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Variations in Lycopene Blood Levels and Tomato Consumption across European Countries Based on the European Prospective Investigation into Cancer and Nutrition (EPIC) Study[1]

Mazda Jenab,* Pietro Ferrari,* Mathieu Mazuir,* Anne Tjonneland,† Françoise Clavel-Chapelon,** Jakob Linseisen,‡ Antonia Trichopoulou,†† Rosario Tumino,‡‡ Hendrik B. Bueno-de-Mesquita,# Eiliv Lund,§ Carlos A. Gonzalez,*** Gerd Johansson,††† Timothy J. Key,## and Elio Riboli*[2]

**Nutrition and Hormones Group, EPIC Team, International Agency for Research on Cancer (IARC-WHO), Lyon, France; †Institute of Cancer Epidemiology, Danish Cancer Society, Copenhagen, Denmark; **INSERM U XR 521, Institut Gustave Roussy, Villejuif, France; ‡Division of Clinical Epidemiology, German Cancer Research Center (DKFZ), Heidelberg, Germany; ††University of Athens Medical School, Athens, Greece; ‡‡Cancer Registry, Azienda Ospedaliera "Civile - M.P. Arezzo," Ragusa, Italy; #National Institute of Public Health and the Environment (RIVM), Bilthoven, Netherlands; §Institute of Community Medicine, University of Tromsø, Norway; ***Department of Epidemiology, Catalan Institute of Oncology (ICO), Hospitalet de Llobregat, Barcelona, Spain; †††Department of Nutritional Research, Umeå University, Umeå, Sweden; and ##Cancer Research UK, Radcliffe Infirmary, University of Oxford, UK*

EXPANDED ABSTRACT

Increased plasma concentrations of lycopene, a diet-derived carotenoid, have been suggested to be associated with a decreased risk of chronic diseases, such as cardiovascular disease (1) and prostate cancer (2). Lycopene accounts for ~50% of the carotenoids found in human blood. It is believed that the major dietary sources of lycopene are tomatoes and tomato products (3,4). However, tomatoes and tomato products vary in their lycopene bioavailability, depending on whether they are processed, consumed raw, or cooked (5). Although in controlled settings, the intake of tomatoes and tomato products has been shown to modulate blood lycopene levels in cancer patients (6,7) and in healthy volunteers (8–11), epidemiological data on the intake of tomatoes and tomato products, estimated from various dietary recall instruments, and correlation with blood lycopene levels are lacking. In epidemiological observational studies, blood lycopene levels have been shown to be only weakly correlated with intake of total fruits and vegetables (12) and tomatoes or tomato products (13,14). From these studies, only a modest variability of blood lycopene concentrations can be explained by these dietary factors, likely because of wide variations in the bioavailability, metabolism, and excretion of lycopene (5).

In the over 521,000 subjects who volunteered to participate to the European Prospective Investigation into Cancer and Nutrition (EPIC) study, the consumption of tomatoes (raw and cooked) and tomato products (sauces, pastes, ketchup) has been measured with country-specific dietary questionnaires across 10 countries. Plasma lycopene concentrations have been measured in a subgroup of 3089 subjects from 16 EPIC regions (100 men and 100 women per region). In this communication, these samples are referred to as the EPIC Cross-Sectional Study. The methods of the EPIC study and of the plasma lycopene measurements are detailed elsewhere (15,16). These data were used in the present study to analyze the among-center and the among-subject/within-center variations in intake of tomatoes and tomato products and to calculate correlations with plasma lycopene concentrations.

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[2] To whom correspondence should be addressed. E-mail: nth@iarc.fr.

TABLE 1

Mean intake of tomatoes and tomato products from country-specific dietary questionnaire data, in a subsample of men and women enrolled in the EPIC Cross-Sectional Study[1]

EPIC region	Dietary variables							
	Tomato and tomato products	Tomato, raw[2]	Tomato, cooked[2]	Tomato sauce[2]	Tomato ketchup[2,3]	All cooked and processed tomatoes[2,4]	Tomato ketchup + paste + sauces[2,5]	Plasma lycopene (μmol/L)
	g/d							
Denmark	42.86 ± 25.63	12.64 ± 13.20	13.73 ± 10.60	1.38 ± 1.97	—	30.22 ± 20.17	1.81 ± 2.06	0.56 ± 0.31
France	22.04 ± 17.00	8.64 ± 9.17	12.76 ± 13.24	—	0.64 ± 1.03	13.40 ± 13.25	0.64 ± 1.03	0.69 ± 0.33
Germany, east	26.16 ± 19.41	19.07 ± 18.56	3.75 ± 4.48	1.42 ± 1.51	1.92 ± 3.24	7.09 ± 6.47	3.34 ± 3.85	0.65 ± 0.32
Germany, west	34.48 ± 21.20	23.75 ± 19.82	7.33 ± 6.89	2.94 ± 2.73	0.46 ± 0.98	10.73 ± 8.43	3.40 ± 3.00	0.58 ± 0.29
Greece	163.62 ± 83.72	112.5 ± 77.04	44.05 ± 19.00	6.81 ± 4.85	0.25 ± 0.30	51.12 ± 20.69	7.07 ± 4.93	0.86 ± 0.42
Italy, central	85.37 ± 54.11	63.99 ± 49.94	4.39 ± 3.04	17.00 ± 17.94	—	21.39 ± 18.82	17.00 ± 17.94	0.97 ± 0.37
Italy, north	83.91 ± 49.48	63.43 ± 46.01	3.93 ± 2.96	16.54 ± 16.82	—	20.47 ± 17.39	16.54 ± 16.82	0.97 ± 0.40
Italy, south	48.94 ± 32.75	8.65 ± 19.81	3.47 ± 3.14	19.25 ± 13.44	—	40.28 ± 26.81	19.25 ± 13.44	1.31 ± 0.46
Spain, north	69.15 ± 66.52	55.64 ± 66.61	3.51 ± 4.81	8.91 ± 8.68	0.00 ± 0.00	13.51 ± 11.65	8.91 ± 8.68	0.48 ± 0.31
Spain, south	97.59 ± 67.62	77.67 ± 64.43	11.73 ± 9.65	5.03 ± 6.08	0.01 ± 0.15	19.92 ± 14.43	5.04 ± 6.08	0.70 ± 0.35
Sweden	31.87 ± 32.34	24.53 ± 26.86	3.19 ± 6.06	4.59 ± 11.91	0.92 ± 3.05	7.34 ± 14.02	5.77 ± 12.51	0.50 ± 0.29
The Netherlands	15.70 ± 12.03	5.87 ± 5.85	2.18 ± 2.46	6.88 ± 7.86	—	9.83 ± 9.23	7.65 ± 8.27	0.50 ± 0.30
UK, nonvegetarian	42.41 ± 27.13	—	0.91 ± 1.49	8.48 ± 7.85	2.65 ± 5.21	42.41 ± 27.13	11.13 ± 9.85	0.75 ± 0.34
UK, vegetarian	54.07 ± 39.95	—	0.77 ± 1.21	10.49 ± 10.71	2.06 ± 4.31	54.07 ± 39.95	12.55 ± 12.90	0.93 ± 0.41
All EPIC regions	59.83 ± 58.83	42.08 ± 53.83	8.18 ± 12.81	7.91 ± 11.38	0.89 ± 2.8	22.69 ± 24.03	8.37 ± 11.56	0.72 ± 0.42

[1] — indicates missing dietary variable values from country-specific questionnaires. Values are means ± SD of intake (g/d). Plasma lycopene values are presented as μmol/L.
[2] Subgroup of the main tomato and tomato products variable.
[3] Tomato ketchup is a subgroup of the Tomato sauces variable.
[4] Sum of tomato cooked, tomato sauces, and tomato paste.
[5] Sum of tomato sauces (including tomato ketchup) and tomato paste.

The average intake of tomatoes and various tomato products and plasma lycopene concentrations in men and women of the EPIC Cross-Sectional Study are shown in **Tables 1**, **2**, and **3**. From the dietary questionnaire data, for men and women combined, the intake of tomatoes and all tomato products combined ranged from an average of 15.7 g/d in The Netherlands to 97.6 g/d in the south of Spain to 163.6 g/d in Greece (Table 1). The intake of raw tomatoes (lowest: The

TABLE 2

Mean intake of tomatoes and tomato products from country-specific dietary questionnaire data, in a subsample of men enrolled in the EPIC Cross-Sectional Study[1]

EPIC region	Dietary variables							
	Tomato and tomato products	Tomato, raw	Tomato, cooked	Tomato sauce	Tomato ketchup	All cooked and processed tomatoes	Tomato ketchup + paste + sauces	Plasma lycopene (μmol/L)
	g/d							
Denmark	40.98 ± 20.69	11.95 ± 11.79	15.01 ± 8.78	2.00 ± 2.55	—	29.03 ± 16.32	2.53 ± 2.61	0.59 ± 0.34
Germany, east	26.07 ± 21.76	17.81 ± 20.22	4.34 ± 5.28	1.49 ± 1.48	2.42 ± 3.67	8.25 ± 7.32	3.91 ± 4.34	0.59 ± 0.30
Germany, west	32.83 ± 19.00	20.26 ± 16.25	8.66 ± 7.90	3.37 ± 3.16	0.55 ± 1.14	12.57 ± 9.40	3.92 ± 3.46	0.63 ± 0.31
Greece	162.58 ± 83.43	106.25 ± 74.73	48.44 ± 20.78	7.59 ± 4.68	0.30 ± 0.35	56.32 ± 22.12	7.89 ± 4.78	0.90 ± 0.37
Italy, central	87.66 ± 53.54	58.54 ± 46.02	4.99 ± 3.29	24.13 ± 20.34	—	29.12 ± 21.05	24.13 ± 20.34	1.02 ± 0.38
Italy, north	97.38 ± 52.42	69.38 ± 48.65	4.04 ± 2.89	23.96 ± 19.76	—	28.00 ± 20.38	23.96 ± 19.76	1.04 ± 0.43
Italy, south	50.86 ± 31.79	2.15 ± 7.05	2.85 ± 2.68	19.17 ± 10.62	—	48.70 ± 30.66	19.17 ± 10.62	1.30 ± 0.47
Spain, south	106.89 ± 73.67	83.50 ± 70.96	14.25 ± 11.56	6.07 ± 7.05	0.01 ± 0.21	23.39 ± 16.29	6.09 ± 7.04	0.68 ± 0.35
Spain, north	82.69 ± 77.34	67.49 ± 77.15	4.09 ± 5.34	10.16 ± 8.88	0.00 ± 0.00	15.20 ± 12.44	10.16 ± 8.88	0.53 ± 0.32
Sweden	31.29 ± 34.40	22.58 ± 27.51	3.75 ± 6.90	5.39 ± 13.68	1.12 ± 3.94	8.70 ± 15.62	6.84 ± 14.18	0.52 ± 0.32
The Netherlands	15.01 ± 11.67	5.55 ± 5.77	2.24 ± 2.70	6.38 ± 7.67	—	9.46 ± 9.25	7.21 ± 8.13	0.54 ± 0.34
UK, nonvegetarian	39.35 ± 24.24	—	0.93 ± 1.52	9.08 ± 8.40	3.27 ± 5.89	39.35 ± 24.24	12.35 ± 11.08	0.72 ± 0.30
UK, vegetarian	51.35 ± 37.16	—	0.81 ± 0.93	11.28 ± 10.99	1.96 ± 4.34	51.35 ± 37.16	13.24 ± 13.04	1.01 ± 0.42
All EPIC regions	63.93 ± 62.97	43.75 ± 57.26	9.15 ± 14.27	9.38 ± 12.97	1.05 ± 3.3	25.35 ± 24.72	10.22 ± 13.17	0.74 ± 0.42

[1] — indicates missing dietary variable values from country-specific questionnaires. Values are means ± SD of intake (g/d). Plasma lycopene values are presented as μmol/L. For definition of dietary variables, see Table 1.

TABLE 3

Mean intake of tomatoes and tomato products from country-specific dietary questionnaire data, in a subsample of women enrolled in the EPIC Cross-Sectional Study[1]

EPIC region	Dietary variables							
	Tomato and tomato products	Tomato, raw	Tomato, cooked	Tomato sauce	Tomato ketchup	All cooked and processed tomatoes	Tomato ketchup + paste + sauces	Plasma lycopene (μmol/L)
	g/d							
Denmark	44.70 ± 29.69	13.31 ± 14.49	12.48 ± 12.05	0.77 ± 0.78	—	31.38 ± 23.37	1.10 ± 0.87	0.52 ± 0.29
France	22.04 ± 17.00	8.64 ± 9.17	12.76 ± 13.24	—	0.64 ± 1.03	13.40 ± 13.25	0.64 ± 1.03	0.69 ± 0.34
Germany, east	26.26 ± 16.98	20.28 ± 16.84	3.19 ± 3.48	1.35 ± 1.55	1.44 ± 2.69	5.97 ± 5.33	2.79 ± 3.26	0.69 ± 0.33
Germany, west	36.12 ± 23.17	27.24 ± 22.39	5.99 ± 5.42	2.51 ± 2.16	0.37 ± 0.80	8.88 ± 6.90	2.88 ± 2.36	0.54 ± 0.25
Greece	164.73 ± 84.54	119.2 ± 79.36	39.34 ± 15.67	5.98 ± 4.92	0.21 ± 0.24	45.53 ± 17.51	6.19 ± 4.96	0.83 ± 0.46
Italy, central	83.08 ± 54.85	69.43 ± 53.25	3.78 ± 2.67	9.87 ± 11.44	—	13.65 ± 12.17	9.87 ± 11.44	0.92 ± 0.36
Italy, north	70.57 ± 42.61	57.55 ± 42.68	3.83 ± 3.03	9.20 ± 8.35	—	13.03 ± 9.01	9.20 ± 8.35	0.91 ± 0.36
Italy, south	47.17 ± 33.68	14.62 ± 25.21	4.03 ± 3.43	19.33 ± 15.64	—	32.55 ± 19.92	19.33 ± 15.64	1.32 ± 0.46
Spain, south	88.48 ± 59.92	71.96 ± 56.92	9.27 ± 6.45	4.01 ± 4.76	0.01 ± 0.07	16.51 ± 11.39	4.01 ± 4.77	0.72 ± 0.34
Spain, north	56.03 ± 51.07	44.15 ± 52.39	2.95 ± 4.18	7.70 ± 8.36	0.00 ± 0.00	11.88 ± 10.63	7.70 ± 8.36	0.42 ± 0.29
Sweden	32.48 ± 30.16	26.54 ± 26.10	2.60 ± 5.00	3.77 ± 9.73	0.71 ± 1.69	5.94 ± 12.02	4.67 ± 10.44	0.48 ± 0.27
The Netherlands	16.37 ± 12.39	6.18 ± 5.95	2.12 ± 2.21	7.36 ± 8.05	—	10.19 ± 9.24	8.08 ± 8.42	0.47 ± 0.27
UK, nonvegetarian	45.41 ± 29.51	—	0.89 ± 1.47	7.89 ± 7.26	2.04 ± 4.39	45.41 ± 29.51	9.93 ± 8.37	0.77 ± 0.38
UK, vegetarian	56.45 ± 42.33	—	0.74 ± 1.41	9.80 ± 10.48	2.15 ± 4.30	56.45 ± 42.33	11.95 ± 12.82	0.87 ± 0.40
All EPIC regions	56.04 ± 54.47	40.54 ± 50.43	7.29 ± 11.24	6.47 ± 9.33	0.74 ± 2.26	20.24 ± 23.12	6.67 ± 9.52	0.71 ± 0.41

[1] — indicates missing dietary variable values from country-specific questionnaires. Values are means ± SD of intake (g/d). Plasma lycopene values are presented as μmol/L. For definition of dietary variables, see Table 1.

Netherlands = 5.9 g/d; highest: Greece = 112.5 g/d) was generally higher than that of cooked tomatoes (lowest: The Netherlands = 2.2 g/d; highest: Greece = 44.1 g/d). Average plasma lycopene measures showed the lowest concentrations in the north of Spain (0.48 μmol/L) followed by Sweden (0.49 μmol/L) and The Netherlands (0.50 μmol/L), and with the highest in southern Italy (1.31 μmol/L) (Table 1).

The Pearson correlation coefficients between the plasma lycopene levels and the level of consumption of tomatoes and tomato products in men and women in the EPIC Cross-Sectional Study by EPIC region, adjusted for gender and season of blood donation, are shown in **Table 4**, and the same values for all regions combined are shown in **Table 5**. A wide range of weak to moderate correlations is seen for all tomato and tomato products across EPIC regions (Table 4). However, for all EPIC regions combined (Table 5), the correlations were much stronger for tomato sauces and for the sum of all cooked and processed tomato intake. Using a model to break down between- and within-center correlation coefficients (17), the correlation coefficients at an ecological level (among regions) were much stronger than those at the individual level (within regions), particularly for sauces and for the sum of all cooked and processed tomatoes (Table 5). This is expected given that these products have been shown to have generally greater

TABLE 4

Pearson correlation coefficients between plasma lycopene levels and level of consumption of tomatoes and tomato products in men and women enrolled in the EPIC Cross-Sectional Study by EPIC region[1]

Dietary variables	EPIC Region													
	Denmark	France	Germany, east	Germany, west	Greece	Italy, central	Italy, north	Italy, south	Spain, north	Spain, south	Sweden	The Netherlands	UK, nonvegetarian	UK, vegetarian
Tomato and tomato products	0.15	0.06	0.30	0.06	0.11	0.12	0.21	0.26	0.22	0.24	0.33	0.42	0.15	0.12
Tomato, raw	0.10	0.07	0.22	−0.03	0.13	0.02	0.07	0.09	0.18	0.20	0.25	0.28	—	—
Tomato, cooked	0.14	0.07	0.14	0.22	0.08	0.06	0.11	0.04	−0.07	0.10	0.15	0.35	0.21	0.07
Tomato, sauce	0.37	—	0.16	0.19	0.15	0.18	0.34	0.29	0.17	0.07	0.19	0.35	0.08	0.09
Tomato, ketchup	—	−0.03	0.25	0.07	0.02	—	—	—	—	−0.06	0.16	—	0.14	0.20
All cooked and processed tomatoes	0.13	0.06	0.25	0.23	0.12	0.16	0.31	0.25	0.06	0.11	0.25	0.44	0.15	0.12
Ketchup + paste + sauces	0.39	−0.03	0.26	0.18	0.15	0.18	0.34	0.29	0.17	0.06	0.26	0.39	0.11	0.12

[1] — indicates missing dietary variable values from country-specific dietary questionnaires. Values are Pearson correlation coefficients, adjusted by gender and season of blood donation, between log transformed plasma lycopene levels (μmol/L) and levels of dietary tomato and tomato product intake from the EPIC Cross-Sectional Study. For definition of dietary variables, see Table 1.

lycopene bioavailability than raw tomatoes (5,10). The overall correlation of the total tomatoes and the tomato product intake with plasma lycopene was 0.33 (Table 5). The within-region correlation coefficient was 0.23, whereas the among-region correlation was 0.53. The intraclass correlation coefficient, highlighting the amount of variation among groups over total variability, was 0.43.

The modest correlations found between the dietary consumption of tomato and the lycopene concentration in blood may be because of imprecision of measurements of diet as well as variations of bioavailability and absorption of lycopene, depending on the way tomatoes are seasoned or cooked and their method of consumption (e.g., eaten with added fats, which may increase lycopene absorption). In addition, these generally low correlations of tomatoes and tomato products with plasma lycopene may also be because of the time span between the exposure and the blood sampling, given the strong seasonal variations in the intake of tomato and tomato products.

The Mediterranean diet is rich in tomatoes and tomato products (18), as evidenced by the observation that the Greek EPIC cohort has one of the highest intakes of tomato and tomato products in the EPIC study (Tables 1–3). However, the correlation of plasma lycopene with the Mediterranean diet score in the EPIC Cross-Sectional Study was determined to be weak in most EPIC regions (**Table 6**). These results from the EPIC study indicate that in these European populations, measures of tomato consumption and the Mediterranean diet score are poor predictors of blood lycopene concentrations at the individual level.

In studies of the association of lycopene and cancer risk, the use of tomato consumption data would provide only an imprecise proxy variable of the lycopene blood levels and would lead to substantial attenuation of any hypothetical association. This was the rationale for initiating a study in which 7 carotenoids, including lycopene, are being measured in subjects who developed prostate cancer during the follow-up period and in a group of control subjects who remained free of cancer during the corresponding follow-up time.

TABLE 5

Pearson correlation coefficients between plasma lycopene levels and level of consumption of tomatoes and tomato products in men and women enrolled in the EPIC Cross-Sectional Study, all EPIC regions combined

	Pearson correlation coefficients for plasma lycopene and dietary variables		
Dietary variables	Ecological correlation among regions[1]	Individual correlation within regions[1]	Total correlation
Tomato and tomato products	0.53	0.23	0.33
Tomato, raw	0.17	0.16	0.16
Tomato, cooked	0.07	0.12	0.09
Tomato, sauce	0.79	0.18	0.37
Tomato, ketchup	0.34	0.10	0.15
All cooked and processed tomatoes	0.69	0.20	0.37
Ketchup + paste + sauces	0.67	0.20	0.34

[1] Among- and within-region correlation coefficients, adjusted by gender, between biomarker levels, and all dietary variables. For definition of dietary variables, see Table 1.

TABLE 6

The Mediterranean diet score and correlations with plasma lycopene levels in EPIC regions

EPIC region	Mean Mediterranean diet score[1]	Correlation with plasma lycopene[2]
Denmark	3.53	0.16
France	4.54	0.00
Germany, east	2.90	0.16
Germany, west	3.03	−0.12
Greece	6.18	0.09
Italy, central	5.43	0.11
Italy, north	5.14	0.12
Italy, south	5.77	0.10
Spain, north	5.32	0.06
Spain, south	5.79	0.08
Sweden	2.76	0.12
The Netherlands	2.73	0.10
UK, nonvegetarians	4.06	0.18
UK, vegetarian	5.99	0.07
All EPIC regions	4.45	0.30

[1] Ranges from 0 to 9, with higher scores indicating greater adherence to the Mediterranean diet, based on the sum of 0/1 scores given, depending on intake of 9 specific food groups, based on data from country-specific dietary questionnaires: Vegetables, legumes, fruits and nuts, cereals, fish (score 0 if intake below the gender-specific median; 1 if above); Meat and poultry, dairy products (score 1 if intake below the gender-specific median, 0 if above); ethanol (for men, score 1 for intake > 10 g/d; for women, score 1 for intake > 5 g/d); score 0 if monounsaturated/saturated fatty acid intake ratio is less than 1 and score 1 if ratio is greater than 1.

[2] Values are Pearson correlation coefficients adjusted by gender and season of blood collection.

LITERATURE CITED

1. Arab, L. & Steck, S. (2000) Lycopene and cardiovascular disease. Am. J. Clin. Nutr. 71 (6 suppl.): 1691S–1695S.
2. Giovannucci, E. (2002) A review of epidemiologic studies of tomatoes, lycopene, and prostate cancer. Exp. Biol. Med. (Maywood) 227: 852–859.
3. Mangels, A. R., Holden, J. M., Beecher, G. R., Forman, M. R. & Lanza, E. (1993) Carotenoid content of fruits and vegetables: an evaluation of analytic data. J. Am. Diet. Assoc. 93: 284–296.
4. Scott, K. J., Thurnham, D. I., Hart, D. J., Bingham, S. A. & Day, K. (1996) The correlation between the intake of lutein, lycopene and beta-carotene from vegetables and fruits, and blood plasma concentrations in a group of women aged 50–65 years in the UK. Br. J. Nutr. 75: 409–418.
5. Stahl, W. & Sies, H. (1992) Uptake of lycopene and its geometrical isomers is greater from heat-processed than from unprocessed tomato juice in humans. J. Nutr. 122: 2161–2166.
6. Bowen, P., Chen, L., Stacewicz-Sapuntzakis, M., Duncan, C., Sharifi, R. & Ghosh, L. (2002) Tomato sauce supplementation and prostate cancer: lycopene accumulation and modulation of biomarkers of carcinogenesis. Exp. Biol. Med. (Maywood) 227: 886–893.
7. Chen, L., Stacewicz-Sapuntzakis, M., Duncan, C., Sharifi, R., Ghosh, L., van Breemen, R., Ashton, D. & Bowen, P. E. (2001) Oxidative DNA damage in prostate cancer patients consuming tomato sauce-based entrees as a whole-food intervention. J. Natl. Cancer Inst. 93: 1872–1879.
8. Porrini, M., Riso, P. & Oriani, G. (2002) Spinach and tomato consumption increases lymphocyte DNA resistance to oxidative stress but this is not related to cell carotenoid concentrations. Eur. J. Nutr. 41: 95–100.
9. Maruyama, C., Imamura, K., Oshima, S., Suzukawa, M., Egaml, S., Tonomoto, M., Baba, N., Harada, M., Ayaori, M., et al. (2001) Effects of tomato juice consumption on plasma and lipoprotein carotenoid concentrations and the susceptibility of low density lipoprotein to oxidative modification. J. Nutr. Sci. Vitaminol. (Tokyo) 47: 213–221.
10. Rao, A. V. (2004) Processed tomato products as a source of dietary lycopene: bioavailability and antioxidant properties. Can. J. Diet. Pract. Res. 65: 161–165.

11. Tyssandier, V., Feillet-Coudray, C., Caris-Veyrat, C., Guilland, J. C., Coudray, C., Bureau, S., Reich, M., Amiot-Carlin, M. J., Bouteloup-Demange, C., et al. (2004) Effect of tomato product consumption on the plasma status of antioxidant microconstituents and on the plasma total antioxidant capacity in healthy subjects. J. Am. Coll. Nutr. 23: 148–156.

12. Gomez-Aracena, J., Bogers, R., Van't Veer, P., Gomez-Gracia, E., Garcia-Rodriguez, A., Wedel, H. & Fernandez-Crehuet Navajas, J. (2003) Vegetable consumption and carotenoids in plasma and adipose tissue in Malaga, Spain. Int. J. Vitam. Nutr. Res. 73: 24–31.

13. Casso, D., White, E., Patterson, R. E., Agurs-Collins, T., Kooperberg, C. & Haines, P. S. (2000) Correlates of serum lycopene in older women. Nutr. Cancer 36: 163–169.

14. Jansen, M. C., Van Kappel, A. L., Ocke, M. C., Van 't Veer, P., Boshuizen, H. C., Riboli, E. & Bueno-de-Mesquita, H. B. (2004) Plasma carotenoid levels in Dutch men and women, and the relation with vegetable and fruit consumption. Eur. J. Clin. Nutr. 58: 1386–1395.

15. Bingham, S. & Riboli, E. (2004) Diet and cancer—the European Prospective Investigation into Cancer and Nutrition. Nat. Rev. Cancer 4: 206–215.

16. Al Delaimy, W. K., van Kappel, A. L., Ferrari, P., Slimani, N., Steghens, J. P., Bingham, S., Johansson, I., Wallstrom, P., Overvad, K., et al. (2004) Plasma levels of six carotenoids in nine European countries: report from the European Prospective Investigation into Cancer and Nutrition (EPIC). Public Health Nutr. 7: 713–722.

17. Ferrari, P., Al-Delaimy, W. K., Slimani, N., Boshuizen, H. C., Roddam, A., Orfanos, P., Skeie, G., Rodríguez-Barranco, M., Thiebaut, A., et al. (2005) An approach to estimate between- and within-group correlation coefficients in multi-center studies: plasma carotenoids as biomarkers of intake of fruits and vegetables. Am. J. Epidemiol. (in press).

18. Trichopoulou, A., Benetou, V., Lagiou, P., Gnardellis, C., Stacewicz-Sapunzakis, M. & Papas, A. (2003) Plasma carotenoid levels in relation to the Mediterranean diet in Greece. Int. J. Vitam. Nutr. Res. 73: 221–225.