·00, 1·03
Model 2	1·00 (reference)	1·11	0·87, 1·43	0·88	0·57, 1·33	1·25	0·72, 2·16	**1·61**	**1·07, 2·42**	**0·02**	1·01	1·00, 1·03
Model 3	1·00 (reference)	1·12	0·87, 1·43	0·88	0·58, 1·34	1·25	0·73, 2·16	**1·61**	**1·07, 2·42**	**0·02**	1·02	1·00, 1·03
Diabetes												
No. events	214	45		18		11		19				
Model 1	1·00 (reference)	1·28	0·88, 1·86	1·50	0·84, 2·69	2·00	0·95, 4·21	1·74	0·99, 3·07	0·06	1·02	1·00, 1·04
Model 2	1·00 (reference)	1·14	0·75, 1·73	1·24	0·65, 2·38	1·55	0·69, 3·49	**2·00**	**1·04, 3·81**	**0·04**	1·02	1·00, 1·04
Model 3	1·00 (reference)	1·17	0·77, 1·79	1·28	0·67, 2·46	1·50	0·66, 3·39	**2·04**	**1·07, 3·89**	**0·03**	1·02	1·00, 1·04

Model 1, adjusted for age (years, continuous) and sex (male or female).
Model 2, further adjusted for marital status (married/cohabiting or not), education (less than primary school, primary school, secondary school or high school or higher), job (government employee, non-government employee, self-employed, farmer or fisherman, houseworker, other or not working), income (low, middle or high), smoking status (never, former or current), alcohol consumption (0, < 1, 1–< 2 or ≥ 2 drinks/d), physical activity (< 600, 600–< 1200 or ≥ 1200 MET-min/week), sleep duration (< 6, 6–< 7, 7–< 8, 8–< 9 or ≥ 9 h/d), fruit consumption (0, < 1, 1–< 2 or ≥ 2 servings/d), vegetable consumption (0, < 1, 1–< 2, 2–< 3 or ≥ 3 servings/d), red meat consumption (0, < 100, 100–< 200 or ≥ 200 g/d), rice consumption (< 2, 2–< 3, 3–< 4, 4–< 6, 6–< 8 or ≥ 8 bowls/d), rice noodle consumption (0, < 2, 2–< 4, 4–< 7 or ≥ 7 bowls/week), coffee consumption (0, < 65, 65–< 130 or ≥ 130 ml/d), other tea consumption (0, < 200, 200–< 400, 400–< 600 or ≥ 600 ml/d), family history of diabetes (yes, no or unknown), BMI categories (< 18·5, 18·5–< 23·0, 23·0–< 25·0, 25·0–< 30·0 or ≥ 30·0 kg/m^2), hypertension (yes or no), dyslipidaemia (yes or no) and depressive symptoms (yes or no).
Model 3, further adjusted for use of additives (yes or no).
Bold values were statistically significant.
* $P_{for\ trend}$ was estimated by treating the exposure as a continuous variable in the model for each analysis.
† 40 ml/d is equivalent to 1 Vietnamese tea cup/d.

($P_{for\ trend}$ = 0·03). In addition, OR (95 % CI) of prediabetes and diabetes per 40 ml (1 Vietnamese tea cup)/d was 1·02 (1·00, 1·03) and 1·02 (1·00, 1·04), respectively, in the fully adjusted model, showing the same direction of the associations as the main analysis.

Table 3 shows the results of the linear regression analysis examining the association between green tea consumption and the markers of glucose metabolism (HOMA-IR and HOMA-β). Higher green tea consumption was significantly associated with a higher level of HOMA-IR ($P_{for\ trend}$ = 0·03) in Model 1. The positive association persisted even after further adjustment for the covariates in Model 2 ($P_{for\ trend}$ = 0·04) and Model 3 ($P_{for\ trend}$ = 0·04). In contrast, no statistically significant association was observed between green tea consumption and HOMA-β (*P* for trend = 0·75) (Model 3). The beta coefficient (95 % CI) for HOMA-IR and HOMA-β per 40 ml/d was 0·002 (–0·001, 0·005) and –0·001 (–0·004, 0·003), respectively, in the fully adjusted model.

No statistically significant association was found between other tea consumption and prediabetes or diabetes; the OR for prediabetes and diabetes among those in the highest consumption category (≥ 600 ml/d) for other tea consumption to those who did not drink other teas was 1·11 (95 % CI = 0·69, 1·79) and 0·59 (95 % CI = 0·23, 1·53), respectively (online Supplementary Table S2). In assessments of the markers of glucose metabolism, no statistically significant association was found between other tea consumption and HOMA-IR ($P_{for\ trend}$ = 0·60) or HOMA-β ($P_{for\ trend}$ = 0·09) (Model 3) (online Supplementary Table S3).

Discussion

In this study, higher green tea consumption was associated with increased odds of prediabetes and diabetes among middle-aged residents in rural Vietnam. Higher green tea consumption was also associated with a higher level of HOMA-IR (a marker of insulin resistance), while no clear association was observed in relation to HOMA-β (a marker of insulin secretion).

The positive association between green tea consumption and prediabetes/diabetes in this study contradicts the results of previous studies that showed an inverse association of green tea consumption with diabetes[9] or impaired fasting glucose[8,13]. The finding from the present study was, however, consistent with the results of previous studies conducted in China and Iran[11,12]; more specifically, higher green tea consumption was associated with an increased risk of diabetes in a large cohort of Chinese adults[11]; and Iranian adults who consumed higher amounts of green tea showed a higher prevalence of diabetes in comparison with non-green tea drinkers[12]. The present study extended these studies by examining not only the association between green tea consumption and diabetes but also its association with prediabetes.

The mechanisms underlying the positive association of green tea consumption with prediabetes and diabetes remain largely unknown. According to a previous study showing a positive association between green tea consumption and diabetes in China[11], pesticide residue in tea leaves may underlie this association. This finding is supported by evidence from epidemiological and experimental studies. In a meta-analysis of 22 epidemiological studies, a high exposure to any pesticides, particularly organochlorine pesticides, was associated with an increased OR for type 2 diabetes (OR = 1·68 for the highest *v.* lowest category of exposure)[28]. In an experimental study, exposure to organochlorine pesticides enhanced insulin resistance[29]. As pesticide residues in tea leaves were not assessed in this study, it is uncertain to what extent pesticide residues (even if it exists at all) would have explained the observed association

https://doi.org/10.1017/S0007114524000412 Published online by Cambridge University Press

Table 3. Geometric means and 95 % CI of HOMA-IR and HOMA-β according to green tea consumption categories

	Green tea consumption categories												
	0 ml/d (*n* 2235)		< 200 ml/d (*n* 419)		200–< 400 ml/d (*n* 131)		400–< 600 ml/d (*n* 74)		≥ 600 ml/d (*n* 141)				
	Geometric means	95 % CI	Geometric means	95 % CI	Geometric means	95 % CI	Geometric means	95 % CI	Geometric means	95 % CI	*P* for trend*	β per 40 ml/d†	95 % CI
HOMA-IR													
Model 1	1·64	1·59, 1·69	1·78	1·66, 1·90	1·84	1·64, 2·08	1·79	1·54, 2·10	1·74	1·56, 1·95	**0·03**	0·002	–0·001, 0·006
Model 2	1·74	1·52, 1·98	1·82	1·52, 2·10	1·90	1·61, 2·24	1·78	1·48, 2·14	1·89	1·61, 2·22	**0·04**	0·002	–0·001, 0·005
Model 3	1·74	1·52, 1·98	1·82	1·52, 2·10	1·90	1·61, 2·24	1·78	1·48, 2·14	1·89	1·61, 2·22	**0·04**	0·002	–0·001, 0·005
HOMA-β													
Model 1	75·63	73·57, 77·76	80·14	75·46, 85·11	77·04	69·15, 85·83	75·02	65·04, 86·53	73·18	66·00, 81·15	0·89	–0·001	–0·004, 0·002
Model 2	76·51	67·06, 87·29	80·04	69·33, 92·40	79·25	67·00, 93·75	75·37	62·47, 90·92	77·00	65·47, 90·56	0·72	–0·001	–0·004, 0·003
Model 3	76·50	67·05, 87·28	79·93	69·23, 92·28	79·08	66·85, 93·56	75·40	62·49, 90·96	76·90	65·39, 90·45	0·75	–0·001	–0·004, 0·003

HOMA-IR, homeostatic model assessment of insulin resistance; HOMA-β, homeostatic model assessment of β-cell function.
Model 1, adjusted for age (years, continuous) and sex (male or female).
Model 2, further adjusted for marital status (married/cohabiting or not), education (less than primary school, primary school, secondary school or high school or higher), job (government employee, non-government employee, self-employed, farmer or fisherman, houseworker, other or not working), income (low, middle or high), smoking status (never, former or current), alcohol consumption (0, < 1, 1–< 2 or ≥ 2 drinks/d), physical activity (< 600, 600–< 1200 or ≥ 1200 MET-min/week), sleep duration (< 6, 6–< 7, 7–< 8, 8–< 9 or ≥ 9 h/d), fruit consumption (0, < 1, 1–< 2 or ≥ 2 servings/d), vegetable consumption (0, < 1, 1–< 2, 2–< 3 or ≥ 3 servings/d), red meat consumption (0, < 100, 100–< 200 or ≥ 200 g/d), rice consumption (< 2, 2–< 3, 3–< 4, 4–< 6, 6–< 8 or ≥ 8 bowls/d), rice noodle consumption (0, < 2, 2–< 4, 4–< 7 or ≥ 7 bowls/week), coffee consumption (0, < 65, 65–< 130 or ≥ 130 ml/d), other tea consumption (0, < 200, 200–< 400, 400–< 600 or ≥ 600 ml/d), family history of diabetes (yes, no or unknown), BMI categories (< 18·5, 18·5–< 23·0, 23·0–< 25·0, 25·0–< 30·0 or ≥ 30·0 kg/m^2), hypertension (yes or no), dyslipidaemia (yes or no) and depressive symptoms (yes or no).
Model 3, further adjusted for use of additives (yes or no).
Bold values were statistically significant.
* $P_{\text{for trend}}$ was estimated by treating the exposure as a continuous variable in the model for each analysis.
† 40 ml/d is equivalent to 1 Vietnamese tea cup/d.

https://doi.org/10.1017/S0007114524000412 Published online by Cambridge University Press

between green tea consumption and prediabetes/diabetes. In Vietnam, a variety of chemical pesticides have been used for tea cultivation[30], and their improper use (e.g., pesticide overdosage) has been an issue of concern[31]. According to a previous study using data from the Vietnamese Department of Plant Protection, only 23·5–34·1 % of farmers used the recommended dosage of plant protection chemicals for tea cultivation, while many farmers increased the dosage by 3–5 times[31]. However, more information based on direct assessments is necessary to understand the possible influence of pesticides on this association, including the amount of pesticide residue in green tea leaves consumed in this study population.

The present finding of the positive association between green tea consumption and HOMA-IR was consistent with the finding of a previous cross-sectional study of Japanese working population, which showed an association between higher green tea consumption and higher level of HOMA-IR[32]. In another Japanese study, a positive association was found between green tea consumption and insulin resistance defined as fasting plasma insulin ≥ 50 pmol/l among those with BMI ≥ 25·0 kg/m^2, while no association was found when insulin resistance was defined using HOMA-IR[33]. In a multi-ethnic Asian population in Singapore, no clear association was detected between green tea consumption and HOMA-IR[34]. In comparison with the participants in the Singaporean study[34], the individuals who participated in the present study and the aforementioned previous studies reporting the positive association[32,33] consumed green tea more in quantity and frequency. More specifically, the mean green tea consumption was 1·6 cups (344 ml) per week (approximately 50 ml/d) in the Singaporean study[34] while 11·5 % of the participants in the present study consumed ≥ 600 ml of green tea per day; in the previous study among a Japanese working population, 10·3 % of participants consumed five or more cups of green tea daily (≥ approximately 750 ml/d)[32]; and 27·4 % of participants in the other Japanese consumed ≥ 5 cups per day (≥ 500 ml/d)[33]. Thus, the difference in the association between green tea consumption and insulin resistance may be partly attributable to the differences in the amount of green tea consumed by participants across studies. Despite these findings, no previous study has reported an inverse association between green tea consumption and insulin resistance marker (HOMA-IR). Therefore, high quantity and frequency of green tea consumption are associated with increased insulin resistance.

The null association observed between green tea consumption and HOMA-β in the present study was in consistent with the findings of previous studies; null association was found between green tea consumption and HOMA-β in a Japanese working population[32] and in a multi-ethnic Asian population in Singapore[34]. As aforementioned, the quantity and frequency of green tea consumption varied among these studies, but the current evidence from the present and previous studies in Asian populations did not indicate the link between green tea consumption and insulin secretion as assessed by HOMA-β. Further studies are needed to clarify the association between green tea consumption and insulin secretion.

The null association was found between other tea consumption and prediabetes/diabetes, which was not in line with the finding of a previous study showing a positive association between oolong tea consumption and diabetes[35]. However, while lotus tea, jasmine tea and oolong tea were listed as examples of other tea in the questionnaire in this study, some participants seemed to have also consumed herbal tea, which has a different chemical composition in comparison with tea prepared using leaves from the tea plant, *Camellia sinensis*. Thus, our findings should not be directly compared with those of previous studies investigating the association between consumption of specific tea (e.g. oolong tea[6,7,9,35]) and diabetes.

This study had several limitations that require consideration. First, the cross-sectional design of the present study does not allow us to infer causality in relation to the association between green tea consumption and prediabetes/diabetes. For example, individuals with diabetes might have consumed more green tea than healthy individuals as excessive thirst is one of the clinical symptoms of diabetes[36]. Nevertheless, it is noteworthy that the positive association was also observed among those with prediabetes, who typically have fewer symptoms compared with those with diabetes. The observed association in the prediabetes group suggests that factors beyond symptoms may contribute to the link between green tea consumption and glycaemic conditions. Second, the type of diabetes (type 1 and type 2 diabetes) was not distinguished, although type 2 diabetes accounts for approximately 90 % of all diabetes cases worldwide[2]. Third, the proportion of green tea drinkers was relatively low in this study, which may have been due to underreporting. Fourth, while it was presumed that most participants in this study consumed natural green tea, data on the specific types of green tea products were not collected. Fifth, the convenience sampling may have introduced selection bias as participants were selected based on their availability and accessibility. Finally, the sample population may not represent the entire population in Vietnam as this study was conducted in one district in one province in the country. Thus, the findings should be interpreted with caution.

In conclusion, higher green tea consumption was associated with a higher prevalence of prediabetes and diabetes among rural residents in Vietnam. Higher green tea consumption was also associated with a higher level of HOMA-IR, but not with a lower level of HOMA-β. Further studies should be conducted to understand the mechanisms underlying the associations of green tea consumption with prediabetes, diabetes and markers of glucose metabolism.

Acknowledgements

The authors would like to express deep gratitude to the participants of the Khánh Hòa Cardiovascular Study for their participation.

The Khánh Hòa Cardiovascular Study project was funded by the National Center for Global Health and Medicine (19A06; 22A02) and Pfizer Health Research Foundation and the Japan Society for the Promotion of Science (KAKENHI JP19K20536; JP21J01171; 21K17301). These funders had no role in the study design, execution of the study, statistical analyses and interpretation of the data or decision to submit the manuscript for publication.

All authors contributed to the conception, design and interpretation of the data. T. T. P. P., C. Q. N., D. V. Ho., D. C. P., H. X. L. and H. T. D. contributed to the acquisition of data, T. V. P. conducted the biochemical measurement, A. F. contributed to the data analysis, A. F. drafted the manuscript, M. J., A. Y., T. M. and Y. I. contributed to the critical revision of the manuscript and A. F. had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. All authors reviewed the manuscript and approved the final version.

The authors declared no conflict of interest.

This study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures involving research study participants were approved by the Research Ethics Committee at National Center for Global Health and Medicine (NCGM), Tokyo, Japan (approval number: NCGM-G-003172), Pasteur Institute in Nha Trang, Vietnam (approval number: 02/2019/HĐĐĐ-IPN) and the Research Ethics Committee at the University of Tokyo, Tokyo, Japan (approval number: 2021007NI). Written informed consent was obtained from all the participants. Their participation was voluntary and their confidentiality was secured.

Supplementary material

For supplementary material/s referred to in this article, please visit https://doi.org/10.1017/S0007114524000412

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