博 士 論 文

Nutritional epidemiological study on dietary total antioxidant capacity among Japanese populations

（日本人の食事由来全抗酸化能に関する栄養疫学研究）

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CONTENTS

LIST OF ABBREVIATIONS

BDHQ	Brief-type self-administered diet history questionnaire
BMI	Body mass index
CES-D	Center for Epidemiologic Studies Depression Scale
CI	Confidence interval
CRP	C-reactive protein
CVD	Cardiovascular diseases
DHQ	Self-administered diet history questionnaire
DR	Dietary record
EPIC	European Prospective Investigation into Cancer and Nutrition
FC	Food code
Fe	Iron
FFQ	Food frequency questionnaire
FRAP	Ferric reducing ability of plasma
MET	Metabolic equivalent
OR	Odds ratio
ORAC	Oxygen radical absorbance capacity
PBMC	Peripheral blood mononuclear cells
PUFA	Polyunsaturated fatty acid
SF-36	Short form 36-item health survey
TAC	Total antioxidant capacity
TE	Trolox equivalent
TEAC	Trolox equivalent antioxidant capacity
TRAP	Total radical-trapping antioxidant parameter

UK	United Kingdom
USA	United States of America
WF	Weighting factor

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A part of this thesis is based on the following papers.

- Kobayashi S, Murakami K, Sasaki S, Uenishi K, Yamasaki M, Hayabuchi H, Goda T, Oka J, Baba K, Ohki K, Watanabe R, Sugiyamama Y. Dietary total antioxidant capacity from different assays in relation to serum C-reactive protein among young Japanese women. *Nutr J* **11**: 91, 2012.

  http://www.nutritionj.com/content/11/1/91

- Kobayashi S, Asakura K, Suga H, Sasaki S. Inverse association between dietary habits with high total antioxidant capacity and prevalence of frailty among elderly Japanese women: a multicenter cross-sectional study. *J Nutr Health Aging* (accepted), 2014.

  The final publication is available at link.springer.com

  http://link.springer.com/journal/12603

ABSTRACT

***Objective*:** The aims of this study were to develop a total antioxidant capacity (TAC) database of foods; to describe the estimated value of dietary TAC; and to examine the relation of dietary TAC to serum C-reactive protein (CRP) and frailty among Japanese populations.

***Methods*:** To estimate dietary TAC from two diet history questionnaires for Japanese, the TAC value of each food included in the questionnaires was searched for in the PubMed database and assigned to the food using four different assays. Dietary TAC was then estimated in 4273 young (18-22 y), 3873 middle-aged (34-60 y), and 2154 elderly (65-94 y) Japanese women. The relationship between dietary TAC and CRP concentration was assessed among 443 young women. Dietary TAC in relation to frailty was examined among 2121 elderly women.

***Results*:** TAC databases to estimate dietary TAC for Japanese was developed and dietary TAC was estimated in all four assays. The major food contributors to dietary TAC were green tea, coffee, vegetables, and fruits among three generations of Japanese women. Dietary TAC was inversely associated with serum CRP among young Japanese women. A significant inverse association of dietary TAC with frailty was obtained among elderly Japanese women. Intakes of some antioxidant nutrients and foods were also associated with a lower prevalence of frailty, although the associations were not as strong as those of dietary TAC.

***Conclusion*:** Dietary TAC could be estimated in Japanese populations and showed a stronger inverse association with frailty in elderly Japanese women. Epidemiological studies focusing on dietary TAC may aid the development of dietary strategies aimed at improving the health of Japanese.

Key words: Dietary total antioxidant capacity; Diet history questionnaire; Nutritional epidemiology; Elderly Japanese women; Frailty.

INTRODUCTION

1. Background

Epidemiological studies suggest that diets rich in plant foods such as fruits, vegetables, herbs, and spices provide beneficial effects on health status [1]. For example, these dietary patterns have been reported to reduce the risk of developing cancer and cardiovascular diseases (CVD), as well as other age-related chronic conditions [2]. Plants contain a wide variety of nutrients, including vitamin C, vitamin E, carotenoids (e.g. β-carotene, lycopene, and lutein), and flavonoids (e.g. quercetin, kaempfrol, myricetin, luteolin, and apigenin), which are called antioxidants. They may have the potential to prevent chronic diseases mediated by oxidative stress and inflammation by interfering with oxidative damage to DNA, lipids and proteins [2]. The favorable effects of plants on health are assumed to be caused by the reduction of oxidative stress from these antioxidant nutrients [1, 3]. Experimental studies support this 'antioxidant hypothesis' [4].

Although the scientific rationale and observational studies on the beneficial effects of antioxidant nutrients are convincing, randomized intervention trials have failed to show any consistent benefit from the use of antioxidant supplements on CVD or cancer risk, with some trials even suggesting possible harm in certain subgroups [2, 5]. Although most trials have tested the effect of high doses of one or two antioxidants, accumulating mechanistic and epidemiological data suggest that antioxidants act not only individually but also cooperatively, and in some cases synergistically [2]. This may be one of the reasons why the findings of the randomized trials have differed from those of the observational studies. Considering that people consume a large variety of antioxidants at a single meal in daily life, the effect of complex combinations of antioxidant nutrients and foods on health status warrants investigation.

Recently, the new concept of total antioxidant capacity (TAC) was proposed to assess the combined effect of multiple antioxidants [6]. TAC is a useful tool in investigating the effect of the total antioxidant function of samples, and TAC from diet (dietary TAC) is used in epidemiological studies [7]. Many studies have examined the effects of dietary TAC on health status and several favorable effects have been shown (as reviewed in Chapter 1). These results may lead to dietary strategies which effectively reduce the risk of many diseases without relying on single antioxidant nutrients or foods. In other words, if one does not prefer a certain food with high TAC, he/she can choose another food from several candidate foods according to their food preference.

Although epidemiological studies using dietary TAC have been conducted in some Western countries, no studies have been conducted among Asian populations, including Japan, prior to the present study (as reviewed in Chapter 1). Given that food culture and dietary habits vary by country [8], there is a need to carry out these studies in individual countries. To allow the estimation of dietary TAC among the subjects with Japanese-style diet is meaningful for maintenance their health and progress of the studies focusing on dietary TAC.

2. Aims of the present study and structure of this thesis

This study has three main aims, as follows: to develop a TAC database to estimate dietary TAC for Japanese populations using two diet history questionnaires, which have been widely used in previous epidemiological studies (Aim 1); to estimate dietary TAC among Japanese populations and compare values among different age groups (Aim 2); and to examine the relationship between dietary TAC and the health status of Japanese populations (Aim 3).

The structure of this thesis is as follows:

1) In Chapter 1, the author provides an overview of dietary TAC in nutritional epidemiology, showing epidemiological studies on dietary TAC conducted to date.

2) In Chapter 2, the author provides the development of TAC databases to estimate dietary TAC from two diet history questionnaires for Japanese populations (Aim 1).
3) In Chapter 3, the author estimates dietary TAC among three different generations of Japanese women and compares values (Aim 2).
4) In Chapter 4, the author assesses the relation of dietary TAC to serum C-reactive protein among young Japanese women (Aim 3-1).
5) Finally, in Chapter 5, the author examines the association between dietary TAC and frailty, which may be one health outcome with a relationship with oxidative stress, in elderly Japanese women (Aim 3-2).

CHAPTER 1

Dietary total antioxidant capacity in nutritional epidemiology: A review

1.1. Overview of dietary total antioxidant capacity

Total antioxidant capacity (TAC) is a parameter that represents the cumulative effects of all antioxidants present in a sample (food, blood, or tissue) [9]. The sum TAC value of foods in diet is called 'dietary TAC' [5]. Many epidemiological studies have long focused on the effects of single antioxidant nutrients or foods, but studies using dietary TAC have been conducted recently [7]. The major strength of dietary TAC is that it can evaluate the effects of combinations of multiple antioxidants and take the synergistic effects between them into consideration. Because people consume nutrients with complex combinations in meals, dietary TAC is attracting increasing attention as reflecting daily food intake [5]. Also, dietary TAC has been shown to be a potential indicator of diet quality in healthy subjects [10] and is considered a useful tool in evaluating the overall antioxidant function of the diet [4].

Two types of method to assess dietary TAC have been developed, an experimental method and a theoretical method. The experimental method utilizes a food-based TAC database which was constructed by directly measuring the TAC value of individual foods and then calculates dietary TAC by adding the TAC values of the food items [5]. This method captures the antioxidant effects of a wide variety of dietary nutrients, including those of micronutrients that are not well characterized or well measured [11]. To calculate dietary TAC more precisely, however, the TAC value of all foods appearing in a questionnaire or dietary record should be measured. The theoretical method combines a nutrient-based TAC database and a nutrient composition database of food items to calculate dietary TAC [5]. Although the TAC values of foods can be widely obtained with the theoretical method, the TAC derived from unknown antioxidants cannot be considered. A previous study showed that the theoretical TAC of each food was significantly correlated with the TAC value measured by the experimental method [12].

The TAC is measured by assays which measure the direct action of antioxidants with radicals and transition metals based on the redox reaction. Common examples of TAC assays are the ferric reducing ability of plasma (FRAP), oxygen radical absorbance capacity (ORAC), Trolox equivalent antioxidant capacity (TEAC), and total radical-trapping antioxidant parameter (TRAP) [9]. Other assays have also been recently introduced into food analysis [12]. However, the various TAC assays differ from each other in terms of substrates, reaction conditions, and methods, and it is therefore very difficult to compare the results of these assays [9].

Although TAC is considered to be a useful tool in antioxidant intake assessment, its use to evaluate total antioxidant function *in vivo* is controversial because of no reliably predicting antioxidant capacity *in vivo* [13]. Because the value of dietary TAC used in epidemiological studies was only sum of the TAC values of foods composing the diet, it did not assess synergy and cancel effects of antioxidants from different foods. Further, dietary TAC has been only moderately associated with plasma TAC values [14, 15]. However, several studies have demonstrated that consumption of antioxidant-rich foods increases plasma TAC immediately after ingestion [6]. Additionally, other studies have shown that dietary TAC is inversely associated with inflammatory molecules [16-19] and is an independent predictor of plasma β-carotene [20, 21]. These results may suggest the usefulness of dietary TAC in assessing the effect of antioxidant intake. With regard to long-term diet, however, plasma TAC measurements may not provide an appropriate reference for dietary TAC. Consequently, dietary TAC has been used in many epidemiological studies to date, despite the controversy over its use.

1.2. Epidemiological studies of dietary total antioxidant capacity

Although one review study has partly focused on the associations between dietary TAC and cardiovascular diseases (CVD) [5], no comprehensive review of epidemiological studies focused on dietary TAC has appeared. Therefore, the author searched the PubMed database (National Library of Medicine, Bethesda, MD) to identify epidemiological studies reporting dietary TAC published to date using the following search strategy: (food OR diet OR dietary OR intake OR consumption) AND "total antioxidant". The search was limited to English-language reports published up to the end of September 2013. Studies included in this review were observational or intervention studies that used the concept of dietary TAC. Studies using TAC from single foods were excluded. A total of 1601 articles were identified by this PubMed database search. The titles and abstracts of all articles were reviewed to determine whether they should be included, following which 40 articles were considered eligible. Reference lists from the articles were also reviewed to identify additional papers that were not retrieved in the PubMed search, by which a further five articles were considered eligible, giving a total of 45 articles were identified (**Figure 1**). Among these studies, 10 studies were descriptive studies, which did not examine the relation to health outcome, but rather estimated dietary TAC or validated the estimated dietary TAC (**Table 1-1**). The other 35 studies, including 29 observational studies (**Table 1-2**) and 6 intervention studies (**Table 1-3**), examined the relation to health outcome.

1.3. Descriptive studies of dietary total antioxidant capacity

All descriptive studies [10, 14, 15, 20, 22-27] were conducted in Western countries. The subjects in these studies were adults or elderly subjects. While almost all of the studies estimated dietary TAC using the experimental method, three studies conducted in the USA used the theoretical method [24, 26, 27]. Only three studies described the development of the estimation method, the values obtained, and the major contributing foods to dietary TAC [22-24]. For six validation studies, although dietary TAC from dietary records was correlated with that from a food frequency questionnaire [14] and plasma β-carotene concentration [20], only a modest or no correlation was observed between dietary TAC and plasma TAC level [14, 15, 25]. In terms of theoretical dietary TAC, subjects consuming a high TAC diet showed a high plasma TAC level [26, 27]. Meanwhile, dietary TAC was shown to be associated with a healthy dietary pattern [10].

1.4. Observational studies of dietary total antioxidant capacity

A total of 29 observational studies examining the association of dietary TAC with health outcome were identified in the PubMed search [7, 11, 16-18, 28-51]. Dietary TAC was examined in relation to various health outcomes, including cancers [7, 32, 38, 39, 41-43, 49, 51], CVD [35, 40, 46, 50], inflammation [16-18, 31, 45, 48], metabolic syndrome [29, 30, 35, 37, 44, 47], brain function [11, 33], lung function [36], and mortality [28]. Although some studies [11, 31, 38, 43] showed no significant associations between dietary TAC and health outcomes, others did show favorable associations of dietary TAC with health. Almost all of the studies were conducted in Western populations. Those studies which were conducted in Asian populations, including Iranian [44, 47] and Japanese [45] populations, appeared after 2012, and studies conducted in non-Western populations were sparse.

1.5. Intervention studies of dietary total antioxidant capacity

Six studies obtained from the PubMed search focused on dietary TAC in interventional studies [19, 21, 52-55]. Inflammation [19], gut function [52], endothelial function [53], and metabolic syndrome [55] were examined in relation to dietary TAC, and the favorable effects of dietary TAC on health status were observed. Also, a high TAC diet increased plasma β-carotene concentration level [21]. Meanwhile, high adherence to the Mediterranean diet increased dietary TAC and plasma TAC [54]. All four studies conducted in Italy were targeted at the same cohort [19, 21, 52, 53]. The other two studies were also conducted in Western countries [54, 55].

1.6. Conclusion

Since the first epidemiological study using dietary TAC was conducted in 2002 [7], many epidemiological studies focusing on dietary TAC have been conducted. Despite controversy regarding the evaluation of total antioxidant function *in vivo* [13], many methods to estimate dietary TAC were developed and various health outcomes were examined in relation to dietary TAC. Almost all the previous studies were conducted in Western countries, and many suggested that a high TAC diet had a favorable effect on health status. This review implied that studies focusing on dietary TAC can also provide useful dietary information in non-Western populations. However, studies in non-Western countries, including Japan, were sparse. Before this doctoral thesis was planned in 2011, no study had reported dietary TAC among Japanese populations. This review revealed the shortage of studies focusing on dietary TAC in non-Western populations, and this is the first study to report dietary TAC among a Japanese population.

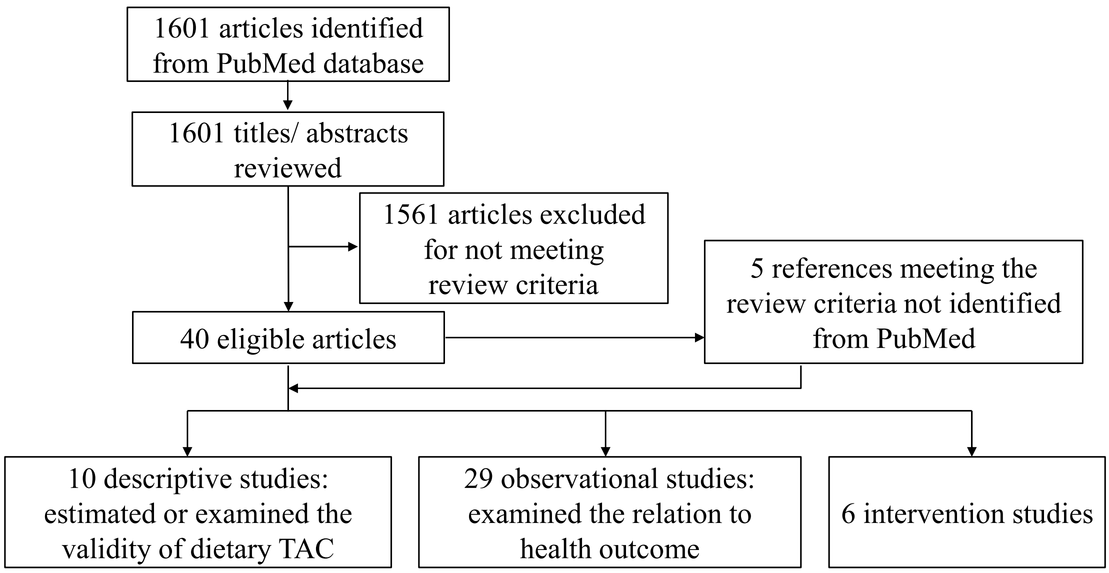

Figure 1. Flow diagram for the literature search and study selection

Table 1-1. Descriptive studies reporting dietary total antioxidant capacity*

No.	Authors and year	Country	Study	Subjects	Sex and sample size	Age	Diet	Reference	TAC assay
1	Valtuena S, et al. 2007 [20]	Italy	Validation	Workers and previous workers of a food company; subjects in a survey, 1981-1993	M+W: 247 (140 + 107)	35-88 y	3d-DR	Plasma (β-carotene)	TEAC [56, 57]
2	Pellegrini N, et al. 2007 [14]	Italy	Validation	Workers and previous workers of a food company; subjects in a survey, 1981-1993	M: 159 W: 126	35-88 y	FFQ 3d-DR	3d-DR Plasma	FRAP [56, 57] TEAC [56, 57] TRAP [56, 57]
3	Rautiainen S, et al. 2008 [15]	Sweden	Validation and reproducibility	Swedish Mammography Cohort, 1987-1990	W Validation: 108 Reproducibility: 300	54-73 y 56-75 y	FFQ1	Plasma FFQ2	FRAP [58] ORAC [59-61] TRAP [56, 57]
4	Haleem MA, et al. 2008 [22]	UK	Estimation	National Diet and Nutrition Survey cohort, 2000-2001	M+W: 1,724	19-64 y	7d-DR	-	FRAP [22] for fruits and vegetables
5	Puchau B, et al. 2009 [10]	Spain	Estimation (comparison with other dietary indicators)	Healthy young adults; subjects in a survey (year is not described)	M+W: 153 (52 + 101)	Mean: 20.8 y	FFQ	-	FRAP [56-58, 62]
6	Dilis V, et al. 2010 [23]	Greece	Estimation	Greek-EPIC cohort, 1994-1999	M: 11,954 W: 16,618	Median: 51 y 54 y	FFQ	-	FRAP [56-58] ORAC [63] TEAC [56, 57] TRAP [56, 57]
7	Yang M, et al. 2011 [24]	USA	Estimation	National Health and Nutrition Examination Survey cohort, 2001-2002	M+W: 4,391 (2,247 + 2,144)	>19 y	24h-recall	-	Theoretical TAC [12]

(Continued)

Table 1-1. (Continued)

No.	Authors and year	Country	Study	Subjects	Sex and sample size	Age	Diet	Reference	TAC assay
8	Khalil A, et al. 2011 [25]	Canada	Validation	Quebec Longitudinal Study on Nutrition and Successful Aging cohort, 2003-2004	M+W: 94 (51 + 43)	68-82 y	24h-recall	Plasma	ORAC [63]
9	Wang Y, et al. 2012 [26]	USA	Validation	Overweight/obese, nonsmoking postmenopausal women; subjects in a survey (year is not described)	W: 40	40-70 y	7d-DR	Plasma	Theoretical TAC [12]
10	Wang Y, et al. 2012 [27]	USA	Validation	Healthy students; subjects in a survey (year is not described)	M+W: 60 (20 + 40)	18-25 y	30d-DR	Plasma	Theoretical TAC [12]

DR, dietary record; FFQ, food frequency questionnaire; FRAP, ferric reducing ability of plasma; M, men; ORAC, oxygen radical absorbance capacity; TAC, total antioxidant capacity; TEAC, Trolox equivalent antioxidant capacity; TRAP, total radical-trapping antioxidant parameter; UK, United Kingdom; W, women

* PubMed database was searched to the end of September 2013 using the following terms: (food OR diet OR dietary OR intake OR consumption) AND "total antioxidant". No study in this table examined the relation of dietary TAC to health outcomes.

Table 1-2. Observational studies reporting dietary total antioxidant capacity*

No.	Authors and year	Country	Design	Subjects	Sex and sample size	Age	Diet	TAC assay	Health outcome
1	Serafini M, et al. 2002 [7]	Sweden	Case-control	Community dwellings; subjects in a survey, 1989-1995	M+W Case: 505 Control: 1116	40-79 y	FFQ	ORAC [64, 65] for fruits and vegetables	Gastric cancer
2	Brighenti F, et al. 2005 [16]	Italy	Cross-sectional	Workers and previous workers of a food company; subjects in a survey, 1981-1993	M+W: 243 (138 + 105)	35-88 y	3d-DR	TEAC [56] and unpublished data	Inflammatory markers from plasma
3	Agudo A, et al. 2007 [28]	Spain	Prospective cohort (11.3-year follow up)	Spain-EPIC cohort, 1992-1996	M+W: 41,358 (15,610 + 25,748)	30-69 y	DHQ	FRAP [56] ORAC [59] TEAC [56] TRAP [56]	Total mortality
4	Puchau B, et al. 2010 [29]	Spain	Cross-sectional	Healthy young adults; subjects in a survey, 1995	M+W: 153 (52 + 101)	Mean: 20.8 y	FFQ	FRAP [56-58, 62, 66]	Metabolic syndrome features
5	Puchau B, et al. 2010 [30]	Spain	Case-control	Children and adolescent; subjects in a survey (year is not described)	M+W Case: 184 Control: 185	6-18 y	FFQ	FRAP [56-58, 62, 66]	Obesity
6	Detopoulou P, et al. 2010 [17]	Greece	Cross-sectional	ATTICA study cohort, 2001-2002	M+W: 532 (310 + 222)	Mean M: 40.7 y W: 38.1 y	FFQ	FRAP [56, 57] TEAC [56, 57] TRAP [56, 57]	Inflammatory markers from blood
7	Costenbader KH, et al. 2010 [31]	USA	Prospective cohort (21.1- and 11.4-year follow up)	Nurses' Health Study (NHS) cohort, 1990 and NHS II cohort, 1991	W NHS: 90,721 NHSII: 93,922	44-69 y 27-44 y	FFQ	FRAP [4, 62]	Rheumatoid arthritis and systemic lupus erythematosus
8	Hermsdorff HH, et al. 2010 [18]	Spain	Cross-sectional	Healthy young adults; subjects in a survey (year is not described)	M+W: 120 (50 + 70)	18-30 y	FFQ	FRAP [56-58, 62, 66]	Inflammatory markers from plasma and gene expression of the markers from PBMC

(Continued)

Table 1-2. (Continued)

No.	Authors and year	Country	Design	Subjects	Sex and sample size	Age	Diet	TAC assay	Health outcome
9	Mekary RA, et al. 2010 [32]	USA	Prospective cohort (18-year follow up)	Health Professionals Follow-up Study cohort, 1986	M: 47,339	40-75 y	FFQ	FRAP [4, 62] and unpublished data	Colorectal cancer
10	Devore EE, et al. 2010 [33]	USA	Prospective cohort (4.2-year follow up)	Nurses' Health Study (NHS) cohort, 1976-	W: 16,010	>70 y	FFQ	FRAP [58]	Cognitive function
11	Psaltopoulou T, et al. 2011 [34]	Greece	Cross-sectional	ATTICA study cohort, 2001-2002	M+W: 1,018 (551 + 467)	Mean M: 41 y W: 38 y	FFQ	FRAP [56, 57] TEAC [56, 57] TRAP [56, 57]	Diabetes biomarkers
12	Del Rio D, et al. 2011 [35]	Italy	Prospective cohort (7.9-year follow up)	Italy-EPIC cohort, 1993-1998	M+W: 41,620	Median: 50 y	FFQ	TEAC [56, 57]	Ischemic and hemorrhagic stroke
13	di Giuseppe R, et al. 2011 [36]	Italy	Cross-sectional	Moli-sani Project cohort, 2005-2009	M: 5,848 W: 5,824	≥35 y	FFQ	FRAP [56, 57] TEAC [56, 57] TRAP [56, 57]	Lung function
14	Hermsdorff HH, et al. 2011 [37]	Brazil Spain	Cross-sectional	Healthy young adults; subjects in a survey, 2005-2006	M+W: 266 (Brazil: 57 + 66, Spain: 48 + 95)	18-35 y	3d-DR FFQ	FRAP[56-58, 62, 66]	Adiposity, metabolic and oxidative stress markers
15	Chang ET, et al. 2011 [38]	USA	Prospective cohort (12.1-year follow up)	California Teachers Study cohort, 1995-1996	W: 110,215	20-85 y	FFQ	ORAC [64, 65] for fruits and vegetables	Lymphoid malignancies
16	Holtan SG, et al. 2012 [39]	USA	Case-control	Patients of Mayo Clinic; subjects in a survey, 2002-2008	M+W Case: 603 Control: 1007	≥20 y	FFQ	ORAC [63]	Non-Hodgkin lymphoma
17	Rautiainen S, et al. 2012 [40]	Sweden	Prospective cohort (11.5-year follow up)	Swedish Mammography Cohort, 1987-1990	W CVD(-): 31,035 CVD(+): 5,680	49-83 y	FFQ	ORAC [59-61]	Stroke

(Continued)

Table 1-2. (Continued)

No.	Authors and year	Country	Design	Subjects	Sex and sample size	Age	Diet	TAC assay	Health outcome
18	Serafini M, et al. 2012 [41]	10 European countries	Prospective cohort (last follow up: 2003-2006)	EPIC cohort, 1992-1998	M: 143,721 W: 339,579	Mostly 35-70 y	FFQ and DR	FRAP [56, 57] TRAP [56, 57]	Gastric cancer
19	Gifkins D, et al. 2012 [42]	USA	Case-control	Estrogen, Diet, Genetics, and Endometrial Cancer Study cohort, 2001-2006	W Case: 417 Control: 395	≥21 y	FFQ	FRAP [67] ORAC [68]	Endometrial cancer
20	Gifkins D, et al. 2012 [43]	USA	Case-control	New Jersey Ovarian Cancer Study cohort, 2004-2008	W Case: 205 Control: 391	≥21 y	FFQ	FRAP [67] ORAC [68]	Epithelial ovarian cancer
21	Bahadoran Z, et al. 2012 [44]	Iran	Prospective cohort (3-year follow up)	Teheran Lipid and Glucose Study cohort, 2006-2008	M+W: 1,938	19-70 y	FFQ	ORAC [68]	Metabolic syndrome components
22	Kobayashi S, et al. 2012 [45]	Japan	Cross-sectional	Young women; subjects in a survey, 2006	W: 474	18-22 y	DHQ	FRAP (Chapter 2) ORAC (Chapter 2) TEAC (Chapter 2) TRAP (Chapter 2)	C-reactive protein from serum
23	Rautiainen S, et al. 2012 [46]	Sweden	Prospective cohort (9.9-year follow up)	Swedish Mammography Cohort, 1987-1990	W: 32,561	49-83 y	FFQ	ORAC [59-61]	Myocardial infarction
24	Farvid MS, et al. 2013 [47]	Iran	Cross-sectional	Type 2 diabetic patients; subjects in a survey (year is not described)	M+W: 506 (228 + 278)	28-75 y	FFQ	ORAC [68] for fruits, vegetables, legumes, and nuts	Hypertension
25	Devore EE, et al. 2013 [11]	Netherland	Prospective cohort (13.8-year follow up)	Rotterdam Study cohort, 1990	M+W: 5,395	≥55 y	FFQ	FRAP [67]	Dementia, stroke, and brain volume

(Continued)

Table 1-2. (Continued)

No.	Authors and year	Country	Design	Subjects	Sex and sample size	Age	Diet	TAC assay	Health outcome
26	Yang M, et al. 2013 [48]	USA	Cross-sectional	National Health and Nutrition Examination Survey cohort, 2001-2002	M+W: 4,391	>19 y	24h-rec all	Theoretical TAC [12]	C-reactive protein from serum and total homocysteine from plasma
27	La Vecchia C, et al. 2013 [49]	Italy	Case-control	Multicenter case-control study cohort, 1992-1996	M+W Case: 1,953 Control: 4,154	19-74 y	FFQ	FRAP [56, 57] TEAC [56, 57] TRAP [56, 57]	Colorectal cancer
28	Rautiainen S, et al. 2013 [50]	Sweden	Prospective cohort (11.3-year follow up)	Swedish Mammography Cohort, 1987-1990	W: 33,713	49-83 y	FFQ	ORAC [59, 61]	Heart failure
29	Russnes KM, et al. 2013 [51]	USA	Prospective cohort (22-year follow up)	Health Professionals Follow-up Study cohort, 1986	M: 47,896	40-75 y	FFQ	FRAP [67]	Prostate cancer

DHQ, diet history questionnaire; DR, dietary record; EPIC, European Prospective Investigation into Cancer and Nutrition; FFQ, food frequency questionnaire; FRAP, ferric reducing ability of plasma; M, men; ORAC, oxygen radical absorbance capacity; PBMC, peripheral blood mononuclear cells; TAC, total antioxidant capacity; TEAC, Trolox equivalent antioxidant capacity; TRAP, total radical-trapping antioxidant parameter; USA, United States of America; W, women.
* PubMed database was searched to the end of September 2013 using the following terms: (food OR diet OR dietary OR intake OR consumption) AND "total antioxidant". All studies in this table are observational studies which examined the relation of dietary TAC with health outcomes.

Table 1-3. Intervention studies reporting dietary total antioxidant capacity*

No.	Authors and year	Country	Subjects	Sex and sample size	Age	Diet	TAC assay	Intervention	Health outcome
1	Valtuena S, et al. 2008 [19]	Italy	Workers and previous workers of a food company; subjects in a survey, 1981-1993	M+W: 33 (19 +14)	35-88 y	FFQ 3d-DR	FRAP [56, 57]	Crossover design: High-TAC diet (2 wk), low-TAC diet (2 wk), washout (2 wk)	Inflammatory markers from blood and liver dysfunction
2	Del Rio D, et al. 2009 [21]	Italy	Workers and previous workers of a food company; subjects in a survey, 1981-1993	M+W: 33 (19 +14)	35-88 y	FFQ 3d-DR	TEAC [56, 57]	Crossover design: High-TAC diet (2 wk), low-TAC diet (2 wk), washout (2 wk)	Carotenoids from plasma
3	Bianchi MA, et al. 2010 [52]	Italy	Workers and previous workers of a food company; subjects in a survey, 1981-1993	M+W: 19 (9 +10)	35-88 y	FFQ 3d-DR	FRAP [56, 57]	Crossover design: High-TAC diet (2 wk), low-TAC diet (2 wk), washout (2 wk)	Gut function
4	Franzini L, et al. 2012 [53]	Italy	Workers and previous workers of a food company; subjects in a survey, 1981-1993	M+W: 24 (11 +13)	35-88 y	FFQ 3d-DR	FRAP [56, 57]	Crossover design: High-TAC diet (2 wk), low-TAC diet (2 wk), washout (2 wk)	Endothelial function
5	Kolomvotsou AI, et al. 2013 [54]	Greece	Abdominal obesity adults; subjects in a survey (year is not described)	M+W: 82 (43 + 29)	≤70 y	3d-DR (2 times)	ORAC [68]	Randomized controlled trial: Mediterranean diet (8 wk)	Dietary TAC and TAC from plasma
6	Lopez Legarrea P, et al. 2013 [55]	Spain	Metabolic Syndrome Reduction in Navarra-Spain cohort, 2009	M+W: 96 (51 +45)	Mean: 49 y	FFQ 2d-DR	FRAP [67]	Randomized controlled trial: Energy restricted and high antioxidants diet composed of 7 meals/day (8 wk)	Metabolic syndrome markers

DR, dietary record; FFQ, food frequency questionnaire; FRAP, ferric reducing ability of plasma; M, men; ORAC, oxygen radical absorbance capacity; TAC, total antioxidant capacity; TEAC, Trolox equivalent antioxidant capacity; W, women.

* PubMed database was searched to the end of September, 2013 using the following terms: (food OR diet OR dietary OR intake OR consumption) AND "total antioxidant". All studies in this table were interventional studies which examined the relation of dietary TAC with health outcomes.

CHAPTER 2

Development of a total antioxidant capacity database of foods in diet history questionnaires for Japanese populations

2.1. Introduction

Although previous studies showed that dietary TAC was associated with many health outcomes and suggested that dietary TAC had a favorable effect on health (Chapter 1), these studies were conducted in Western countries only. Given that food culture and dietary habits vary by country [8], the food source of dietary TAC at the intake level may differ in each country, and thus the association should be evaluated in non-Western countries, including Japan. To date, however, no such study of dietary TAC in a Japanese population has been conducted. Further, no method for estimating dietary TAC in Japanese has been available.

In this chapter, the author developed TAC databases of individual foods to allow the estimation of dietary TAC from two diet history questionnaires developed for Japanese populations. The experimental method was selected for its ability to estimate dietary TAC in consideration of its ability to capture antioxidant effects of unknown micronutrients, and of the wide availability of TAC databases of foods.

2.2. Methods

2.2.1. Structure of diet history questionnaires

The author developed TAC databases for previously validated self-administered diet history questionnaire (DHQ) and brief-type self-administered diet history questionnaire (BDHQ) among Japanese adults [69-71].

The DHQ in this chapter is a 22-page semi-quantitative questionnaire slightly modified with previous version [69-71] that asks dietary habits during the previous month and can assess habitual dietary intake. Since the food item of skim milk was deleted from and soybean milk and salted green and yellow vegetable pickles were added to the previous version, a total of 151 foods and beverages can be estimated. The DHQ consists of the following six sections: 1) general dietary behavior, including preference for seasonings; 2) usual cooking methods for fish and shellfish, meat, eggs and vegetables; 3) consumption frequency and amount of six alcoholic beverages; 4) consumption frequency and semi-quantitative portion size of selected food and nonalcoholic beverage items; 5) consumption frequency and semi-quantitative portion size of staple foods (rice, other grains, noodles, bread and other wheat products), and miso (fermented soybean paste) soup, assessed for each eating occasion (breakfast, lunch, dinner and snacks) separately, with questions on the size of the bowl or cup usually used for rice and miso soup; and 6) open-ended items for foods consumed more than once weekly but not appearing in the DHQ. The food and beverage items were selected as foods commonly consumed in Japan, mainly from a food list used in the National Nutrition Survey of Japan, whereas standard portion sizes and sizes of bowls and cups for rice and miso soup were derived mainly from several recipe books for Japanese dishes [69]. Estimates of dietary intake for 151 food and beverage items and selected nutrients were calculated using an *ad hoc* computer algorithm for the DHQ. A previous validation study among 92 adult women aged 31 to 69 years by using the 16-day dietary record (DR) as a reference reported Pearson's correlation coefficients was 0.32 for energy and the median value of nutrients was 0.57 (range: 0.27 to 0.87) [71]. In addition, the median value of Spearman's correlation coefficients of food groups was 0.43 (range: -0.09 to 0.77) [70].

The BDHQ is originally a four-page structured questionnaire. Because the BDHQ in this chapter is written with large letters to make it easier for elderly to read and write and has the same structure as the original version [70, 71], it consists of 10-pages. The BDHQ assesses the intakes of 58 food and beverage items and dietary habits during the preceding month. The following five sections are consisted: 1) intake frequency of forty-six food and non-alcoholic beverage items; 2) daily intake of rice, including type of rice (refined or unrefined, etc), and miso soup; 3) frequency of drinking alcoholic beverages and amount per drink for five alcoholic beverages; 4) usual cooking methods; and 5) general dietary behavior. Most food and beverage items were selected from the food list of the DHQ as those that are very commonly consumed in Japan, with some modifications using a food list used in the National Health and Nutrition Survey of Japan as additional information [69, 72]. Standard portion sizes, and adult sizes of bowls for rice and cups for miso soup, were derived from several recipe books for Japanese dishes. Estimates of dietary intake for 58 food and beverage items and selected nutrients were calculated using an *ad hoc* computer algorithm for the BDHQ. Pearson's correlation coefficients between the BDHQ and the 16-day DR among 92 adult women was 0.31 for energy. The median value of nutrients was 0.54 (range: 0.34 to 0.87) [71]. In addition, the median value of Spearman's correlation coefficients of food groups was 0.44 (range: 0.14 to 0.82) [70].

2.2.2. Development of a dietary total antioxidant capacity database for the DHQ

TAC values were assigned to items in the DHQ. Among the 151 food items in the DHQ, 53 foods were determined to contain no TAC value because they contained no or only trace amount of antioxidant nutrients such as carotenes, vitamin C, or vitamin E (e.g., animal foods and refined foods). We therefore searched for the analytical TAC value of the remaining 98 foods in the DHQ using four assays such as FRAP, ORAC, TEAC, and TRAP (**Figure 2**).

Studies reporting the analytical TAC value of foods were identified by searching the PubMed database, which resulted in many TAC values for assignment to specific foods (about 70% of 98 foods). If we could not obtain a TAC value from PubMed, we searched the database of one journal, *Food Chemistry*, which was frequently referred to in the papers obtained from the PubMed search. The TAC values of four foods for ORAC and 11 foods for TEAC were obtained from this journal database only [73-78]. We therefore used papers in the literature reporting TAC values of food in analytical data for FRAP [56-58, 62, 67, 79, 80], ORAC [61, 64, 65, 68, 73, 74, 81-90], TEAC[56, 57, 75-78, 91-93], and TRAP [56, 57]. TAC values were expressed as mmol Fe^{2+}/100 g of food for FRAP or as mmol of Trolox equivalent (mmol TE)/100 g of food for ORAC, TEAC, and TRAP.

To determine the TAC values of the 98 foods in the DHQ, the TAC values of 145 individual foods, which composed food items in the DHQ and listed in the *Standard Tables of Food Composition in Japan* [94], were needed (**Table 2-1**). When the individual food was fresh food, the TAC value of fresh food was searched. When the individual food was cooked food, the TAC value of cooked food was searched. The author assigned these TAC values according to the following steps.

Step 1. Assigning the analytical value.

When the analytical TAC value for a specific food could be obtained, the mean TAC value was calculated by weighting the number of foods analyzed in each study, and the mean value was assigned (FRAP: n = 58, ORAC: n = 30, TEAC: n = 30, and TRAP: n = 29; "n" means the number of TAC values of individual foods).

Step 2. Assigning a substituted value.

When the analytical TAC value for a specific food could not be obtained by Step 1, the mean value of similar foods or a different form of the same food was assigned (FRAP: n = 30, ORAC: n = 29, TEAC: n = 34, and TRAP: n = 27).

Step 3. Assigning a calculated value.

For fresh foods, if the TAC value of the food was obtained in dry matter only, the TAC value was calculated using the dry matter value and the proportion of water in the fresh food. For processed foods, if we obtained the TAC values of the ingredient foods, TAC values were calculated by the values of the ingredient foods and their proportion of the total food component. When we obtained a TAC value by these calculations, this calculated value was assigned (FRAP: n = 36, ORAC: n = 49, TEAC: n = 51, and TRAP: n = 31).

Step 4. Assigning no value.

When we could not determine the TAC value by any of the above steps, no TAC value was assigned (FRAP: n = 21, ORAC: n = 37, TEAC: n = 30, and TRAP: n = 58).

The TAC value of each food in the DHQ was determined from the assigned TAC values of individual foods above steps and weighting factors included in an *ad hoc* computer algorithm for the DHQ [70, 71].

2.2.3. Development of a dietary total antioxidant capacity database for the BDHQ

The BDHQ assesses a total of 58 food and beverage items. Here, using the same method of the DHQ, we assigned a TAC value of FRAP, ORAC, TEAC, and TRAP assay to each food item in the BDHQ. Among the 58 food items in the BDHQ, 22 were determined to contain no TAC value, therefore, the author searched for the analytical TAC value of the remaining 36 foods in the BDHQ (Figure 2). To determine the TAC values of the 36 foods in the BDHQ, the TAC values of 90 individual foods listed in the *Standard Tables of Food Composition in Japan* were needed (**Table 2-2**).

According to the same methods of the DHQ, the author assigned the individual foods to the analytical TAC value by Step 1 (FRAP: n = 37, ORAC: n = 31, TEAC: n = 28, and TRAP: n = 27), the substituted TAC value by Step 2 (FRAP: n = 20, ORAC: n = 11, TEAC: n = 20, and TRAP: n = 16), the calculated TAC value by Step 3 (FRAP: n = 21, ORAC: n = 24, TEAC: n = 24, and TRAP: n = 12), and no TAC value by Step 4 (FRAP: n = 12, ORAC: n = 24, TEAC: n = 18, and TRAP: n = 35).

The TAC value of each food in the BDHQ was determined from the assigned TAC values of individual foods and weighting factors for the BDHQ [70, 71].

2.3. Results

Of the 98 foods in the DHQ whose TAC values were sought, 12 could not be assigned a value by any of the four methods. Values for the remaining 86 food items in the DHQ were presented in **Table 2-3**. The TAC values were determined in 82 foods for FRAP, 72 foods for ORAC, 75 foods for TEAC, and 59 foods for TRAP. For the BDHQ, TAC values of the 36 foods in the BDHQ were sought. Since three foods could not be assigned a value by any of the four methods, TAC values for the remaining 33 food items in the BDHQ were presented in **Table 2-4**. The TAC values were determined in 32 foods for FRAP, 26 foods for ORAC, 31 foods for TEAC, and 25 foods for TRAP.

For the foods which could obtain TAC values in all four assays, TAC values of chocolate and coffee was the two highest in those of all foods. Some fruits and vegetables also had relatively high TAC values.

2.4. Discussion

In the present chapter, TAC databases for the DHQ and the BDHQ were developed in four different assays of FRAP, ORAC, TEAC, and TRAP. The TRAP databases [56, 57] contain the TAC values of only a limited number of foods, and those of 39 foods in the DHQ and 11 foods in the BDHQ could not be obtained. In contrast, the FRAP databases [58, 62, 67, 79] contain an extensive number of foods, and values could not be obtained for only 16 foods in the DHQ and four in the BDHQ. Further, most foods in the FRAP assay were assigned an analytical rather than a substituted or calculated TAC value compared to the other assays. These different results were probably due to the different antioxidant mechanisms derived from different substrates, reaction conditions, and quantification methods [9].

TAC data on Japanese foods were available from only one ORAC database [88]. Available databases of TAC values are based on the foods in other countries. This is the limitation of the present study. Although no study compared the TAC values of foods from different regions, different values were likely to be observed if the TAC values were obtained from the analysis of foods consumed in Japan, because the antioxidant content can vary with geographic location and growing condition [95]. However, the rank order of the TAC values of each food in the food groups was similar in four assays. These similar trends of TAC values in all four assays implied that the effect of using TAC databases in several countries might not be critical problem in the present study.

In this chapter, the preparation of estimating dietary TAC among Japanese from the DHQ and the BDHQ was completed.

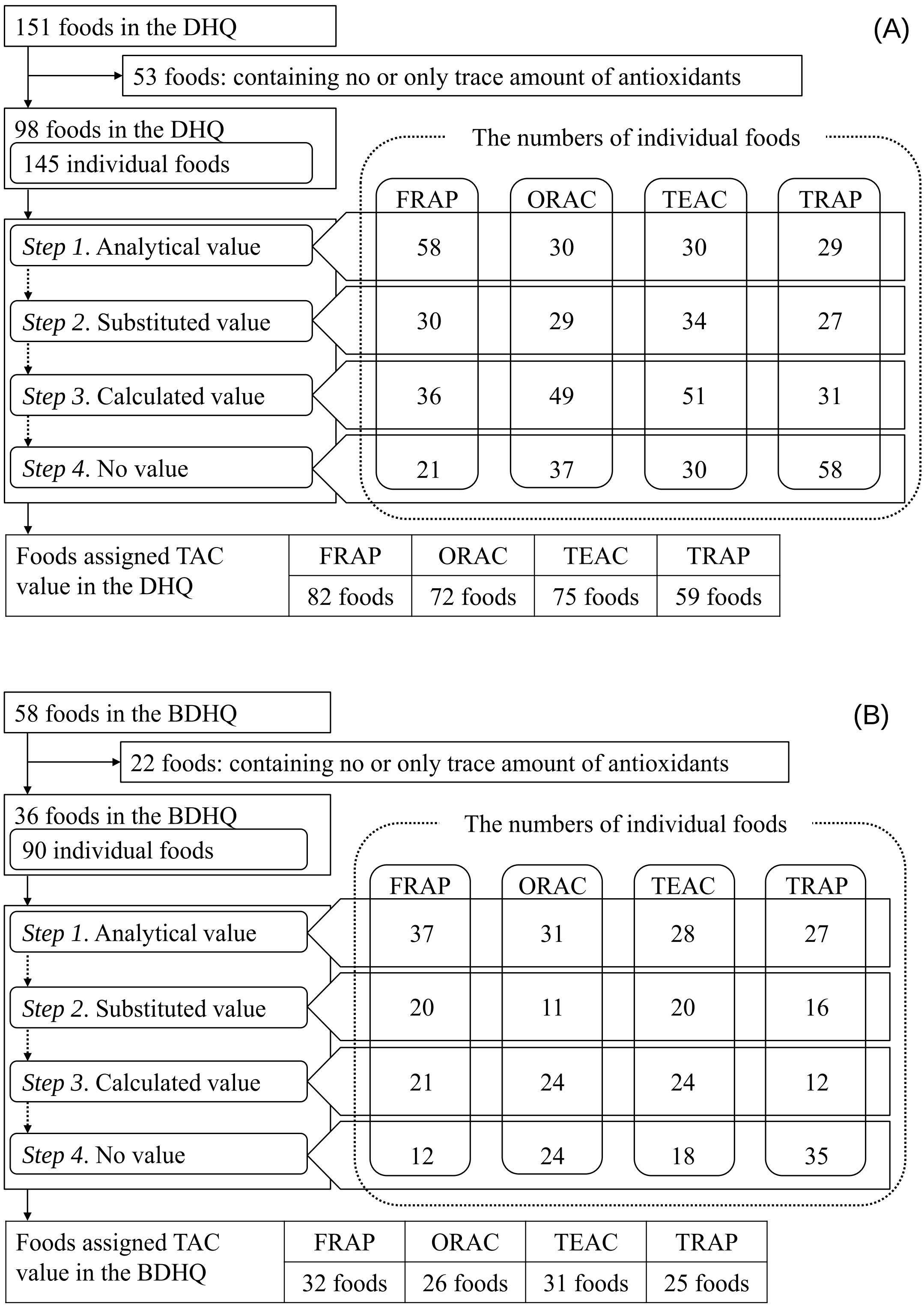

Figure 2. Number of foods included in the DHQ or BDHQ and assigned a TAC value. The numbers of the foods in the DHQ were shown in (A) and those in the BDHQ were shown in (B). BDHQ, brief-type self-administered diet history questionnaire; DHQ, self-administered diet history questionnaire; FRAP, ferric reducing ability of plasma; ORAC, oxygen radical absorbance capacity; TAC, total antioxidant capacity; TEAC, Trolox equivalent antioxidant capacity; TRAP, total radical-trapping antioxidant parameter.

Table 2-1. Total antioxidant capacity of 145 individual food items composed of 98 foods in the self-administered diet history questionnaire

			FRAP (mmol Fe^{2+}/100 g)			ORAC (mmol TE/ 100g)			TEAC (mmol TE/100g)			TRAP (mmol TE/100g)		
Food item in the DHQ*	FC†	WF‡	Step§	Reference	TAC	Step§	Reference	TAC	Step§	Reference	TAC	Step§	Reference	TAC
Cereals														
Well-milled rice	01088	1.00	1	Instant white rice, cooked [58]	0.02	4	-	-	3	Rice (white) [57]	0.10	3	Rice (white) [57]	0.18
Well-milled rice mixed with barley‖	01083	0.29	1	Rice (NS; grain, fast; grain, Jasmin; whole grain) [67]; Rice, grains, milled white [62]; Rice (white) [57]	0.17	4	-	-	1	Rice (white) [57]	0.22	1	Rice (white) [57]	0.37
	01005	0.13	3	Barley, wholemeal flour, crushed [67]; Barley, wholemeal flour [62]; Barley [57]	0.83	3	Bareley, whole ground, yellow [81]	3.13	3	Barley [57]	0.30	3	Barley [57]	0.27
Well-milled rice with germ	01089	1.00	3	Rice (NS; grain, fast; grain, Jasmin; whole grain); Rice, brown, (ecologically, grown; grain, Basmati) [67]; Rice, grains, milled white; Rice, grains, milled brown [62]; Rice (white); Rice (brown) [57]	0.10	3	Rice bran, crude [68]	0.13	3	Rice (white); Rice (brown) [57]	0.11	3	Rice (white); Rice (brown) [57]	0.18
Half-milled rice	01086	1.00	3	Rice (NS; grain, fast; grain, Jasmin; whole grain); Rice, brown, (ecologically, grown; grain, Basmati) [67]; Rice, grains, milled white; Rice, grains, milled brown [62]; Rice (white); Rice (brown) [57]	0.21	3	Rice bran, crude [68]	0.60	3	Rice (white); Rice (brown) [57]	0.14	3	Rice (white); Rice (brown) [57]	0.20

(Continued)

Table 2-1. (Continued)

Food item in the DHQ*	FC†	WF‡	FRAP (mmol Fe^{2+}/100 g) Step§	Reference	TAC	ORAC (mmol TE/ 100g) Step§	Reference	TAC	TEAC (mmol TE/100g) Step§	Reference	TAC	TRAP (mmol TE/100g) Step§	Reference	TAC
70% milled rice	01087	1.00	3	Rice (NS; grain, fast; grain, Jasmin; whole grain); Rice, brown, (ecologically, grown; grain, Basmati) [67]; Rice, grains, milled white; Rice, grains, milled brown [62]; Rice (white); Rice (brown) [57]	0.13	3	Rice bran, crude [68]	0.25	3	Rice (white); Rice (brown) [57]	0.12	3	Rice (white); Rice (brown) [57]	0.18
Brown rice	01085	1.00	1	Rice, brown, grain, Basmati, cooked [67]	0.27	3	Rice bran, crude [68]	1.14	3	Rice (brown) [57]	0.18	3	Rice (brown) [57]	0.22
Japanese noodles (buckwheat and Japanese wheat noodles)	01128	0.50	3	Buckwheat, white, flour; Wheat, white flour (NS; sieved; imported) [67]; Buck wheat, white flour; Wheat, white flour [62]; Buckwheat (whole meal); Wheat (white) [57]	0.23	3	Buckwheat, raw groats [82]	1.29	3	Buckwheat (whole meal); Wheat (white) [57]	0.39	3	Buckwheat (whole meal); Wheat (white) [57]	0.24
	01039	0.50	4	-	-	4	-	-	4	-	-	4	-	-
Instant noodles	01048	1.00	4	-	-	4	-	-	4	-	-	4	-	-
Chinese noodles	01048	1.00	4	-	-	4	-	-	4	-	-	4	-	-
Spaghetti	01064	1.00	1	Elbow macaroni, cooked; Spaghetti, regular, cooked [58]	0.03	4	-	-	3	Pasta (white) [57]	0.08	3	Pasta (white) [57]	0.06
White bread	01026	0.50	1	Bread, white [67]; White bread (NS; sliced) [58]	0.23	4	-	-	4	-	-	4	-	-
	01031	0.50	1	French bread [58]	0.17	4	-	-	4	-	-	4	-	-
Butter roll	-	1.00	4	-	-	4	-	-	4	-	-	4	-	-
Croissant	01035	1.00	4	-	-	4	-	-	4	-	-	4	-	-

(Continued)

Table 2-1. (Continued)

Food item in the DHQ*	FC†	WF‡	FRAP (mmol Fe^{2+}/100 g) Step§	Reference	TAC	ORAC (mmol TE/ 100g) Step§	Reference	TAC	TEAC (mmol TE/100g) Step§	Reference	TAC	TRAP (mmol TE/100g) Step§	Reference	TAC
Pizza	01026	0.50	1	Bread, white [67]; White bread (NS; sliced) [58]	0.23	4	-	-	4	-	-	4	-	-
	01031	0.50	1	French bread [58]	0.17	4	-	-	4	-	-	4	-	-
Japanese-style pancakes	-	1.00	4	-	-	4	-	-	4	-	-	4	-	-
Cornflakes	01137	1.00	1	Corn Flakes (NS; ecological; Honey Crunch) [67]; Corn Flakes [58]; Cornflakes [57]	0.93	1	Cereals, ready-to-eat, corn flakes [68]	2.36	1	Cornflakes [57]	0.22	1	Cornflakes [57]	0.28
Nuts and pulses														
Peanuts	05034	1.00	1	Ground nut/ peanut [62]; Peanuts [57]	1.20	1	Peanuts, all types, raw [68]	3.17	1	Peanuts [57]	0.48	1	Peanuts [57]	0.33
Other nuts	05002	0.33	2	Almonds, with pellicle (NS; sliced) [67]; Almonds [58]; Almond [62]; Almonds [57]	0.74	2	Nuts, almonds [68]	4.45	2	Almonds [57]	1.34	2	Almonds [57]	0.63
	05005	0.33	1	Cashews, without pellicle, roasted [67]	0.40	2	Nuts cashew nuts, raw [68]	1.95	3	Cashew nuts, high-temperature whole soluble [92]	6.81	4	-	-
	05026	0.33	1	Pistachios, roasted with salt and spices [67]	1.38	2	Nuts, pistachio nuts, raw [68]	7.68	2	Pistachios [57]	6.15	2	Pistachios [57]	2.59
Tofu (soybean curd)	04032	0.50	2	Tofu naturell [67]	0.09	3	Soybeans, all species except for black soybean [89]; Yellow soybeans [90]	0.91	3	*Glycine max* cv. (*jutro*, raw; *merit*, raw) [76]	0.82	4	-	-
	04033	0.50	2	Tofu naturell [67]	0.09	3	Soybeans, all species except for black soybean [89]; Yellow soybeans [90]	0.68	3	*Glycine max* cv. (*jutro*, raw; *merit*, raw) [76]	0.61	4	-	-

(Continued)

Table 2-1. (Continued)

Food item in the DHQ*	FC†	WF‡	FRAP (mmol Fe^{2+}/100 g) Step§	FRAP Reference	FRAP TAC	ORAC (mmol TE/ 100g) Step§	ORAC Reference	ORAC TAC	TEAC (mmol TE/100g) Step§	TEAC Reference	TEAC TAC	TRAP (mmol TE/100g) Step§	TRAP Reference	TRAP TAC
Tofu (soybean curd) products	04039	0.33	3	Soybeans, white, small size, dry [67]; Soya beans [62]	0.26	3	Soybeans, all species except for black soybean [89]; Yellow soybeans [90]	1.48	3	*Glycine max* cv. (*jutro*, raw; *merit*, raw) [76]	1.33	4	-	-
	04041	0.33	3	Soybeans, white, small size, dry [67]; Soya beans [62]	0.37	3	Soybeans, all species except for black soybean [89]; Yellow soybeans [90]	2.11	3	*Glycine max* cv. (*jutro*, raw; *merit*, raw) [76]	1.90	4	-	-
	04040	0.33	3	Soybeans, white, small size, dry [67]; Soya beans [62]	0.45	3	Soybeans, all species except for black soybean [89]; Yellow soybeans [90]	2.56	3	*Glycine max* cv. (*jutro*, raw; *merit*, raw) [76]	2.31	4	-	-
Natto (fermented soybeans)	04046	1.00	3	Soybeans, white, small size, dry [67]; Soya beans [62]	0.40	3	Soybeans, all species except for black soybean [89]; Yellow soybeans [90]	2.27	3	*Glycine max* cv. (*jutro*, raw; *merit*, raw) [76]	2.05	4	-	-
Boiled beans	04031	0.50	3	Soybeans, white, small size, dry [67]; Soya beans [62]	0.34	3	Soybeans, all species except for black soybean [89]; Yellow soybeans [90]	1.94	3	*Glycine max* cv. (*jutro*, raw; *merit*, raw) [76]	1.75	4	-	-
	04009	0.50	3	Berlotti beans; Kidney beans (dry; medium size, dry; striped, large size, dry); Navy beans; Pinto beans [67]; Navy beans, dry; Pinto beans, dried [58]; Pinto bean/black bean; Kidney beans [62]	0.33	3	Beans, all species except for boiled [68]; Bean, French [73]	2.25	1	*Phaseolus vulgaris var* (red), steamed; (yellow), steamed; (French), steamed [75]	0.17	4	-	-

(Continued)

Table 2-1. (Continued)

Food item in the DHQ*	FC†	WF‡	FRAP (mmol Fe^{2+}/100 g) Step§	FRAP Reference	FRAP TAC	ORAC (mmol TE/ 100g) Step§	ORAC Reference	ORAC TAC	TEAC (mmol TE/100g) Step§	TEAC Reference	TEAC TAC	TRAP (mmol TE/100g) Step§	TRAP Reference	TRAP TAC
Miso as seasoning	17045	1.00	3	Soybeans, white, small size, dry [67]; Soya beans [62]	0.31	3	Soybeans, all species except for black soybean [89]; Yellow soybeans [90]	1.72	3	*Glycine max* cv. (*jutro*, raw; *merit*, raw) [76]	1.55	4	-	-
Miso for miso soup	17045	1.00	3	Soybeans, white, small size, dry [67]; Soya beans [62]	0.31	3	Soybeans, all species except for black soybean [89]; Yellow soybeans [90]	1.72	3	*Glycine max* cv. (*jutro*, raw; *merit*, raw) [76]	1.55	4	-	-
Soybean milk	04052	0.50	1	Soy milk (ecological; Soy dream original) [67]	0.08	3	Soybeans, all species except for black soybean [89]; Yellow soybeans [90]	0.50	3	*Glycine max* cv. (*jutro*, raw; *merit*, raw) [76]	0.45	4	-	-
	04053	0.50	2	Soy milk (ecological; Soy dream original) [67]	0.08	3	Soybeans, all species except for black soybean [89]; Yellow soybeans [90]	0.44	3	*Glycine max* cv. (*jutro*, raw; *merit*, raw) [76]	0.40	4	-	-
Potatoes														
French fries	02020	1.00	1	French fries (NS; light) [67]; French fries; French fried potatoes, frozen, all species, cooked [58]	0.26	3	Potatoes, white, flesh and skin, raw [68]; Potato, tuber [88]; Potato [65]; Potato [73]	1.24	3	Potato [56]	0.15	3	Potato [56]	0.16
Potatoes	02017	1.00	1	Potatoes (NS; Beate; Roseval) [67]; Potatoes, white [58]; Potato [62]; Poteto [56]	0.13	1	Potatoes, white, flesh and skin, raw [68]; Potato, tuber [88]; Potato [65]; Potato [73]	0.67	1	Potato [56]	0.08	1	Potato [56]	0.09

(Continued)

Table 2-1. (Continued)

Food item in the DHQ*	FC†	WF‡	FRAP (mmol Fe^{2+}/100 g) Step§	FRAP Reference	FRAP TAC	ORAC (mmol TE/ 100g) Step§	ORAC Reference	ORAC TAC	TEAC (mmol TE/100g) Step§	TEAC Reference	TEAC TAC	TRAP (mmol TE/100g) Step§	TRAP Reference	TRAP TAC
Sweet potatoes, yams, and taro	02006	0.33	1	Sweet potatoe (NS; pale; red/white; yellow) [67]; Sweet potatoes [58]; Sweet potato/batat [62]	0.19	1	Sweet potato, raw [68]; Sweet potato, tuberous root [88]; Sweet potato [65]; Sweet potato [73]	0.95	2	*Ipomoea batatas var* (orange), boiled; (*Vulatolu*), boiled; (*Papua*), boiled; *(Honiara*), boiled [75]	0.11	4	-	-
	02010	0.33	2	Yam [67]; Yam [62]	0.22	1	Taro (satoimo), corm [88]; Taro/cocoyam [73]	1.14	2	*Colocasia esculenta var* (*Tausala Samoa*), boiled; (*Wararasa*) (greenish), boiled; common (white), boiled [75]	0.09	4	-	-
	02022	0.33	2	Yam [67]; Yam [62]	0.22	2	Taro (satoimo), corm [88]; Taro/cocoyam [73]	1.14	2	*Dioscorea alata var* (*Veiwa*) (red), boiled; (*Vurai*) (white), boiled; *Discorea esculenta var* (red), boiled; (white), boiled; *Discorea nummularia*, boiled [75]	0.08	4	-	-
Konnyaku (devil's tongue jelly)	02003	1.00	3	Yam [67]; Yam [62]	0.04	3	Taro (satoimo), corm [88]; Taro/cocoyam [73]	0.20	3	*Colocasia esculenta var* (*Tausala Samoa*), boiled; (*Wararasa*) (greenish), boiled; common (white), boiled [75]	0.01	4	-	-

(Continued)

Table 2-1. (Continued)

Food item in the DHQ*	FC†	WF‡	FRAP (mmol Fe^{2+}/100 g) Step§	FRAP Reference	FRAP TAC	ORAC (mmol TE/ 100g) Step§	ORAC Reference	ORAC TAC	TEAC (mmol TE/100g) Step§	TEAC Reference	TEAC TAC	TRAP (mmol TE/100g) Step§	TRAP Reference	TRAP TAC
Sugar and confectioneries														
Jam and marmalade	07046	0.25	3	Orange [67]; Orange [62]; Orange [56]	0.30	3	Oranges, raw, all commercial varieties [68]; Orange [64]; Orange (NS; mandarin) [74]	0.56	3	Orange [56]	0.23	3	Orange [56]	0.15
	07013	0.25	1	Strawberries, jam [67]	0.64	3	Strawberries, raw [68]; Strawberry [64]; Strawberry [74]	1.71	3	Strawberry (cultivated) [56]	0.51	3	Strawberry (cultivated) [56]	0.40
	07123	0.25	3	Grapes (bule; blue, Don Marino; blue, Salvi; green; green, Mario de Cristo; green, Salvi; green, without stone; red) [67]; Grapes (green; red) [58]; Grape [62]; Grape (black; white) [56]	1.07	3	Grapes (black; red, raw; white or green, raw) [68]; Grape (red; white) [64]; Grape (green; red) [74]	1.78	3	Grape (black; white) [56]	0.47	3	Grape (black; white) [56]	0.28
	07154	0.25	1	Jam, apple [67]	0.82	3	Apples, raw, with skin [68]; Apple (green; red) [74]	2.24	3	Apple (red Delicious; yellow Golden) [56]	0.12	3	Apple (red Delicious; yellow Golden) [56]	0.15
Japanese bread with a sweet filling	15069	0.50	3	Black eye beans, (haricot balance; white, cornille; white, medium size, dry) [67]; Black-eye pea/bean [62]	0.07	3	Cowpeas, common (blackeyes, crowder, southern), mature [68]	0.49	3	Cowpeas, raw [77]	0.26	4	-	-
	15070	0.50	4	-	-	4	-	-	4	-	-	4	-	-
Doughnuts	15077	0.50	2	Doughnuts, cake, plain [58]	0.15	4	-	-	4	-	-	4	-	-
	15078	0.50	1	Doughnuts, cake, plain [58]	0.15	4	-	-	4	-	-	4	-	-

(Continued)

Table 2-1. (Continued)

Food item in the DHQ*	FC†	WF‡	FRAP ($mmol Fe^{2+}/100 g$) Step§	FRAP Reference	FRAP TAC	ORAC (mmol TE/ 100g) Step§	ORAC Reference	ORAC TAC	TEAC (mmol TE/100g) Step§	TEAC Reference	TEAC TAC	TRAP (mmol TE/100g) Step§	TRAP Reference	TRAP TAC
Pancakes	15083	1.00	2	Butter milk pancakes, frozen (microwaved; toasted) [58]	0.15	4	-	-	4	-	-	4	-	-
Potato chips	15103	1.00	1	Potato chips, Potetgull, classic, salt [67]; Potato chips (all species) [58]	0.59	3	Potatoes, white, flesh and skin, raw [68]; Potato, tuber [88]; Potato [65]; Potato [73]	2.09	3	Potato [56]	0.25	3	Potato [56]	0.26
Rice crackers	15060	0.50	4	-	-	4	-	-	4	-	-	4	-	-
	15059	0.50	4	-	-	4	-	-	4	-	-	4	-	-
Snacks made from wheat flour	15102	1.00	4	-	-	4	-	-	4	-	-	4	-	-
Japanese sweets with azuki beans	15023	0.33	3	Black eye beans, (haricot balance; white, cornille; white, medium size, dry) [67]; Black-eye pea/bean [62]	0.07	3	Cowpeas, common (blackeyes, crowder, southern), mature [68]	0.49	3	Cowpeas, raw [77]	0.26	4	-	-
	15031	0.33	3	Chest nuts, with perricle (purchased with shell) [67]; Chestnut [57]	1.44	4	-	-	3	Chestnut [57]	0.19	3	Chestnut [57]	0.55
	15038	0.33	3	Black eye beans, (haricot balance; white, cornille; white, medium size, dry) [67]; Black-eye pea/bean [62]	0.11	3	Cowpeas, common (blackeyes, crowder, southern), mature [68]	0.77	3	Cowpeas, raw [77]	0.41	4	-	-
Japanese sweets without azuki beans	15045	0.50	4	-	-	4	-	-	4	-	-	4	-	-
	15025	0.50	4	-	-	4	-	-	4	-	-	4	-	-
Cakes	15009	1.00	4	-	-	4	-	-	4	-	-	4	-	-

(Continued)

Table 2-1. (Continued)

Food item in the DHQ*	FC†	WF‡	FRAP (mmol Fe^{2+}/100 g) Step§	FRAP Reference	FRAP TAC	ORAC (mmol TE/ 100g) Step§	ORAC Reference	ORAC TAC	TEAC (mmol TE/100g) Step§	TEAC Reference	TEAC TAC	TRAP (mmol TE/100g) Step§	TRAP Reference	TRAP TAC
Cookies and biscuits	15097	0.33	2	Biscuits, Bixit [67]; Biscuits, all species, cooked [58]	0.42	4	-	-	4	-	-	4	-	-
	15098	0.67	2	Biscuits, Bixit [67]; Biscuits, all species, cooked [58]	0.42	4	-	-	4	-	-	4	-	-
Chocolate	15116	1.00	1	Chocolate (NS; milk chocolate; milk chocolate, Feria Melkesjokolade; Milky Way; Mokkabnonner; New Energy; Noir Nestle Dessert; Selskapssjokolade; Snickers) [67]; Milk chocolate (candy; candy bar) [58]; Chocolate (milk) [57]	3.96	1	Candies, milk chocolate [68]	7.52	1	Chocolate (milk) [57]	3.62	1	Chocolate (milk) [57]	1.16
Jellies	15087	1.00	2	Gelatin, prepared, snack, strawberry orange flavor [58]	0.01	4	-	-	4	-	-	4	-	-
Oils														
Margarine	14020	1.00	1	Margarine (Brelett Oliven, light; Brelett, light; Bremykt; Melange; Per; Soft Fola; Soft light; Soya) [67]	1.05	4	-	-	4	-	-	4	-	-
Mayonnaise	17043	1.00	1	Mayonnaise, original [67]	1.08	4	-	-	4	-	-	4	-	-
Salad dressing	17040	1.00	1	Dressing, French, salad dressing [67]; French salad dressing (NS; fat-free; lite) [58]	0.25	4	-	-	4	-	-	4	-	-

(Continued)

Table 2-1. (Continued)

Food item in the DHQ*	FC†	WF‡	FRAP (mmol Fe^{2+}/100 g) Step§	Reference	TAC	ORAC (mmol TE/ 100g) Step§	Reference	TAC	TEAC (mmol TE/100g) Step§	Reference	TAC	TRAP (mmol TE/100g) Step§	Reference	TAC
Oil used during cooking	14006	1.00	3	Soy bean oil; Canola oil, cold-pressed [67]; Canola oil; Vegetable oil (soybean oil) [58]	0.44	4	-	-	2	Oil, soybean [56]	0.22	4	-	-
Fruits														
Raisins	07117	1.00	1	Currant (raisins of Korinth); Raisins (NS; big; green) [67]; Raisins [58]; Raisins [62]; Raisin [57]	1.28	1	Raisins (golden seedless; seedless) [68]	5.75	1	Raisin [57]	0.66	1	Raisin [57]	0.62
Canned fruits	07035	0.50	3	Clementines [67]; Clementines [58]; Clementine [62]; Clementine [56]	0.71	3	Tangerines, (mandarin oranges), raw; Oranges, raw (all species) [68]; Orange [64]; Orange (NS; mandarin) [74]	1.61	3	Clementine [56]	0.25	3	Clementine [56]	0.22
	07089	0.50	3	Pears [67]; Pears (all species) [58]; Pear [62]; Pear [56]	0.12	3	Pears (green cultivars, with peel, raw; red anjou, raw) [68]; Pear (green; yellow) [74]	1.03	3	Pear [56]	0.13	3	Pear [56]	0.22
Oranges	07029	0.33	2	Clementines [67]; Clementines [58]; Clementine [62]; Clementine [56]	0.87	2	Tangerines, (mandarin oranges), raw; Oranges, raw (all species) [68]; Orange [64]; Orange (NS; mandarin) [74]	1.97	2	Clementine [56]	0.31	2	Clementine [56]	0.27
	07105	0.33	2	Grapefruit, yellow [67]; Grapefruit, yellow [62]; Grapefruit (yellow) [56]	0.87	2	Grapefruit, raw (pink and red and white; pink and red), all areas [68]; Grapefruit, pink [64]; Grapefruit, red [74]	1.62	2	Grapefruit (yellow) [56]	0.31	2	Grapefruit (yellow) [56]	0.40

(Continued)

Table 2-1. (Continued)

Food item in the DHQ*	FC†	WF‡	FRAP (mmol Fe^{2+}/100 g) Step§	Reference	TAC	ORAC (mmol TE/ 100g) Step§	Reference	TAC	TEAC (mmol TE/100g) Step§	Reference	TAC	TRAP (mmol TE/100g) Step§	Reference	TAC
Oranges	07062	0.33	1	Grapefruit, yellow [67]; Grapefruit, yellow [62]; Grapefruit (yellow) [56]	0.87	1	Grapefruit, raw (pink and red and white; pink and red), all areas [68]; Grapefruit, pink [64]; Grapefruit, red [74]	1.62	1	Grapefruit (yellow) [56]	0.31	1	Grapefruit (yellow) [56]	0.40
Bananas	07107	1.00	1	Banana [67]; Banana [58]; Banana [62]; Banana [23]	0.19	1	Bananas, raw [68]; Banana [64]; Banana [74]	0.74	1	Banana [56]	0.06	1	Banana [56]	0.11
Apples	07148	1.00	1	Apples (all species except for dried and without peel) [67]; Apples (all species except for without peel [58]; Apple [62]; Apple (red Delicious; yellow Golden) [56]	0.39	1	Apples, raw, with skin [68]; Apple (green; red) [74]	2.80	1	Apple (red Delicious; yellow Golden) [56]	0.15	1	Apple (red Delicious; yellow Golden) [56]	0.19
Strawberries	07012	1.00	1	Strawberries, Corona, cultivated [67]; Strawberries [58]; Strawberry, cultivated [62]; Strawberry (cultivated) [56]	2.16	1	Strawberries, raw [68]; Strawberry [64]; Strawberry [74]	3.67	1	Strawberry (cultivated) [56]	1.09	1	Strawberry (cultivated) [56]	0.86
Grapes	07116	1.00	1	Grapes (all species) [67]; Grapes (green; red) [58]; Grape [62]; Grape (black; white) [56]	0.78	1	Grapes (black; red, raw; white or green, raw) [68]; Grape (red; white) [64]; Grape (green; red) [74]	1.29	1	Grape (black; white) [56]	0.32	1	Grape (black; white) [56]	0.20
Peaches	07136	1.00	1	Peaches [67]; Peaches [58]; Peach (yellow) [56]	0.24	1	Peaches, raw [68]	1.92	1	Peach (yellow) [56]	0.17	1	Peach (yellow) [56]	0.15

(Continued)

Table 2-1. (Continued)

Food item in the DHQ*	FC†	WF‡	FRAP (mmol Fe^{2+}/100 g) Step§	Reference	TAC	ORAC (mmol TE/ 100g) Step§	Reference	TAC	TEAC (mmol TE/100g) Step§	Reference	TAC	TRAP (mmol TE/100g) Step§	Reference	TAC
Pears	07088	1.00	2	Pears [67]; Pears (all species) [58]; Pear [62]; Pear [56]	0.22	2	Pears (green cultivars, with peel, raw; red anjou, raw) [68]; Pear (green; yellow) [74]	1.80	2	Pear [56]	0.22	2	Pear [56]	0.39
Persimmons	07049	1.00	1	Sharon [67]; Kaki/sharon [62]	0.49	1	Persimmon [74]	0.74	3	Persimmon, dry [78]	6.86	4	-	-
Kiwi fruits	07054	1.00	1	Kiwi (green; yellow) [67]; Kiwi (NS; gold) [58]; Kiwi fruit [62]; Kiwi fruit [56]	0.95	1	Kiwi fruit, (chinese gooseberries), fresh, raw [68]; Kiwi fruit [64]; Kiwifruit [74]	0.83	1	Kiwi fruit [56]	0.23	1	Kiwi fruit [56]	0.23
Melons	07134	1.00	1	Melon (Cantaloupe; Cantaloupe, small; pattern; yellow) [67]; Honeydew [58]; Cantaloupe melon [62]; Melon (cantaloupe; honeydew) [56]	0.18	1	Melons (cantaloupe; honeydew), raw [68]; Melon [64]; Melon (cantaloupe; honeydew) [74]	0.24	1	Melon (cantaloupe; honeydew) [56]	0.09	1	Melon (cantaloupe; honeydew) [56]	0.10
Watermelons	07077	1.00	1	Watermelon (NS; red seedless) [67]; Watermelon [58]; Watermelon [62]; Watermelon [56]	0.05	1	Watermelon, raw [68]; Watermelon (red; yellow) [74]	0.17	1	Watermelon [56]	0.07	1	Watermelon [56]	0.05
Vegetables														
Carrots	06215	1.00	2	Carrots, cooked [58]	0.10	2	Carrots, boiled [68]	0.33	2	Carrot [56]	0.04	2	Carrot [56]	0.07
Pumpkins	06049	1.00	2	Pumpkin; Pumpkins [67]; Squash [62]; Pumpkin [56]	0.11	2	Pumpkin, raw [68]	0.48	2	Pumpkin [56]	0.37	2	Pumpkin [56]	0.00

(Continued)

Table 2-1. (Continued)

			FRAP (mmol Fe^{2+}/100 g)			ORAC (mmol TE/ 100g)			TEAC (mmol TE/100g)			TRAP (mmol TE/100g)		
Food item in the DHQ*	FC†	WF‡	Step§	Reference	TAC	Step§	Reference	TAC	Step§	Reference	TAC	Step§	Reference	TAC
Tomatoes	06182	1.00	1	Tomatoes (NS; chopped; cluster tomatoes; cluster tomatoes, small; plum-; steak-) [67]; Tomatoes [58]; Tomato, except for cherry tomato [62]; Tomato (salad) [56]	0.27	1	Tomatoes, plum (raw; red, ripe, raw, year round average) [68]; Tomato, fruit [88]; Tomato [64]; Tomato [73]	0.39	1	Tomato (salad) [56]	0.17	1	Tomato (salad) [56]	0.13
Green peppers	06245	1.00	1	Pepper, bell-, green [67]; Peppers, green [58]; Red/green pepper, green [62]	1.02	1	Peppers, sweet, green, raw [68]; Green sweet pepper, fruit [88]	0.93	2	Pepper (red bell) [56]	0.84	2	Pepper (red bell) [56]	0.55
Broccoli	06264	1.00	1	Broccoli, cooked [67]; Broccoli, cooked [58]	0.96	2	Broccoli, raw [68]; Broccoli, inflorescence [88]; Broccoli flowers [65]; Broccoli [73]	1.48	2	Broccoli [56]	0.30	2	Broccoli [56]	0.31
Green leafy vegetables	06268	0.20	2	Spinach, all species (boiled; microwave cooked) [58]	1.15	2	Spinach, raw [68]; Spinach, leaves [88]; Spinach [65]; Spinach [73]	1.49	2	Spinach [56]	0.85	2	Spinach [56]	0.58
	06087	0.20	2	Spinach [67]; Spinach [62]; Spinach [56]	1.20	2	Cabbage, all species except for Chinese celery; red; round [73]	1.36	2	Spinach [56]	0.85	2	Spinach [56]	0.58
	06227	0.20	3	Chives [79]	0.64	2	Chives, raw [68]	2.09	2	Leek [56]	0.07	2	Leek [56]	0.10
	06161	0.20	2	Spinach [67]; Spinach [62]; Spinach [56]	1.20	2	Cabbage, all species except for Chinese celery; red; round [73]	1.36	2	Spinach [56]	0.85	2	Spinach [56]	0.58
	06131	0.20	2	Spinach [67]; Spinach [62]; Spinach [56]	1.20	2	Cabbage, all species except for Chinese celery; red; round [73]	1.36	2	Spinach [56]	0.85	2	Spinach [56]	0.58

(Continued)

Table 2-1. (Continued)

Food item in the DHQ*	FC†	WF‡	FRAP (mmol Fe^{2+}/100 g) Step§	Reference	TAC	ORAC (mmol TE/ 100g) Step§	Reference	TAC	TEAC (mmol TE/100g) Step§	Reference	TAC	TRAP (mmol TE/100g) Step§	Reference	TAC
Cabbage	06062	1.00	1	Cabbage, cooked [58]	0.45	2	Cabbage, raw [68]; Cabbage, head [88]; Cabbage [65]; Cabbage, round [73]	0.52	2	Cabbage (green) [56]	0.12	2	Cabbage (green) [56]	0.28
Cucumbers	06065	1.00	1	Cucumber (NS; Cucumis sativus; small, russian) [67]; Cucumber, with peel [58]; Cucumber [62]; Cucumber [56]	0.05	1	Cucumber, with peel, raw [68]; Cucumber, fruit [88]; Cucumber [65]; Cucumber [73]	0.21	1	Cucumber [56]	0.04	1	Cucumber [56]	0.00
Lettuce	06312	1.00	1	Lettuce, iceberg [58]; Lettuce [62]; Lettuce [56]	0.27	1	Lettuce, iceberg (includes crisphead types), raw [68]; Crisp lettuce, head [88]; Iceberg lettuce [65]; Lettuce, iceberg [73]	0.32	1	Lettuce [56]	0.13	1	Lettuce [56]	0.23
Chinese cabbage	06234	1.00	2	Chinese cabbage [67]	0.45	2	Chinese cabbage, head [88]; Cabbage, Chinese celery [73]	0.52	2	Cabbage (green) [56]	0.12	2	Cabbage (green) [56]	0.28
Bean sprouts	06290	1.00	4	-	-	2	Soybeans, mature seeds, sprouted, raw [68]; Mung bean sprout [88]; Bean sprout (NS; soy) [73]	1.72	3	*Vigna radiata* cv. *emmerald*, germination 4 days [76]	0.15	4	-	-
Radishes	06133	1.00	2	Radishes [67]; Radishes [58]; Radish [62]	0.31	2	Radishes [68]; Chinese radish [73]	1.50	2	Turnip tops [56]	0.55	2	Turnip tops [56]	0.66

(Continued)

Table 2-1. (Continued)

Food item in the DHQ*	FC†	WF‡	FRAP (mmol Fe^{2+}/100 g) Step§	Reference	TAC	ORAC (mmol TE/ 100g) Step§	Reference	TAC	TEAC (mmol TE/100g) Step§	Reference	TAC	TRAP (mmol TE/100g) Step§	Reference	TAC
Onions	06155	1.00	1	Onion, boiled [67]; Onions, yellow, cooked [58]	0.29	2	Onions, yellow, sauteed [68]	1.22	2	Onion (yellow) [56]	0.18	2	Onion (yellow) [56]	0.24
Cauliflower	06055	1.00	1	Cauliflower, boiled [67]	0.80	2	Cauliflower, raw [68]; Cauliflowers [65]; Cauliflower [73]	0.85	2	Cauliflower [56]	0.11	2	Cauliflower [56]	0.16
Eggplants	06192	1.00	2	Aubergine (NS; native, red; native, white) [67]; Aubergines/eggplant [62]; Eggplant [56]	0.18	2	Eggplant, boiled [68]	0.25	2	Eggplant [56]	0.11	2	Eggplant [56]	0.28
Burdock	06085	1.00	4	-	-	2	Edible burdock, root [88]	5.22	2	Burdock roots [91]	0.00	4	-	-
Lotus root	06318	1.00	3	White lotus root [80]	1.58	2	East Indian lotus root, rhizome [88]; Lotus root [73]	2.10	4	-	-	4	-	-
Salted pickled plums	07023	1.00	2	Japanese plum pulp, paste [67]	0.45	3	Apricots, raw [68]	3.62	3	Apricot [56]	0.47	3	Apricot [56]	0.75
Salted green and yellow vegetable pickles	06148	0.33	3	Spinach [67]; Spinach [62]; Spinach [56]	2.72	3	Cabbage, all species except for Chinese celery; red; round [73]	3.08	3	Spinach [56]	1.92	3	Spinach [56]	1.31
	06231	0.67	3	Spinach [67]; Spinach [62]; Spinach [56]	2.11	3	Cabbage, all species except for Chinese celery; red; round [73]	2.39	3	Spinach [56]	1.49	3	Spinach [56]	1.01
Other salted pickles	06139	0.30	3	Radishes [67]; Radishes [58]; Radish [62]	0.64	3	Radishes [68]; Chinese radish [73]	3.12	3	Turnip tops [56]	1.14	3	Turnip tops [56]	1.37
	06066	0.10	3	Cucumber (NS; Cucumis sativus; small, russian) [67]; Cucumber, with peel [58]; Cucumber [62]; Cucumber [56]	0.09	3	Cucumber, with peel, raw [68]; Cucumber, fruit [88]; Cucumber [65]; Cucumber [73]	0.36	3	Cucumber [56]	0.07	3	Cucumber [56]	0.00

(Continued)

Table 2-1. (Continued)

Food item in the DHQ*	FC†	WF‡	FRAP (mmol Fe^{2+}/100 g) Step§	Reference	TAC	ORAC (mmol TE/ 100g) Step§	Reference	TAC	TEAC (mmol TE/100g) Step§	Reference	TAC	TRAP (mmol TE/100g) Step§	Reference	TAC
Other salted pickles	06068	0.10	3	Cucumber (NS; Cucumis sativus; small, russian) [67]; Cucumber, with peel [58]; Cucumber [62]; Cucumber [56]	0.16	3	Cucumber, with peel, raw [68]; Cucumber, fruit [88]; Cucumber [65]; Cucumber [73]	0.65	3	Cucumber [56]	0.13	3	Cucumber [56]	0.00
	06195	0.10	3	Aubergine (NS; native, red; native, white) [67]; Aubergines/eggplant [62]; Eggplant [56]	0.25	3	Eggplant, raw [68]; Eggplant, fruit [88]; Eggplant [65]; Eggplant/brinjal [73]	1.37	3	Eggplant [56]	0.16	3	Eggplant [56]	0.40
	06196	0.10	3	Aubergine (NS; native, red; native, white) [67]; Aubergines/eggplant [62]; Eggplant [56]	0.29	3	Eggplant, raw [68]; Eggplant, fruit [88]; Eggplant [65]; Eggplant/brinjal [73]	1.61	3	Eggplant [56]	0.18	3	Eggplant [56]	0.47
	06235	0.30	3	Chinese cabbage [67]	0.74	3	Chinese cabbage, head [88]; Cabbage, Chinese celery [73]	0.84	3	Cabbage (green) [56]	0.19	3	Cabbage (green) [56]	0.46
Mushrooms	08011	0.50	2	Mushrooms, shiitake, stir-fried [58]	0.33	2	Mushrooms, shiitake, dried [68]; Shiitake mushroom [88]; Mushroom, shiitake [73]	0.58	2	Mushroom [56]	0.49	2	Mushroom [56]	0.63
	08016	0.50	2	Mushrooms (oyster; maitake) [58]	0.10	2	Mushroom, oyster, raw; Mushrooms, maitake, raw [68]; Mushroom, oyster [73]	0.72	2	Mushroom [56]	0.49	2	Mushroom [56]	0.63
Wakame and hijiki seaweed	09045	1.00	4	-	-	3	Seaweed, dried [73]	0.45	3	*Undaria pinnatifida* [93]	0.15	4	-	-
Laver (dried, edible seaweed)	09004	0.50	4	-	-	2	Seaweed, dried [73]	6.11	2	*Porphyra tennera* [93]	2.30	4	-	-
	09005	0.50	4	-	-	2	Seaweed, dried [73]	6.11	2	*Porphyra tennera* [93]	2.30	4	-	-

(Continued)

Table 2-1. (Continued)

Food item in the DHQ*	FC†	WF‡	FRAP (mmol Fe^{2+}/100 g) Step§	FRAP Reference	FRAP TAC	ORAC (mmol TE/ 100g) Step§	ORAC Reference	ORAC TAC	TEAC (mmol TE/100g) Step§	TEAC Reference	TEAC TAC	TRAP (mmol TE/100g) Step§	TRAP Reference	TRAP TAC
Alcoholic beverages														
Beer	16006	1.00	1	Beer (all species except for Guinnes Draught; Limfjords Porter, double brown stout; Porter) [67]; Beer (light; regular) [58]; Beer (lager) [56]	0.24	4	-	-	1	Beer (lager) [56]	0.10	1	Beer (lager) [56]	0.00
Whiskey	16016	0.50	1	Whisky, Finest Scotch Whisky [67]; Whiskey [56]	0.20	4	-	-	1	Whiskey [56]	0.17	1	Whiskey [56]	0.23
	16017	0.50	1	Brandy, Napoleon V.S.O.P.; Cognac (V.S.Martell, Fine Cognac; X.O.Braastad, FineChampagne) [67]; Cognac [56]	0.31	4	-	-	1	Cognac [56]	0.13	1	Cognac [56]	0.15
Wine	16010	0.50	1	Cockburn's Port; Wine, red (all species) [67]; Wine, white [58]; Wine (Vernaccia, white; Pinot, white; Greco di Tufo, white) [56]	0.39	1	Alcoholic beverage, wine, table, white [68]; Wine, white, all species [61]	0.35	1	Wine (Vernaccia, white; Pinot, white; Greco di Tufo, white) [56]	0.17	1	Wine (Vernaccia, white; Pinot, white; Greco di Tufo, white) [56]	0.21
	16011	0.50	1	Wine, white (all species) [67]; Wine, red [58]; Wine (Aglianico, red; Chianti, red; Sauvignon, red) [56]	2.43	1	Alcoholic beverage, wine, table, red [68]; Wine, red, all species [61]	1.99	1	Wine (Aglianico, red; Chianti, red; Sauvignon, red) [56]	1.08	1	Wine (Aglianico, red; Chianti, red; Sauvignon, red) [56]	1.42

(Continued)

Table 2-1. (Continued)

Food item in the DHQ*	FC†	WF‡	FRAP (mmol Fe^{2+}/100 g) Step§	Reference	TAC	ORAC (mmol TE/ 100g) Step§	Reference	TAC	TEAC (mmol TE/100g) Step§	Reference	TAC	TRAP (mmol TE/100g) Step§	Reference	TAC
Non-alcoholic beverages														
Fruit juice (100%)	07031	0.33	2	Juice, orange [67]; Orange juice, 100% (juice box), from concentrate [58]; Orange juice [56]	0.70	2	Orange juice (canned, unsweetened; raw) [68]; Common commercial fruits juice, orange [64]	0.72	2	Orange juice [56]	0.30	2	Orange juice [56]	0.23
	07150	0.33	1	Juice, apple [67]; Apple juice [56]	0.29	1	Apple juice, canned or bottled, unsweetened, without added ascorbic acid [68]; Common commercial fruit juice, apple [64]	0.41	1	Apple juice [56]	0.18	1	Apple juice [56]	0.20
	07064	0.33	1	Juice, grapefruits [67]; Grapefruit juice [56]	0.85	1	Grapefruit juice, white, raw [68]; Common commercial fruit juice, grapefruit [64]	0.79	1	Grapefruit juice [56]	0.33	1	Grapefruit juice [56]	0.27
Tomato juice	06185	1.00	1	Tomato juice (NS; ecological; Premium; Sun-C) [67]	0.48	1	Tomato juice, canned [68]; Common commercial fruit juice, tomato [64]	0.43	2	Tomato (salad) [56]	0.17	2	Tomato (salad) [56]	0.13
Vegetable juice	06186	0.50	2	Vegetable juice [67]	0.48	1	Vegetable juice cocktail, canned [68]	0.55	2	Tomato (salad) [56]	0.17	2	Tomato (salad) [56]	0.13
	07150	0.50	1	Juice, apple [67]; Apple juice [56]	0.29	1	Apple juice, canned or bottled, unsweetened, without added ascorbic acid [68]; Common commercial fruit juice, apple [64]	0.41	1	Apple juice [56]	0.18	1	Apple juice [56]	0.20

(Continued)

Table 2-1. (Continued)

Food item in the DHQ*	FC†	WF‡	FRAP (mmol Fe^{2+}/100 g) Step§	Reference	TAC	ORAC (mmol TE/ 100g) Step§	Reference	TAC	TEAC (mmol TE/100g) Step§	Reference	TAC	TRAP (mmol TE/100g) Step§	Reference	TAC
Green, barley, and oolong tea (including other Chinese tea)	16037	0.50	1	Tea, green (all species except for Jasmine and mint, prepared) [67]; Tea (green) [56]	1.49	3	Tea, green, ready-to-drink [68]; Green tea [65]; Green tea, all species [84]; Green tea [85]	2.03	1	Tea (green) [56]	0.60	1	Tea (green) [56]	0.76
	16042	0.50	2	Tea, green (all species except for Jasmine and mint, prepared); Tea, black, all species, prepared [67]; Tea (green); Tea (black) [56]	1.32	3	Tea, green, ready-to-drink; Tea, black, ready-to-drink, plain and flavored [68]; Green tea; Black tea [65]; Black tea, all species [83]; Green tea, all species; Black tea, all species except for black tea [84]; Green tea [85]	1.69	2	Tea (green); Tea (black) [56]	0.48	2	Tea (green); Tea (black) [56]	0.63
Black tea	16044	1.00	1	Tea, black, all species, prepared [67]; Tea (black) [56]	0.97	3	Tea, black, ready-to-drink, plain and flavored [68]; Black tea [65]; Black tea, all species [83]; Black tea, all species except for black tea [84]	1.48	1	Tea (black) [56]	0.36	1	Tea (black) [56]	0.49
Coffee	16045	1.00	1	Coffee (all species except for instant, Caffe Latte, Cappucino, Espresso, caffein free, Ice coffee, and double, filter brewed; prepared [67]; Coffee [58]; Coffee (extracted; soluble) [56]	3.23	3	Coffee brew [86]; coffee fruit powder 1 [87]	4.24	1	Coffee (extracted; soluble) [56]	3.14	1	Coffee (extracted; soluble) [56]	5.60

(Continued)

Table 2-1. (Continued)

Food item in the DHQ*	FC†	WF‡	FRAP (mmol Fe^{2+}/100 g) Step§	FRAP Reference	FRAP TAC	ORAC (mmol TE/ 100g) Step§	ORAC Reference	ORAC TAC	TEAC (mmol TE/100g) Step§	TEAC Reference	TEAC TAC	TRAP (mmol TE/100g) Step§	TRAP Reference	TRAP TAC
Cocoa‖	16048	0.05	1	Cacao, for baking, powder, Regia [67]	13.7	1	Cocoa, dry powder, unsweetened [68]	55.7	3	Chocolate (milk) [57]	26.0	3	Chocolate (milk) [57]	8.29
	16049	0.05	1	Instant cocoa, all species, powder [67]	3.87	3	Cocoa, dry powder, unsweetened [68]	11.0	3	Chocolate (milk) [57]	5.04	3	Chocolate (milk) [57]	1.61
Fruit juice, excluding 100% juice	07033	0.33	3	Juice, orange [67]; Orange juice, 100% (juice box), from concentrate [58]; Orange juice [56]	0.35	3	Orange juice (canned, unsweetened; raw) [68]; Common commercial fruits juice, orange [64]	0.36	3	Orange juice [56]	0.16	3	Orange juice [56]	0.11
	07151	0.33	3	Juice, apple [67]; Apple juice [56]	0.14	3	Apple juice, canned or bottled, unsweetened, without added ascorbic acid [68]; Common commercial fruit juice, apple [64]	0.21	3	Apple juice [56]	0.09	3	Apple juice [56]	0.10
	07065	0.33	3	Juice, grapefruits [67]; Grapefruit juice [56]	0.43	3	Grapefruit juice, white, raw [68]; Common commercial fruit juice, grapefruit [64]	0.39	3	Grapefruit juice [56]	0.17	3	Grapefruit juice [56]	0.13
Seasonings														
Soy sauce	17007	1.00	2	Sauce, soya sauce (NS; dark) [67]	1.68	3	Soybeans, all species except for black soybean [89]; Yellow soybeans [90]	1.06	3	*Glycine max* cv. (*jutro*, raw; *merit*, raw) [76]	0.96	4	-	-
Tomato ketchup	17036	1.00	1	Tomato ketchup (NS; classico; organic; original) [67]; Tomato ketchup [58]	0.37	1	Catsup [68]	0.58	2	Tomato (sauce) [56]	0.15	2	Tomato (sauce) [56]	0.17

(Continued)

Table 2-1. (Continued)

Food item in the DHQ*	FC†	WF‡	FRAP (mmol Fe^{2+}/100 g) Step§	Reference	TAC	ORAC (mmol TE/ 100g) Step§	Reference	TAC	TEAC (mmol TE/100g) Step§	Reference	TAC	TRAP (mmol TE/100g) Step§	Reference	TAC
Other foods														
Curry or stew roux and meat sauce	17051	1.00	4	-	-	4	-	-	4	-	-	4	-	-
Nutritional supplement drinks	-	1.00	4	-	-	4	-	-	4	-	-	4	-	-
Nutritional supplement bars	-	1.00	4	-	-	4	-	-	4	-	-	4	-	-

DHQ, self-administered diet history questionnaire; FC, food code; Fe, iron; FRAP, ferric reducing ability of plasma; NS, no species; ORAC, oxygen radical absorbance capacity; TAC, total antioxidant capacity; TE, Trolox equivalent; TEAC, Trolox equivalent antioxidant capacity; TRAP, total radical-trapping antioxidant parameter; WF, weighting factor.

* The TAC values of these 98 food items from the 151 items in the DHQ were searched in the present study. The following 53 were determined to contain no TAC value: all 15 items in fish and shellfish (dried fish; small fish with bones; canned tuna; eel; white meat fish; oily fish; red meat fish; ground fish meat products; shrimp and crab; squid and octopus; oysters: other shellfish; fish eggs; boiled fish and shellfish in soy sauce; and salted fish intestines); all 7 items in meat (ground beef and pork; chicken; pork; beef; liver; ham and sausages; and bacon); all 8 items in dairy products (full-fat milk; low-fat milk; sweetened yogurt; non-sweetened yogurt; moderately sweetened yogurt; cheese; cottage cheese; and cream or creamer added to coffee); 5 items in other animal foods (ice cream [regular]; ice cream [premium]; ice cream [unspecified varieties]; butter; and eggs); and 18 items in other foods (sugar for coffee and black tea; sugar used during cooking; artificial sweeteners; candies, caramels, and chewing gum; non-oil dressings; table salt; salt used during cooking; corn soup; Chinese soup; soup consumed with noodles; water for miso soup; sake; shochu; shochu mixed with water or a carbonated beverage; lactic acid bacteria beverages; cola and sugar-sweetened soft drinks [including sports drinks]; sugar-free soft drinks and diet cola; and drinking water. Food items were categorized into food groups according to our previous study [70]. Tomato ketchup and soy sauce were included in seasonings. Curry or stew roux and meat sauce; nutritional supplement drinks; and nutritional supplement bars were included in other foods. Soybean milk was included in nuts and pulses. Salted green and yellow vegetable pickles was included in vegetables.

† Listed in the Standard Tables of Food Composition in Japan [94].

‡ Included in in an *ad hoc* computer algorithm for the DHQ [70, 71].

§ Step 1, TAC value was assigned an analytical value; Step 2, TAC value was assigned a substituted value; Step 3, TAC value was assigned a calculated value; Step 4, TAC value was assigned no value.

|| Remaining individual food composing this food item is water.

Table 2-2. Total antioxidant capacity of 90 individual food items composed of 36 foods in the brief-type self-administered diet history questionnaire

			FRAP (mmol Fe^{2+}/100g)			ORAC (mmol TE/100g)			TEAC (mmol TE/100g)			TRAP (mmol TE/100g)		
Food item in the BDHQ*	FC†	WF‡	Step§	Reference	TAC	Step§	Reference	TAC	Step§	Reference	TAC	Step§	Reference	TAC
Cereals														
Rice	01088	1.00	1	Instant white rice, cooked [58]	0.02	4	-	-	3	Rice (white) [57]	0.10	3	Rice (white) [57]	0.18
Buckwheat noodles	01128	1.00	3	Buckwheat, white, flour; Wheat, white flour (NS; sieved; imported) [67]; Buck wheat, white flour; Wheat, white flour [62]; Buckwheat (whole meal); Wheat (white) [57]	0.23	3	Buckwheat, raw groats [82]	1.29	3	Buckwheat (whole meal); Wheat (white) [57]	0.39	3	Buckwheat (whole meal); Wheat (white) [57]	0.24
Japanese wheat noodles	01039	1.00	4	-	-	4	-	-	4	-	-	4	-	-
Instant noodles and Chinese noodles	01048	1.00	4	-	-	4	-	-	4	-	-	4	-	-
Spaghetti and macaroni	01064	1.00	1	Elbow macaroni, cooked; Spaghetti, regular, cooked [58]	0.03	4	-	-	3	Pasta (white) [57]	0.08	3	Pasta (white) [57]	0.06
Breads (including white bread and Japanese bread with a sweet filling)	01026	0.36	1	Bread, white [67]; White bread (NS; sliced) [58]	0.23	4	-	-	4	-	-	4	-	-
	01031	0.14	1	French bread [58]	0.17	4	-	-	4	-	-	4	-	-
	15069	0.14	3	Black eye beans, (haricot balance; white, cornille; white, medium size, dry) [67]; Black-eye pea/ bean [62]	0.07	3	Cowpeas, common (blackeyes, crowder, southern), mature [68]	0.49	3	Cowpeas, raw [77]	0.26	4	-	-
	15070	0.14	4	-	-	4	-	-	4	-	-	4	-	-
	15076	0.22	2	Toaster pastries, strawberry, plain (not frosted) [58]	0.17	4	-	-	4	-	-	4	-	-

(Continued)

Table 2-2. (Continued)

			FRAP (mmol Fe^{2+}/100g)			ORAC (mmol TE/100g)			TEAC (mmol TE/100g)			TRAP (mmol TE/100g)		
Food item in the BDHQ*	FC†	WF‡	Step§	Reference	TAC	Step§	Reference	TAC	Step§	Reference	TAC	Step§	Reference	TAC
Pulses														
Tofu (soybean curd) and tofu products	04032	0.49	2	Tofu naturell [67]	0.09	3	Soybeans, all species except for black soybean [89]; Yellow soybeans [90]	0.91	3	*Glycine max* cv. (*jutro*, raw; *merit*, raw) [76]	0.82	4	-	-
	04033	0.49	2	Tofu naturell [67]	0.09	3	Soybeans, all species except for black soybean [89]; Yellow soybeans [90]	0.68	3	*Glycine max* cv. (*jutro*, raw; *merit*, raw) [76]	0.61	4	-	-
	04039	0.01	3	Soybeans, white, small size, dry [67]; Soya beans [62]	0.26	3	Soybeans, all species except for black soybean [89]; Yellow soybeans [90]	1.48	3	*Glycine max* cv. (*jutro*, raw; *merit*, raw) [76]	1.33	4	-	-
	04041	0.01	3	Soybeans, white, small size, dry [67]; Soya beans [62]	0.37	3	Soybeans, all species except for black soybean [89]; Yellow soybeans [90]	2.56	3	*Glycine max* cv. (*jutro*, raw; *merit*, raw) [76]	1.90	4	-	-
	04040	0.01	3	Soybeans, white, small size, dry [67]; Soya beans [62]	0.45	3	Soybeans, all species except for black soybean [89]; Yellow soybeans [90]	2.11	3	*Glycine max* cv. (*jutro*, raw; *merit*, raw) [76]	2.31	4	-	-
Natto (fermented soybeans)	04046	1.00	3	Soybeans, white, small size, dry [67]; Soya beans [62]	0.40	3	Soybeans, all species except for black soybean [89]; Yellow soybeans [90]	2.27	3	*Glycine max* cv. (*jutro*, raw; *merit*, raw) [76]	2.05	4	-	-
Miso for miso soup‖	17045	0.05	3	Soybeans, white, small size, dry [67]; Soya beans [62]	0.31	3	Soybeans, all species except for black soybean [89]; Yellow soybeans [90]	1.72	3	*Glycine max* cv. (*jutro*, raw; *merit*, raw) [76]	1.55	4	-	-

(Continued)

Table 2-2. (Continued)

Food item in the BDHQ*	FC†	WF‡	FRAP (mmol Fe^{2+}/100g) Step§	FRAP Reference	FRAP TAC	ORAC (mmol TE/100g) Step§	ORAC Reference	ORAC TAC	TEAC (mmol TE/100g) Step§	TEAC Reference	TEAC TAC	TRAP (mmol TE/100g) Step§	TRAP Reference	TRAP TAC
Potatoes														
Potatoes (all varieties)	02017	0.61	1	Potatoes (NS; Beate; Roseval) [67]; Potatoes, white [58]; Potato [62]; Poteto [56]	0.13	1	Potatoes, white, flesh and skin, raw [68]; Potato, tuber [88]; Potato [65]; Potato [73]	0.67	1	Poteto [56]	0.08	1	Poteto [56]	0.09
	02006	0.13	1	Sweet potatoe (NS; pale; red/white; yellow) [67]; Sweet potatoes [58]; Sweet potato/batat [62]	0.19	1	Sweet potato, raw [68]; Sweet potato, tuberous root [88]; Sweet potato [65]; Sweet potato [73]	0.95	2	*Ipomoea batatas var* (orange), boiled; (*Vulatolu*), boiled; (*Papua*), boiled; *(Honiara*), boiled [75]	0.11	4	-	-
	02010	0.13	2	Yam [67]; Yam [62]	0.22	1	Taro (satoimo), corm [88]; Taro/ cocoyam [73]	1.14	2	*Colocasia esculenta var* (*Tausala Samoa*), boiled; (*Wararasa*) (greenish), boiled; common (white), boiled [75]	0.09	4	-	-
	02022	0.13	2	Yam [67]; Yam [62]	0.22	2	Taro (satoimo), corm [88]; Taro/ cocoyam [73]	1.14	2	*Dioscorea alata var* (*Veiwa*) (red), boiled; (*Vurai*) (white), boiled; *Discorea esculenta var* (red), boiled; (white), boiled; *Discorea nummularia*, boiled [75]	0.08	4	-	-
Confectionaries														
Rice crackers, rice cakes, and	15060	0.50	4	-	-	4	-	-	4	-	-	4	-	-
Japanese-style pancakes	15059	0.50	4	-	-	4	-	-	4	-	-	4	-	-

(Continued)

Table 2-2. (Continued)

Food item in the BDHQ*	FC†	WF‡	FRAP (mmol Fe^{2+}/100g) Step§	Reference	TAC	ORAC (mmol TE/100g) Step§	Reference	TAC	TEAC (mmol TE/100g) Step§	Reference	TAC	TRAP (mmol TE/100g) Step§	Reference	TAC
Japanese sweets	15023	0.13	3	Black eye beans, (haricot balance; white, cornille; white, medium size, dry) [67]; Black-eye pea/bean [62]	0.07	3	Cowpeas, common (blackeyes, crowder, southern), mature [68]	0.49	3	Cowpeas, raw [77]	0.26	4	-	-
	15031	0.58	3	Chest nuts, with perricle (purchased with shell) [67]; Chestnut [57]	1.44	4	-	-	3	Chestnut [57]	0.19	3	Chestnut [57]	0.55
	15038	0.10	3	Black eye beans, (haricot balance; white, cornille; white, medium size, dry) [67]; Black-eye pea/bean [62]	0.11	3	Cowpeas, common (blackeyes, crowder, southern), mature [68]	0.77	3	Cowpeas, raw [77]	0.41	4	-	-
	15045	0.10	4	-	-	4	-	-	4	-	-	4	-	-
	15025	0.10	4	-	-	4	-	-	4	-	-	4	-	-
Cakes, cookies, and biscuits	15009	0.11	4	-	-	4	-	-	4	-	-	4	-	-
	15075	0.27	4	-	-	4	-	-	4	-	-	4	-	-
	15073	0.27	4	-	-	4	-	-	4	-	-	4	-	-
	15097	0.12	2	Biscuits, Bixit [67]; Biscuits, all species, cooked [58]	0.42	4	-	-	4	-	-	4	-	-
	15098	0.24	2	Biscuits, Bixit [67]; Biscuits, all species, cooked [58]	0.42	4	-	-	4	-	-	4	-	-
Oil														
Mayonnaise and salad dressing	17043	0.66	1	Mayonnaise, original [67]	1.08	4	-	-	4	-	-	4	-	-
	17040	0.34	1	Dressing, French, salad dressing [67]; French salad dressing (NS; fat-free; lite) [58]	0.25	4	-	-	4	-	-	4	-	-

(Continued)

Table 2-2. (Continued)

Food item in the BDHQ*	FC†	WF‡	FRAP (mmol Fe^{2+}/100g) Step§	FRAP Reference	FRAP TAC	ORAC (mmol TE/100g) Step§	ORAC Reference	ORAC TAC	TEAC (mmol TE/100g) Step§	TEAC Reference	TEAC TAC	TRAP (mmol TE/100g) Step§	TRAP Reference	TRAP TAC
Oil used during cooking	14006	1.00	3	Soy bean oil; Canola oil, cold-pressed [67]; Canola oil; Vegetable oil (soybean oil) [58]	0.44	4	-	-	2	Oil, soybean [56]	0.22	4	-	-
Fruits														
Citrus fruit including oranges	07029	0.33	2	Clementines [67]; Clementines [58]; Clementine [62]; Clementine [56]	0.87	2	Tangerines, (mandarin oranges), raw; Oranges, raw (all species) [68]; Orange [64]; Orange (NS; mandarin) [74]	1.97	2	Clementine [56]	0.31	2	Clementine [56]	0.27
	07105	0.33	2	Grapefruit, yellow [67]; Grapefruit, yellow [62]; Grapefruit (yellow) [56]	0.87	2	Grapefruit, raw (pink and red and white; pink and red), all areas [68]; Grapefruit, pink [64]; Grapefruit, red [74]	1.62	2	Grapefruit (yellow) [56]	0.31	2	Grapefruit (yellow) [56]	0.40
	07062	0.33	1	Grapefruit, yellow [67]; Grapefruit, yellow [62]; Grapefruit (yellow) [56]	0.87	1	Grapefruit, raw (pink and red and white; pink and red), all areas [68]; Grapefruit, pink [64]; Grapefruit, red [74]	1.62	1	Grapefruit (yellow) [56]	0.31	1	Grapefruit (yellow) [56]	0.40
Strawberries, persimmons, and kiwi fruits	07012	0.25	1	Strawberries, Corona, cultivated [67]; Strawberries [58]; Strawberry, cultivated [62]; Strawberry (cultivated) [56]	2.16	1	Strawberries, raw [68]; Strawberry [64]; Strawberry [74]	3.67	1	Strawberry (cultivated) [56]	1.09	1	Strawberry (cultivated) [56]	0.86
	07054	0.63	1	Kiwi (green; yellow) [67]; Kiwi (NS; gold) [58]; Kiwi fruit [62]; Kiwi fruit [56]	0.95	1	Kiwi fruit, (chinese gooseberries), fresh, raw [68]; Kiwi fruit [64]; Kiwifruit [74]	0.83	1	Kiwi fruit [56]	0.23	1	Kiwi fruit [56]	0.23

(Continued)

Table 2-2. (Continued)

Food item in the BDHQ*	FC†	WF‡	FRAP (mmol Fe^{2+}/100g) Step§	FRAP Reference	FRAP TAC	ORAC (mmol TE/100g) Step§	ORAC Reference	ORAC TAC	TEAC (mmol TE/100g) Step§	TEAC Reference	TEAC TAC	TRAP (mmol TE/100g) Step§	TRAP Reference	TRAP TAC
Strawberries, persimmons, and kiwi fruits	07049	0.12	1	Sharon [67]; Kaki/sharon [62]	0.49	1	Persimmon [74]	0.74	3	Persimmon, dry [78]	6.86	4	-	-
Other fruits	07107	0.25	1	Banana [67]; Banana [58]; Banana [62]; Banana [56]	0.19	1	Bananas, raw [68]; Banana [64]; Banana [74]	0.74	1	Banana [56]	0.06	1	Banana [56]	0.11
	07148	0.43	1	Apples (all species except for dried and without peel) [67]; Apples (all species except for without peel [58]; Apple [62]; Apple (red Delicious; yellow Golden) [56]	0.39	1	Apples, raw, with skin [68]; Apple (green; red) [74]	2.80	1	Apple (red Delicious; yellow Golden) [56]	0.15	1	Apple (red Delicious; yellow Golden) [56]	0.19
	07116	0.11	1	Grapes (all species) [67]; Grapes (green; red) [58]; Grape [62]; Grape (black; white) [56]	0.78	1	Grapes (black; red, raw; white or green, raw) [68]; Grape (red; white) [64]; Grape (green; red) [74]	1.29	1	Grape (black; white) [56]	0.32	1	Grape (black; white) [56]	0.20
	07136	0.07	1	Peaches [67]; Peaches [58]; Peach (yellow) [56]	0.24	1	Peaches, raw [68]	1.92	1	Peach (yellow) [56]	0.17	1	Peach (yellow) [56]	0.15
	07088	0.14	2	Pears [67]; Pears (all species) [58]; Pear [62]; Pear [56]	0.22	2	Pears (green cultivars, with peel, raw; red anjou, raw) [68]; Pear (green; yellow) [74]	1.80	2	Pear [56]	0.22	2	Pear [56]	0.39
Vegetables														
Carrots and pumpkins	06212	0.66	1	Carrots [67]; Carrots [58]; Carrot [62]; Carrot [56]	0.04	1	Carrots, raw [68]; Carrot, root with skin [88]; Carrot [65]; Carrot [73]	0.66	1	Carrot [56]	0.04	1	Carrot [56]	0.07
	06048	0.34	1	Pumpkin; Pumpkins [67]; Squash [62]; Pumpkin [56]	0.11	1	Pumpkin, raw [68]	0.48	1	Pumpkin [56]	0.37	1	Pumpkin [56]	0.00

(Continued)

Table 2-2. (Continued)

Food item in the BDHQ*	FC†	WF‡	FRAP (mmol Fe^{2+}/100g) Step§	FRAP Reference	FRAP TAC	ORAC (mmol TE/100g) Step§	ORAC Reference	ORAC TAC	TEAC (mmol TE/100g) Step§	TEAC Reference	TEAC TAC	TRAP (mmol TE/100g) Step§	TRAP Reference	TRAP TAC
Tomatoes, tomato ketchup, boiled tomato, and stewed tomato	06182	1.00	1	Tomatoes (NS; chopped; cluster tomatoes; cluster tomatoes, small; plum-; steak-) [67]; Tomatoes [58]; Tomato, except for cherry tomato [62]; Tomato (salad) [56]	0.27	1	Tomatoes, plum (raw; red, ripe, raw, year round average) [68]; Tomato, fruit [88]; Tomato [64]; Tomato [73]	0.39	1	Tomato (salad) [56]	0.17	1	Tomato (salad) [56]	0.13
Green leafy vegetables including broccoli	06267	0.38	1	Spinach [67]; Spinach [62]; Spinach [56]	1.20	1	Spinach, raw [68]; Spinach, leaves [88]; Spinach [65]; Spinach [73]	1.49	1	Spinach [56]	0.85	1	Spinach [56]	0.58
	06086	0.38	2	Spinach [67]; Spinach [62]; Spinach [56]	1.20	2	Cabbage, all species except for Chinese celery; red; round [73]	1.36	2	Spinach [56]	0.85	2	Spinach [56]	0.58
	06227	0.12	3	Chives [79]	0.64	2	Chives, raw [68]	2.09	2	Leek [56]	0.07	2	Leek [56]	0.10
	06160	0.08	2	Spinach [67]; Spinach [62]; Spinach [56]	1.20	1	Cabbage, all species except for Chinese celery; red; round [73]	1.36	2	Spinach [56]	0.85	2	Spinach [56]	0.58
	06130	0.04	2	Spinach [67]; Spinach [62]; Spinach [56]	1.20	2	Cabbage, all species except for Chinese celery; red; round [73]	1.36	2	Spinach [56]	0.85	2	Spinach [56]	0.58
Raw vegetables used salad (cabbage and lettuce)	06061	0.33	1	Cabbage [67]; Cabbage [58]; Cabbage [62]; Cabbage (green) [56]	0.15	1	Cabbage, raw [68]; Cabbage, head [88]; Cabbage [65]; Cabbage, round [73]	0.52	1	Cabbage (green) [56]	0.12	1	Cabbage (green) [56]	0.28
	06065	0.33	1	Cucumber (NS; Cucumis sativus; small, russian) [67]; Cucumber, with peel [58]; Cucumber [62]; Cucumber [56]	0.05	1	Cucumber, with peel, raw [68]; Cucumber, fruit [88]; Cucumber [65]; Cucumber [73]	0.21	1	Cucumber [56]	0.04	1	Cucumber [56]	0.00

(Continued)

Table 2-2. (Continued)

Food item in the BDHQ*	FC†	WF‡	FRAP (mmol Fe^{2+}/100g) Step§	Reference	TAC	ORAC (mmol TE/100g) Step§	Reference	TAC	TEAC (mmol TE/100g) Step§	Reference	TAC	TRAP (mmol TE/100g) Step§	Reference	TAC
Raw vegetables used salad (cabbage and lettuce)	06312	0.33	1	Lettuce, iceberg [58]; Lettuce [62]; Lettuce [56]	0.27	1	Lettuce, iceberg (includes crisphead types), raw [68]; Crisp lettuce, head [88]; Iceberg lettuce [65]; Lettuce, iceberg [73]	0.32	1	Lettuce [56]	0.13	1	Lettuce [56]	0.23
Cabbage and Chinese cabbage	06061	0.55	1	Cabbage [67]; Cabbage [58]; Cabbage [62]; Cabbage (green) [56]	0.15	1	Cabbage, raw [68]; Cabbage, head [88]; Cabbage [65]; Cabbage, round [73]	0.52	1	Cabbage (green) [56]	0.12	1	Cabbage (green) [56]	0.28
	06233	0.45	1	Chinese cabbage [67]	0.45	1	Chinese cabbage, head [88]; Cabbage, Chinese celery [73]	0.52	2	Cabbage (green) [56]	0.12	2	Cabbage (green) [56]	0.28
Radishes and turnips	06134	0.90	2	Radishes [67]; Radishes [58]; Radish [62]	0.31	1	Japanese radish (daikon), root without skin [88]	0.39	2	Turnip tops [56]	0.55	2	Turnip tops [56]	0.66
	06038	0.10	2	Turnip [67]; Turnip [62]	0.29	2	Japanese radish (daikon), root without skin [88]	0.39	2	Turnip tops [56]	0.55	2	Turnip tops [56]	0.66
Other root vegetables (onions, burdock, and lotus root)	06153	0.79	1	Onion (NS; small; yellow) [67]; Onions, yellow [58]; Onion, yellow [62]; Onion (yellow) [56]	0.35	1	Onions (NS; sweet; white), raw [68]; Onion, bulb [88]; Onion [65]; Onion (NS; yellow) [73]	0.89	1	Onion (yellow) [56]	0.18	1	Onion (yellow) [56]	0.24
	06084	0.16	4	-	-	1	Edible burdock, root [88]	5.22	1	Burdock roots [91]	0.00	4	-	-
	06317	0.05	3	White lotus root [80]	1.58	1	East Indian lotus root, rhizome [88]; Lotus root [73]	2.10	4	-	-	4	-	-

(Continued)

Table 2-2. (Continued)

Food item in the BDHQ*	FC†	WF‡	FRAP (mmol Fe^{2+}/100g) Step§	Reference	TAC	ORAC (mmol TE/100g) Step§	Reference	TAC	TEAC (mmol TE/100g) Step§	Reference	TAC	TRAP (mmol TE/100g) Step§	Reference	TAC
Salted green and yellow vegetable pickles	06148	0.33	3	Spinach [67]; Spinach [62]; Spinach [56]	2.72	3	Cabbage, all species except for Chinese celery; red; round [73]	3.08	3	Spinach [56]	1.92	3	Spinach [56]	1.31
	06231	0.67	3	Spinach [67]; Spinach [62]; Spinach [56]	2.11	3	Cabbage, all species except for Chinese celery; red; round [73]	2.39	3	Spinach [56]	1.49	3	Spinach [56]	1.01
Other salted vegetable pickles (excluding salted pickled plum)	06139	0.30	3	Radishes [67]; Radishes [58]; Radish [62]	0.64	3	Radishes [68]; Chinese radish [73]	3.12	3	Turnip tops [56]	1.14	3	Turnip tops [56]	1.37
	06066	0.10	3	Cucumber (NS; Cucumis sativus; small, russian) [67]; Cucumber, with peel [58]; Cucumber [62]; Cucumber [56]	0.09	3	Cucumber, with peel, raw [68]; Cucumber, fruit [88]; Cucumber [65]; Cucumber [73]	0.36	3	Cucumber [56]	0.07	3	Cucumber [56]	0.00
	06068	0.10	3	Cucumber (NS; Cucumis sativus; small, russian) [67]; Cucumber, with peel [58]; Cucumber [62]; Cucumber [56]	0.16	3	Cucumber, with peel, raw [68]; Cucumber, fruit [88]; Cucumber [65]; Cucumber [73]	0.65	3	Cucumber [56]	0.13	3	Cucumber [56]	0.00
	06195	0.10	3	Aubergine (NS; native, red; native, white) [67]; Aubergines/eggplant [62]; Eggplant [56]	0.25	3	Eggplant, raw [68]; Eggplant, fruit [88]; Eggplant [65]; Eggplant/brinjal [73]	1.37	3	Eggplant [56]	0.16	3	Eggplant [56]	0.40
	06196	0.10	3	Aubergine (NS; native, red; native, white) [67]; Aubergines/eggplant [62]; Eggplant [56]	0.29	3	Eggplant, raw [68]; Eggplant, fruit [88]; Eggplant [65]; Eggplant/brinjal [73]	1.61	3	Eggplant [56]	0.18	3	Eggplant [56]	0.47
	06235	0.30	3	Chinese cabbage [67]	0.74	3	Chinese cabbage, head [88]; Cabbage, Chinese celery [73]	0.84	3	Cabbage (green) [56]	0.19	3	Cabbage (green) [56]	0.46

(Continued)

Table 2-2. (Continued)

Food item in the BDHQ*	FC†	WF‡	FRAP ($mmol\ Fe^{2+}$/100g) Step§	Reference	TAC	ORAC (mmol TE/100g) Step§	Reference	TAC	TEAC (mmol TE/100g) Step§	Reference	TAC	TRAP (mmol TE/100g) Step§	Reference	TAC
Mushrooms (all varieties)	08011	0.50	2	Mushrooms, shiitake, stir-fried [58]	0.33	2	Mushrooms, shiitake, dried [68]; Shiitake mushroom [88]; Mushroom, shiitake [73]	0.58	2	Mushroom [56]	0.49	2	Mushroom [56]	0.63
	08016	0.50	2	Mushrooms (oyster; maitake) [58]	0.10	2	Mushroom, oyster, raw; Mushrooms, maitake, raw [68]; Mushroom, oyster [73]	0.72	2	Mushroom [56]	0.49	2	Mushroom [56]	0.63
Seaweeds (all varieties)	09045	1.00	4	-	-	3	Seaweed, dried [73]	0.45	3	*Undaria pinnatifida* [93]	0.15	4	-	-
Alcohol beverages														
Beer	16006	1.00	1	Beer (all species except for Guinnes Draught; Limfjords Porter, double brown stout; Porter) [67]; Beer (light; regular) [58]; Beer (lager) [56]	0.24	4	-	-	1	Beer (lager) [56]	0.10	1	Beer (lager) [56]	0.00
Whiskey	16016	0.50	1	Whisky, Finest Scotch Whisky [67]; Whiskey [56]	0.20	4	-	-	1	Whiskey [56]	0.17	1	Whiskey [56]	0.23
	16017	0.50	1	Brandy, Napoleon V.S.O.P.; Cognac (V.S.Martell, Fine Cognac; X.O.Braastad, FineChampagne) [67]; Cognac [56]	0.31	4	-	-	1	Cognac [56]	0.13	1	Cognac [56]	0.15

(Continued)

Table 2-2. (Continued)

Food item in the BDHQ*	FC†	WF‡	FRAP (mmol Fe^{2+}/100g) Step§	Reference	TAC	ORAC (mmol TE/100g) Step§	Reference	TAC	TEAC (mmol TE/100g) Step§	Reference	TAC	TRAP (mmol TE/100g) Step§	Reference	TAC
Wine	16010	0.50	1	Cockburn's Port; Wine, red (all species) [67]; Wine, white [58]; Wine (Vernaccia, white; Pinot, white; Greco di Tufo, white) [56]	0.39	1	Alcoholic beverage, wine, table, white [68]; Wine, white, all species [61]	0.35	1	Wine (Vernaccia, white; Pinot, white; Greco di Tufo, white) [56]	0.17	1	Wine (Vernaccia, white; Pinot, white; Greco di Tufo, white) [56]	0.21
	16011	0.50	1	Wine, white (all species) [67]; Wine, red [58]; Wine (Aglianico, red; Chianti, red; Sauvignon, red) [56]	2.43	1	Alcoholic beverage, wine, table, red [68]; Wine, red, all species [61]	1.99	1	Wine (Aglianico, red; Chianti, red; Sauvignon, red) [56]	1.08	1	Wine (Aglianico, red; Chianti, red; Sauvignon, red) [56]	1.42
Non-alcohol beverages														
Fruits juice and vegetable juice (100%)	06186	0.11	2	Vegetable juice [67]	0.48	1	Vegetable juice cocktail, canned [68]	0.55	2	Tomato (salad) [56]	0.17	2	Tomato (salad) [56]	0.13
	07031	0.26	2	Juice, orange [67]; Orange juice, 100% (juice box), from concentrate [58]; Orange juice [56]	0.70	2	Orange juice (canned, unsweetened; raw) [68]; Common commercial fruits juice, orange [64]	0.72	2	Orange juice [56]	0.30	2	Orange juice [56]	0.23
	07150	0.26	1	Juice, apple [67]; Apple juice [56]	0.29	1	Apple juice, canned or bottled, unsweetened, without added ascorbic acid [68]; Common commercial fruit juice, apple [64]	0.41	1	Apple juice [56]	0.18	1	Apple juice [56]	0.20
	07064	0.26	1	Juice, grapefruits [67]; Grapefruit juice [56]	0.85	1	Grapefruit juice, white, raw [68]; Common commercial fruit juice, grapefruit [64]	0.79	1	Grapefruit juice [56]	0.33	1	Grapefruit juice [56]	0.27
	06185	0.11	1	Tomato juice (NS; ecological; Premium; Sun-C) [67]	0.48	1	Tomato juice, canned [68]; Common commercial fruit juice, tomato [64]	0.43	2	Tomato (salad) [56]	0.17	2	Tomato (salad) [56]	0.13

(Continued)

Table 2-2. (Continued)

Food item in the BDHQ*	FC†	WF‡	FRAP (mmol Fe^{2+}/100g) Step§	FRAP Reference	FRAP TAC	ORAC (mmol TE/100g) Step§	ORAC Reference	ORAC TAC	TEAC (mmol TE/100g) Step§	TEAC Reference	TEAC TAC	TRAP (mmol TE/100g) Step§	TRAP Reference	TRAP TAC
Green tea	16037	1.00	1	Tea, green (all species except for Jasmine and mint, prepared) [67]; Tea (green) [56]	1.49	3	Tea, green, ready-to-drink [68]; Green tea [65]; Green tea, all species [84]; Green tea [85]	2.03	1	Tea (green) [56]	0.60	1	Tea (green) [56]	0.76
Black and oolong tea (including other Chinese tea)	16044	0.50	1	Tea, black, all species, prepared [67]; Tea (black) [56]	0.97	3	Tea, black, ready-to-drink, plain and flavored [68]; Black tea [65]; Black tea, all species [83]; Black tea, all species except for black tea [84]	1.48	1	Tea (black) [56]	0.36	1	Tea (black) [56]	0.49
	16042	0.50	2	Tea, green (all species except for Jasmine and mint, prepared); Tea, black, all species, prepared [67]; Tea (green); Tea (black) [56]	1.32	3	Tea, green, ready-to-drink; Tea, black, ready-to-drink, plain and flavored [68]; Green tea; Black tea [65]; Black tea, all species [83]; Green tea, all species; Black tea, all species except for black tea [84]; Green tea [85]	1.69	2	Tea (green); Tea (black) [56]	0.48	2	Tea (green); Tea (black) [56]	0.63
Coffee	16045	1.00	1	Coffee (all species except for instant, Caffe Latte, Cappucino, Espresso, caffein free, Ice coffee, and double, filter brewed; prepared [67]; Coffee [58]; Coffee (extracted; soluble) [56]	3.23	3	Coffee brew [86]; coffee fruit powder 1 [87]	4.24	1	Coffee (extracted; soluble) [56]	3.14	1	Coffee (extracted; soluble) [56]	5.60

BDHQ, brief-type self-administered diet history questionnaire; FC, food code; Fe, iron; FRAP, ferric reducing ability of plasma; NS, no species; ORAC, oxygen radical absorbance capacity; TAC, total antioxidant capacity; TE, Trolox equivalent; TEAC, Trolox equivalent antioxidant capacity; TRAP, total radical-trapping antioxidant parameter; WF, weighting factor.

* The TAC values of these 36 food items from the 58 items in the BDHQ were searched in the present study. The following 22 items were determined to contain no TAC value: all 6 items in fish and shellfish (dried fish and salted fish; small fish with bones; canned tuna; oily fish; non-oily fish; and squid, octopus, shrimp, and clam); all 4 items in meat (chicken; pork and beef; ham, sausages, and bacon; and liver); all 2 items in dairy products (full-fat milk and yogurt; and low-fat milk and yogurt); 2 items in other animal foods (ice cream; and eggs); and 8 items in other foods (sugar for coffee and black tea; sugar used during cooking; table salt and salt-containing seasonings used at the table such as soya sauce; salt used during cooking; soup consumed with noodles; sake; shochu and shochu mixed with water or a carbonated beverage; and cola and sweetened soft drinks). Food items were categorized into food groups according to our previous study [70].

† Listed in the Standard Tables of Food Composition in Japan [94].

‡ Included in in an *ad hoc* computer algorithm for the BDHQ [70, 71].

§ Step 1, TAC value was assigned an analytical value; Step 2, TAC value was assigned a substituted value; Step 3, TAC value was assigned a calculated value; Step 4, TAC value was assigned no value.

|| Remaining individual food composing this food item is water.

Table 2-3. Total antioxidant capacity of 86 food items included in the self-administered diet history questionnaire

Food item in the DHQ*	FRAP (mmol Fe^{2+} /100 g)	ORAC (mmol TE /100g)	TEAC (mmol TE /100g)	TRAP (mmol TE /100g)
Cereals				
Cornflakes	0.93	2.36	0.22	0.28
Brown rice	0.27	1.14	0.18	0.22
Half-milled rice	0.21	0.60	0.14	0.20
White bread	0.20	-	-	-
Pizza	0.20	-	-	-
Well-milled rice mixed with barley	0.15	0.39	0.10	0.14
70% milled rice	0.13	0.25	0.12	0.18
Japanese noodles (buckwheat and Japanese wheat noodles)	0.12	0.65	0.19	0.12
Well-milled rice with germ	0.10	0.13	0.11	0.18
Spaghetti	0.03	-	0.08	0.06
Well-milled rice	0.02	-	0.10	0.18
Nuts and pulses				
Peanuts	1.20	3.17	0.48	0.33
Other nuts	0.84	4.69	4.76	1.08
Natto (fermented soybeans)	0.40	2.27	2.05	-
Tofu (soybean curd) products	0.36	2.05	1.85	-
Boiled beans	0.34	2.09	0.96	-
Miso as seasoning	0.31	1.72	1.55	-
Miso for miso soup	0.31	1.72	1.55	-
Tofu (soybean curd)	0.09	0.79	0.71	-
Soybean milk	0.08	0.47	0.42	-
Potatoes				
French fries	0.26	1.24	0.15	0.16
Sweet potatoes, yams, and taro	0.21	1.08	0.09	-
Potatoes	0.13	0.67	0.08	0.09
Konnyaku (devil’s tongue jelly)	0.04	0.20	0.01	-
Sugar and confectioneries				
Chocolate	3.96	7.16	3.62	1.16
Jam and marmalade	0.71	1.57	0.33	0.25
Potato chips	0.59	2.09	0.25	0.26
Japanese sweets with azuki beans	0.54	0.42	0.29	0.18
Cookies and biscuits	0.42	-	-	-
Pancakes	0.15	-	-	-
Doughnuts	0.15	-	-	-
Japanese bread with a sweet filling	0.03	0.25	0.13	-
Jellies	0.01	-	-	-
Oils				
Mayonnaise	1.08	-	-	-
Margarine	1.05	-	-	-
Oil used during cooking	0.44	-	0.22	-
Salad dressing	0.25	-	-	-

(Continued)

Table 2-3. (Continued)

Food item in the DHQ*	FRAP (mmol Fe^{2+} /100 g)	ORAC (mmol TE /100g)	TEAC (mmol TE /100g)	TRAP (mmol TE /100g)
Fruits				
Strawberries	2.16	3.67	1.09	0.86
Raisins	1.28	5.75	0.66	0.62
Kiwi fruits	0.95	0.83	0.23	0.23
Oranges	0.87	1.74	0.31	0.36
Grapes	0.78	1.29	0.32	0.20
Persimmons	0.49	0.74	6.86	-
Canned fruits	0.42	1.32	0.19	0.22
Apples	0.39	2.80	0.15	0.19
Peaches	0.24	1.92	0.17	0.15
Pears	0.22	1.80	0.22	0.39
Bananas	0.19	0.74	0.06	0.11
Melons	0.18	0.24	0.09	0.10
Watermelons	0.05	0.17	0.07	0.05
Vegetables				
Salted green and yellow vegetable pickles	2.31	2.62	1.63	1.11
Lotus root	1.58	2.10	-	-
Green leafy vegetables	1.08	1.53	0.69	0.48
Green peppers	1.02	0.93	0.84	0.55
Broccoli	0.96	1.48	0.30	0.31
Cauliflower	0.80	0.85	0.11	0.16
Other salted pickles	0.49	1.52	0.45	0.64
Chinese cabbage	0.45	0.52	0.12	0.28
Salted pickled plums	0.45	3.62	0.47	0.75
Cabbage	0.45	0.52	0.12	0.28
Radishes	0.31	1.50	0.55	0.66
Onions	0.29	1.22	0.18	0.24
Lettuce	0.27	0.32	0.13	0.23
Tomatoes	0.27	0.39	0.17	0.13
Mushrooms	0.22	0.65	0.49	0.63
Eggplants	0.18	0.25	0.11	0.28
Pumpkins	0.11	0.48	0.37	0.00
Carrots	0.10	0.33	0.04	0.07
Cucumbers	0.05	0.21	0.04	0.00
Laver (dried, edible seaweed)	-	6.11	2.30	-
Burdock	-	5.22	-	-
Bean sprouts	-	1.72	0.15	-
Wakame and hijiki seaweed	-	0.45	0.15	-
Alcoholic beverages				
Wine	1.41	1.17	0.63	0.82
Whiskey	0.25	-	0.15	0.19
Beer	0.24	-	0.10	0.00

(Continued)

Table 2-3. (Continued)

Food item in the DHQ*	FRAP (mmol Fe^{2+} /100 g)	ORAC (mmol TE /100g)	TEAC (mmol TE /100g)	TRAP (mmol TE /100g)
Non-alcoholic beverages				
Coffee	3.23	4.24	3.14	5.60
Green, barley, and oolong tea (including other Chinese tea)	1.41	1.86	0.54	0.69
Black tea	0.97	1.48	0.36	0.49
Cocoa	0.80	3.03	1.41	0.45
Fruit juice (100%)	0.62	0.64	0.27	0.23
Tomato juice	0.48	0.43	0.17	0.13
Vegetable juice	0.38	0.48	0.17	0.16
Fruit juice, excluding 100% juice	0.31	0.32	0.14	0.11
Seasonings				
Soy sauce	1.68	1.06	0.96	-
Tomato ketchup	0.37	0.58	0.15	0.17

DHQ, self-administered diet history questionnaire; Fe, iron; FRAP, ferric reducing ability of plasma; ORAC, oxygen radical absorbance capacity; TE, Trolox equivalent; TEAC, Trolox equivalent antioxidant capacity; TRAP, total radical-trapping antioxidant parameter.

* Among the 98 foods included in the DHQ whose TAC value was searched, the following 12 items were not be listed because these foods could not be assigned a TAC value for all four methods: instant noodles; Chinese noodles; butter roll; croissant; Japanese-style pancakes; rice crackers; snacks made from wheat flour; Japanese sweets without azuki beans; cakes; curry or stew roux and meat sauce; nutritional supplement drinks; and nutritional supplement bars. Food items were categorized into food groups according to our previous study [70]. Food items were listed in descending order according to the FRAP value in each food group. Four food items not having a FRAP value were listed in descending order according to ORAC value.

Table 2-4. Total antioxidant capacity of 33 food items included in the brief-type self-administered diet history questionnaire

Food item in the BDHQ*	FRAP (mmol Fe^{2+}/ 100g)	ORAC (mmol TE/ 100g)	TEAC (mmol TE/ 100g)	TRAP (mmol TE/ 100g)
Cereals				
Buckwheat noodles	0.23	1.29	0.39	0.24
Breads (including white bread and Japanese bread with a sweet filling)	0.15	0.07	0.04	-
Rice	0.02	-	0.10	0.18
Spaghetti and macaroni	0.03	-	0.08	0.06
Pulses				
Natto (fermented soybeans)	0.40	2.27	2.05	-
Tofu (soybean curd) and tofu products	0.10	0.82	0.74	-
Miso for miso soup	0.02	0.09	0.08	-
Potatoes				
Potatoes (all varieties)	0.16	0.83	0.08	0.05
Confectionaries				
Japanese sweets	0.85	0.14	0.18	0.32
Cakes, cookies, and biscuits	0.15	-	-	-
Oil				
Mayonnaise and salad dressing	0.80	-	-	-
Oil used during cooking	0.44	-	0.22	-
Fruits				
Strawberries, persimmons, and kiwi fruits	1.19	1.52	1.26	0.36
Citrus fruit including oranges	0.87	1.74	0.31	0.36
Other fruits	0.35	1.92	0.16	0.19
Vegetables				
Salted green and yellow vegetable pickles	2.31	2.62	1.63	1.11
Green leafy vegetables including broccoli	1.14	1.50	0.76	0.52
Other salted vegetable pickles (excluding salted pickled plum)	0.49	1.59	0.45	0.64
Other root vegetables (onions, burdock, and lotus root)	0.35	1.63	0.14	0.19
Radishes and turnips	0.30	0.39	0.55	0.66
Cabbage and Chinese cabbage	0.29	0.52	0.12	0.28
Tomatoes, tomato ketchup, boiled tomato, and stewed tomato	0.27	0.39	0.17	0.13
Mushrooms (all varieties)	0.22	0.65	0.49	0.63
Raw vegetables used salad (cabbage and lettuce)	0.16	0.35	0.10	0.17
Carrots and pumpkins	0.07	0.60	0.15	0.05
Seaweeds (all varieties)	-	0.45	0.15	-

(Continued)

Table 2-4. (Continued)

Food item in the BDHQ*	FRAP (mmol Fe^{2+}/ 100g)	ORAC (mmol TE/ 100g)	TEAC (mmol TE/ 100g)	TRAP (mmol TE/ 100g)
Alcohol beverages				
Wine	1.41	1.17	0.63	0.82
Whiskey	0.25	-	0.15	0.19
Beer	0.24	-	0.10	0.00
Non-alcohol beverages				
Coffee	3.23	4.24	3.14	5.60
Green tea	1.49	2.03	0.60	0.76
Black and oolong tea (including other Chinese tea)	1.15	1.58	0.42	0.56
Fruits juice and vegetable juice (100%)	0.57	0.61	0.25	0.21

BDHQ, brief-type self-administered diet history questionnaire; Fe, iron; FRAP, ferric reducing ability of plasma; ORAC, oxygen radical absorbance capacity; TE, Trolox equivalent; TEAC, Trolox equivalent antioxidant capacity; TRAP, total radical-trapping antioxidant parameter.
* Among the 36 food items in the BDHQ whose TAC values were searched, the following 3 items were not listed because these foods could not be assigned a TAC value for all four methods: instant noodles and Chinese noodles; Japanese wheat noodles; rice crackers, rice cakes, and Japanese-style pancakes. Food items were categorized into food groups according to our previous study [70]. Food items were listed in descending order according to the FRAP value in each food group.

CHAPTER 3

Estimation and comparison of dietary total antioxidant capacity among Japanese women in three different age groups

3.1. Introduction

TAC databases of food items included in the DHQ and BDHQ were completed. Dietary TAC can be estimated using the TAC value described in these databases and the intake of each food. The ability to estimate dietary TAC and identify the food contributors in Japanese populations in different age groups will provide basic information in conducting epidemiological studies focusing on dietary TAC.

In this chapter, the author compared the value of dietary TAC among young, middle-aged, and elderly Japanese women and the food contributors to dietary TAC in these different generations.

3.2. Subjects and methods

3.2.1. Subjects

The subjects in this chapter were based on a cross-sectional multicenter study among three generations, which consisted of dietetic students (freshmen), their mothers, and grandmothers. A total of 85 institutions (universities, colleges, and technical schools) in 35 of 47 prefectures in Japan participated. The survey of institutions in northern and western Japan was conducted from April to May 2011 and that in eastern Japan from April to May 2012. All measurements at each institution were conducted according to the survey protocol. A collaborator at each institution explained the general purpose and an outline of the survey to the total of 7016 participants (dietetic students) and distributed a dietary assessment questionnaire and lifestyle questionnaire during the orientation session or a first lecture designed for freshmen in April 2011 or 2012. The students were required to answer these questions by the first week of May to minimize the influence of dietetic education on their responses. The collaborators also requested those students able to directly distribute the questionnaires to their mothers and grandmothers to invite their mother and one grandmother to join the study. Recruitment priority was given first to the maternal grandmother; or if unavailable, to the paternal grandmother; or finally to a 65-89 year-old female acquaintance of the student. The student provided written and oral explanations of the general purpose and an outline of the survey to his/her mother and grandmother. Written informed consent was obtained from all participants, and also from a parent for participants aged <20 years. A total of 4933 students, including 4656 women and 277 men (response rate: 70.3%), 4044 women for the mother's generation (57.6%), and 2332 women for the grandmother's generation (33.2%) answered both questionnaires. The protocol of the study was approved by the Ethics Committee at the University of Tokyo Faculty of Medicine (No. 3249).

The subjects in this chapter were limited to women (**Figure 3-1**). As subjects of young women, therefore, only female students were included (n = 4656). The author excluded those who lived in eastern Japan and answered questionnaires in 2011, because the author assumed that they could not report their usual dietary habits and lifestyle due to the occurrence of the Great East Japan Earthquake in March 2011 (n = 44). Additionally, the subjects answered the questionnaires on and after May 20th were excluded (n = 78) because their dietary and lifestyle habits may be changed to those until the first week of May for the influence of dietetic education. The author also excluded women who were in an institution where the response rate was extremely low (2%; n = 2). Further, subjects whose age, height, weight, or residential area were missing (n = 5); those aged ≥21 years (n = 117); and those with a reported energy intake less than half of the energy requirement for the lowest physical activity category according to the Dietary Reference Intakes for Japanese, 2010 (<850 kcal/d; n = 69) [96], or more than 1.5 times of the energy requirement for the highest physical activity category (>3375 kcal/d; n = 68) were excluded. The final sample thus comprised 4273 women aged 18-20 years.

For the participants in the mother's generation (n = 4044), those subjects who lived in eastern Japan and answered questionnaires in 2011 (n = 63); those who were in the low response rate institution (n = 2); those whose age, height, weight, or residential area were missing (n = 4); those aged ≥61 years (n = 32); and those with a reported energy intake were low (<825 kcal/d; n = 19) or high (>3450 kcal/d; n = 51) were excluded. As final sample of middle-aged women, the author got 3873 women aged 34-60 years from the mother's generation.

As subjects of elderly women, the participants in the grandmother's generation (n = 2332) were eligible. The author excluded those subjects who lived in eastern Japan and answered the questionnaires in 2011 (n = 47); a woman who was in a low response institution (n = 1); subjects whose age, height, weight, or residential area were missing (n = 20); those aged <65 years (n = 65); and those with a reported energy intake were low (<725 kcal/d; n = 16) or high (>3300 kcal/d; n = 32). The final sample thus comprised 2151 women aged 65-94 years.

3.2.2. Dietary assessment

Dietary habits during the preceding month were assessed using the DHQ for the young and middle-aged women and the BDHQ for the elderly women. The structures of these questionnaires were described in 2.2.1. Responses to the DHQ and the BDHQ as well as accompanying lifestyle questionnaire were checked once by research staff at the study office. If any missing or erroneous responses were given to questions which were essential for the analysis, the subjects were asked to complete those questions again.

Estimates of the intake of the 151 items in the DHQ and 58 items in the BDHQ, and energy intakes were calculated using an *ad hoc* computer algorithm for the DHQ and the BDHQ which was based on the *Standard Tables of Food Composition in Japan* [94]. Dietary TAC was estimated based on intake and the TAC value of each food. Although dietary supplement use was queried in the lifestyle questionnaire, intake from supplements was not included in the analysis due to the lack of a reliable composition table of dietary supplements in Japan and a database of dietary TAC.

3.2.3. *Other variables*

The subjects reported birth date and body height in the DHQ and the BDHQ. Body mass index (BMI) was calculated as current body weight (kg) divided by the square of body height (m). In the lifestyle questionnaire, the subject reported her residential area, which was grouped into six regions (Hokkaido and Tohoku, Kanto, Hokuriku and Tokai, Kinki, Chugoku and Shikoku, and Kyushu) and also into three categories according to population size (city with a population ≥1 million, city with a population <1 million, and town and village). The subject also reported current smoking status (yes or no), and dietary supplement use (yes or no) in the lifestyle questionnaire. Alcohol drinking (yes or no) was assessed as part of the DHQ and the BDHQ.

3.2.4. *Statistical analysis*

The percentage contribution of each individual food item to dietary TAC was calculated by dividing the crude TAC value from each individual food item by the daily individual crude dietary TAC. Dietary TAC and TAC value from each food group were adjusted for energy by the residual method using a linear regression model [97]. The characteristics of the subjects, intakes of energy, and their dietary TAC were shown separately for the three-generation.

All statistical analyses were performed with SAS statistical software, version 9.3 (SAS Institute Inc., Cary, NC, USA).

3.3. Results

Subject characteristics of 4273 young, 3873 middle-aged, and 2151 elderly Japanese women were shown in **Table 3-1**. The mean ages were 18.1 years for young women, 47.7 years for middle-aged women, and 74.7 years for elderly women. The mean estimated daily energy intakes for young, middle-aged, and elderly women were 1710, 1820, and 1735 kcal/d, respectively.

Means and standard deviations of dietary TAC were estimated by using the DHQ and the BDHQ (**Table 3-2**). Young women had a lowest TAC value in the three-generation. The mean TAC value were 11.0 mmol Fe^{2+}/d for FRAP, 16.5 mmol TE/d for ORAC, 6.14 mmol TE/d for TEAC, and 7.05 mmol TE/d for TRAP. Middle-aged women had a highest TAC value in the three-generation. The mean TAC values among the middle-aged women were 19.6 mmol Fe^{2+}/d for FRAP, 28.0 mmol TE/d for ORAC, 14.8 mmol TE/d for TEAC, and 22.1 mmol TE/d for TRAP. The TAC values of elderly women were 13.6 mmol Fe^{2+}/d for FRAP, 20.7 mmol TE/d for ORAC, 9.59 mmol TE/d for TEAC, and 12.5 mmol TE/d for TRAP. The range of Pearson's correlation coefficients of dietary TAC between each assay was 0.84-0.99 for young, 0.90-0.99 for middle-aged, 0.85-0.99 for elderly women (data not shown).

TAC value from each food group and contribution of each food group to dietary TAC was estimated by using the DHQ and the BDHQ (Table 3-2, **Figure 3-2**). The major contributor of dietary TAC in young women was green and oolong tea in all four assay (FRAP: 57%, ORAC: 50%, TEAC: 41%, and TRAP: 49%) and vegetables was the second contributor in FRAP, ORAC and TEAC assay (FRAP: 10%, ORAC: 14%, and TEAC: 11%). For TRAP assay, not vegetables (11%) but coffee (14%) was the second contributor. For middle-aged women, coffee was the major contributor (FRAP: 45%, ORAC: 42%, TEAC: 55%, and TRAP: 65%) and green and oolong tea was the second contributor (FRAP: 34%, ORAC: 31%, TEAC: 21%, and TRAP: 21%) in all four assays. For elderly women, green tea for FRAP (41%) and ORAC (36%) and coffee for TEAC (33%) and TRAP (42%) were the major contributors. While coffee for FRAP (26%) and ORAC (23%) and green tea for TEAC (26%)

and TRAP (30%) were the second contributors. TAC value from coffee in middle-aged women was about 9 times higher than young women and about 2 times higher than elderly women. TAC values from fruits and vegetables increased with old generation.

3.4. Discussion

In this chapter, dietary TAC was estimated among Japanese women in the three-generation, separately. The TAC value of middle-aged women was higher than that of young and elderly women. Young women had a lowest dietary TAC in the three-generation. Green tea, coffee, and vegetables were main contributors of dietary TAC in all generation.

One of the reasons why middle-aged women had the highest TAC value was that TAC from coffee was very high in middle-aged women. Although TAC from other food groups was similar to all generations, TAC from fruits and vegetables in young women were lower than middle-aged and elderly women. For young women, to consume more fruits and vegetables was one of the means to increase their dietary TAC and improve their dietary habit.

Dietary TAC was estimated using the DHQ and the BDHQ for the four different assays of FRAP, ORAC, TEAC, and TRAP. While the most analytical TAC values for FRAP were assigned as shown in Chapter 2, there were many missing values in the other TAC databases. For example, all TRAP values of the foods included in the group of pulses were deficient values. However, the major sources of dietary TAC were similar among the TAC assays. Additionally, the correlation coefficients between respective dietary TAC values were high in each generation. These results may suggest that similar dietary TAC can be estimated regardless of assay.

Whereas previous Western studies showed that the main contributors of dietary TAC were coffee, fruits, vegetables, and alcohol beverages [14, 15, 29, 36, 37], one of the main contributor in the present Japanese population was green tea. In young women and elderly women for FRAP and ORAC, green tea (green and oolong tea) was the first contributor to dietary TAC. Additionally, vegetables commonly consumed in Japan differ from those in Italy [56, 88], and fruit and vegetable items consumed by contemporary young Japanese women differ from those by young Spanish adults [18]. These results may suggest that, even if the dietary TAC among Japanese populations is comparable with Western populations, the kinds of antioxidant nutrients contributing dietary TAC of Japanese populations may be different from those in Western country.

Dietary TAC was estimated from the DHQ in young and middle-aged women and from the BDHQ in elderly women. Although satisfactory validity for antioxidant foods and nutrients from both the DHQ and the BDHQ were obtained in the previous studies [70, 71], we cannot compare the value of dietary TAC estimated from the DHQ and the BDHQ easily. For example, the DHQ asks the intake of chocolate, whose TAC value is very high, whereas the BDHQ does not. However, the contribution of chocolate to dietary TAC estimated from the DHQ among the young and middle-aged women was relatively low (1.7%-4.8% for young women and 0.5%-1.9% for middle-aged women; data not shown). Although the number of foods included in the BDHQ is smaller than that in the DHQ, the major contributors to dietary TAC may be included in the BDHQ. We should compare dietary TAC estimated from the DHQ with that from the BDHQ, carefully.

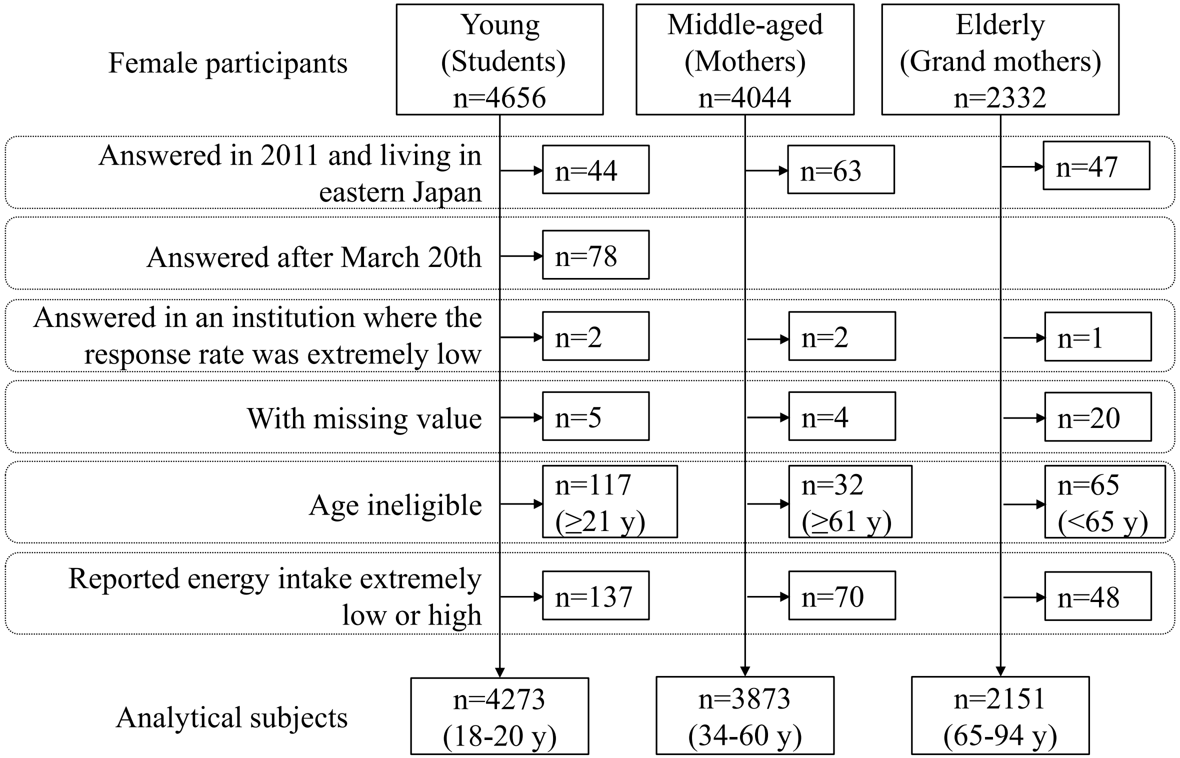

Figure 3-1. Flow chart of subjects in each age group

Table 3-1. Characteristics of 4273 young (18-20 y), 3873 middle-aged (34-60 y), and 2151 elderly (65-94 y) Japanese women*

	Young (n = 4273)	Middle-aged (n = 3873)	Elderly (n = 2151)
Age (y)	18.1 ± 0.3	47.7 ± 4.0	74.7 ± 5.0
Body height (cm)	157.8 ± 5.3	157.3 ± 5.1	150.4 ± 5.5
Body weight (kg)	52.0 ± 7.8	54.5 ± 8.2	51.4 ± 7.9
Body mass index (kg/m^2)	20.9 ± 2.8	22.0 ± 3.1	22.7 ± 3.2
Residential block [n (%)]			
Hokkaido and Tohoku	422 (9.9)	387 (10.0)	199 (9.3)
Kanto	1235 (28.9)	1092 (28.2)	535 (24.9)
Hokuriku and Tokai	862 (20.2)	854 (22.1)	521 (24.2)
Kinki	509 (11.9)	509 (13.1)	267 (12.4)
Chugoku and Shikoku	594 (13.9)	529 (13.7)	347 (16.1)
Kyushu	651 (15.2)	502 (13.0)	282 (13.1)
Size of residential area [n (%)]			
City with a population ≥1 million	825 (19.3)	602 (15.5)	281 (13.1)
City with a population <1 million	3110 (72.8)	2876 (74.3)	1627 (75.6)
Town and village	338 (7.9)	395 (10.2)	243 (11.3)
Current smoking [n (%)]			
No	4264 (99.8)	3577 (92.4)	2097 (97.5)
Yes	9 (0.2)	296 (7.6)	54 (2.5)
Alcohol drinking [n (%)]			
No	3996 (93.5)	1963 (50.7)	1734 (80.6)
Yes	277 (6.5)	1910 (49.3)	417 (19.4)
Dietary supplement use [n (%)]			
No	3983 (93.2)	2863 (73.9)	1506 (70.0)
Yes	277 (6.5)	1010 (26.1)	645 (30.0)
Energy intake (kcal/d)	1710 ± 462	1820 ± 456	1735 ± 475

*All values are mean ± SD for continuous variables and n (%) for categorical variables.

Table 3-2. TAC value from each food group and the contribution of each food group to dietary TAC estimated from the self-administered diet history questionnaire or brief-type self-administered diet history questionnaire among 4273 young (18-20 y), 3873 middle-aged (34-60 y), and 2151 elderly (65-94 y) Japanese women*

	FRAP‡		ORAC‡		TEAC‡		TRAP‡	
Food group†	(mmol Fe^{+2}/d)	(%)	(mmol TE/d)	(%)	(mmol TE/d)	(%)	(mmol TE/d)	(%)
Young (n = 4273)								
Dietary TAC	11.0 ± 7.38	-	16.5 ± 10.1	-	6.14 ± 4.50	-	7.05 ± 7.13	-
Green and oolong tea	6.93 ± 5.87	56.6	9.15 ± 7.74	49.8	2.66 ± 2.25	41.4	3.39 ± 2.87	49.1
Vegetables	0.84 ± 0.61	10.4	1.85 ± 1.23	14.0	0.57 ± 0.41	11.3	0.54 ± 0.37	11.1
Coffee	1.10 ± 3.60	7.39	1.44 ± 4.73	6.47	1.07 ± 3.50	10.1	1.91 ± 6.24	13.7
Black tea	0.48 ± 1.17	4.85	0.73 ± 1.78	4.63	0.18 ± 0.43	3.20	0.24 ± 0.59	4.17
Fruits	0.35 ± 0.42	4.30	0.89 ± 1.04	6.41	0.16 ± 0.25	3.14	0.15 ± 0.17	3.04
Sugar and confectionaries	0.33 ± 0.38	4.25	0.61 ± 0.71	4.71	0.28 ± 0.34	5.55	0.09 ± 0.11	1.93
Cereals	0.20 ± 0.16	2.90	0.33 ± 0.59	2.62	0.35 ± 0.13	8.20	0.54 ± 0.20	13.2
Fruits and vegetable juice	0.25 ± 0.56	2.88	0.27 ± 0.62	2.04	0.11 ± 0.24	2.09	0.09 ± 0.22	1.92
Oil	0.12 ± 0.09	1.63	-	-	0.02 ± 0.01	0.51	-	-
Soft drinks	0.13 ± 0.38	1.50	0.37 ± 1.33	2.35	0.17 ± 0.62	2.73	0.06 ± 0.02	1.26
Nuts and pulses	0.10 ± 0.08	1.38	0.62 ± 0.49	4.81	0.51 ± 0.41	10.2	0.01 ± 0.03	0.15
Seasonings	0.09 ± 0.05	1.25	0.06 ± 0.03	0.52	0.05 ± 0.03	1.11	0.00 ± 0.00	0.05
Potatoes	0.04 ± 0.03	0.55	0.21 ± 0.17	1.68	0.02 ± 0.02	0.48	0.02 ± 0.02	0.40
Alcohol beverages	0.00 ± 0.08	0.04	0.00 ± 0.01	0.01	0.00 ± 0.03	0.03	0.00 ± 0.01	0.01
Middle-aged (n = 3873)								
Dietary TAC	19.6 ± 10.4	-	28.0 ± 13.9	-	14.8 ± 8.85	-	22.1 ± 15.6	-
Coffee	9.84 ± 8.92	45.1	12.9 ± 11.7	41.8	9.57 ± 8.67	54.6	17.1 ± 15.5	64.9
Green and oolong tea	6.47 ± 5.42	33.8	8.53 ± 7.15	30.8	2.48 ± 2.08	20.5	3.17 ± 2.65	20.8
Vegetables	1.01 ± 0.62	6.49	2.30 ± 1.24	9.77	0.71 ± 0.42	6.34	0.67 ± 0.38	4.97
Black tea	0.47 ± 1.17	3.00	0.72 ± 1.79	3.00	0.18 ± 0.44	1.75	0.24 ± 0.59	2.01
Fruits	0.45 ± 0.50	2.78	1.10 ± 1.16	4.46	0.20 ± 0.28	1.73	0.19 ± 0.20	1.38
Sugar and confectionaries	0.32 ± 0.33	1.99	0.57 ± 0.62	2.40	0.26 ± 0.30	2.28	0.09 ± 0.10	0.61
Alcohol beverages	0.22 ± 0.54	1.44	0.04 ± 0.23	0.18	0.09 ± 0.23	0.85	0.03 ± 0.16	0.19
Cereals	0.19 ± 0.14	1.33	0.30 ± 0.53	1.35	0.33 ± 0.12	3.33	0.52 ± 0.19	4.29

(Continued)

Table 3-2. (Continued)

	FRAP‡		ORAC‡		TEAC‡		TRAP‡	
Food group†	(mmol Fe^{+2}/d)	(%)	(mmol TE/d)	(%)	(mmol TE/d)	(%)	(mmol TE/d)	(%)
Nuts and pulses	0.15 ± 0.10	0.97	0.86 ± 0.56	3.71	0.71 ± 0.48	6.42	0.01 ± 0.03	0.09
Oil	0.14 ± 0.10	0.90	-	-	0.02 ± 0.01	0.23	-	-
Fruits and vegetable juice	0.14 ± 0.35	0.88	0.16 ± 0.39	0.65	0.06 ± 0.15	0.55	0.05 ± 0.13	0.40
Seasonings	0.10 ± 0.05	0.68	0.07 ± 0.03	0.30	0.06 ± 0.03	0.54	0.00 ± 0.00	0.01
Soft drinks	0.05 ± 0.20	0.34	0.15 ± 0.68	0.60	0.07 ± 0.31	0.61	0.03 ± 0.10	0.22
Potatoes	0.05 ± 0.04	0.30	0.23 ± 0.20	1.01	0.02 ± 0.02	0.23	0.02 ± 0.02	0.14
Elderly (n = 2151)								
Dietary TAC	13.6 ± 5.51	-	20.7 ± 7.58	-	9.59 ± 4.49	-	12.5 ± 7.77	-
Green tea	5.51 ± 3.20	41.1	7.51 ± 4.36	36.4	2.22 ± 1.29	26.4	2.81 ± 1.63	29.7
Coffee	4.16 ± 4.49	26.2	5.45 ± 5.90	23.0	4.04 ± 4.37	32.6	7.20 ± 7.79	42.0
Vegetables	1.58 ± 0.77	13.6	3.02 ± 1.36	16.2	1.22 ± 0.57	14.8	1.15 ± 0.52	13.0
Fruits	0.80 ± 0.56	6.68	1.94 ± 1.28	10.0	0.48 ± 0.39	5.69	0.32 ± 0.22	3.58
Black and oolong tea	0.65 ± 1.27	4.80	0.89 ± 1.75	4.26	0.24 ± 0.47	2.71	0.32 ± 0.62	3.13
Fruits and vegetable juice	0.20 ± 0.41	1.64	0.22 ± 0.44	1.13	0.09 ± 0.18	1.07	0.08 ± 0.15	0.84
Confectionaries	0.16 ± 0.14	1.40	0.02 ± 0.02	0.10	0.02 ± 0.03	0.30	0.04 ± 0.05	0.50
Pulses	0.15 ± 0.08	1.38	0.95 ± 0.51	5.31	0.86 ± 0.46	10.8	-	-
Cereals	0.14 ± 0.05	1.28	0.16 ± 0.22	0.88	0.34 ± 0.12	4.67	0.53 ± 0.20	6.79
Potatoes	0.09 ± 0.07	0.84	0.48 ± 0.35	2.63	0.05 ± 0.03	0.59	0.03 ± 0.02	0.35
Oil	0.09 ± 0.04	0.77	-	-	0.02 ± 0.01	0.25	-	-
Alcohol beverages	0.04 ± 0.25	0.33	0.01 ± 0.14	0.07	0.02 ± 0.11	0.20	0.01 ± 0.01	0.08

Fe, iron; FRAP, ferric reducing ability of plasma; ORAC, oxygen radical absorbance capacity; TAC, total antioxidant capacity; TE, Trolox equivalent; TEAC, Trolox equivalent antioxidant capacity; TRAP, total radical-trapping antioxidant parameter.

*All values are mean ± SD for TAC values and mean (%) for contributions.

† Food items included in each food group are shown in our previous study [70]. Food groups were listed in descending order according to the contribution of FRAP in each generation.

‡ TAC values were energy-adjusted according to the residual method and contributions were calculated using crude TAC values.

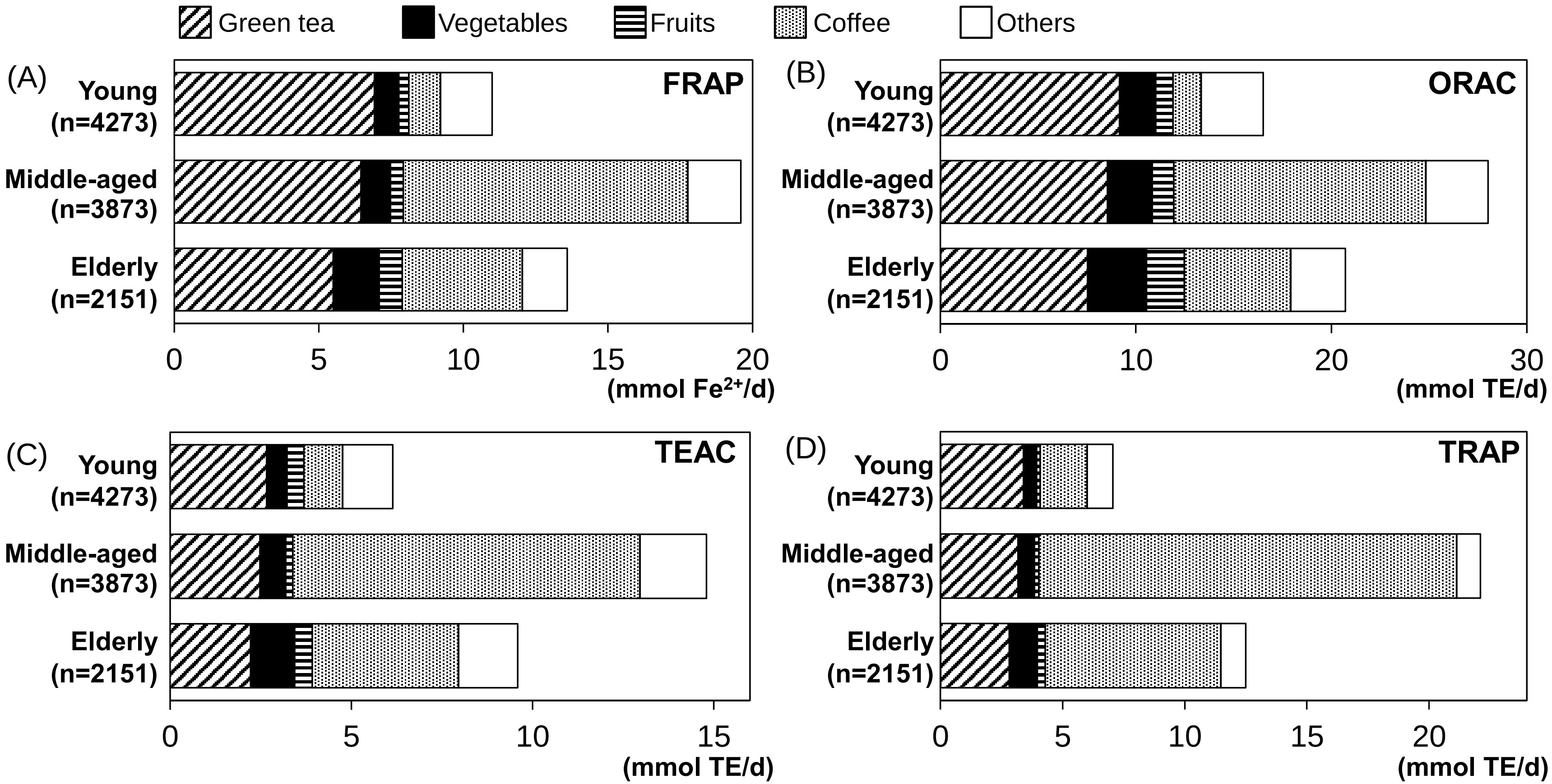

Figure 3-2. Dietary TAC from each food group estimated from the self-administered diet history questionnaire or brief-type self-administered diet history questionnaire among 4273 young (18-20 y), 3873 middle-aged (34-60 y), and 2151 elderly (65-94 y) Japanese women. Dietary TAC was estimated by four different assays in FRAP (A), ORAC (B), TEAC (C), and TRAP (D). TAC values were energy-adjusted according to the residual method and the mean values were shown. Fe, iron; FRAP, ferric reducing ability of plasma; ORAC, oxygen radical absorbance capacity; TAC, total antioxidant capacity; TE, Trolox equivalent; TEAC, Trolox equivalent antioxidant capacity; TRAP, total radical-trapping antioxidant parameter.

CHAPTER 4

Dietary total antioxidant capacity in relation to serum C-reactive protein among young Japanese women

4.1. Introduction

C-reactive protein (CRP) is produced by hepatocytes as part of the acute-phase response and represents a sensitive and non-specific marker of inflammation [98]. CRP is associated with CVD, type 2 diabetes mellitus, and cancer [99], and identification of the factors associated with serum CRP concentration is important to their prevention. Dietary factors represent one major modifiable factor related to CRP, and several previous studies have shown that increasing the intake of antioxidant nutrients (e.g., vitamin C and vitamin E) or foods (e.g., tea, fruits, and vegetables) is associated with decreased CRP concentrations [99-101]. In other studies, however, these single nutrients or foods were shown to have no effect [99, 102-104]. As mentioned in the previous chapter, antioxidants may act not only individually but also co-operatively, and in some cases synergistically [2]. The effect of complex combinations of antioxidant nutrients and foods on CRP concentrations therefore warrants investigation and previous observational studies [16-18] and an interventional study [19] showed that dietary TAC was inversely related to CRP among Italian, Spanish, and Greek populations.

The association between dietary TAC and CRP was also assumed to be observed among Japanese populations. Therefore, the author tried to investigate the association between dietary TAC and CRP concentration in a Japanese population. Given that CRP concentration tends to increase with age [105] and smoking affects to plasma antioxidant capacity [13], healthy young women, whose CRP level and smoking rate are relatively low, are suitable as subjects to investigate the association between dietary TAC and CRP in minimizing the effect of age, some diseases, and smoking.

Here, the author examined the association between dietary TAC and serum CRP concentration among young Japanese women.

4.2. Subjects and methods

4.2.1. Subjects

The present study was based on a multicenter survey conducted from February to March 2006 among female dietetic students from 10 institutions in Japan. The study protocol was approved by the Ethics Committee of the National Institutes of Health and Nutrition (No. 4045), and written informed consent was obtained from each subject, and also from a parent for subjects aged less than 20 years. A total of 474 women took part. The author excluded subjects whose CRP concentrations had not been measured (n = 22), those with CRP concentrations ≥1 mg/dL (n = 2) on the basis that such high concentrations were likely caused by infection or an underlying medical problem not related to diet [106], and those aged <18 or ≥23 years (n = 7). The final sample thus comprised 443 women aged 18-22 years (**Figure 4-1**). All women were free from diabetes, hypertension, and cardiovascular disease, and none reported extremely low [less than half of the energy requirement for the lowest physical activity category (<775 kcal/day)] or high [more than 1.5 times of the energy requirement for the highest physical activity category (>3450 kcal/day)] energy intake with reference to the Recommended Dietary Allowance for Japanese [107].

4.2.2. Dietary assessment

Dietary habits were assessed using the DHQ [70, 71]. Detailed information of the DHQ concerning its structure, calculation of dietary intake, and validity are provided in Chapter 2 (see 2.2.1.). Responses to the DHQ as well as to an accompanying lifestyle questionnaire were checked at least twice for completeness, and reviewed with the subject when necessary to ensure the clarity of answers. Estimates of dietary intake for a total of 150 food items, energy, and n-3 polyunsaturated fatty acid (PUFA) were calculated using an *ad hoc* computer algorithm for the DHQ [70, 71]. Dietary TAC was estimated by the method developed in

Chapter 2 and 3. Although dietary supplement use was queried in the DHQ, intake from supplements was not included in analyses due to the lack of a reliable composition table of dietary supplements in Japan.

4.2.3. Serum CRP concentrations

Peripheral blood samples were obtained from subjects after an overnight fast. Blood was collected in evacuated tubes containing no additives, allowed to clot, and centrifuged at 3000 × g for 10 min at room temperature to separate serum. Blood samples were transported at -20 °C to a laboratory (SRL Inc, Tokyo, Japan). Serum CRP concentrations were measured by highly sensitive nephelometry at SRL Inc. In-house quality-control procedures were fulfilled at SRL Inc, and showed within- and between-assay coefficients of variation of 3.1% and 2.7%, respectively. The assay is sufficiently sensitive to detect 0.0050 mg/dL. Undetectable CRP values were recorded as 0.0025 mg/dL (n = 81). Serum CRP concentrations ≥0.1 mg/dL were considered elevated for several reasons. First, previous studies have consistently shown that the median serum CRP concentration in Japanese (0.009-0.058 mg/dL) was lower than those in Western populations (0.15-0.62 mg/dL) [108, 109]. Therefore to use cutoff value mainly based on Western populations (0.3 mg/dL [106]) might not be appropriate. Second, a higher serum CRP concentration is unfavorable for Japanese, although this value was not as high as those of other countries [108]. Finally, some previous Japanese studies used 0.1 mg/dL of serum CRP concentration as cutoff value [102, 109].

4.2.4. Other variables

Body height was measured to the nearest 0.1 cm with the subject standing without shoes. Body weight in light indoor clothes was measured to the nearest 0.1 kg. BMI was calculated as body weight (kilograms) divided by the square of body height (meters). In the lifestyle questionnaire, the subject reported her residential area, which was grouped into one of three regions (north, Kanto and Tohoku; central, Tokai and Hokuriku; or south, Kyushu and Chugoku) and also into three categories according to population size (city with population ≥1 million, city with population <1 million, or town and village). These variables were considered to be unmeasured variables influencing diet and CRP. Current smoking status (yes or no) was self-reported in the lifestyle questionnaire. Alcohol drinking (yes or no) and dietary supplement use (yes or no) were assessed as part of the DHQ. Physical activity was computed as average metabolic equivalent-hours per day [110] on the basis of the frequency and duration of five different activities over the preceding month, as reported in the lifestyle questionnaire.

4.2.5. Statistical analysis

All statistical analyses were performed with SAS statistical software, version 9.2 (SAS Institute Inc., Cary, NC, USA). All reported *P* values are two-tailed, with a *P* value of <0.05 considered statistically significant. Dietary TAC was adjusted for energy by the residual method using a linear regression model [97]. The percentage contribution of each individual food item to dietary TAC was calculated by dividing the TAC from each individual food item by the daily individual dietary TAC.

Significant differences between participants with normal and elevated CRP concentrations (cutoff 0.1 mg/dL) were assessed using Student's *t* test or chi-square test. Associations with elevated serum CRP concentration were examined for energy-adjusted dietary TAC. Participants were divided into two categories according to the median value of dietary TAC. Odds ratios (ORs) and 95% confidence intervals (CIs) for elevated serum CRP concentrations were calculated after multivariate adjustment for potential confounding factors, including residential region, size of residential area, current smoking, alcohol drinking, dietary supplement use, physical activity (continuous), and BMI (continuous). All these variables were used in the previous study [102]. The author included these factors in the model to compare the result from the present study and that from the previous study. Additionally, the author adjusted for n-3 PUFA intake (energy-adjusted by residual method, continuous) because n-3 PUFA was the only dietary variable significantly associated with CRP [102]. Pearson's correlation coefficients of each TAC and n-3 PUFA were 0.14 for FRAP, 0.14 for ORAC, 0.06 for TEAC, and 0.02 for TRAP.

4.3. Results

Subject characteristics by normal and elevated CRP concentration are shown in **Table 4-1**. Mean serum CRP concentration was 0.0302 mg/dL, with a range of 0.0025 to 0.710 mg/L. The prevalence of elevated CRP concentration was 5.6%. Mean dietary TAC was 12.0 mmol Fe^{2+}/d for FRAP, 18.6 mmol TE/d for ORAC, 7.17 mmol TE/d for TEAC, and 8.26 mmol TE/d for TRAP. The only significant difference between the elevated and normal CRP concentration groups was seen for dietary TAC, with respective ratios for each dietary TAC of only 65-82% of those of the normal CRP concentration group. The range of Pearson's correlation coefficients between each dietary TAC was 0.78-0.99. For the contribution of each food to dietary TAC, green, barley, and oolong tea was the major contributor (FRAP: 53%, ORAC: 45%, TEAC: 37%, and TRAP: 44%) and coffee (FRAP: 12%, ORAC: 10%, TEAC: 16%, and TRAP: 21%) and vegetables (FRAP: 10%, ORAC: 13%, TEAC: 10%, and TRAP: 10%) were also main contributors in all four assays (data not shown).

Table 4-2 and **Figure 4-2** shows the association between dietary TAC and elevated serum CRP concentration. The percentages of participants with elevated CRP levels in the low dietary TAC group (7.7-8.6%) were about two to three times higher than those in the high dietary TAC group (2.7-3.6%). ORs for elevated serum CRP concentration in the high versus low dietary TAC group were 0.30-0.45 in the crude model, and were hardly changed after adjustment for possible confounders. TAC from FRAP was inversely associated with serum CRP concentration [adjusted OR (95%CI) for elevated CRP concentration in high versus low dietary TAC group: 0.39 (0.16, 0.98); P = 0.04]. With regard to TAC from ORAC, the inverse association between dietary TAC and serum CRP concentration was also observed with this method [adjusted OR: 0.48 (0.20, 1.14); P = 0.10], although the association did not reach statistical significance. TAC from TEAC was inversely associated with serum CRP concentration [adjusted OR: 0.32 (0.12, 0.82); P = 0.02]. Additionally, TAC from TRAP was also inversely associated with serum CRP concentration [adjusted OR: 0.31 (0.12, 0.81); P = 0.02].

4.4. Discussion

In this chapter, a higher dietary TAC was associated with a lower prevalence of elevated CRP concentration among young Japanese women. Dietary TAC from FRAP, TEAC, and TRAP were significantly inversely associated with serum CRP concentration. Dietary TAC from ORAC also showed an inverse association with serum CRP. The dietary TAC values of elevated serum CRP concentration group were significantly lower than those of normal CRP group. To our knowledge, this is the first study to examine the association between dietary TAC and elevated CRP concentration in a non-Western population.

As mentioned in Chapter 2, the number of food which could obtain the TAC value was different in each assay. Nevertheless, the major sources of dietary TAC in the present study were the same among the TAC assays and the correlation coefficients between respective dietary TAC values were high as well as Chapter 3.This chapter showed that dietary TAC from FRAP, TEAC, and TRAP were significantly inversely associated with serum CRP concentration. Dietary TAC from ORAC also showed an inverse association with serum CRP, albeit without statistical significance. These results may suggest that dietary TAC was inversely associated with serum CRP concentration regardless of assay.

Whereas previous Western studies showed that the main contributors of dietary TAC were coffee, fruits, vegetables, and alcohol beverages [14, 15, 29], the major contributor in this present young Japanese population was green, barley, and oolong tea. Additionally, vegetables commonly consumed in Japan differ from those in Italy [56, 88], and fruit and vegetable items consumed by contemporary young Japanese women differ from those by young Spanish adults [18]. Nevertheless, dietary TAC was inversely associated with CRP in our Japanese population, as with Italian and Spanish populations [16, 18], suggesting that a high dietary TAC is important for a low prevalence of elevated CRP level regardless of the type or origin of food. The present finding of a significant association between dietary TAC and CRP contrasts with a previous study in the same population which found no association between single intakes of vitamin C, fruits, and vegetables and serum CRP [102]. This difference in turn suggests that complex combinations of antioxidant nutrients and foods might be more strongly associated with CRP than any single nutrient or food alone.

The cutoff value (0.1 mg/dL) of elevated CRP concentration was defined by the previous studies as described in the Methods section (4.2.3.). Additionally, the author examined the association of dietary TAC with serum CRP using different cutoff value of elevated CRP. In the case of 0.15 mg/dL, because the small numbers of subjects (n = 16) were defined as elevated CRP, the inverse but non-significant relationship between dietary TAC and CRP was observed. However, when the author used 0.08 mg/dL as cutoff value, 31 subjects were elevated CRP concentration and dietary TAC from ORAC, TEAC, and TRAP was inversely associated with CRP (data not shown). These results may suggest that similar results as Table 4-2 are obtained even if we use <0.1 mg/dL as cutoff value and 0.1 mg/dL was an acceptable cutoff value for elevated CRP concentrations.

Several limitations of the present study should be mentioned. First, because TAC data on Japanese foods were available from only a single database [88], dietary TAC was estimated using databases developed in other countries. Additionally, many foods were assigned a substituted or calculated TAC value. Further, because a reliable TAC database for dietary supplements could not be obtained, the author did not consider the intake of dietary supplements in calculating dietary TAC. However, dietary TAC estimated from the method in this study was inversely associated with serum CRP as well as previous Western studies [16-18]. This result implied that dietary TAC can be estimated well in this study. Second, the DHQ was not specifically designed to measure dietary TAC. In assessing dietary TAC, the author were unable to investigate the validity of the DHQ against the 16-day dietary records we previously used to investigate the validity of other dietary variables [70, 71] because the dietary record contained a small number of foods assigned with TAC values (n = 143-373). However, a previous validation study among 92 adult women reported Pearson correlation coefficients of 0.64 for β-carotene, 0.52 for vitamin C, and 0.47 for α-tocopherol [71], and Spearman correlation coefficients for food groups were 0.75 for coffee, 0.59 for green and oolong tea, and 0.56 for total vegetables [70]. This satisfactory validity of the DHQ for a wide range of antioxidant nutrients and foods provides some reassurance. Third, participants of the present study were selected female dietetic students, not a random sample of Japanese women. In addition, because of our recruitment procedure, the exact response rate was unknown, which might have produced recruitment bias. Thus, our results cannot easily be extrapolated to the general Japanese population. However, to minimize the influence of nutritional education, we finished the survey within almost one month after their entrance to the course. Fourth, it is possible that high intakes of dietary antioxidants are acting as markers, either of more health conscious lifestyles or of other important differences in diet, which could confound associations with dietary TAC and CRP. Although wide range of potential confounding variables were attempted to adjust for, the author is unable to rule out residual confounding. For example, oral contraceptive use and hormone replacement therapy have been shown to increase the level of CRP [111-113] and women had higher CRP concentration than men [113]. These findings imply that some sexual hormones are associated with CRP level, but the author unfortunately did not ask oral contraceptive use and menstrual status. Further, other factors may confound the relationship between dietary TAC and CRP. Further research examining association of lifestyle factors with circulating CRP should take into account these situations. Finally, the cross-sectional nature of the study hampers the drawing of any conclusions on causal inferences among dietary TAC and serum CRP concentration.

This chapter showed that dietary TAC was inversely associated with serum CRP concentration among young Japanese women regardless of assay. This result may support that dietary TAC estimated from the DHQ may be useful for nutritional epidemiological study.

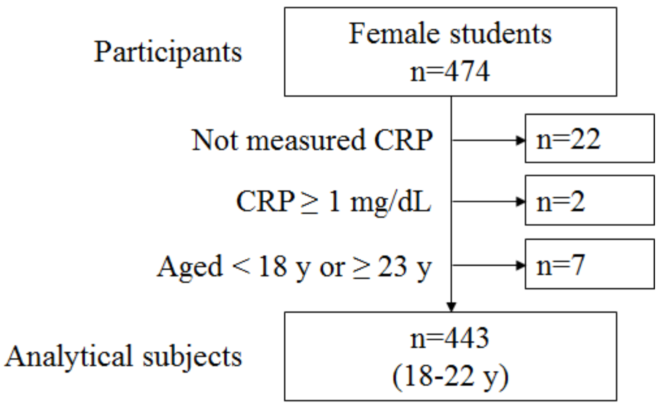

Figure 4-1. Flow chart of subjects. CRP, C-reactive protein.

Table 4-1. Characteristics of 443 Japanese women aged 18-22 years categorized by normal or elevated (cutoff 0.1 mg/dL) serum CRP concentration*

	Total (n = 443)	Normal CRP (CRP <0.1 mg/dL) (n = 418)	Elevated CRP (CRP ≥0.1 mg/dL) (n = 25)	*P*†
Serum CRP concentration (mg/dL)	0.030 ± 0.073	0.017 ± 0.018	0.259 ± 0.185	
Age (years)	19.5 ± 1.0	19.5 ± 1.0	19.5 ± 0.8	0.95
Body height (cm)	158.1 ± 5.6	158.1 ± 5.6	157.5 ± 4.4	0.59
Body weight (kg)	53.3 ± 8.1	53.3 ± 7.7	53.9 ± 13.6	0.83
Body mass index (kg/m^2)	21.3 ± 2.9	21.3 ± 2.7	21.7 ± 5.4	0.71
Residential region [n (%)]				0.37
North (Kanto and Tohoku)	268 (60.5)	250 (59.8)	18 (72.0)	
Central (Tokai and Hokuriku)	73 (16.5)	69 (16.5)	4 (16.0)	
South (Kyushu and Chugoku)	102 (23.0)	99 (23.7)	3 (12.0)	
Size of residential area [n (%)]				0.75
City with population ≥1 million	77 (17.4)	74 (17.7)	3 (12.0)	
City with population <1 million	329 (74.3)	309 (73.9)	20 (80.0)	
Town and village	37 (8.4)	35 (8.4)	2 (8.0)	
Current smoking [n (%)]				0.86
No	428 (96.6)	404 (96.7)	24 (96.0)	
Yes	15 (3.5)	14 (3.4)	1 (4.0)	
Alcohol drinking [n (%)]				0.10
No	248 (56.0)	230 (55.0)	18 (72.0)	
Yes	195 (44.0)	188 (45.0)	7 (28.0)	
Dietary supplement use [n (%)]				0.33
No	357 (80.6)	335 (80.1)	22 (88.0)	
Yes	86 (19.4)	83 (19.9)	3 (12.0)	
Physical activity (total metabolic equivalents-hours/d)	34.1 ± 3.5	34.1 ± 3.5	34.3 ± 3.5	0.77
Energy intake (kcal/d)	1748 ± 416	1749 ± 414	1735 ± 453	0.87
Total n-3 PUFA intake (g/d)‡	2.3 ± 0.6	2.3 ± 0.6	2.2 ± 0.7	0.93
Dietary TAC‡				
FRAP (mmol Fe^{2+}/d)	12.0 ± 6.52	12.3 ± 6.58	8.45 ± 4.12	0.0002
ORAC (mmol TE/d)	18.6 ± 8.94	18.9 ± 9.02	13.6 ± 5.67	0.0001
TEAC (mmol TE/d)	7.17 ± 3.80	7.27 ± 3.85	5.43 ± 2.35	0.0009
TRAP (mmol TE/d)	8.26 ± 6.15	8.42 ± 6.24	5.68 ± 3.51	0.001

CRP, C-reactive protein; PUFA, polyunsaturated fatty acid; TAC, total antioxidant capacity; Fe, Iron; FRAP, ferric reducing ability of plasma; ORAC, oxygen radical absorbance capacity; TEAC, trolox equivalent antioxidant capacity; TRAP, total radical-trapping antioxidant parameter; TE, trolox equivalent.
* All values are mean ± SD for continuous variables and n (%) for categorical variables.
† *P* value between normal CRP and elevated CRP groups. For continuous values, the t test was used; for categorical values, the chi-square test was used.
‡ Energy adjustment was performed according to the residual method.

Table 4-2. Odds ratio and 95% confidence intervals for elevated (cutoff 0.1 mg/dL) serum CRP concentrations by low or high dietary TAC groups in 443 Japanese women aged 18-22 years

	Category of dietary TAC	
	Low (n=221)	High (n=222)
FRAP (mmol Fe^{2+}/d)*†	7.41 (0.71-10.60)	16.03 (10.61-37.17)
n (%) with elevated CRP	18 (8.1)	7 (3.2)
Crude model	1 (Reference)	0.37 (0.15, 0.90)
Multivariate adjusted model‡	1 (Reference)	0.39 (0.16, 0.98)
ORAC (mmol TE/d)*†	12.43 (1.18-16.73)	24.13 (16.78-50.77)
n (%) with elevated CRP	17 (7.7)	8 (3.6)
Crude model	1 (Reference)	0.45 (0.19, 1.06)
Multivariate adjusted model‡	1 (Reference)	0.48 (0.20, 1.14)
TEAC (mmol TE/d)*†	4.67 (0.44-6.25)	8.83 (6.26-31.75)
n (%) with elevated CRP	19 (8.6)	6 (2.7)
Crude model	1 (Reference)	0.30 (0.12, 0.75)
Multivariate adjusted model‡	1 (Reference)	0.32 (0.12, 0.82)
TRAP (mmol TE/d)*†	4.34 (0.31-6.66)	10.23 (6.71-52.42)
n (%) with elevated CRP	19 (8.6)	6 (2.7)
Crude model	1 (Reference)	0.30 (0.12, 0.75)
Multivariate adjusted model‡	1 (Reference)	0.31 (0.12, 0.81)

CRP, C-reactive protein; TAC, total antioxidant capacity; Fe, Iron; FRAP, ferric reducing ability of plasma; ORAC, oxygen radical absorbance capacity; TEAC, Trolox equivalent antioxidant capacity; TRAP, total radical-trapping antioxidant parameter; TE, Trolox equivalent.
* Values are medians (ranges).
† Energy adjustment was performed according to the residual method.
‡ Adjusted for residential region [north (Kanto and Tohoku), central (Tokai and Hokuriku), and south (Kyushu and Chugoku)], size of residential area (city with a population ≥1 million, city with a population <1 million, and town and village), current smoking (yes or no), alcohol drinking (yes or no), dietary supplement use (yes or no), physical activity level (total metabolic equivalents-hours/d, continuous), body mass index (kg/m^2, continuous), and n-3 polyunsaturated fatty acid intake (g/d, energy-adjusted, continuous).

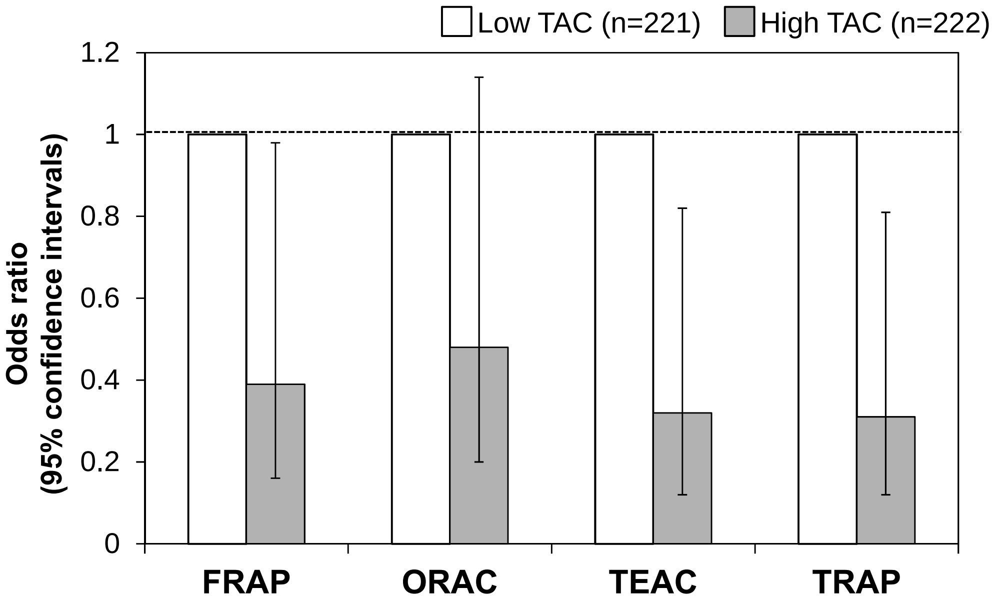

Figure 4-2. Multivariate adjusted odds ratio and 95% confidence intervals for elevated (cutoff 0.1 mg/dL) serum CRP concentrations by low or high dietary TAC groups in 443 Japanese women aged 18-22 years. Dietary TAC was energy adjusted according to the residual method. Odds ratio and 95% confidence intervals were adjusted for residential region [north (Kanto and Tohoku), central (Tokai and Hokuriku), and south (Kyushu and Chugoku)], size of residential area (city with a population ≥1 million, city with a population <1 million, and town and village), current smoking (yes or no), alcohol drinking (yes or no), dietary supplement use (yes or no), physical activity level (total metabolic equivalents-hours/d, continuous), body mass index (kg/m^2, continuous), and n-3 polyunsaturated fatty acid intake (g/d, energy-adjusted, continuous). CRP, C-reactive protein; TAC, total antioxidant capacity; FRAP, ferric reducing ability of plasma; ORAC, oxygen radical absorbance capacity; TEAC, Trolox equivalent antioxidant capacity; TRAP, total radical-trapping antioxidant parameter.

CHAPTER 5

Dietary total antioxidant capacity and frailty among elderly Japanese women

5.1. Introduction

Frailty is the health condition of older adults characterized by low physiological reserves and vulnerability to several stressors including illness [114]. People with frailty have to face high risk of death, disability, and institutionalization. A systematic review including 21 community-based studies showed that the prevalence of frailty or pre-frailty in elderly adults aged 65 years and older ranged from 6.3 to 62.9% [115], while 10.6 to 34.9% elderly Japanese are classified frail or pre-frail [116-118]. Further the number of people aged 65 years or older will increase from 524 million (8% of the world population) in 2010 to 1.5 billion (16%) in 2050, and more importantly the proportion of people at very old ages will also increase [119]. The prevalence of frailty increases with age [115]. Thus the number of elderly with frailty is already high, and continues to increase in the world. Because the rising proportion of older people is placing upward pressure on overall health care spending in both the developed and developing world [119], to reduce the health care cost of older people is important to stop growing financial burden on societies.

Considering these situations, interventions aimed at improving frailty in frail subjects have been conducted [120, 121]. Although several exercise programs were shown to improve grip strength and gait speed, which are components of frailty [120], and one exercise and nutritional program improved frailty status over the short (3-months) but not the long term (6- or 12-months) [121], no interventions reported to date have been successful in preventing or improving the state of frailty. The development of more effective strategies for frailty prevention is thus critically dependent on the identification of other factors related to frailty.

Although the essential biological mechanism that causes frailty has never been adequately explained, hypotheses have proposed roles for inflammation and oxidative stress mediated by nutrition deficiencies [122, 123]. Previous research in Western populations has shown significant associations between lower serum levels of micronutrients such as carotenoids and vitamin E and frailty in both cross-sectional [124-126] and cohort studies[126]. Further, in terms of dietary intake, low intakes of vitamin C, vitamin E, and folate have also been related to frailty [127]. Importantly, however, while all of these studies examined the effect of a “single nutrient” or “single antioxidant” on frailty, foods and nutrients are consumed in combination and antioxidants are assumed to act co-operatively rather than individually, and in some cases synergistically [2]. Although the role of micronutrients with antioxidative capacity in the development of frailty has been highlighted [123], to our knowledge no study has examined the relationship between the total antioxidant function of the habitual diet and frailty.

Dietary TAC is considered as a useful tool in antioxidant intake assessment as shown in Chapter 1. As higher dietary TAC is associated with decreased levels of inflammatory molecules [16-19], dietary TAC may have potential in preventing the development of frailty. Here, we evaluated the relationship of dietary habits with high TAC to frailty in a large group of elderly Japanese women together with foods contribute to dietary TAC and nutrients related to antioxidation.

5.2. Subjects and methods

5.2.1. Subjects

The participants in this Chapter were the same as those of elderly women in Chapter 3. Details of the participants have been reported in Chapter 3 (see 3.2.1.). Briefly, all of the participants were grandmothers or acquaintances of the dietetic freshmen entering 85 institutions (universities, colleges, and technical schools) in Japan. The survey was conducted from April to May 2011 in northern and western Japan and from April to May 2012 in eastern Japan. A total 2332 elderly women for the grandmother’s generation (33.2%) answered both dietary assessment questionnaire and lifestyle questionnaire.

The author excluded those subjects who lived in eastern Japan and answered questionnaires in 2011, because the author assumed that they could not report their usual dietary habits and lifestyle due to the occurrence of the Great East Japan Earthquake in March 2011 (n = 47). The author also excluded a woman who was in an institution where the response rate was extremely low (2%). Further, the author excluded subjects whose age, height, weight, or residential area were missing (n = 20); those aged <65 years (n = 65); and those with a reported energy intake less than half of the energy requirement for the lowest physical activity category according to the Dietary Reference Intakes for Japanese, 2010 (<725 kcal/d; n = 14) [96], or more than 1.5 times of the energy requirement for the highest physical activity category (>3300 kcal/d; n = 32). The author further excluded those with Parkinson's disease (n = 8), those who were unable to walk (n = 20), and those with missing information on the variables used for the purpose of multivariate analysis (n = 4). The final sample thus comprised 2121 women aged 65-94 years (**Figure 5-1**).

5.2.2. Dietary assessment

Dietary habits were assessed using BDHQ [70, 71]. Detailed information of the BDHQ concerning its structure, calculation of dietary intake, and validity are provided in Chapter 2 (see 2.2.1.). Responses to the BDHQ as well as an accompanying lifestyle questionnaire were checked once by research staff at the study office. If any missing or erroneous responses were given to questions which were essential for the analysis, the subject was asked to complete those questions again.

Estimates of the intake of the 58 food and beverage items and the intakes of energy, macronutrients, and 12 nutrients related to antioxidation, namely retinol, vitamin A, α-carotene, β-carotene, β-carotene equivalent, cryptoxanthin, vitamin D, α-tocopherol, vitamin B_6, vitamin B_{12}, folate, and vitamin C, were calculated using an *ad hoc* computer algorithm for the BDHQ which was based on the *Standard Tables of Food Composition in Japan* [94]. Although dietary supplement use was queried in the lifestyle questionnaire, intake from supplements was not included in the analysis due to the lack of a reliable composition table of dietary supplements in Japan. Dietary TAC was estimated in four assays of FRAP, ORAC, TEAC, and TRAP, based on the method developed in Chapter 2 and 3.

5.2.3. Frailty

Although frailty was operationally defined by Fried and colleagues [114] to include the measures of walking speed for slowness and grip strength for weakness, we did not obtain these measures in our study, but rather used the modified definition developed by Woods and colleagues [128]. Frailty was assessed using the following four components.

1) *Slowness and weakness*

The physical functioning scale of the Japanese version short-form 36-item health survey (SF-36) [129-131] in the lifestyle questionnaire was used to estimate slow walking speed and muscle weakness. The score <75 was defined as slowness and weakness.

2) *Exhaustion*

The vitality scale of SF-36 [129-131] was used as an indicator of exhaustion. The score <55 was defined as exhaustion.

3) *Low physical activity*

Physical activity was calculated as the average metabolic equivalent-hours, on the basis of the self-reported duration of five activities (walking, bicycling, standing, running, and high-intensity activities) and sleeping and sitting hours over the preceding month in the lifestyle questionnaire, and metabolic equivalent (MET) value assigned to each activity. Sleeping hours were calculated from the time the subject usually went to bed and arose in the morning. If the number of sleeping hours thereby calculated was <3 h, self-reported hours of actual sleep were used instead. For subjects whose combined total hours of five activities and sleeping hours were <24 h, unrecorded hours were assumed to be spent sitting, while for those whose total hours were >24 h, the combined hours spent daily were proportionately decreased to equal 24 h. These assigned MET values were 3.5 for walking, 7.5 for bicycling, 3.2 for standing, 7.0 for running, 8.0 for high-intensity activities, 1.0 for sleeping, and 1.3 for sitting [132]. The subjects in the lowest quartile were classified as low physical activity.

4) *Unintentional weight loss*

Weight loss was calculated from the self-reported weight at the time the BDHQ questionnaire was completed and that one year previously. Subjects with weight loss in the previous one year >5% were asked the question, “Did you lose weight intentionally in the previous year?”, with an answer of no considered to indicate unintentional weight loss. All the questions, except for current weight, were incorporated in the lifestyle questionnaires. Current weight was obtained from the response to the BDHQ.

Slowness and weakness was scored as two points, and the other components as one point each. Total frailty score was the sum of all available scores (0-5), with those subjects with a total score ≥3 defined as frailty [128].

5.2.4. *Other variables*

The subjects reported birth date and body height in the BDHQ. BMI was calculated as current body weight (kg) divided by the square of body height (m). In the lifestyle questionnaire, the subject reported her residential area, which was grouped into six regions (Hokkaido and Tohoku, Kanto, Hokuriku and Tokai, Kinki, Chugoku and Shikoku, and Kyushu) and also into three categories according to population size (city with a population ≥1 million, city with a population <1 million, and town and village). These variables were considered to be unmeasured variables influencing diet and frailty. The subject also reported in the lifestyle questionnaire if she was living alone (yes or no), as well as her marital status (single, married, widowed, and separated), education (≤junior high school and others, high school, and ≥college), current smoking status (yes or no), and dietary supplement use (yes or no). A history of chronic disease including stroke, myocardial infarction, hypertension, diabetes, and chronic rheumatism (yes or no) was considered to be a factor which influenced the current state of frailty. Alcohol drinking (yes or no) was assessed as part of the BDHQ. Depression symptoms were assessed using a Center for Epidemiologic Studies Depression (CES-D) scale [133, 134] incorporated in the lifestyle questionnaire, with subjects with a CES-D score ≥16 considered to have depression symptoms.

5.2.5. Statistical analysis

Dietary TAC, food intakes, and nutrient intakes were adjusted for energy by the residual method using a linear regression model [97]. The characteristics of subjects with and without frailty were compared using Student's *t* test or the chi-square test. Associations between frailty and the dietary variables, including energy-adjusted dietary TAC, intake of foods mainly contributing to dietary TAC, and intake of selected 12 nutrients were examined below. The subjects were divided into quintiles according to the dietary variables. ORs and 95% CIs for frailty were calculated after adjusting for potential confounding factors. The initial logistic regression model was a crude model into which covariates were added using a forward selection method. Final multivariate models were adjusted for age (continuous), BMI (continuous), residential region, size of residential area, living alone, current smoking, alcohol drinking, dietary supplement use, history of chronic disease, depression symptoms, and energy intake (continuous). These variables influenced the relationship between dietary variables and frailty (P <0.10). Survey year, marital status, and education were not included in the models, because these variables had no influence on the relationship between dietary variables and frailty (*P* >0.10).

All statistical analyses were performed with SAS statistical software, version 9.3 (SAS Institute Inc., Cary, NC, USA). All reported *P* values were two-tailed, with a *P* value of <0.05 considered statistically significant.

5.3. Results

The prevalence of frailty was 22.9% (**Table 5-1**). Mean age of the study population was 74.7 years. Mean of dietary TAC was 13.6 mmol Fe^{2+}/d for FRAP, 20.7 mmol TE/d for ORAC, 9.63 mmol TE/d for TEAC, and 12.5 mmol TE/d for TRAP. Compared with the non-frail group, the frail group was significantly older, had higher BMI, and included more current smokers and less alcohol drinkers. Also, a higher proportion of subjects with frailty had a history of chronic disease and depression symptoms. The proportion of supplement users was lower among subjects with frailty, and energy intake was lower. Dietary TAC in the frail group was significantly lower than that in the non-frail group, with respective ratios for each dietary TAC of 78-86% of those of the non-frail group.

The number of subjects with frailty was inversely proportional to a groupwise higher intake of dietary TAC (all *P* for trend <0.0001) (**Table 5-2**). Multivariate adjusted OR (95% CI) for frailty in the highest compared to the lowest quintile was 0.35 (0.24, 0.53) for FRAP assay (*P* <0.0001). Similarly, the corresponding OR was 0.35 (0.23, 0.52) for ORAC (*P* <0.0001), 0.40 (0.27, 0.60) for TEAC (*P* <0.0001), and 0.41 (0.28, 0.62) for TRAP (*P* <0.0001). Regarding the intake of main foods contributing to dietary TAC, higher intakes of all foods, except green tea, were also associated with a lower prevalence of frailty in the multivariate adjusted model (all *P* for trend ≤0.02). Although green tea was significantly associated with frailty in an age-adjusted model (*P* for trend = 0.04) and in a model adjusted for factors in a multivariate adjusted model except for depression symptoms [ORs (95%CI) in the first, second, third, fourth, and fifth quintiles were 1 (reference), 0.79 (0.56, 1.12), 0.84 (0.59, 1.17), 0.69 (0.48, 1.00), 0.67 (0.48, 0.98), respectively; *P* for trend = 0.03 (data not shown)], the association became insignificant when depression symptoms were added to the multivariate adjusted model as a covariate (*P* for trend = 0.19). Multivariate adjusted OR (95% CI) for frailty in the highest compared to the lowest quintile was 0.77 (0.53, 1.15) for green tea (*P* = 0.17), 0.48 (0.32, 0.72) for coffee (*P* = 0.0004), 0.47 (0.33, 0.69) for vegetables (*P* <0.0001), and 0.71 (0.49, 1.03) for fruits (*P* = 0.07). For the selected 12 nutrient, higher intakes of all nutrients, except for retinol and vitamin B_{12}, were also associated with a lower prevalence of frailty in the multivariate adjusted model (all *P* for trend ≤0.04). Relatively strong associations were seen for α-carotene, β-carotene, β-carotene equivalent, vitamin D, α-tocopherol, vitamin B_6, folate, and vitamin C, with the range of multivariate adjusted OR for frailty in the highest compared to the lowest quintile of 0.50 for β-carotene equivalent - 0.68 for α-carotene. Multivariate adjusted OR (95% CI) for frailty in each quintile for ORAC, vegetables, and β-carotene equivalent, which showed the strongest association among dietary TAC, food intake, and nutrient intake, respectively, were also shown in **Figure 5-2**.The ORs for these foods and nutrients were less marked than those for dietary TAC.

5.4. Discussion

In this chapter, a higher dietary TAC was associated with a lower prevalence of frailty among elderly Japanese women. Although the intakes of individual food such as coffee, vegetables, and fruits, which were the main contributors to dietary TAC in the present population (see Table 3-2), and 10 nutrients related to antioxidation were also inversely associated with frailty, the associations of FRAP, ORAC, TEAC, and TRAP were more marked than those of any of the foods and nutrients examined, namely, dietary habits with high TAC might be more important than increasing a certain food with high TAC to prevent frailty.

In the present subjects, although green tea was the major contributor to dietary TAC (see Chapter 3), the intake of green tea was not significantly different between the subjects of frailty and no frailty by *t* test. Further, adjustment for depression symptoms attenuated the association between green tea and frailty in the analysis using logistic regression model. Previously, a cross-sectional study reported that the intake of green tea was inversely associated with depression symptoms in an elderly population [135] while one cohort study among breast cancer survivors found that regular tea (mainly green tea) consumption was inversely associated with depression [136]. Meanwhile, depression symptoms were associated with subsequent frailty in a cohort study among elderly women [137]. These results might suggest that depression symptoms mediate the effect of green tea intake on frailty. However, the association of other dietary variables examined in the present study with frailty did not change after adjustment in the multivariate model which included depression symptoms as a covariate.

Among the four foods examined, vegetables and coffee intake showed larger effect of reducing the proportion of frail people than fruits and green tea. Although increase in the green tea intake may be relatively easy means to increase dietary TAC among this population, vegetables or coffee might be better choice to prevent frailty as individual foods. Meanwhile, the association of dietary TAC to frailty was more marked than those of any of these foods. Further investigation considering the synergistic effect of foods on frailty is required to propose effective dietary intervention to prevent frailty.

To our knowledge, this is the first study to examine the association between dietary TAC and frailty. Two studies showed that higher adherence to a Mediterranean-style diet, rather than single nutrients, was associated with lower multivariate odds of developing frailty compared to lower adherence among Western populations in the cross-sectional [138] and prospective cohort [139] studies. The Mediterranean-style diet is generally associated with a high intake of fruits, vegetables, and legumes [139], and close adherence to a Mediterranean-style diet increases dietary TAC [54]. The association of Mediterranean-style diet with frailty may be partly explained by the effect of dietary TAC on frailty. Meanwhile, the food contributors to the dietary TAC in the present population were different from those in Italian diet [14, 49]. Additionally, although vegetables were one of the major contributors of dietary TAC in the present elderly Japanese women (see Chapter 3), vegetable items commonly consumed in Japan [88] differ to those in Italy [56]. Nevertheless, both close adherence to a Mediterranean-style diet in the Italian population and high dietary TAC in the present Japanese population were inversely associated with frailty. These results may suggest the importance of a high dietary TAC for preventing frailty regardless of the food origin of the antioxidants or the kind of nutrients included in the diet. This suggestion may be useful for the people with different food cultures and dietary habits because they can improve dietary TAC with various and available foods in accordance with their habits.

The major strength of our study is that we analyzed the association of dietary TAC and nutrients with frailty in a large number of elderly women using multicenter epidemiological data. In particular, the subjects lived over a wide geographical range of Japan, where they have various dietary and lifestyle habits. Further, given the effect of smoking on plasma antioxidant capacity [6], their very low rate of smoking (2.6%) made them suitable for evaluation of the effects of dietary TAC and intake of antioxidant nutrients. Additionally, the dietary questionnaire used has been validated [70, 71] in Japanese adults.

Several limitations of this study also warrant mention. First, the most important limitation of this study is its cross-sectional design, which prevents the establishment of a causal role of dietary TAC in frailty. However, we tried to minimize the effect of reverse causality (worse status of frailty causes worse quality of diet) by excluding the subjects with Parkinson's disease and those who were unable to walk and adjusting the OR by the history of chronic diseases. Further, to exclude subjects who were likely to cause the reverse causality from the analyses, we examined the association between dietary TAC and frailty in four different subpopulations which did not include the subjects with unintentional weight loss (analyzed subjects: n = 2005), those who cut down the amount of time for daily activities as a result of physical problems during the previous month (n = 1632), those who accomplished daily activities less than they would like as a result of physical problems during the previous month (n = 1615), and those with worse health compared to one year ago (n = 1650), respectively. Three sub-analysis showed consistently the almost similar significant relationship between dietary TAC and frailty as Table 5-2. For even the remaining one sub-analysis excluding the subjects who reported worse health condition compared to one year ago, similar significant relationship was obtained from FRAP, ORAC, and TEAC assay. These sub-analyses implied that there was minimal effect of reverse causality in the present study. Second, we used the score of the physical functioning scale of the SF-36 as a surrogate for walking speed and grip strength. This score may change with time. However, all the criteria we used to define frailty were almost the same as those proposed by Woods and colleagues [128]. They showed that the physical functioning scale dichotomized at the 25th percentile was strongly associated with poor walking speed and moderately associated with poor grip strength, and maintained that their definition predicted outcomes as well as Fried's definition [128]. These results may indicate the appropriateness of the criteria we used. Also, the physical activity level might be calculated inaccurately. The MET value assigned to each activity may need to be reconsidered, considering that the subjects were elderly. Third, almost all subjects of the present study were grandmothers of selected dietetic students, not a random sample of Japanese elderly women. Not all Japanese adolescents enter college or university (enrollment ratio: 56% [140]) and the grandmothers of students who do might accordingly have a relatively high social and economic status. Thus, our results cannot be readily extrapolated to the general Japanese elderly population. Finally, we should have excluded subjects with poor cognitive function because poor cognition is related to frailty [122, 141] and might also be associated with dietary TAC [33]. Although our self-reported questionnaire did not examine cognitive function, the study subjects answered it by themselves, and this implies that they kept enough cognitive function to do so.

Dietary habits with high TAC was strongly and inversely associated with frailty in a large cohort of elderly Japanese women. The association was more marked than those observed with the individual food and nutrient. Several foods including green tea, coffee, vegetables, and fruits can be chosen to increase dietary TAC in Japanese populations. Further epidemiological studies with better designs in various populations with different dietary habits are strongly warranted, particularly in view of the rapid increase in elderly populations worldwide.

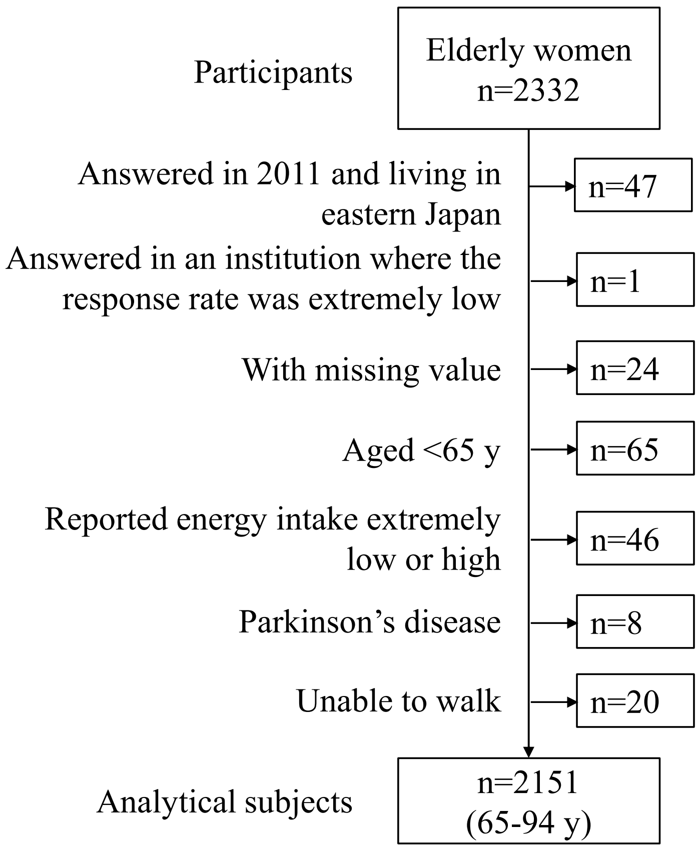

Figure 5-1. Flow chart of subjects

Table 5-1. Characteristics of 2121 Japanese elderly women aged 65-94 years categorized by no frailty and frailty*

	Total (n = 2121)	No frailty† (n = 1635)	Frailty† (n = 486)	*P*‡
Frailty† [n (%)]				-
No	1635 (77.1)	-	-	
Yes	486 (22.9)	-	-	
Frailty criteria, [n (%)]				
Slowness and weakness	717 (33.8)	236 (11.1)	481 (99.0)	-
Exhaustion	546 (25.8)	207 (12.7)	339 (69.9)	-
Low physical activity	529 (24.9)	226 (23.8)	303 (62.4)	-
Unintentional weight loss	116 (5.5)	51 (3.1)	65 (13.4)	-
Age (y)	74.7 ± 5.0	73.9 ± 4.6	77.3 ± 5.4	<0.0001
Body height (cm)	150.4 ± 5.5	150.7 ± 5.2	149.1 ± 6.1	<0.0001
Body weight (kg)	51.4 ± 7.8	51.4 ± 7.4	51.4 ± 9.2	0.99
Body mass index (kg/m^2)	22.7 ± 3.2	22.6 ± 3.0	23.1 ± 3.6	0.01
Survey year [n (%)]				0.27
2011	1350 (63.7)	1051 (64.3)	299 (61.5)	
2012	771 (36.4)	584 (35.7)	187 (38.5)	
Residential block [n (%)]				0.37
Hokkaido and Tohoku	196 (9.3)	144 (8.8)	52 (10.7)	
Kanto	529 (24.9)	406 (24.8)	123 (25.3)	
Hokuriku and Tokai	514 (24.2)	413 (25.3)	101 (20.8)	
Kinki	263 (12.4)	200 (12.2)	63 (13.0)	
Chugoku and Shikoku	343 (16.2)	265 (16.2)	78 (16.1)	
Kyushu	276 (13.0)	207 (12.7)	69 (14.2)	
Size of residential area [n (%)]				0.31
City with a population ≥1 million	275 (13.0)	205 (12.5)	70 (14.4)	
City with a population <1 million	1609 (75.9)	1253 (76.6)	356 (73.3)	
Town and village	237 (11.2)	177 (10.8)	60 (12.4)	
Living alone [n (%)]	350 (16.5)	263 (16.1)	87 (17.9)	0.34
Marital status [n (%)]				<0.0001
Single	4 (0.2)	3 (0.2)	1 (0.2)	
Married	1284 (60.5)	1042 (63.7)	242 (49.8)	
Widowed	781 (36.8)	547 (33.5)	234 (48.2)	
Separated	52 (2.5)	43 (2.6)	9 (1.9)	
Education [n (%)]				0.05
≤Junior high school and others	983 (46.4)	736 (45.0)	247 (50.8)	
High school	937 (44.2)	735 (45.0)	202 (41.6)	
≥Some college	201 (9.5)	164 (10.0)	37 (7.6)	
Current smoker [n (%)]	54 (2.6)	32 (2.0)	22 (4.5)	0.002
Alcohol drinker [n (%)]	414 (19.5)	349 (21.4)	65 (13.4)	<0.0001
Dietary supplement user [n (%)]	638 (30.1)	523 (32.0)	115 (23.7)	0.0004
Physical activity (total metabolic equivalents-hours/d)	39.0 ± 6.6	40.3 ± 6.3	34.4 ± 5.2	<0.0001
History of chronic disease§ [n (%)]	1060 (50.0)	769 (47.0)	291 (59.9)	<0.0001
Depression symptoms‖ [n (%)]	497 (23.4)	267 (16.3)	230 (47.3)	<0.0001
Energy intake (kcal/d)	1735 ± 475	1766 ± 474	1633 ± 464	<0.0001
Dietary TAC¶				
FRAP (mmol Fe^{2+}/d)	13.6 ± 5.47	14.1 ± 5.51	12.0 ± 5.03	<0.0001
ORAC (mmol TE/d)	20.7 ± 7.54	21.4 ± 7.56	18.4 ± 7.01	<0.0001
TEAC (mmol TE/d)	9.63 ± 4.48	10.0 ± 4.54	8.24 ± 3.97	<0.0001
TRAP (mmol TE/d)	12.5 ± 7.77	13.2 ± 7.93	10.3 ± 6.75	<0.0001

(Continued)

Table 5-1. (Continued)

	Total (n = 2121)	No frailty† (n = 1635)	Frailty† (n = 486)	*P*‡
Food intake¶				
Green tea (g/d)	371 ± 214	375 ± 213	358 ± 216	0.12
Coffee (g/d)	129 ± 139	139 ± 143	93 ± 120	<0.0001
Vegetables (g/d)	316 ± 138	322 ± 136	297 ± 143	0.0003
Fruits (g/d)	109 ± 73	113 ± 74	99 ± 67	0.0004
Nutrient intake¶				
Retinol (μg/d)	432 ± 415	435 ± 415	422 ± 415	0.55
Vitamin A (μg retinol equivalent/d)	836 ± 471	847 ± 472	797 ± 465	0.04
α-carotene (μg/d)	489 ± 336	496 ± 334	468 ± 341	0.10
β-carotene (μg/d)	4354 ± 2267	4449 ± 2266	4035 ± 2242	0.0004
β-carotene equivalent (μg/d)	4807 ± 2425	4909 ± 2424	4467 ± 2398	0.0004
Cryptoxanthin (μg/d)	417 ± 298	424 ± 297	394 ± 298	0.05
Vitamin D (μg/d)	19.8 ± 11.4	20.2 ± 11.6	18.6 ± 10.5	0.005
α-tocopherol (μg/d)	7.82 ±1.77	7.92 ± 1.78	7.50 ± 1.69	<0.0001
Vitamin B_6 (mg/d)	1.35 ± 0.32	1.37 ± 0.32	1.30 ± 0.30	<0.0001
Vitamin B_{12} (μg/d)	11.7 ± 6.0	11.9 ± 6.1	11.2 ± 5.6	0.02
Folate (μg/d)	413 ± 122	420 ± 123	389 ± 119	<0.0001
Vitamin C (mg/d)	148 ± 52	150 ± 52	139 ± 50	<0.0001

Fe, Iron; FRAP, ferric reducing ability of plasma; ORAC, oxygen radical absorbance capacity; TAC, total antioxidant capacity; TE, Trolox equivalent; TEAC, Trolox equivalent antioxidant capacity; TRAP, total radical-trapping antioxidant parameter.

* All values are mean ± SD for continuous variables and n (%) for categorical variables.

† Frailty score (0-5) was defined as the sum of poor physical function (two points), exhaustion (one point), low physical activity (one point), and unintentional weight loss (one point). A score of ≥3 was classified as indicating frailty.

‡ Means for continuous values were compared by Student's t test and proportions for categorical values were compared by the chi-square test.

§ History of chronic disease was defined as having any of the following self-reported disease: stroke, myocardial infarction, hypertension, diabetes, or chronic rheumatism.

|| Depression symptoms were defined as a Center for Epidemiologic Studies Depression score ≥16.

¶ All dietary variables were energy-adjusted according to the residual method.

Table 5-2. Odds ratios and 95% confidence intervals for frailty compared to no frailty by quintile of dietary variables among 2121 Japanese elderly women aged 65-94 years

	Q1 (Lowest) (n = 424)	Q2 (n = 424)	Q3 (n = 425)	Q4 (n = 424)	Q5 (Highest) (n = 424)	*P* for trend
Dietary TAC*						
FRAP (mmol Fe^{2+}/d)	≤9.2	9.2-11.9	11.9-14.3	14.3-17.8	≥17.8	
n of frailty/no frailty†	148/276	104/320	104/321	84/340	46/378	
Age-adjusted model	1 (Reference)	0.65 (0.48, 0.90)	0.62 (0.45, 0.84)	0.52 (0.38, 0.72)	0.29 (0.20, 0.43)	<0.0001
Multivariate adjusted model‡	1 (Reference)	0.72 (0.51, 1.01)	0.70 (0.50, 0.99)	0.55 (0.38, 0.78)	0.35 (0.24, 0.53)	<0.0001
ORAC (mmol TE/d)	≤14.5	14.5-18.5	18.5-21.9	21.9-26.7	≥26.7	
n of frailty/no frailty†	147/277	105/319	102/323	86/338	46/378	
Age-adjusted model	1 (Reference)	0.68 (0.50, 0.93)	0.59 (0.43, 0.81)	0.56 (0.40, 0.77)	0.29 (0.20, 0.42)	<0.0001
Multivariate adjusted model‡	1 (Reference)	0.70 (0.50, 0.98)	0.68 (0.49, 0.96)	0.60 (0.42, 0.85)	0.35 (0.23, 0.52)	<0.0001
TEAC (mmol TE/d)	≤6.0	6.0-7.7	7.7-9.6	9.6-12.8	≥12.8	
n of frailty/no frailty†	149/275	111/313	93/332	85/339	48/376	
Age-adjusted model	1 (Reference)	0.70 (0.51, 0.95)	0.62 (0.45, 0.85)	0.53 (0.39, 0.74)	0.34 (0.24, 0.50)	<0.0001
Multivariate adjusted model‡	1 (Reference)	0.78 (0.56, 1.09)	0.62 (0.44, 0.87)	0.58 (0.41, 0.83)	0.40 (0.27, 0.60)	<0.0001
TRAP (mmol TE/d)	≤6.2	6.2-8.8	8.8-12.6	12.6-16.5	≥16.5	
n of frailty/no frailty†	145/279	105/319	104/321	82/342	50/374	
Age-adjusted model	1 (Reference)	0.68 (0.49, 0.92)	0.79 (0.58, 1.08)	0.55 (0.40, 0.77)	0.39 (0.27, 0.56)	<0.0001
Multivariate adjusted model‡	1 (Reference)	0.67 (0.48, 0.95)	0.78 (0.56, 1.10)	0.57 (0.40, 0.81)	0.41 (0.28, 0.62)	<0.0001
Food intake*						
Green tea (g/d)	≤123	124-364	364-421	422-592	≥592	
n of frailty/no frailty†	109/315	89/335	107/318	78/346	103/321	
Age-adjusted model	1 (Reference)	0.69 (0.49, 0.96)	0.88 (0.63, 1.21)	0.53 (0.38, 0.75)	0.76 (0.55, 1.06)	0.04
Multivariate adjusted model‡	1 (Reference)	0.72 (0.50, 1.10)	0.83 (0.58, 1.19)	0.70 (0.48, 1.03)	0.77 (0.53, 1.15)	0.19
Coffee (g/d)	≤11.3	11.3-44.4	44.6-140	140-174	≥175	
n of frailty/no frailty†	123/301	126/298	94/331	85/339	58/366	
Age-adjusted model	1 (Reference)	1.04 (0.76, 1.41)	0.85 (0.61, 1.17)	0.76 (0.55, 1.06)	0.57 (0.40, 0.82)	0.0007
Multivariate adjusted model‡	1 (Reference)	0.66 (0.46, 0.96)	0.77 (0.54, 1.10)	0.60 (0.41, 0.87)	0.48 (0.32, 0.72)	0.0008
Vegetables (g/d)	≤208	208-266	267-328	328-412	≥412	
n of frailty/no frailty†	128/296	108/316	94/331	84/340	72/352	
Age-adjusted model	1 (Reference)	0.79 (0.58, 1.08)	0.66 (0.48, 0.91)	0.57 (0.41, 0.79)	0.45 (0.32, 0.63)	<0.0001
Multivariate adjusted model‡	1 (Reference)	0.71 (0.50, 1.00)	0.57 (0.40, 0.81)	0.55 (0.38, 0.78)	0.47 (0.33, 0.69)	<0.0001

(Continued)

Table 5-2. (Continued)

	Q1 (Lowest) (n = 424)	Q2 (n = 424)	Q3 (n = 425)	Q4 (n = 424)	Q5 (Highest) (n = 424)	*P* for trend
Fruits (g/d)	≤47.1	47.1-78.8	78.9-116	116-167	≥167	
n of frailty/no frailty†	109/315	106/318	111/314	78/346	82/342	
Age-adjusted model	1 (Reference)	1.04 (0.75, 1.44)	0.97 (0.70, 1.34)	0.64 (0.46, 0.91)	0.71 (0.51, 1.00)	0.003
Multivariate adjusted model‡	1 (Reference)	0.86 (0.60, 1.22)	0.88 (0.62, 1.25)	0.61 (0.42, 0.88)	0.71 (0.49, 1.03)	0.02
Nutrient intake*						
Retinol (μg/d)	≤226	226-294	294-370	370-573	≥573	
n of frailty/no frailty†	97/327	101/323	96/329	103/320	89/335	
Age-adjusted model	1 (Reference)	1.03 (0.74, 1.43)	1.03 (0.74, 1.44)	1.15 (0.83, 1.61)	0.97 (0.69, 1.37)	0.85
Multivariate adjusted model‡	1 (Reference)	0.80 (0.55, 1.16)	0.71 (0.48, 1.05)	0.78 (0.52, 1.15)	0.76 (0.52, 1.11)	0.23
Vitamin A (μg retinol equivalent/d)	≤545	545-684	684-820	820-1051	≥1053	
n of frailty/no frailty†	107/317	116/308	96/329	83/341	84/340	
Age-adjusted model	1 (Reference)	1.17 (0.85, 1.16)	0.91 (0.66, 1.27)	0.73 (0.52, 1.03)	0.76 (0.54, 1.07)	0.009
Multivariate adjusted model‡	1 (Reference)	0.99 (0.69, 1.40)	0.74 (0.51, 1.07)	0.67 (0.46, 0.97)	0.72 (0.49, 1.04)	0.01
α-carotene (μg/d)	≤229	229-350	351-502	503-728	≥728	
n of frailty/no frailty†	103/321	108/316	105/320	87/337	83/341	
Age-adjusted model	1 (Reference)	1.05 (0.75, 1.45)	0.96 (0.69, 1.33)	0.71 (0.51, 1.00)	0.69 (0.49, 0.97)	0.004
Multivariate adjusted model‡	1 (Reference)	0.85 (0.59, 1.22)	0.76 (0.53, 1.10)	0.70 (0.48, 1.00)	0.68 (0.47, 0.98)	0.02
β-carotene (μg/d)	≤2546	2551-3498	3500-4465	4468-5840	≥5844	
n of frailty/no frailty†	124/300	104/320	107/318	76/348	75/349	
Age-adjusted model	1 (Reference)	0.79 (0.57, 1.08)	0.84 (0.61, 1.15)	0.51 (0.36, 0.71)	0.49 (0.35, 0.69)	<0.0001
Multivariate adjusted model‡	1 (Reference)	0.66 (0.47, 0.93)	0.72 (0.51, 1.02)	0.47 (0.32, 0.67)	0.53 (0.36, 0.76)	<0.0001
β-carotene equivalent (μg/d)	≤2851	2857-3912	3914-4926	4929-6409	≥6412	
n of frailty/no frailty†	122/302	108/316	100/325	84/340	72/352	
Age-adjusted model	1 (Reference)	0.81 (0.59, 1.11)	0.75 (0.54, 1.04)	0.75 (0.54, 1.04)	0.47 (0.33, 0.66)	<0.0001
Multivariate adjusted model‡	1 (Reference)	0.69 (0.49, 0.98)	0.65 (0.46, 0.93)	0.55 (0.38, 0.79)	0.50 (0.35, 0.73)	0.0001

(Continued)

Table 5-2. (Continued)

	Q1 (Lowest) (n = 424)	Q2 (n = 424)	Q3 (n = 425)	Q4 (n = 424)	Q5 (Highest) (n = 424)	*P* for trend
Cryptoxanthin (μg/d)	≤169	169-279	279-436	437-655	≥655	
n of frailty/no frailty†	105/319	114/310	96/329	83/341	88/336	
Age-adjusted model	1 (Reference)	1.10 (0.80, 1.53)	0.86 (0.62, 1.20)	0.73 (0.52, 1.02)	0.78 (0.55, 1.08)	0.02
Multivariate adjusted model‡	1 (Reference)	1.00 (0.70, 1.42)	0.72 (0.50, 1.03)	0.71 (0.50, 1.03)	0.78 (0.54, 1.12)	0.04
Vitamin D (μg/d)	≤11.4	11.4-15.7	15.7-20.5	20.5-27.8	≥27.8	
n of frailty/no frailty†	100/324	107/317	117/308	89/335	73/351	
Age-adjusted model	1 (Reference)	1.17 (0.85, 1.63)	1.22 (0.88, 1.68)	0.86 (0.61, 1.21)	0.71 (0.50, 1.01)	0.01
Multivariate adjusted model‡	1 (Reference)	0.96 (0.67, 1.38)	0.96 (0.67, 1.38)	0.65 (0.45, 0.95)	0.67 (0.46, 0.98)	0.005
α-tocopherol (μg/d)	≤6.42	6.42-7.34	7.35-8.10	8.10-9.17	≥9.18	
n of frailty/no frailty†	128/296	121/303	78/347	79/345	80/344	
Age-adjusted model	1 (Reference)	0.93 (0.68, 1.27)	0.48 (0.34, 0.67)	0.56 (0.40, 0.78)	0.49 (0.35, 0.72)	<0.0001
Multivariate adjusted model‡	1 (Reference)	0.82 (0.58, 1.15)	0.41 (0.28, 0.59)	0.53 (0.36, 0.76)	0.51 (0.36, 0.74)	<0.0001
Vitamin B_6 (mg/d)	≤1.10	1.10-1.26	1.26-1.41	1.41-1.59	≥1.59	
n of frailty/no frailty†	127/297	107/317	97/328	82/342	73/351	
Age-adjusted model	1 (Reference)	0.77 (0.56, 1.05)	0.63 (0.46, 0.87)	0.53 (0.38, 0.74)	0.49 (0.35, 0.68)	<0.0001
Multivariate adjusted model‡	1 (Reference)	0.70 (0.49, 0.98)	0.53 (0.37, 0.76)	0.48 (0.33, 0.69)	0.50 (0.34, 0.72)	<0.0001
Vitamin B_{12} (μg/d)	≤7.3	7.3-9.8	9.8-12.2	12.2-15.3	≥15.3	
n of frailty/no frailty†	102/322	100/324	108/317	92/332	84/340	
Age-adjusted model	1 (Reference)	1.05 (0.76, 1.47)	1.11 (0.80, 1.54)	0.89 (0.64, 1.25)	0.83 (0.59, 1.17)	0.17
Multivariate adjusted model‡	1 (Reference)	0.86 (0.60, 1.24)	0.86 (0.60, 1.24)	0.69 (0.48, 1.00)	0.77 (0.53, 1.11)	0.08
Folate (μg/d)	≤316	316-371	371-425	425-501	≥501	
n of frailty/no frailty†	128/296	108/316	98/327	79/345	73/351	
Age-adjusted model	1 (Reference)	0.78 (0.57, 1.06)	0.68 (0.49, 0.93)	0.51 (0.37, 0.72)	0.44 (0.31, 0.62)	<0.0001
Multivariate adjusted model‡	1 (Reference)	0.73 (0.52, 1.03)	0.64 (0.45, 0.91)	0.51 (0.36, 0.74)	0.52 (0.36, 0.76)	<0.0001

(Continued)

Table 5-2. (Continued)

	Q1 (Lowest) (n = 424)	Q2 (n = 424)	Q3 (n = 425)	Q4 (n = 424)	Q5 (Highest) (n = 424)	*P* for trend
Vitamin C (mg/d)	≤105	105-130	130-154	154-188	≥188	
n of frailty/no frailty†	119/305	107/317	99/326	84/340	77/347	
Age-adjusted model	1 (Reference)	0.84 (0.61, 1.16)	0.73 (0.53, 1.01)	0.58 (0.42, 0.82)	0.51 (0.37, 0.72)	<0.0001
Multivariate adjusted model‡	1 (Reference)	0.82 (0.58, 1.15)	0.72 (0.50, 1.03)	0.61 (0.42, 0.88)	0.61 (0.42, 0.88)	0.002

Fe, Iron; FRAP, ferric reducing ability of plasma; CI, confidence interval; OR, odds ratio; ORAC, oxygen radical absorbance capacity; TAC, total antioxidant capacity; TE, Trolox equivalent; TEAC, Trolox equivalent antioxidant capacity; TRAP, total radical-trapping antioxidant parameter.

* All dietary variables were energy-adjusted according to the residual method.

† Frailty score (0-5) was defined as the sum of poor physical function (two points), exhaustion (one point), low physical activity (one point), and unintentional weight loss (one point). A score ≥3 were classified as indicating frailty.

‡ Adjusted for age (y, continuous), body mass index (kg/m2, continuous), residential block (Hokkaido and Tohoku, Kanto, Hokuriku and Tokai, Kinki, Chugoku and Shikoku, and Kyushu), size of residential area (city with a population ≥1 million, city with a population <1 million, and town and village), living alone (yes or no), current smoking (yes or no), alcohol drinking (yes or no), dietary supplement use (yes or no), history of chronic disease (any of stroke, myocardial infarction, hypertension, diabetes, or chronic rheumatism; yes or no), depression symptoms (yes or no), and energy intake (kcal/d, continuous).

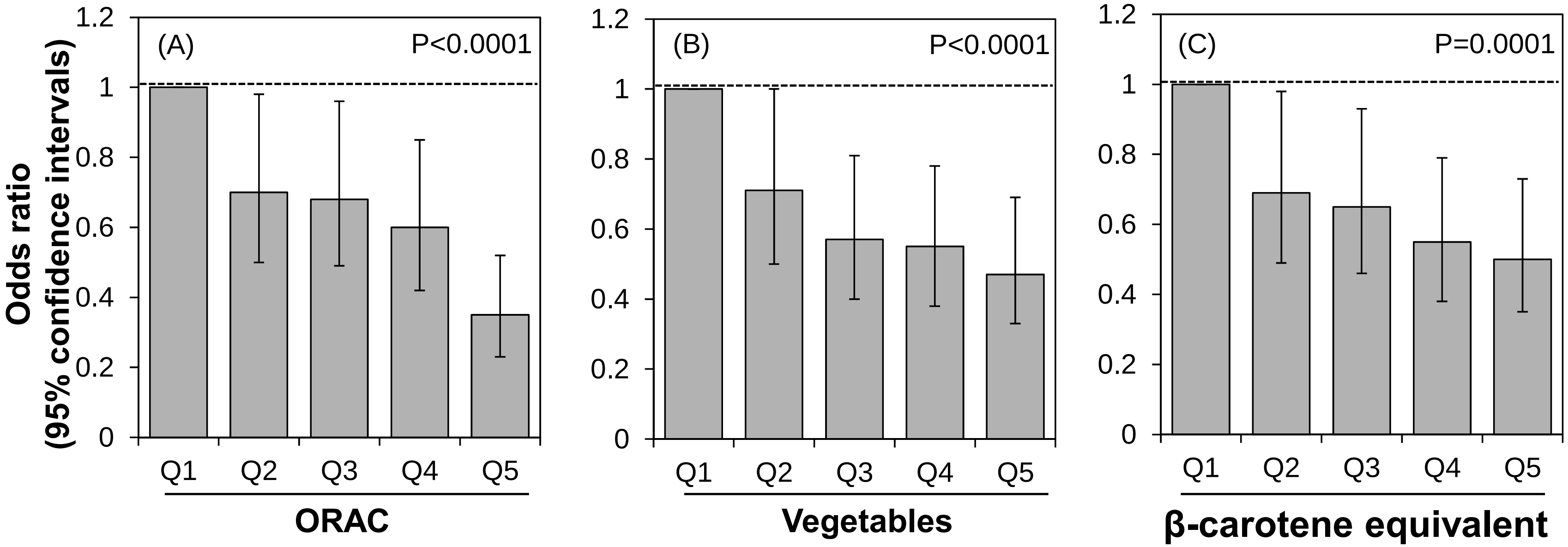

Figure 5-2. Multivariate adjusted odds ratios and 95% confidence intervals for frailty compared to no frailty by quintile of ORAC (A), vegetables (B), and β-carotene equivalent (C) among 2121 Japanese elderly women aged 65-94 years. All dietary variables were energy-adjusted according to the residual method. Frailty score (0-5) was defined as the sum of poor physical function (two points), exhaustion (one point), low physical activity (one point), and unintentional weight loss (one point). A score ≥3 were classified as indicating frailty. Odds ratio was adjusted for age (y, continuous), body mass index (kg/m2, continuous), residential block (Hokkaido and Tohoku, Kanto, Hokuriku and Tokai, Kinki, Chugoku and Shikoku, and Kyushu), size of residential area (city with a population ≥1 million, city with a population <1 million, and town and village), living alone (yes or no), current smoking (yes or no), alcohol drinking (yes or no), dietary supplement use (yes or no), history of chronic disease (any of stroke, myocardial infarction, hypertension, diabetes, or chronic rheumatism; yes or no), depression symptoms (yes or no), and energy intake (kcal/d, continuous). ORAC, oxygen radical absorbance capacity.

CONCLUSION

The concept of dietary TAC was initially proposed to assess the combined effect of multiple antioxidants in the diet, and is now used in epidemiological studies [7]. Although many epidemiological studies have focused on showing the favorable effects of dietary TAC on health status, these studies have all been conducted in Western countries only, and no study had been conducted in a non-Western country prior to the present study (see Chapter 1). To identify the effect of dietary TAC on health in Japanese, epidemiological studies reporting dietary TAC among Japanese populations are required. However, even a method of estimating dietary TAC for Japanese had not been available. Therefore, the author developed TAC databases of foods. She then used these databases to estimate dietary TAC in Japanese populations, and examined the association between dietary TAC and health status in this population.

The author reported the following findings in this thesis:

1) TAC databases of food items included in the DHQ and BDHQ were developed using FRAP, ORAC, TEAC, and TRAP assay to estimate dietary TAC among Japanese populations. The TAC value of each food was searched for and an analytical, substituted, or calculated value was assigned to each food. Although the number of food items assigned a TAC value differed among the assays, TAC databases were completed for all four assays. Dietary TAC could be estimated based on intake and the TAC value of each food item (corresponding to Aim 1).
2) Dietary TAC was estimated among young, middle-aged, and elderly Japanese women in the four assays. The main food contributors to dietary TAC were green tea, coffee, and vegetables and the correlation coefficients between the respective dietary TAC values were high in all generations. Middle-aged women had the highest and young women had

the lowest dietary TAC among the three generations. High consumption of coffee provided a higher dietary TAC to middle-aged women than to young and elderly women and TAC from fruits and vegetables was slightly low in young women (corresponding to Aim 2).

3) The association between dietary TAC and serum CRP concentration was examined among young Japanese women. Dietary TAC was inversely associated with serum CRP regardless of assay method. The association observed in this study was the same as those from previous studies in Western countries (corresponding to Aim 3-1).
4) The association between dietary TAC and frailty was investigated among elderly Japanese women. A higher dietary TAC was associated with a lower prevalence of frailty among elderly Japanese women. Although the intake of individual foods such as coffee, vegetables, and fruits, which were the main contributors to dietary TAC in the study population, and 10 nutrients related to antioxidation was also inversely associated with frailty, dietary TAC showed larger effect of reducing the proportion of frailty than any of the foods and nutrients examined (corresponding to Aim 3-2).

An estimation method for dietary TAC in Japanese populations was established, and favorable associations between dietary TAC and serum CRP in young Japanese women, and between dietary TAC and frailty among elderly Japanese women were seen. Use of dietary TAC as estimated from the method used in this study will allow the evaluation of many other health outcomes mediated by oxidative stress and inflammation. For Japanese populations at high risk of particular chronic diseases associated with dietary TAC who drink little green tea or coffee, or have a low intake of fruits and vegetables, increased consumption of these foods may be a relatively easy means of increasing dietary TAC. In other populations, appropriate food selection consistent with food culture and dietary habits might allow for an increase in dietary TAC. Meanwhile, dietary TAC estimated in the present study was only sum of the TAC values of the foods included in the DHQ or BDHQ. The author could not assess synergy and cancel effects of antioxidants. Also, TAC values of the foods do not reflect the antioxidative status *in vivo*. This is the limitation of the present study. Additionally, it is possible that the intake of diet with high TAC is acting as markers, either of more health conscious life-styles or of other important differences in diet. Further studies are needed to examine additive or synergistic antioxidative effects between foods to prevent many diseases, and clarify the causal pathway from dietary habits with high TAC to better health status.

Epidemiological studies focusing on dietary TAC may also provide effective dietary strategies for improving the health of Japanese. The use of dietary TAC in preventive medicine awaits further epidemiological studies of the association between dietary TAC and various health outcomes in Japanese populations.

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