British Journal of Nutrition (2015), **113**, 1129–1138
doi:10.1017/S0007114515000331

High consumption of vegetable and fruit colour groups is inversely associated with the risk of colorectal cancer: a case–control study

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(Submitted 21 September 2014 – Final revision received 3 December 2014 – Accepted 19 January 2015 – First published online 16 March 2015)

Abstract

The colour of the edible portion of vegetables and fruit reflects the presence of specific micronutrients and phytochemicals. No existing studies have examined the relationship between the intake of vegetable and fruit colour groups and the risk of colorectal cancer. The present study, therefore, aimed to investigate these associations in a Chinese population. A case–control study was conducted between July 2010 and July 2014 in Guangzhou, China, in which 1057 consecutively recruited cases of colorectal cancer were frequency-matched to 1057 controls by age (5-year interval), sex and residence (rural/urban). A validated FFQ was used to collect dietary information during face-to-face interviews. Vegetables and fruit were classified into four groups according to the colour of their primarily edible parts: green; orange/yellow; red/purple; white. Unconditional logistic regression models were used to estimate the OR and 95 % CI. A higher consumption of orange/yellow, red/purple and white vegetables and fruit was inversely associated with the risk of colorectal cancer, with adjusted OR of 0·16 (95 % CI 0·12, 0·22) for orange/yellow, 0·23 (95 % CI 0·17, 0·31) for red/purple and 0·53 (95 % CI 0·40, 0·70) for white vegetables and fruit when the highest and lowest quartiles were compared. Total vegetable intake and total fruit intake have also been found to be inversely associated with colorectal cancer risk. However, the intake of green vegetable and fruit was not associated with colorectal cancer risk. The results of the present study, therefore, suggest that a greater intake of orange/yellow, red/purple and white vegetables and fruit is inversely associated with the risk of colorectal cancer.

Key words: **Case–control studies: China: Colorectal cancer risk: Fruit: Vegetables**

The association between the intake of vegetables and fruit and the risk of colorectal cancer is only suggestive[1]. Most case–control studies have shown strong evidence of an inverse association between vegetable and fruit intake and colorectal cancer risk[2–5], whereas most[6–11] but not all[12,13] prospective cohort studies have found no statistically significant associations with total fruit and/or vegetable intake. All the previous studies have categorised vegetables and fruit by botanical family or the parts of the plant. Recently, Pennington & Fisher[14,15] devised a novel definition of fruit and vegetable colour groups based on a combination of their unique nutritional value and characteristics. The colour of the edible portion of vegetables and fruit reflects the presence of pigmented phytochemicals, such as carotenoids and flavonoids, and could, therefore, be an indicator of their nutrient profile and be used in their classification[14,15].

Studies that have examined the association between the intake of individual vegetable and fruit groups and the risk of colorectal cancer have yielded inconsistent results. One study carried out in Switzerland has shown a statistically significantly decreased risk of colorectal cancer with a high consumption of citrus fruit[16], whereas the NIH-AARP Diet and Health Study has shown no statistically significant association[17]. Consistent evidence of a relationship between subgroups of fruit and vegetables and colorectal cancer risk has not been found, because previous studies have focused on only a limited number of fruit and vegetables selected on the basis of their botanical family or their content of one specific micronutrient or bioactive compound. However,

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the beneficial effect of vegetables and fruit may also depend on the combined effects of these different components in the natural food matrix[18]. Thus, a further analysis of vegetable and fruit colour groups classified by the colour of their edible portion is needed.

To the best of our knowledge, no study has clearly investigated the consumption of various vegetable and fruit colour groups in relation to the risk of colorectal cancer. Therefore, the present case–control study focused on the associations between the intake of vegetable and fruit colour groups and colorectal cancer risk in a Chinese population residing in Guangdong Province.

Materials and methods

Study subjects

Potential case subjects were recruited consecutively from patients admitted to the surgical units of the Sun Yat-sen University Cancer Centre, Guangzhou, China, from July 2010 to July 2014. The inclusion criteria were age 30–75 years, native of the Guangdong Province or having lived in Guangdong for at least 5 years, and an incident, primary, histologically confirmed colorectal cancer diagnosed no more than 3 months before the interview. The subjects were excluded if they had a history of colorectal cancer or other cancers, and could not understand or speak Mandarin/Cantonese. A total of 1174 eligible cases were identified, and 1057 were successfully interviewed, yielding a participation rate of 90 %; seventy-four patients did not finish the interview because of the lengthy questionnaire or fatigue, and the remaining forty-three refused to participate.

Controls were frequency-matched to cases by 5-year age group and sex. The eligibility criteria for controls were the same as those for cases, except for the history of colorectal cancer. Two control groups were used. The first group was recruited from in-patients admitted to three affiliated hospitals of the Sun Yat-sen University during the same period as the cases with the following diseases: eye disorders; ear–nose–throat diseases; trigeminal neuralgia; varicose veins; osteoarthritis; degenerate joint disease; orthopaedics; facial paralysis; acute appendicitis. The second group was obtained from residents of the same community as the cases through a variety of strategies, such as advertisements, written invitations or referrals. In total, 718 hospital-derived controls were identified, and 625 were successfully interviewed in the study, yielding a participation rate of 87 %; in addition, 432 community-derived controls were interviewed.

The present study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all the procedures involving human subjects were approved by The Ethical Committee of School of Public Health, Sun Yat-sen University. All the participants signed informed consent forms before the interview.

Data collection

Trained interviewers conducted face-to-face interviews using a structured questionnaire to collect information on sociodemographic factors, body weight and height, lifestyle factors (e.g. active and passive smoking, alcohol drinking and physical activity) and family history of cancer. Relevant medical information, medical diagnosis and histological findings were abstracted from the hospital medical records. For the female participants, menstrual and reproductive histories were also obtained. In the present study, regular smokers were defined as those who had smoked at least one cigarette a day for more than six consecutive months; passive smoking was defined as an exposure to the tobacco smoke of others for at least 5 min/d during the previous 5 years; regular drinking was defined as alcohol drinking at least once a week during the past year; and postmenopausal status was defined as at least 12 months since the last menstrual cycle. Physical activity was assessed based on self-reported occupational, household and recreational activities. To evaluate labour intensity, the respondents were asked to describe their activities during work in the past year as (1) not working or being retired, (2) mainly sitting, (3) low intensity, (4) moderate intensity or (5) vigorous intensity, with examples provided. Household and recreational activities were combined and categorised into light (e.g. walking), moderate (e.g. jogging, mountaineering and playing table tennis) and vigorous (e.g. running, weightlifting and playing football/basketball) physical activities, and data were collected on their frequency (d/week) and typical duration (h/d). The mean metabolic equivalent task hours value of each activity was obtained by estimating the average of all comparable activities in the Compendium of Physical Activities[19,20]. Metabolic equivalent task hours/week (how many days/week × how many hours/d × metabolic equivalent task for a specific type of activity = metabolic equivalent task hours/week) over the past 12 months were computed. BMI was calculated as weight (kg) divided by height squared (m^2).

Information on dietary intake was assessed using an interviewer-administered FFQ that covered the habitual diet of the participants during the previous year and comprised eighty-one food items, including eighteen on fresh vegetables and twelve on fruit. A commonly used portion size was specified for most of the fruit (e.g. slice, glass or unit, such as one apple or a banana), and a Liang (the common unit of weight in China; 1 Liang = 50 g) was used to estimate the usual portion size for vegetables and some types of fruit, such as watermelon. Food photographs were used to help the participants quantify the portions consumed. The Chinese Food Composition Table was used to estimate the energy and nutrient intakes[21].

The development and validation of this FFQ have been described previously[22], and have been used in previous studies[23,24]. The energy-adjusted Pearson correlation coefficients comparing the FFQ and the six 3-d dietary records were 0·25–0·65 for nutrients, 0·30–0·68 for food groups, 0·37 for total vegetables and 0·56 for total fruit. The correlation coefficients for the reproducibility of the FFQ were 0·46–0·71 for nutrients, 0·36–0·66 for food groups, 0·57 for total vegetables and 0·64 for total fruit.

Classification of vegetables and fruit

Vegetables and fruit were classified into colour groups and subgroups (Table 1). First, we categorised the vegetables

Table 1. Classification of vegetables and fruit according to colour groups*

Colour groups	Vegetable and fruit subgroups	Proportion of subgroups to colour group among control subjects (%)	Vegetable and fruit items
Green	Dark green leafy vegetables	51	Leaf mustard, spinach, sprouts and leek
	Lettuces	18	Endive and lettuce
	Green cucumbers	11	Green cucumber
	Kidney beans	9	Green beans
	Cabbages	9	Chinese cabbage and green cabbages
	Green peppers	2	Green pepper
Orange/yellow	Deep orange vegetables and fruit	75	Cantaloupe, carrot, pumpkin, sweet potatoes, maize and mango
	Citrus fruit	25	Citrus fruit, grapefruit, orange and tangerine
Red/purple	Red vegetables	73	Tomatoes
	Berries	27	Grapes, watermelon and strawberries
White	Hard fruit	39	Apple, pear and durian
	Cauliflower	32	Cauliflower, white radish, yam bean and celery
	Banana	18	Banana
	Allium family bulbs	6	Garlic, leek and onion
	Mushrooms	5	Mushrooms and fungi

* Vegetables and fruit were classified into subgroups as recently proposed by Pennington & Fisher[14,15].

and fruit into four groups according to the colour of the primarily edible part: green; orange/yellow; red/purple; white. Secondly, they were subdivided within the four colour groups as recently proposed by Pennington & Fisher[14,15]. The green colour group included dark green leafy vegetables, lettuces, green cucumbers, kidney beans, cabbages and green peppers; the orange/yellow colour group included deep orange vegetables and fruit, and citrus fruit; the red/purple colour group included red vegetables and berries; and the white colour group included hard fruit, cauliflower, banana, allium family bulbs and mushroom. To ensure greater compatibility with our FFQ, we made small adjustments to the classification of the colour groups.

Statistical analyses

All data analyses were carried out using SPSS 17.0 (SPSS, Inc.). The χ^2 test was used to test the difference between cases and controls in terms of categorical variables, and a *t* test or the Wilcoxon signed-rank test was used for continuous variables. Quartiles for each dietary factor were defined based on the distribution among the controls for men and women separately. Unconditional logistic regression models were used to estimate the OR and 95% CI for the associations between vegetable and fruit intake and the risk of colorectal cancer, with the lowest quartile as the reference group. Multivariate-adjusted models included education, marital status, occupation, income, a first-degree relative with cancer, smoking status, passive smoking, alcohol drinking, occupational activity, household and leisure-time activities, BMI, total energy intake, red and processed meat intake, and grain intake based on a comparison of the baseline characteristics of cases and controls. Intakes of vegetable and fruit were adjusted for total energy intake using the residual method[25]. Tests for trend were carried out by entering the categorical variables as continuous variables in multiple regression models. Stratified analyses by sex were conducted for the associations between the intake of each vegetable and fruit colour group and colorectal cancer risk. The interaction between sex and the intake of each colour group in relation to the risk of colorectal cancer was evaluated in multiplicative models by including the product term in multivariate logistic regression. Subgroup analyses by cancer site (colon or rectal cancer) and the source of controls (hospital or community) were also conducted. In addition, because the socio-economic factors of the cases and controls were not well balanced, stratification analyses by socio-economic status (levels of income and education) were performed. In the present study, all *P* values are two-sided, and statistical significance was determined as a *P* value less than 0·05.

Results

Among the 1057 cases, 583 were men and 474 were women; 647 were diagnosed with colon cancer (373 men and 274 women), and 410 were diagnosed with rectal cancer (210 men and 200 women). Among the 647 cases of colon cancer, 265 had proximal colon cancer and 382 had distal colon cancer. Compared with controls, the case subjects had a lower level of education, a lower BMI, a more strenuous occupational activity, a higher household income and fewer smoked (Table 2). They were also more likely to be less physically active, to be exposed to passive smoking and to have a first-degree relative with cancer. No significant differences were found between the case and control subjects in age, residence, marital status or regular drinking.

Compared with controls, cases had lower intakes of various vegetable and fruit colour groups, total vegetables, total fruit and total energy. The intakes of each vegetable and fruit colour subgroup were also significantly lower in cases than in controls, except for cabbage and lettuce (Table 3).

As shown in Table 4, no significant association was found between green vegetable and fruit intake and colorectal cancer risk, with an adjusted OR of 0·91 (95% CI 0·70, 1·18; $P_{trend} = 0·46$). Intakes of orange/yellow, red/purple and white vegetable and fruit colour groups were found to be

Table 2. Sociodemographic characteristics and selected risk factors of colorectal cancer in the study population*

(Mean values and standard deviations; median values and 25th, 75th percentiles)

	Cases (*n* 1057)		Controls (*n* 1057)		
Variables	*n*	%	*n*	%	*P*
Age (years)					0·79
Mean	56·6		56·5		
SD	10·2		10·0		
Sex					1·00
Men	583	55·2	583	55·2	
Women	474	44·8	474	44·8	
Residence					1·00
Rural	352	33·3	352	33·3	
Urban	705	66·7	705	66·7	
Marital status					0·17
Married	1010	95·6	996	94·2	
Unmarried/divorced/widowed	47	4·4	61	5·8	
Education level					< 0·01
Primary school or below	340	32·2	248	23·5	
Junior high school	269	25·4	280	26·5	
Senior high school/secondary technical school	263	24·9	289	27·3	
College or above	185	17·5	240	22·7	
Occupation					0·01
Administrator/other white-collar worker	140	13·2	168	15·9	
Blue-collar worker	195	18·4	239	22·6	
Farmer/other	722	68·3	650	61·5	
Income (yuan/month)					< 0·01
< 2000	138	13·1	155	14·7	
2001–5000	335	31·7	374	35·4	
5001–8000	305	28·9	338	32·0	
> 8001	279	26·4	190	18·0	
Occupational activity					< 0·01
Non-working	500	47·3	584	55·3	
Sedentary	164	15·5	101	9·6	
Light occupation	161	15·2	154	14·6	
Moderate occupation	96	9·1	113	10·7	
Heavy activity occupation	136	12·9	105	9·9	
Household and leisure-time activities (MET-h/week)					< 0·01
Median	29·6		37·0		
25th, 75th percentiles	9·0, 52·5		20·0, 58·5		
Regular smoker	273	25·8	318	30·1	0·03
Passive smoker	679	64·2	504	47·7	< 0·01
Regular drinker	165	15·6	147	13·9	0·27
First-degree relative with cancer	160	15·1	93	8·8	< 0·01
BMI					0·02
Mean	22·9		23·3		
SD	3·4		3·1		

MET, metabolic equivalent task.

* Continuous variables were evaluated using *t* tests or Wilcoxon rank-sum tests. Categorical variables were evaluated using χ^2 tests.

inversely associated with the risk of colorectal cancer. The adjusted OR for the highest *v.* the lowest quartile were 0·16 (95 % CI 0·12, 0·22; $P_{trend} < 0·01$) for orange/yellow vegetables and fruit, 0·23 (95 % CI 0·17, 0·31; $P_{trend} < 0·01$) for red/purple vegetables and fruit and 0·53 (95 % CI 0·40, 0·70; $P_{trend} < 0·01$) for white vegetables and fruit. A strong inverse association was also found between total vegetable and fruit consumption and colorectal cancer risk: the adjusted OR for the highest *v.* the lowest quartile were 0·58 (95 % CI 0·44, 0·76; $P_{trend} < 0·01$) for total vegetables, 0·35 (95 % CI 0·27, 0·47; $P_{trend} < 0·01$) for total fruit and 0·37 (95 % CI 0·28, 0·49; $P_{trend} < 0·01$) for total vegetables and fruit.

In the green colour subgroup, consumption of green cucumbers, kidney beans, cabbage and green peppers was found to be inversely related to colorectal cancer risk, with adjusted OR of 0·47 (95 % CI 0·35, 0·62; $P_{trend} < 0·01$), 0·33 (95 % CI 0·25, 0·44; $P_{trend} < 0·01$), 0·73 (95 % CI 0·56, 0·96; $P_{trend} = 0·02$) and 0·23 (95 % CI 0·17, 0·31; $P_{trend} < 0·01$), respectively. In the orange/yellow colour subgroup, high intakes of deep orange vegetables and fruit and citrus fruit were inversely associated with colorectal cancer risk, with adjusted OR of 0·25 (95 % CI 0·18, 0·33; $P_{trend} < 0·01$) and 0·37 (95 % CI 0·28, 0·49; $P_{trend} < 0·01$), respectively. In the red/purple colour subgroup, the adjusted OR for the highest *v.* the lowest quartile were 0·33 (95 % CI 0·25, 0·44; $P_{trend} < 0·01$) for red vegetables and 0·29 (95 % CI 0·22, 0·39; $P_{trend} < 0·01$) for berries. In the white colour subgroup, consumption of cauliflower (OR 0·63, 95 % CI 0·48, 0·84;

Table 3. Intake of vegetables and fruit between cases and controls*
(Mean values; median values and 25th, 75th percentiles)

	Cases			Controls			
	Mean	Median	25th, 75th percentiles	Mean	Median	25th, 75th percentiles	*P*
Energy (kJ/d)	6577	6305	5092, 7785	7308	6931	5659, 8484	<0·01
Green (g/d)	292·3	271·4	187·8, 372·3	308·4	287·8	190·0, 392·3	0·04
Orange/yellow (g/d)	54·1	43·3	24·7, 69·9	94·8	71·8	41·4, 123·2	<0·01
Red/purple (g/d)	31·6	21·4	10·5, 40·0	61·1	41·4	22·3, 70·7	<0·01
White (g/d)	126·9	108·3	64·1, 167·6	165·3	134·5	83·6, 211·5	<0·01
Total vegetable (g/d)	388·8	360·5	264·7, 483·3	451·9	416·1	295·8, 561·0	<0·01
Total fruit (g/d)	116·0	91·8	48·7, 158·8	177·6	140·4	76·7, 228·4	<0·01
Total vegetable and fruit (g/d)	504·8	475·3	353·0, 621·3	629·5	568·6	425·1, 784·2	<0·01
Dark green leafy vegetable (g/d)	165·3	152·4	97·2, 215·2	158·2	141·6	90·9, 206·0	0·03
Lettuce (g/d)	57·7	51·2	30·7, 76·8	56·2	48·3	24·1, 72·4	0·07
Green cucumbers (g/d)	24·7	19·2	11·5, 32·0	33·7	23·3	12·1, 44·4	<0·01
Kidney beans (g/d)	17·1	12·8	6·0, 23·0	27·0	17·8	8·4, 33·0	<0·01
Cabbage (g/d)	24·2	17·9	7·2, 31·5	26·2	18·3	8·3, 35·6	0·21
Green peppers (g/d)	3·3	0·0	0·0, 1·2	7·1	1·1	0·0, 6·7	0·02
Deep orange vegetables and fruit (g/d)	41·1	31·7	16·7, 53·8	70·8	51·0	29·0, 92·7	<0·01
Citrus fruit (g/d)	12·9	6·8	3·4, 15·8	24·0	13·2	5·5, 29·6	<0·01
Red vegetables (g/d)	23·1	14·4	7·5, 27·9	44·8	27·9	14·3, 49·3	<0·01
Berries (g/d)	8·5	3·4	0·3, 10·4	16·3	8·2	3·3, 17·7	<0·01
Hard fruit (g/d)	52·6	35·2	13·3, 71·4	64·2	41·1	16·6, 85·7	<0·01
Cauliflower (g/d)	45·1	37·1	19·9, 59·8	53·2	39·0	18·7, 72·1	0·02
Banana (g/d)	18·5	10·0	4·1, 21·4	30·0	13·7	4·5, 32·9	<0·01
Allium family bulbs (g/d)	3·4	0·0	0·0, 2·5	9·7	3·8	0·1, 8·5	<0·01
Mushroom (g/d)	6·5	4·2	1·7, 8·3	8·5	5·0	1·5, 12·9	<0·01
Red and processed meat (g/d)	122·0	107·1	73·2, 154·1	110·1	94·9	59·0, 146·1	<0·01
Grains (g/d)	314·5	297·2	236·2, 381·3	343·6	324·5	248·5, 418·4	<0·01

* Wilcoxon rank-sum test comparing the median consumption levels between cases and controls.

$P_{trend} < 0·01$), bananas (OR 0·72, 95 % CI 0·55, 0·95; $P_{trend} = 0·02$), allium family bulbs (OR 0·30, 95 % CI 0·23, 0·40; $P_{trend} < 0·01$) and mushroom (OR 0·58, 95 % CI 0·43, 0·77; $P_{trend} < 0·01$) were also related to a decreased risk of colorectal cancer. No significant association was found between the intakes of other vegetable and fruit subgroups and the risk of colorectal cancer. The adjusted OR for the highest *v.* the lowest quartile were 0·95 (95 % CI 0·73, 1·24; $P_{trend} = 0·73$) for dark green leafy vegetables, 1·06 (95 % CI 0·82, 1·38; $P_{trend} = 0·66$) for lettuce and 0·93 (95 % CI 0·71, 1·21; $P_{trend} = 0·57$) for hard fruit.

The interaction between green, orange/yellow and white vegetable and fruit intake and sex in the risk of colorectal cancer was significant ($P_{interaction} < 0·01$ for green, $P_{interaction} = 0·02$ for orange/yellow and $P_{interaction} = 0·03$ for white). Stratified analyses by sex showed that a high intake of green vegetables and fruit was inversely associated with colorectal cancer risk among men but not among women. The adjusted OR were 0·58 (95 % CI 0·39, 0·86; $P_{trend} = 0·01$) in men and 1·34 (95 % CI 0·91, 1·99; $P_{trend} = 0·14$) in women when the highest and lowest quartiles of green vegetables and fruit were compared. The inverse associations between orange/yellow, red/purple and white vegetables and fruit intake and colorectal cancer risk were observed in both men and women (Table 5).

Subgroup analysis by cancer site showed that the protective effect of orange/yellow, red/purple and white vegetables and fruit was active in both colon and rectal cancers. However, green vegetables and fruit were found to be inversely associated with rectal cancer but not with colon cancer, with adjusted OR of 0·67 (95 % CI 0·48, 0·95; $P_{trend} = 0·02$) for rectal cancer and 1·09 (95 % CI 0·80, 1·49; $P_{trend} = 0·57$) for colon cancer (online supplementary Table S1). The inverse association between orange/yellow, red/purple and white vegetable and fruit intake and colorectal cancer risk was observed among populations with different socio-economic status (data not shown), and proximal or distal colon cancer (online supplementary Table S2). We further carried out subgroup analyses of the association between the intake of each vegetables and fruit colour group and colorectal cancer risk according to the source of the control participants. The observed inverse associations between orange/yellow, red/purple and white vegetables and fruit intakes and colorectal cancer risk did not differ by source (data not shown).

Discussion

The present study focused on the relationship between four vegetable and fruit colour groups and the risk of colorectal cancer. The results suggested that intakes of orange/yellow, red/purple and white vegetable and fruit colour groups were inversely associated with colorectal cancer risk and were consistent across the sources of controls and socio-economic status. No statistically significant association was found between the intake of green vegetables and fruit and the risk of colorectal cancer.

In the present study, we found no evidence for a protective effect of green vegetable and fruit intake on the risk of

Table 4. OR of colorectal cancer according to quartiles (Q) of vegetable and fruit colour group intake
(Odds ratios and 95 % confidence intervals)

	Q1	Q2		Q3		Q4		
	OR	OR	95 % CI	OR	95 % CI	OR	95 % CI	P_{trend}
Green								
Median intake (g/d)								
Male	154·50	253·52		348·41		498·56		
Female	136·79	214·18		315·85		456·03		
No. of cases	261	278		245		273		
No. of controls	264	265		265		263		
Crude	1·00	1·06	0·84, 1·35	0·94	0·73, 1·19	1·05	0·83, 1·34	0·69
Adjusted*	1·00	1·08	0·83, 1·39	0·86	0·66, 1·12	0·91	0·70, 1·18	0·46
Orange/yellow								
Median intake (g/d)								
Male	28·49	58·32		99·11		184·93		
Female	27·50	50·96		83·25		155·60		
No. of cases	478	316		183		80		
No. of controls	263	266		265		263		
Crude	1·00	0·65	0·52, 0·82	0·38	0·30, 0·48	0·17	0·13, 0·22	<0·01
Adjusted*	1·00	0·60	0·48, 0·77	0·35	0·27, 0·46	0·16	0·12, 0·22	<0·01
Red/purple								
Median intake (g/d)								
Male	14·04	32·05		50·64		110·68		
Female	11·43	29·05		47·12		92·74		
No. of cases	487	261		188		121		
No. of controls	264	265		265		263		
Crude	1·00	0·53	0·43, 0·67	0·39	0·30, 0·49	0·25	0·19, 0·32	<0·01
Adjusted*	1·00	0·49	0·38, 0·62	0·36	0·28, 0·47	0·23	0·17, 0·31	<0·01
White								
Median intake (g/d)								
Male	50·25	98·00		150·45		276·89		
Female	63·51	114·23		173·78		290·82		
No. of cases	375	249		239		194		
No. of controls	263	266		265		263		
Crude	1·00	0·66	0·52, 0·83	0·63	0·50, 0·80	0·52	0·41, 0·66	<0·01
Adjusted*	1·00	0·65	0·51, 0·84	0·64	0·50, 0·83	0·53	0·40, 0·70	<0·01
Total vegetables								
Median intake (g/d)								
Male	241·36	357·72		485·21		697·23		
Female	221·52	337·59		464·23		641·10		
No. of cases	319	288		249		201		
No. of controls	263	266		264		264		
Crude	1·00	0·89	0·71, 1·13	0·78	0·61, 0·99	0·63	0·49, 0·80	<0·01
Adjusted*	1·00	0·91	0·71, 1·17	0·71	0·55, 0·92	0·58	0·44, 0·76	<0·01
Total fruit								
Median intake (g/d)								
Male	53·29	106·44		164·38		296·85		
Female	43·01	109·77		167·50		291·62		
No. of cases	437	243		218		159		
No. of controls	264	264		266		263		
Crude	1·00	0·56	0·44, 0·70	0·50	0·39, 0·63	0·37	0·29, 0·47	<0·01
Adjusted*	1·00	0·56	0·44, 0·72	0·50	0·39, 0·65	0·35	0·27, 0·47	<0·01
Total vegetables and fruit								
Median intake (g/d)								
Male	348·49	490·05		651·31		967·63		
Female	337·34	480·33		614·32		892·30		
No. of cases	380	280		243		154		
No. of controls	263	266		265		263		
Crude	1·00	0·73	0·58, 0·92	0·64	0·50, 0·80	0·41	0·32, 0·52	<0·01
Adjusted*	1·00	0·68	0·53, 0·87	0·58	0·44, 0·74	0·37	0·28, 0·49	<0·01

* OR adjusted for education, marital status, occupation, income, a first degree relative with cancer, smoking status, passive smoking, alcohol drinking, occupational activity, household and leisure-time activities, BMI, total energy intake, red and processed meat intake and grains intake.

colorectal cancer. Dark green leafy vegetables were the primary source (51 %) and lettuce was the secondary source (18 %) of green vegetables and fruit in the present study population. In the analysis of colour subgroups, intakes of dark green leafy vegetables and lettuce were also not significantly related to the risk of colorectal cancer. No study concerning the relationship between the intake of green vegetable and fruit colour groups and colorectal cancer risk has been conducted previously. However, a number of studies have examined the effect of dark green leafy vegetable intake on

Table 5. OR of colorectal cancer according to quartiles (Q) of vegetable and fruit colour group intake stratified by sex
(Odds ratios and 95 % confidence intervals)

	Men								Women*								
	Q1	Q2		Q3		Q4			Q1	Q2		Q3		Q4			
	OR	OR	95 % CI	OR	95 % CI	OR	95 % CI	P_{trend}	OR	OR	95 % CI	OR	95 % CI	OR	95 % CI	P_{trend}	$P_{interaction}$
Green																	
No. of cases	168	163		119		133			93	115		126		140			
No. of controls	146	146		146		145			118	119		119		118			
Crude	1·00	0·97	0·71, 1·33	0·71	0·51, 0·98	0·80	0·58, 1·10	0·17	1·00	1·23	0·84, 1·78	1·34	0·93, 1·94	1·51	1·04, 2·17	0·03	
Adjusted†	1·00	1·03	0·70, 1·50	0·57	0·39, 0·86	0·58	0·39, 0·86	0·01	1·00	1·30	0·87, 1·92	1·34	0·91, 1·99	1·34	0·91, 1·99	0·14	< 0·01
Orange/yellow																	
No. of cases	283	182		78		40			195	134		105		40			
No. of controls	145	147		146		145			118	119		119		118			
Crude	1·00	0·63	0·47, 0·85	0·27	0·20, 0·39	0·14	0·09, 0·21	< 0·01	1·00	0·68	0·49, 0·95	0·53	0·38, 0·76	0·21	0·13, 0·31	< 0·01	
Adjusted†	1·00	0·57	0·40, 0·81	0·23	0·15, 0·34	0·10	0·06, 0·16	< 0·01	1·00	0·64	0·45, 0·92	0·54	0·37, 0·78	0·21	0·13, 0·33	< 0·01	0·02
Red/purple																	
No. of cases	270	143		101		69			217	118		87		52			
No. of controls	146	146		146		145			118	119		119		118			
Crude	1·00	0·53	0·39, 0·72	0·37	0·27, 0·52	0·26	0·18, 0·37	< 0·01	1·00	0·54	0·38, 0·76	0·40	0·28, 0·57	0·24	0·16, 0·36	< 0·01	
Adjusted†	1·00	0·50	0·34, 0·72	0·29	0·19, 0·43	0·18	0·12, 0·29	< 0·01	1·00	0·50	0·35, 0·72	0·40	0·28, 0·60	0·23	0·15, 0·36	< 0·01	0·96
White																	
No. of cases	185	143		132		123			190	106		107		71			
No. of controls	145	147		146		145			118	119		119		118			
Crude	1·00	0·76	0·56, 1·05	0·71	0·51, 0·98	0·67	0·48, 0·92	0·01	1·00	0·56	0·39, 0·78	0·56	0·39, 0·79	0·37	0·26, 0·54	< 0·01	
Adjusted†	1·00	0·68	0·47, 0·99	0·64	0·43, 0·95	0·60	0·40, 0·89	0·01	1·00	0·53	0·37, 0·78	0·57	0·39, 0·84	0·33	0·22, 0·51	< 0·01	0·03

* OR adjusted for the various confounders mentioned above and menopausal status in women.
† OR adjusted for age, residence, education, marital status, occupation, income, a first-degree relative with cancer, smoking status, passive smoking, alcohol drinking, occupational activity, household and leisure-time activities, BMI, total energy intake, red and processed meat intake, and grains intake.

the risk of colorectal cancer[8,17,26–29]. With the exception of one[17], most of these studies[8,26–29] have not observed significant associations between the intake of dark green leafy vegetables and the risk of colorectal cancer, which was consistent with the present study. Although we observed that high intakes of green cucumbers (11 %), kidney beans (9 %) and green peppers (2 %) were inversely associated with colorectal cancer risk, their median intakes were 34, 27 and 7 g/d, respectively. The level of intake of these vegetables and fruit was much lower than that of dark green leafy vegetables (158 g/d) and lettuce (56 g/d). Therefore, any protective effect that they might have contributed little to the overall effect of the green vegetable and fruit colour group.

Although no previous studies have examined the association of the intake of the orange/yellow vegetable and fruit colour group with the risk of colorectal cancer, a population-based case–control study conducted in Hawaii has shown that the intake of orange/yellow vegetables was significantly associated with a reduced risk of colorectal cancer (OR 0·6, 95 % CI 0·4, 0·9; $P_{trend} = 0{\cdot}04$ for men; and OR 0·6, 95 % CI 0·3, 0·9; $P_{trend} = 0{\cdot}08$ for women)[30]. Similar results were observed in a case–control study conducted in Western Australia, which found that the risk of distal colon cancer was significantly decreased for the intake of carrots and pumpkins (OR 0·61, 95 % CI 0·41, 0·92; $P_{trend} = 0{\cdot}02$)[29]. One study conducted in Switzerland has also reported that citrus fruit intake was inversely associated with colorectal cancer risk (OR 0·86, 95 % CI 0·78, 0·96)[16], although other studies have not found any significant associations[17,26,29]. In the present study, the intake of deep orange vegetables and fruit, the primary source of orange/yellow vegetables and fruit (75 %), and citrus fruit, a subgroup of orange/yellow vegetables and fruit (25 %), was found to be inversely associated with colorectal cancer risk, suggesting that the lower risk of colorectal cancer associated with orange/yellow vegetable and fruit intake could be due to the protective effect of deep orange vegetables and fruit and citrus fruit. Orange/yellow vegetables and fruit mainly contain carotene, which may help to protect cellular systems from oxidative damage and also may lower the risk of cancer[31]. Moreover, orange/yellow vegetables and fruit are known for their high content of vitamin C, which is an antioxidant and may protect cell membranes and DNA from oxidative damage[32].

Red/purple vegetable and fruit intake was inversely associated with the risk of colorectal cancer risk in the present study. Red vegetables, the primary source of red/purple vegetables and fruit (73 %), including tomatoes, were found to be inversely associated with the colorectal cancer risk. Consumption of berries (27 %), cherries, grapes and watermelon was also inversely associated with colorectal cancer risk. Some previous studies have focused on the anticancer effects of specific red/purple vegetables and fruit[17,26,29,33]. In agreement with the present study, a cohort study conducted in Shanghai observed that watermelon intake was inversely associated with the risk of colorectal cancer (relative risk 0·77, 95 % CI 0·59, 0·99; $P_{trend} = 0{\cdot}04$)[26]. However, two studies conducted in the USA and Australia did not detect any significant associations between the intake of tomatoes and the risk of colorectal cancer[17,29]. The protective effect of red/purple vegetables and fruit might be because berries, especially grapes, are rich in flavonoids, such as catechins, resveratrol and anthocyanin, which may act through antioxidant, pro-oxidant, anti-oestrogenic and cell signalling pathways, modulation or mitochondrial toxicity to inhibit carcinogenesis[34]. Red vegetables, including tomatoes, are a source of lycopene, which has been reported to be inversely associated with the risk of colorectal cancer[35].

The present study also suggested that a high consumption of white vegetables and fruit protected against the risk of colorectal cancer. However, hard fruit, a major source of white vegetables and fruit (39 %), was not found to be significantly associated with colorectal cancer risk. Similar findings were reported in a prospective cohort study conducted in the Netherlands[11]. Among other white vegetables and fruit, consumption of cauliflower (32 %), bananas (18 %), allium family bulbs (6 %) and mushrooms (5 %) was found to be inversely related to the risk of colorectal cancer. Consistent with the present result, a meta-analysis conducted in 2000 pointed out that a high intake of garlic was associated with a low risk of colorectal cancer, with a relative risk of 0·69 (95 % CI 0·55, 0·89)[36]. The median intakes of cauliflower, bananas, allium family bulbs and mushrooms were 53, 30, 10 and 9 g/d, respectively, the sum of which was much greater than the intake of hard fruit (64 g/d). Thus, the protective effect of white vegetables and fruit might result from the influence of cauliflower, banana, allium family bulbs and mushrooms. The mechanism of the protective effect of white vegetables and fruit may be that allium vegetables contain allyl sulphur compounds, which may interrupt the growth of abnormal cells[37]. Mushrooms are a source of several bioactive compounds, such as polysaccharides, which have anti-tumour and immunomodulating functions[38].

The protective effect of total vegetable and fruit intake on the risk of colorectal cancer observed in the present study was in agreement with most previous case–control studies conducted in other countries[2–5]. A meta-analysis of twenty-eight case–control studies conducted in 2003 has reported that the estimated OR for colorectal cancer is 13 % lower with an increase in vegetable intake of 100 g/d and 7 % lower with an increase in fruit intake of 100 g/d[39]. However, the individual cohort studies[6–11] may have had insufficient power to detect a relatively weaker or more modest association than that observed in the meta-analysis from 2011[40]. This meta-analysis included fifteen prospective cohort studies and showed that the summary relative risk for the highest *v.* the lowest intake was 0·91 (95 % CI 0·86, 0·96) for vegetables, 0·90 (95 % CI 0·83, 0·98) for fruit and 0·92 (95 % CI 0·86, 0·99) for a combination of vegetables and fruit [40]. The possible explanation for these inconsistent results may be that the levels and ranges of vegetable and fruit intake differed between various populations.

Stratified analyses by sex showed that the inverse associations between the intake of orange/yellow, red/purple and white vegetables and fruit and colorectal cancer risk were valid in both men and women. However, the intake of green vegetables and fruit was inversely associated with colorectal cancer risk among men but not among women. A cohort study carried out in America has observed that consumption of dark green leafy vegetables, a major contributor to the intake of green vegetables and fruit, is associated with a lower risk of colorectal cancer only for men[17]. This sex difference may be partially explained by sex differences in the composition of bile acids in human subjects[41]. The exact mechanism of this sex difference is unclear; however, it has been suggested that green vegetables and fruit are good sources of fibre and that dietary fibre intake is more protective against colorectal neoplasia in men than in women[42]. However, because this was a stratified analysis, chance findings might arise. More studies with a larger sample size might be needed to confirm this association.

Subgroup analysis by cancer site showed that the protective effects of orange/yellow, red/purple and white vegetable and fruit colour groups were consistent across colon and rectal cancers. However, the green vegetable and fruit colour group was found to be inversely associated with rectal cancer but not with colon cancer. The mechanisms for the different effects of green vegetables and fruit on different sites of the large bowel have not yet been determined. Green vegetables and fruit are rich in dietary fibre[14]. Some studies have suggested that the fibre content of green vegetables and fruit dilutes carcinogens and decreases transit time in the bowel[11]. Therefore, if the effect was due to decreased transit time, this would suggest that the protective effect of green vegetables and fruit on the rectum would be even stronger than that on the colon[29].

The present study had some methodological strengths. A validated FFQ was used to assess the frequency and portion size of vegetable and fruit intake. Information on a wide range of potential confounders was available, including dietary and non-dietary factors, and these could be adjusted for in the analyses. In addition, this was the first epidemiological study to investigate the relationship between the intake of vegetable and fruit colour groups and the risk of colorectal cancer, which could be used to translate the science of nutrition into dietary guidelines for the public.

The present study also had some limitations. First, case–control studies are prone to selection bias. To minimise this bias, we tried to recruit controls from different departments of three general hospitals with ailments that had no apparent association with dietary issues. Although the cases and controls recruited from the university hospitals might have a relatively higher socio-economic status, stratified analyses showed that the inverse association between the intake of orange/yellow, red/purple and white vegetables and fruit and the risk of colorectal cancer existed among populations of different socio-economic status. Moreover, similar results in the controls from different sources suggested that their selection did not affect the results. In addition, the high participation rates (90 and 87 % for cases and hospital-derived controls, respectively) indicated that the probability of selection bias should have been reduced in the present study. Secondly, recall bias is also of concern in case–control studies. Participants can recall dietary practices in different ways. The control subjects did not have a malignant ailment and might have recalled their dietary intake differently from the cases. The awareness of the colorectal cancer patients of their own diagnosis might have led them to change their lifestyle consciously to improve their health and well-being. To reduce this bias, we tried to interview the cases as soon as the diagnosis was made. The average time interval between their diagnosis of colorectal cancer and the study interview was 11·0 d. A standardised questionnaire interview method was also used to improve the comparability of recall between cases and controls. Moreover, food photographs referencing the portion sizes were provided as visual aids to reduce recall bias to a minimum in the present study. Thirdly, random measurement error of diet is inevitable, and non-differential misclassification among the cases and controls would tend to attenuate any association between diet intake and the risk of colorectal cancer. Fourthly, the subgroup analyses performed in the present study may have produced chance findings, because they involved additional comparisons. Fifthly, although we adjusted for several potential confounders, residual confounding bias may have occurred because of unmeasured or poorly measured variables.

In summary, the present study showed that consumption of orange/yellow, red/purple and white vegetable and fruit colour groups was inversely associated with the risk of colorectal cancer in a Chinese population.

Supplementary material

To view supplementary material for this article, please visit http://dx.doi.org/10.1017/S0007114515000331

Acknowledgements

The authors gratefully acknowledge the participation of the study subjects, without whom the study would not be possible.

The present study was supported by the Sun Yat-sen University Hundred Talents Program (No. 51000-3181301). The funders had no role in the design and analysis of the study or in the writing of this article.

The authors' contributions are as follows: W.-P. L. conducted the data collection, analysed the data and wrote the paper; Y.-J. F. was responsible for connecting and coordinating the field work; M.-S. L. and X. Z. participated in the data collection; Y.-M. C. provided significant advice regarding the analyses and interpretation of the data; C.-X. Z. constructed the project design, supervised the study and contributed to the writing of the manuscript.

The authors declare that they have no conflicts of interest.

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