Report of the Second Hong Kong Total Diet Study: Nitrate and nitrite

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Executive Summary
The Second Hong Kong Total Diet Study: Nitrate and nitrite

The Centre for Food Safety is conducting the Second Hong Kong Total Diet Study (2nd HKTDS) to estimate the latest dietary exposure of the Hong Kong population and various population subgroups to a range of chemical substances of potential food safety concern, and to assess the associated health risks. This report presents an analysis of nitrate and nitrite levels, and the results of dietary exposure assessment of nitrate and nitrite from all food sources.

2. Nitrate and nitrite are part of the nitrogen cycle, and are ubiquitous in the environment including the soil, water, and air. Nitrate plays an important role in plant nutrition and function, and is found naturally in plant-based foods with a wide range of concentrations, with the highest concentrations typically found in leafy vegetables. Nitrate and nitrite are also produced endogenously in animals and humans. As food additives, nitrate and nitrite (in the form of sodium or potassium salts), are used as preservative and colour retention agent in specified food products such as cured meats and certain cheeses. Human exposure to nitrate is mainly through the consumption of vegetables and, to a lesser extent water and other foods, while exposure to nitrite is mostly from endogenous conversion from nitrate.

3. Nitrate itself is relatively non-toxic, but it can be converted to nitrite by bacteria in the mouth, which can oxidise haemoglobin to methaemoglobin in the blood and render it unable to carry oxygen inside the human body. Nitrite may also contribute to the formation of a group of compounds known as N-nitroso compounds, some of which are carcinogenic. However, it is important to note that when nitrate is consumed as part of a normal diet rich in vegetables, other

bioactive substances in vegetables, such as vitamin C, may inhibit the endogenous formation of N-nitroso compounds.

4. In an evaluation conducted by the European Food Safety Authority (EFSA) in 2017, the Panel on Food Additives and Nutrient Sources Added to Food (EFSA Panel) derived an alternative range of acceptable daily intake (ADI) values [*] estimated for nitrate as between 1.05 and 9.4 mg/kg body weight (bw)/day (expressed as nitrate ion), based on elevated blood concentrations of methaemoglobin caused by nitrite converted from nitrate in human saliva. For nitrite, the ADI established by the Joint Food and Agriculture Organization of the United Nations / World Health Organization Expert Committee on Food Additives (JECFA) and EFSA in 2002 and 2017, respectively, is the same (between 0 and 0.07 mg/kg bw/day, expressed as nitrite ion).

Results

5. Out of the 187 TDS food items tested, nitrate was detected in the vast majority (97%) of TDS food items. Among all TDS food groups, "Vegetables and their products" had the highest mean concentration of nitrate (690-690 mg/kg) (lower bound-upper bound (LB-UB)). For the average consumers of the adult and younger populations, the vast majority of dietary sources of nitrate came from the food group "Vegetables and their products", contributing to 91% and 87% of the total dietary exposure to nitrate, respectively. Leafy vegetables alone contributed to 70-80% of the total daily nitrate exposure. For the adult population, the estimated dietary exposure to nitrate was 3.8-3.8 mg/kg bw/day (LB-UB) for the average consumers and 8.0-8.0 mg/kg bw/day (LB-UB) for the high consumers (90th percentile). For the younger population, the estimated

[*] Considering there were large variations in the data on the nitrate-to-nitrite conversion rate in the saliva in humans, the EFSA Panel considered that it was not possible to derive a single value of ADI for nitrate from the available data, and in turn estimated a range of ADI values for nitrate.

dietary exposure to nitrate was 4.1-4.1 mg/kg bw/day (LB-UB) for the average consumers and 8.9-8.9 mg/kg bw/day (LB-UB) for the high consumers.

6. Regarding nitrite, it was only detected in 59 out of the 187 TDS food items tested (32%). The TDS food items detected with relatively highest mean concentration of nitrite, in descending order, were green string beans (with pod) (12 mg/kg), fruit and/or vegetable juice (9.9 mg/kg), turnip cake (8.2 mg/kg), Chinese kale (6.8 mg/kg), European variety cabbage (6.7 mg/kg) and watermelon (6.4 mg/kg). For the adult population, the estimated dietary exposure to nitrite was 0.014-0.018 mg/kg bw/day (LB-UB) for the average consumers and 0.025-0.029 mg/kg bw/day (LB-UB) for the high consumers. For the younger population, the estimated dietary exposure to nitrite was 0.019-0.025 mg/kg bw/day (LB-UB) for the average consumers and 0.038-0.045 mg/kg bw/day (LB-UB) for the high consumers.

Conclusion and Recommendations

7. The dietary nitrate exposure estimates of the average and high consumers of the overall adult and younger populations fell within the alternative range of ADI values estimated for nitrate as derived by the EFSA Panel in 2017, indicating the general population is unlikely to experience any immediate health risk. For nitrite, the dietary nitrite exposure estimates of the average and high consumers of the overall adult and younger populations were below the ADI established by JECFA and EFSA, indicating a low health risk.

8. Vegetables are important components of a healthy diet, and there is convincing evidence that their consumption has strong beneficial effects against chronic diseases and cancers. On the other hand, inadequate consumption of vegetables is linked to poor health and increased risk of non-communicable diseases.

9. To maximise the health benefits from vegetable consumption, members of the public are advised to maintain a balanced diet and consume the recommended daily intake of vegetables[†]. They are advised to incorporate a greater variety of vegetables into their diet, such as to consume more flowerhead brassica vegetables (e.g. broccoli, cauliflower), fruiting vegetables (e.g. eggplant, tomato, cucumber, pumpkin), mushrooms and fungus. Additionally, using appropriate preparation methods can further reduce nitrate levels in vegetables. These methods include thorough washing, peeling as appropriate, and boiling vegetables in water instead of stir-frying. Besides, vegetables should be stored properly (e.g. keep under refrigeration if they are not consumed or sold immediately) to prolong freshness and minimise nitrite formation.

[†] The Department of Health recommends a daily intake of at least 3 servings of vegetables and 2 servings of fruits (about 80 grams per serving leading to a minimum of 400 grams of vegetables and fruits every day, which is in line with the recommendation of the World Health Organization).

Chapter 1
Background

1.1 Total Diet Study (TDS) is a tool for estimating population chronic dietary exposure to a wide range of chemicals across the whole diet within one study, which is an internationally well-recognised approach for quantifying the presence of chemical substances in the food supply and for estimating dietary exposure. The Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) have been promoting and supporting the TDS approach since the 1970's. The Centre for Food Safety (CFS) conducted the First Hong Kong Total Diet Study (1st HKTDS) in 2010-2014.[1]

Introduction of the Second Hong Kong Total Diet Study (2nd HKTDS)

1.2 With the availability of an updated set of food consumption data as obtained from the Second Population-based Food Consumption Survey (2nd FCS) (2018-2020), the CFS has taken the opportunity to conduct the Second Hong Kong Total Diet Study (2nd HKTDS). The 2nd HKTDS aims to estimate the latest dietary exposure of the Hong Kong population and various population subgroups to a range of chemical substances of potential food safety concern, and assess the associated health risks.

1.3 Similar to the 1st HKTDS, the 2nd HKTDS comprises selection of chemical substances, development of a TDS food list, food sampling, sample preparation, laboratory analysis, dietary exposure estimation and publication of results. The 2nd HKTDS covers the majority of foods normally consumed by the Hong Kong population, with laboratory analysis conducted for over 130 chemical substances in total, covering mainly contaminants and pesticide residues in food and for the first time, some food additives of local concern.

Food Additives in the 2nd HKTDS

1.4 Food additive means any substance not normally consumed as a food by itself and not normally used as a typical ingredient of the food, whether or not it has nutritive value. The intentional addition of this substance to food is to achieve a technological purpose in the manufacture, processing, preparation, treatment, packing, packaging, transport or holding of such food which results, or may be reasonably expected to result, in it or its by-products becoming a component of or otherwise affecting the characteristics of such foods.[2] With the globalization of trade and the advent of food processing, the application of food additives plays an important role in providing a variety of safe and wholesome foods from different parts of the world to meet the consumers' need. There are many types of food additives in use, with various technological functions, some examples include emulsifiers, stabilizers, thickeners, acidity regulators, preservatives, antioxidants, colours and colour retention agents.

1.5 In the 2nd HKTDS, two groups of food additives, namely, sulphites and nitrate/nitrite, have been included as selected chemical substances. This report focuses on the dietary exposure assessment of nitrate and nitrite, in which all dietary sources (including non-additive sources and their use as food additives) are considered.

Nitrate and Nitrite

<u>Previous studies conducted by the CFS</u>

1.6 The CFS conducted a risk assessment study on "Nitrate and nitrite in vegetables available in Hong Kong" in 2008-09, analysing a wide variety of fresh vegetables in their "as purchased" status to determine their nitrate and nitrite concentrations. The study revealed a large variation in the nitrate levels across different types of vegetables, with mean levels ranging from 5-4800 mg/kg (middle-bound). In contrast, the nitrite concentrations of the vegetable samples were generally low, with less than 1 mg/kg on average (middle-bound). While the study included a dietary exposure assessment for nitrate and nitrite, the estimation was limited to vegetable consumption only.[3]

1.7 In addition, the CFS conducted another risk assessment study on "Changes of nitrate and nitrite levels in cooked vegetables during storage" in 2021 to address public and local media concerns on the changes in the levels of nitrate and nitrite of leftover cooked vegetables stored overnight. This study focused on analytical measurement of nitrate and nitrite but did not include dietary exposure assessment.[4]

1.8 Prior to this study, no comprehensive dietary exposure assessment for nitrate and nitrite had been conducted in Hong Kong. The results of this study can address this data gap.

<u>Sources of and exposure to nitrate and nitrite</u>

1.9 Nitrate and nitrite are part of the nitrogen cycle, and are ubiquitous in the environment including the soil, water, and air. Moreover, nitrate and nitrite can enter the environment through agricultural activities (nitrogen fertilizers and manure), wastewater treatment, nitrogenous waste products from humans and discharges from industrial processes and motor vehicles.[5] Nitrate plays an important role in the nutrition and function of plants. It is found naturally in plant foods, with a wide range of reported concentrations and the highest concentrations have been noted in leafy vegetables.[6] Nitrate and nitrite are also produced endogenously in animals and humans. As sodium or potassium salts, nitrate and nitrite have been used as food additives, primarily as preservative and colour retention agent in specified food products such as cured meats and certain cheeses. Human exposure to nitrate occurs mainly through the consumption of vegetables and to a lesser extent, water and other foods, whereas exposure to nitrite is largely from endogenous conversion from nitrate.

Regulatory control on the use of nitrate and nitrite in foods

1.10 Humans have a long history of using nitrite and nitrate in curing meats. In this process, nitrite is considered the principal food additive responsible for imparting the characteristic red colouration in cured meats, creating a unique flavour profile, controlling lipid oxidation, and serving as an effective antimicrobial agent particularly in inhibiting the growth of *Clostridium botulinum*.[7] The use of nitrate in cured meats serves mainly as a reservoir for nitrite production to achieve the above-mentioned technological functions.[8]

1.11 As stipulated in the Preservatives in Food Regulation (Cap. 132BD), maximum permitted levels for nitrate and nitrite are established in specified foods, including certain cheeses, processed meat and poultry products.[9]

Health effects of nitrate and nitrite

Kinetics and metabolism

1.12 Nitrate is primarily absorbed from the upper part of the human digestive tract, and absorption occurs rapidly. Approximately 20-25% of ingested nitrate is secreted in the saliva and about 5-36% of the secreted saliva nitrate is converted to nitrite by commensal bacteria on the surface of the tongue. Consequently, the overall conversion of nitrate to nitrite is estimated at a range between 1% and 9%.[8] Oral reduction of nitrate represents the most important source of nitrite for humans, accounting for approximately 70-80% of total human nitrite exposure. Most of the absorbed nitrate is ultimately excreted in the urine.[6, 8]

1.13 After nitrite is transported to the stomach, the acidic conditions rapidly transform it into nitrous acid, which spontaneously decomposes into nitrogen oxides. A low pH (i.e. pH 1-2) in the fasting stomach is considered too low for bacterial nitrate reduction. However, infants younger than 3 months are highly susceptible to gastric bacterial nitrate reduction due to their limited production of gastric acid.[6]

Toxicity

Methaemoglobinaemia

1.14 Nitrate itself is relatively non-toxic, but it can be converted to nitrite as mentioned in paragraph 1.12 above. Absorbed nitrite can oxidise haemoglobin to methaemoglobin (metHb) in the blood, rendering it incapable of carrying oxygen within the human body. This medical condition is known as methaemoglobinaemia. Infants younger than 3 months of age are particularly susceptible to methaemoglobinaemia.[6]

1.15 The Joint Food and Agriculture Organization of the United Nations (FAO) / World Health Organization (WHO) Expert Committee on Food Additives (JECFA) has not established an acute reference dose for nitrate or nitrite that causes methaemoglobinaemia. Nevertheless, according to the assessment conducted by the Food Standards Australia New Zealand (FSANZ) in 2011, exposure to up to 15 mg/kg bw/day sodium nitrate (equivalent to 10.95 mg/kg bw/day, expressed as nitrate ion) or 0.75 mg/kg bw/day of sodium nitrite (equivalent to 0.5025 mg/kg bw/day, expressed as nitrite ion) was not associated with elevated MetHb in the blood of adults, children, or infants in experimental and drinking water studies.[10]

Chronic toxicity

1.16 In a 2-year study, experimental animals (rats) were fed with sodium nitrate, and slight growth depression was observed at a dose equivalent to 5% of the diet.[11] In another 2-year toxicity study, experimental animals (rats) were administered drinking water containing varying amounts of sodium nitrite. The metHb levels in some high dose groups were significantly elevated throughout the study. The main histopathological changes occurred in the lungs and heart. Focal degeneration and fibrosis of the heart muscle were observed in animals receiving the highest dose of nitrite.[12]

Genotoxicity

1.17 Based on the available experimental data, nitrate does not raise concern for genotoxicity. Similarly, the available information does not indicate *in vivo* genotoxic potential for nitrite.[8, 13]

Carcinogenicity

1.18 The epidemiological studies reviewed by JECFA in 2002 did not provide evidence that nitrite and nitrate are carcinogenic to humans.[14] In the evaluation conducted by the International Agency for Research on Cancer (IARC) on ingested nitrate or nitrite in 2010, IARC noted that there was inadequate evidence in humans for the carcinogenicity of nitrate in food. Nevertheless, there was limited evidence in humans for the carcinogenicity of nitrite in food, which was associated with an increased incidence of stomach cancer. IARC also highlighted the active endogenous nitrogen cycle in humans, which involves nitrate and nitrite interconversion *in vivo*. Nitrosating agents derived from nitrite under acidic gastric conditions can react readily with nitrosatable compounds, especially secondary amines and amides, to form N-nitroso compounds. Some of the N-nitroso compounds that can be generated in humans under such conditions, are known carcinogens. IARC concluded that ingested nitrate or nitrite under conditions leading to endogenous nitrosation is probably carcinogenic to humans (i.e. Group 2A agent).[15]

1.19 In the subsequent evaluation of epidemiological studies conducted by the European Food Safety Authority Panel on Food Additives and Nutrient Sources Added to Food (EFSA Panel) in 2017, it was concluded that there was either no evidence or insufficient evidence for a positive association between ingested nitrate and nitrite and various cancers (including prostate cancer, breast cancer, non-Hodgkin lymphoma (NHL), ovarian cancer, thyroid cancer, etc). However, the results were inconsistent regarding a positive association between dietary nitrite and gastric cancer.[8, 13]

Health-based guidance values

1.20 The acceptable daily intake (ADI) for nitrate was first established by JECFA in 1961 as 0-5 mg/kg bw, expressed as sodium nitrate (equivalent to 0-3.7 mg/kg bw, expressed as nitrate ion). This ADI was retained in multiple subsequent evaluations conducted by JECFA, with the most recent evaluation conducted in 2002.[16] In the earlier evaluations conducted in the 1960's, JECFA already noted that the ADI for nitrate was established with a view to setting tolerance for added nitrate, and thus the ADI did not include the amounts of nitrate occurring naturally.[17,18] In a subsequent evaluation conducted in 1995, JECFA further noted that it would be inappropriate to directly compare nitrate exposure from vegetables with the ADI for nitrate, given vegetables are an important potential source of dietary nitrate, the well-known benefits of vegetables and the lack of data on the possible effects of vegetable matrices on the bioavailability of nitrate.[19] Indeed, when nitrate is consumed as part of a normal diet containing vegetables, other bioactive substances, such as the antioxidant vitamin C, may inhibit the endogenous formation of nitrosamines.[6]

1.21 In the more recent evaluation conducted by EFSA in 2017, the EFSA Panel considered the most relevant effect for establishing a safe level for nitrate was elevated blood concentrations of metHb, caused by conversion of nitrate to nitrite in human saliva. However, there were large variations in the data on the nitrate-to-nitrite conversion rate in the saliva in humans, and thus the EFSA Panel considered that it was not possible to derive a single value of ADI for nitrate from the available data. With reference to the estimated overall conversion rate of nitrate to nitrite, ranging from 1% to 9%, the EFSA Panel derived an alternative range of ADI values for nitrate, estimated at 1.05 to 9.4 mg/kg bw/day (expressed as nitrate ion). The panel noted that even at exposure on the upper end of this range, the metHb levels resulting from nitrite conversion would not be clinically significant. Nevertheless, the EFSA Panel concluded that currently there was insufficient evidence to withdraw the existing ADI of 3.7 mg/kg bw/day, despite the uncertainty associated with its establishment.[8]

1.22 As for nitrite, the ADI for nitrite established by JECFA and EFSA in 2002 and 2017, respectively, is the same (between 0 and 0.07 mg/kg bw/day, expressed as nitrite ion).[13, 20]

Chapter 2
Methodology and Laboratory Analysis

Methodology of the 2nd HKTDS

2.1 Based on the 2nd FCS, 187 TDS food items (involving 15 food groups) were selected for the Study. Six individual samples of each TDS food item were collected throughout Hong Kong and prepared individually to “as consumed” status on each of the two sampling occasions from February 2023 to January 2024. A total of 2,244 individual food samples were collected, prepared, and combined into 374 composite samples for laboratory chemical analysis.

2.2 The analytical results were integrated with food consumption data from the local population to estimate dietary exposure to the selected chemical substances included in this study. Dietary exposure estimation was performed using an in-house web-based computer system, the Exposure Assessment System 2 (EASY2), which involved food mapping and weighting of data. The mean and 90th percentile exposure levels were used to represent the dietary exposure of the average and high consumers of the local population, respectively. In this report, the dietary exposure estimates for the average and high consumers were compared with the health-based guidance value as appropriate.

2.3 Further details of the methodology are provided in the same series of reports on Methodology.[21]

Laboratory Analysis of Nitrate and Nitrite

2.4 All TDS food items collected during the two sampling occasions were tested for nitrate and nitrite. In other words, 187 TDS food items were processed to form 374 composite samples (2 composite samples for each TDS food item), which were then tested for nitrate and nitrite content.

2.5 Laboratory analysis of nitrate and nitrite was conducted by the Food Research Laboratory (FRL) of the CFS. Nitrate and nitrite levels in samples were analysed by ion chromatography (IC) with ultraviolet (UV) detection with reference to BS EN 12014-2:2017 "Foodstuffs - Determination of nitrate and/or nitrite content - Part 2: HPLC/IC method for the determination of nitrate content of vegetables and vegetable products". Sample extraction was carried out using hot water in a boiling water bath, followed by filtration through a filter paper. The filtrate was then passed through a molecular weight cut-off centrifugal filter device and a membrane filter prior to instrumental analysis. Identification of nitrate and nitrite was confirmed by comparing the retention time with those of corresponding reference standards. The limits of detection (LODs) were 0.20 mg/kg for both nitrate and nitrite in food samples and 0.010 mg/L for both nitrate and nitrite in water samples.

Treatment of analytical results

2.6 In this study, data were treated with both lower bound (LB) and upper bound (UB) approaches. These approaches represent the two extreme scenarios, considering that the true value for results below the LOD could lie anywhere between zero and the LOD. The LB scenario assumes the absence of the chemical, assigning a value of zero to results reported as <LOD. Conversely, the UB scenario assumes the chemical is present at the level of the LOD; thus, assigning the corresponding LOD to results reported as <LOD.

Chapter 3
Results and Discussion

Concentrations of Nitrate and Nitrite in TDS Foods

3.1 All 187 TDS food items, comprising 374 composite samples, were tested for nitrate and nitrite. The results for the 15 TDS food groups are summarised in Tables 1 and 2, while the detailed analytical results of all the 187 TDS food items tested are provided in Appendix 1. In this report, the concentrations of nitrate and nitrite are expressed as nitrate ion and nitrite ion, respectively.

Nitrate

3.2 Nitrate was detected in the vast majority (97%) of TDS food items tested. Only 5 out of 187 TDS food items were found to contain non-detectable level of nitrate in both composite samples. These included mango, vegetable oil, bottled distilled/purified water, granulated white sugar, and chicken powder/cube. Nitrate was detected across all 15 TDS food groups, indicating that nitrate is widely present in the local diet of Hong Kong, even though the detected levels of nitrate varied significantly across different TDS food groups.

3.3 Among all TDS food groups, "Vegetables and their products" had the highest mean concentration of nitrate (690-690 mg/kg) (LB-UB). Nitrate was detected in all but one of the 84 composite samples within this food group, with the exception of a single composite sample of dried shiitake mushroom. A wide range of mean concentrations of nitrate was observed within this TDS food group, ranging from 0.18-0.28 mg/kg (LB-UB) in dried shiitake mushroom to 4880 mg/kg in Chinese amaranth.

3.4 Besides Chinese amaranth (4880 mg/kg), nine other TDS food items were found to have mean concentration of nitrate exceeding 1000 mg/kg. These TDS food items, listed in descending order of mean concentration, are as follows: Chinese pak-choi cabbage (3630 mg/kg) which was composed of individual samples of pak-choi and Shanghai cabbage, Chinese parsley (3060 mg/kg) (categorised under the TDS food group “Condiments, sauces and herbs”), Chinese flowering cabbage (2080 mg/kg), beet root (1930 mg/kg), spinach (1920 mg/kg), leaf mustard (1880 mg/kg), Chinese kale (1500 mg/kg), celery (1290 mg/kg) and Chinese/European/Indian lettuce (1050 mg/kg).

3.5 Vegetable (including legume) TDS food items with relatively lower mean concentration of nitrate (i.e. below 50 mg/kg) are also listed as follows: various mushrooms/fungus (dried shiitake mushroom, ear fungus, bamboo fungus, button mushroom), green peas, mung bean sprout, some fruiting vegetables (tomato, pumpkin), some bulb vegetables (onion, garlic), bamboo shoot and sweet potato. The nitrate contents of vegetable (including legume) TDS food items within individual subgroups are provided in Table 3.

Table 1: Nitrate contents (mg/kg) in TDS food groups of the 2nd HKTDS

	TDS food groups	TDS food items within food group		Composite samples within food group [a]		Mean concentration of food group (mg/kg) [b c]	Range within food group (mg/kg) [b]
		Total number tested	Number with detectable levels	Total number tested	Number with detectable levels		
1	Cereals and their products	21	21	42	41	6.7-6.7	ND-84
2	Vegetables and their products	42	42	84	83	690-690	ND-5060
3	Legumes, nuts and seeds and their products	9	9	18	16	32-32	ND-300
4	Fruits	18	17	36	31	17-17	ND-150
5	Meat, poultry and game and their products	17	17	34	34	4.9-4.9	0.23-20
6	Egg and their products	3	3	6	6	1.8-1.8	1.1-3.0
7	Fish, seafood and their products	24	24	48	48	9.2-9.2	0.67-170
8	Dairy products	8	8	16	16	4.4-4.4	0.43-8.9
9	Fats and oils	2	1	4	2	0.54-0.64	ND-1.2
10	Beverages, alcoholic	2	2	4	4	5.5-5.5	4.7-5.7
11	Beverages, non-alcoholic	12	11	24	22	10-10	ND-88
12	Mixed dishes	12	12	24	24	75-75	3.6-520
13	Snack foods	1	1	2	2	160-160	130-190
14	Sugars and confectionery	5	4	10	8	9.3-9.3	ND-29
15	Condiments, sauces and herbs	11	10	22	19	290-290	ND-3380
	Total	187	182	374	356		

Notes:

[a] Two composite samples were tested for each TDS food item.

[b] Concentration levels < 1000 mg/kg are rounded to two significant figures while concentration levels ≥ 1000 mg/kg are rounded to three significant figures. ND denotes non-detected, i.e. results less than limit of detection (LOD).

[c] Mean concentrations for those food groups with detectable levels in TDS food items are presented as a range (lower bound-upper bound). For those food groups with non-detected results in all TDS food items, mean concentrations are not calculated and are marked as "–".

Table 2: Nitrite contents (mg/kg) in TDS food groups of the 2nd HKTDS

TDS food groups		TDS food items within food group		Composite samples within food group [a]		Mean concentration of food group (mg/kg) [b c]	Range within food group (mg/kg) [b]
		Total number tested	Number with detectable levels	Total number tested	Number with detectable levels		
1	Cereals and their products	21	8	42	11	0.14-0.29	ND-0.81
2	Vegetables and their products	42	21	84	31	1.1-1.2	ND-8.1
3	Legumes, nuts and seeds and their products	9	2	18	4	1.4-1.5	ND-14
4	Fruits	18	6	36	7	0.53-0.69	ND-7.8
5	Meat, poultry and game and their products	17	1	34	2	0.054-0.24	ND-1.3
6	Egg and their products	3	1	6	1	0.11-0.28	ND-0.66
7	Fish, seafood and their products	24	8	48	12	0.18-0.33	ND-1.2
8	Dairy products	8	0	16	0	–	ND-ND
9	Fats and oils	2	0	4	0	–	ND-ND
10	Beverages, alcoholic	2	1	4	1	0.30-0.45	ND-1.2
11	Beverages, non-alcoholic	12	3	24	5	0.99-1.1	ND-10
12	Mixed dishes	12	5	24	7	0.88-1.0	ND-15
13	Snack foods	1	1	2	1	1.7-1.8	ND-3.3
14	Sugars and confectionery	5	0	10	0	–	ND-ND
15	Condiments, sauces and herbs	11	2	22	2	0.17-0.35	ND-2.8
	Total	187	59	374	84		

Notes:

[a] Two composite samples were tested for each TDS food item.

[b] Concentration levels < 1000 mg/kg are rounded to two significant figures while concentration levels ≥ 1000 mg/kg are rounded to three significant figures. ND denotes non-detected, i.e. results less than limit of detection (LOD).

[c] Mean concentrations for those food groups with detectable levels in TDS food items are presented as a range (lower bound-upper bound). For those food groups with non-detected results in all TDS food items, mean concentrations are not calculated and are marked as "–".

Table 3: Nitrate contents (mg/kg) of vegetable (including legume) TDS food items within individual subgroups of the 2nd HKTDS

TDS food items under individual subgroups [a]	Mean concentration (mg/kg) [b, c]
Leafy vegetables	
• Chinese amaranth (Chinese spinach)	4880
• Cabbage, Pak-choi Chinese	3630
• Cabbage, Chinese flowering	2080
• Spinach	1920
• Leaf mustard	1880
• Chinese kale	1500
• Lettuce, Chinese / European / Indian	1050
• Watercress	920
• Water spinach	580
• Mung bean sprout	3.6
Brassica vegetables	
• Cabbage, European variety	950
• Cabbage, Chinese (including Pe-tsai / Celery cabbage)	740
• Broccoli / Cauliflower	370
Stalk and stem vegetables	
• Celery	1290
• Bamboo shoot	17
Root and tuber vegetables	
• Beet root	1930
• Carrot / Radish	310
• Potato	83
• Sweet potato	29
Bulb vegetables	
• Spring onion	670
• Blanching chives	420
• Garlic	26
• Onion	14
Cucurbits fruiting vegetables	
• Zucchini	530
• Bitter melon	240
• Cucumber	240
• Hairy gourd / wax gourd	220
• Sponge gourd	170
• Pumpkin	13
Fruiting vegetables	
• Eggplant	260
• Peppers (sweet pepper / chili pepper)	54
• Tomato	7.3
Legume vegetables	
• Green string beans (with pod)	270
• Green peas	0.85

TDS food items under individual subgroups [a]	Mean concentration (mg/kg) [b, c]
Mushroom / Seaweed	
• Seaweed	300
• Mushroom, button	25
• Bamboo fungus	1.3
• Ear fungus	0.54
• Mushroom, shiitake, dried	0.18-0.28

Notes:
[a] Two composite samples were tested for each TDS food item.
[b] Concentration levels < 1000 mg/kg are rounded to two significant figures while concentration levels ≥ 1000 mg/kg are rounded to three significant figures.
[c] Mean concentrations for those TDS food items detected in both sampling occasions are presented as a single value, whereas those detected only in one of the two sampling occasions are presented as a range (LB-UB).

3.6 Among vegetable subgroups, leafy vegetables (e.g. Chinese amaranth, Chinese Pak-choi cabbage and Chinese flowering cabbage) exhibited the highest nitrate concentrations, while storage organs such as potato, onion, cucumber, eggplant and green peas had relatively lower nitrate concentrations. A pattern of decreasing nitrate content in vegetable organs was found in the study, which aligns with the findings reported in the literature, i.e. leaf > stem > root and tuber > flower > bulb > fruit > seed.[22]

3.7 Some vegetable items covered in the current study were also tested in the previous studies conducted by the CFS, and variations in the nitrate content were observed. Such variations are expected because nitrate concentrations are influenced by different factors such as the status of the vegetable samples ("as purchased" vs "as consumed"), cooking methods (boiling vs stir-frying), and external factors like season, light, temperature, growing conditions, fertilizer use and storage. Due to these variabilities, a detailed comparison of nitrate levels between studies is not attempted.

3.8 Among all fruits tested, melon had the highest mean concentration of nitrate at 150 mg/kg, while the remaining fruit items had mean concentration of nitrate below 50 mg/kg. A related TDS food item, fruit and/or vegetable juice (categorised under the TDS food group "Beverages, non-alcoholic"), had a mean concentration of nitrate at 82 mg/kg, the highest among all non-alcoholic beverage food items tested.

3.9 In the TDS food group "Snack foods", the mean concentration of nitrate was represented by potato chips (160 mg/kg), the only TDS food item in this food group. The main ingredient of potato chips is potatoes, which naturally contain nitrate. Due to the concentration effect during the processing of fresh potatoes to potato chips, the mean concentration of nitrate in potato chips was approximately double that of boiled/stewed fresh potatoes in this study.

3.10 Regarding the TDS food group "Mixed dishes", turnip cake had the highest mean concentration of nitrate at 520 mg/kg. This is attributed to its main ingredient, radish, which naturally contains significant level of nitrate. Besides, traditional Chinese preserved meat products (e.g. preserved sausage, preserved pork), often included in turnip cake recipes, may contain nitrite/nitrate as preservative, further contributing to the total nitrite/nitrate content.

3.11 Regarding the TDS food group "Meat, poultry and game and their products", higher mean concentrations of nitrate were detected in processed meat/poultry products, including meat sausage (18 mg/kg), pork ham (16 mg/kg) and luncheon meat (13 mg/kg). In contrast, unprocessed meat/poultry food items generally had much lower mean nitrate concentrations compared to their processed counterparts.

Nitrite

3.12 Regarding nitrite, it was only detected in a smaller proportion (32%) of TDS food items. Specifically, 59 out of 187 TDS food items were found to contain detectable levels of nitrite in either one or both of the composite samples. Nitrite was not detected in 3 TDS food groups, namely "Dairy products", "Fats and oils" and "Sugars and confectionery".

3.13 The TDS food item with the highest mean concentration of nitrite was green string beans (with pod) (12 mg/kg). Vegetables with relatively high levels of nitrite included Chinese kale (6.8 mg/kg), European variety cabbage (6.7 mg/kg) and water spinach (5.5 mg/kg). Among fruits, watermelon had the highest mean concentration of nitrite (6.4 mg/kg). For non-alcoholic beverages, fruit and/or vegetable juice had the highest mean concentration of nitrite (9.9 mg/kg). Within the "Mixed dishes" food group, turnip cake had the highest mean concentration of nitrite (8.2 mg/kg).

3.14 Notably, nitrite was not detected in processed meat/poultry products including meat sausage, pork ham and luncheon meat in this study. This absence can be attributed to the high chemical reactivity of nitrite and its oxidation to nitrate over time during storage, which reduces nitrite concentration in food. Besides, the cooking process of boiling and pan-frying during sample preparation of the TDS food items likely further reduced residual nitrite that was present in the processed meat/poultry product samples.[13]

Dietary Exposure to Nitrate and Major Food Contributors

Dietary exposure to nitrate

3.15 Table 4 shows the overall dietary exposure estimates of the local adult and younger populations to nitrate. For the adult population, the dietary exposure estimates of the average and high consumers (90th percentile) were 3.8-3.8 mg/kg bw/day (LB-UB) and 8.0-8.0 mg/kg bw/day (LB-UB), respectively. For the younger population, the dietary exposure estimates of the average and high consumers were 4.1-4.1 mg/kg bw/day (LB-UB) and 8.9-8.9 mg/kg bw/day (LB-UB), respectively. Further details of age-gender subgroup analysis of dietary exposure to nitrate are presented in Table 5.

Table 4: Estimates of overall dietary exposure to nitrate for the average and high consumers of the local adult and younger populations

Population	Dietary Exposure Estimates (LB-UB) (mg/kg bw/day)	
	Average consumers	High consumers
Adults aged 18+	3.8-3.8	8.0-8.0
Younger population aged 6-17	4.1-4.1	8.9-8.9

Exposure of the high consumers refers to the exposure at 90th percentile.
LB and UB denotes lower bound and upper bound respectively.
Figures for dietary exposure estimates are rounded to 2 significant figures.

Table 5: Estimates of dietary exposure to nitrate for the average and high consumers of age-gender subgroups

Age-gender groups	Dietary Exposure Estimates (LB-UB) (mg/kg bw/day)	
	Average consumers	High consumers
Adults		
Adults aged 18-49	3.3-3.3	6.9-6.9
● Male	2.8-2.8	5.7-5.7
● Female	3.7-3.7	7.7-7.7
Adults aged 50-64	4.0-4.0	8.3-8.3
● Male	3.7-3.7	7.6-7.6
● Female	4.4-4.4	8.8-8.8
Adults aged 65+	4.8-4.8	9.6-9.6
● Male	4.4-4.4	9.0-9.0
● Female	5.1-5.1	10-10
Adults aged 18+	3.8-3.8	8.0-8.0
● Male	3.4-3.4	7.0-7.0
● Female	4.2-4.2	8.4-8.4
Younger population		
Children aged 6-11	4.9-4.9	10-10
Adolescents aged 12-17	3.3-3.3	6.9-6.9
● Male	3.4-3.4	6.9-6.9
● Female	3.2-3.2	6.9-6.9

Exposure of high consumers refers to the exposure at 90th percentile.
LB and UB denotes lower bound and upper bound respectively.
Figures for dietary exposure estimates are rounded to 2 significant figures.

Contributors to dietary exposure to nitrate

3.16 Dietary exposure estimates (based on LB exposure) to nitrate for the average consumers from the 15 TDS food groups are shown in Table 6 and their contributions to the total dietary exposure to nitrate are shown in Figures 1 and 2.

Table 6: Dietary exposure to nitrate for average consumers and percentage contribution from TDS food groups

TDS food groups	Adults aged 18+		Younger population aged 6-17	
	Dietary Exposure (LB) (mg/kg bw/day)	% Contribution to total dietary exposure	Dietary Exposure (LB) (mg/kg bw/day)	% Contribution to total dietary exposure
Vegetables and their products	3.5	91%	3.6	87%
Beverages, non-alcoholic	0.14	3.6%	0.20	4.9%
Mixed dishes	0.088	2.3%	0.14	3.5%
Condiments, sauces and herbs	0.028	0.73%	0.038	0.93%
Fruits	0.023	0.60%	0.033	0.81%
Cereals and their products	0.023	0.59%	0.042	1.0%
Legumes, nuts and seeds and their products	0.014	0.37%	0.023	0.57%
Meat, poultry and game and their products	0.0055	0.14%	0.0092	0.22%
Dairy products	0.0012	0.032%	0.0085	0.21%
Other food groups	0.010	0.27%	0.025	0.60%

Figures for dietary exposure estimates and % contribution to overall dietary exposure are rounded to 2 significant figures.
Other food groups included "Fish and seafood and their products", "Snack foods", "Beverages, alcoholic", "Egg and egg products", "Sugars and confectionery" and "Fats and oils".

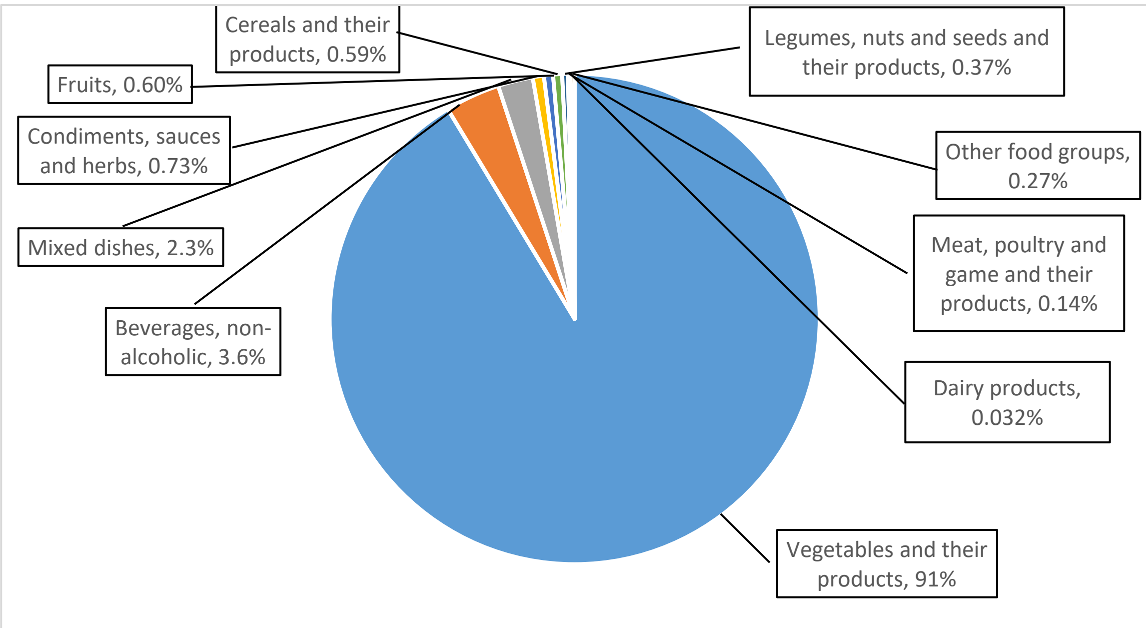

Figure 1: Percentage contribution to dietary exposure to nitrate by TDS food group in the adult population

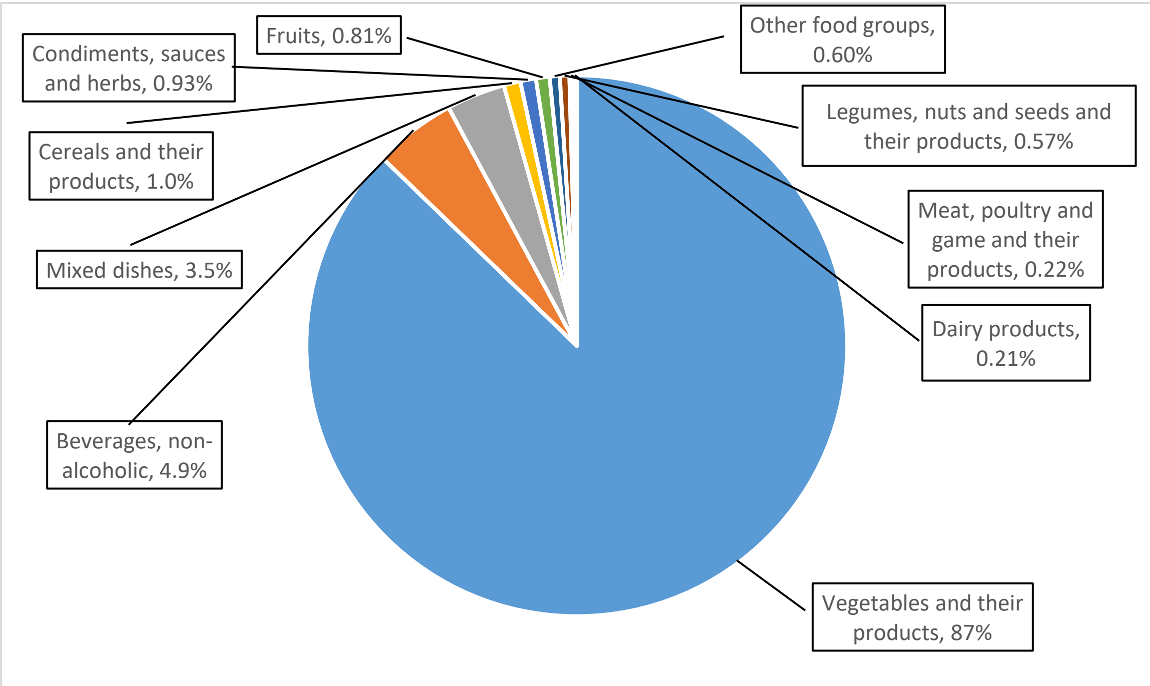

Figure 2: Percentage contribution to dietary exposure to nitrate by TDS food group in the younger population

3.17 For both the adult and younger populations (Figures 1 and 2), the vast majority of dietary sources of nitrate originated from the food group "Vegetables and their products", contributing 91% and 87% of the total dietary exposure to nitrate, respectively. A breakdown analysis revealed that leafy vegetables alone accounted for 70-80% of the total daily nitrate exposure. In this study, the top three food items contributing to total daily nitrate exposure were identified as: Chinese flowering cabbage (47% for adults and 35% for younger population), Chinese pak-choi cabbage (13% for adults and 15% for younger population) and Chinese lettuce (4.7% for adults and 4.5% for younger population).

3.18 Given that the vast majority (87-91%) of dietary sources of nitrate in the local adult and younger population originated from the food group "Vegetables and their products", and considering JECFA's long-standing opinion (paragraph 1.20) that (i) ADI for nitrate was established with a view to setting tolerance for added nitrate (not including naturally occurring nitrate) and (ii) it is inappropriate to compare dietary exposure to nitrate from vegetables directly with the ADI for nitrate, this study does not compare the estimated dietary exposure to nitrate of the local population against the ADI established by JECFA.

3.19 It is noteworthy that, with reference to paragraph 1.21, the dietary nitrate exposure estimates of the overall adult and younger populations fell within the alternative range of ADI values‡ estimated for nitrate as derived by the EFSA Panel in 2017, i.e. between 1.05 and 9.4 mg/kg bw/day (expressed as nitrate ion). Exceptions were observed for the high consumers in two age-gender subgroups: adult females aged 65+ and children aged 6-11, both with estimated dietary nitrate exposure of 10-10 mg/kg bw/day (LB-UB), slightly exceeding the upper range of the alternative ADI values derived by the EFSA Panel. Nevertheless, as referenced in paragraph 1.15, the dietary nitrate exposure estimates of the average and high consumers of all age-gender subgroups were lower than the exposure level associated with elevated MetHb in the blood of adults, children or infants (up to 10.95 mg/kg bw/day, expressed as nitrate ion) identified by FSANZ. Although high consumers of two age-gender subgroups were found to slightly exceed the upper range of the alternative ADI values derived by the EFSA Panel, an intake above the ADI range does not automatically mean that health is at risk provided that the average intake over a long period does not exceed the ADI, which emphasises on lifetime exposure.

3.20 Dietary exposure to nitrate from food additive sources can be roughly estimated by the contribution from three concerned food groups, i.e. “Meat, poultry and game and their products”, “Mixed dishes” and “Dairy products”,

‡ Considering there were large variations in the data on the nitrate-to-nitrite conversion rate in the saliva in humans, the EFSA Panel considered that it was not possible to derive a single value of ADI for nitrate from the available data, and in turn estimated a range of ADI values for nitrate.

which include processed meat/poultry products, mixed dishes containing processed meat/poultry products ingredients, and cheeses. The combined dietary exposure to nitrate from these three food groups was 0.095 mg/kg bw/day (2.5% of total dietary exposure) for the adult population, and 0.16 mg/kg bw/day (3.9% of total dietary exposure) for the younger population. In other words, the estimated dietary exposure (LB) to nitrate solely from food additive sources was less than 4% of the total daily dietary exposure for the average consumers in both populations, amounting to less than 5% of the ADI for nitrate allocated by JECFA (i.e. 2.6% and 4.3% of the ADI for the adult and younger populations, respectively).

Dietary Exposure to Nitrite and Major Food Contributors

Dietary exposure to nitrite

3.21 Table 7 shows the overall dietary exposure estimates of the local adult and younger populations to nitrite. For the adult population, the estimated dietary exposure of the average consumers was 0.014-0.018 mg/kg bw/day (LB-UB), which accounted for 19-25% (LB-UB) of the ADI allocated for nitrite. Among the high consumers (90^{th} percentile) of the adult population, the estimated dietary exposure was 0.025-0.029 mg/kg bw/day (LB-UB), which accounted for 35-42% (LB-UB) of the ADI. For the younger population, the estimated dietary exposure of the average consumers was 0.019-0.025 mg/kg bw/day (LB-UB), which accounted for 27-36% (LB-UB) of the ADI. Among the high consumers of the younger population, the estimated dietary exposure was 0.038-0.045 mg/kg bw/day (LB-UB), which accounted for 54-65% (LB-UB) of the ADI. Further details of age-gender subgroup analysis of dietary exposure to nitrite are presented in Table 8.

Table 7: Estimates of overall dietary exposure to nitrite for the average and high consumers of the local adult and younger populations and their contribution to Acceptable Daily Intake (ADI)

Population	Dietary Exposure Estimates (LB-UB) (mg/kg bw/day)		% ADI (LB-UB)	
	Average consumers	High consumers	Average consumers	High consumers
Adults aged 18+	0.014-0.018	0.025-0.029	19-25	35-42
Younger population aged 6-17	0.019-0.025	0.038-0.045	27-36	54-65

Exposure of the high consumers refers to the exposure at 90th percentile.
LB and UB denotes lower bound and upper bound respectively.
Figures for dietary exposure estimates and contribution to ADIs are rounded to 2 significant figures.

Table 8: Estimates of dietary exposure to nitrite for the average and high consumers of age-gender subgroups and their contribution to Acceptable Daily Intake (ADI)

Age-gender groups	Dietary Exposure Estimates (LB-UB) (mg/kg bw/day)		% ADI (LB-UB)	
	Average consumers	High consumers	Average consumers	High consumers
Adults				
Adults aged 18-49	0.014-0.018	0.026-0.031	20-25	37-44
● Male	0.012-0.016	0.023-0.027	18-23	33-39
● Female	0.015-0.019	0.029-0.033	21-27	41-47
Adults aged 50-64	0.013-0.017	0.023-0.028	19-25	33-40
● Male	0.013-0.017	0.022-0.027	18-24	31-39
● Female	0.014-0.018	0.024-0.029	19-25	35-41
Adults aged 65+	0.013-0.017	0.023-0.027	19-25	33-39
● Male	0.013-0.017	0.024-0.028	19-25	34-40
● Female	0.014-0.017	0.023-0.027	19-24	33-39
Adults aged 18+	0.014-0.018	0.025-0.029	19-25	35-42
● Male	0.013-0.017	0.023-0.027	18-24	33-39
● Female	0.014-0.018	0.026-0.031	20-26	37-44
Younger population				
Children aged 6-11	0.023-0.030	0.045-0.053	33-43	64-76
Adolescents aged 12-17	0.014-0.019	0.028-0.035	21-27	41-50
● Male	0.015-0.020	0.029-0.035	21-28	41-50
● Female	0.014-0.019	0.028-0.032	20-27	40-46

Exposure of high consumers refers to the exposure at 90th percentile.
LB and UB denotes lower bound and upper bound respectively.
Figures for dietary exposure estimates and contribution to ADI are rounded to 2 significant figures.

3.22 Among all individual age-gender subgroups, the dietary exposure estimates to nitrite of the average and high consumers were below the ADI allocated for nitrite.

Contributors to dietary exposures to nitrite

3.23 Dietary exposure estimates (based on LB exposure) to nitrite for the average consumers from the 15 TDS food groups are shown in Table 9 and their contributions to the total dietary exposure are shown in Figures 3 and 4.

Table 9: Dietary exposure to nitrite for average consumers and percentage contribution from TDS food groups

TDS food groups	Adults aged 18+		Younger population aged 6-17	
	Dietary Exposure (LB) (mg/kg bw/day)	% Contribution to total dietary exposure	Dietary Exposure (LB) (mg/kg bw/day)	% Contribution to total dietary exposure
Vegetables and their products	0.0041	30%	0.0045	24%
Cereals and their products	0.0029	22%	0.0047	25%
Mixed dishes	0.0024	18%	0.0032	17%
Beverages, non-alcoholic	0.0021	16%	0.0027	14%
Fruits	0.0010	7.4%	0.0021	11%
Legumes, nuts and seeds and their products	0.00061	4.5%	0.0010	5.3%
Fish and seafood and their products	0.00022	1.6%	0.00021	1.1%
Beverages, alcoholic	0.000041	0.30%	0.00000011	0.00056%
Sugars and confectionery	0.000038	0.28%	0.00037	2.0%
Meat, poultry and game and their products	0.000035	0.26%	0.000021	0.11%
Other food groups	0.000037	0.27%	0.00015	0.80%

Figures for dietary exposure estimates and % contribution to overall dietary exposure are rounded to 2 significant figures.
Other food groups included "Snack foods", "Condiments, sauces and herbs", "Egg and egg products", "Dairy products" and "Fats and oils".

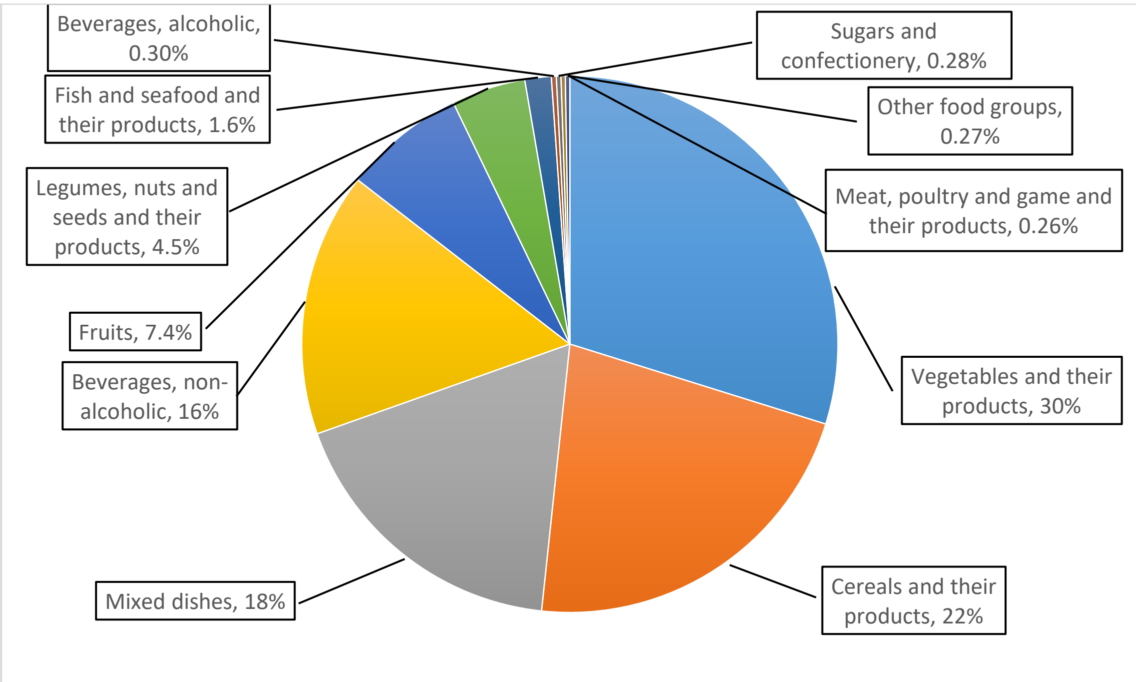

Figure 3: Percentage contribution to dietary exposure to nitrite by TDS food group in the adult population

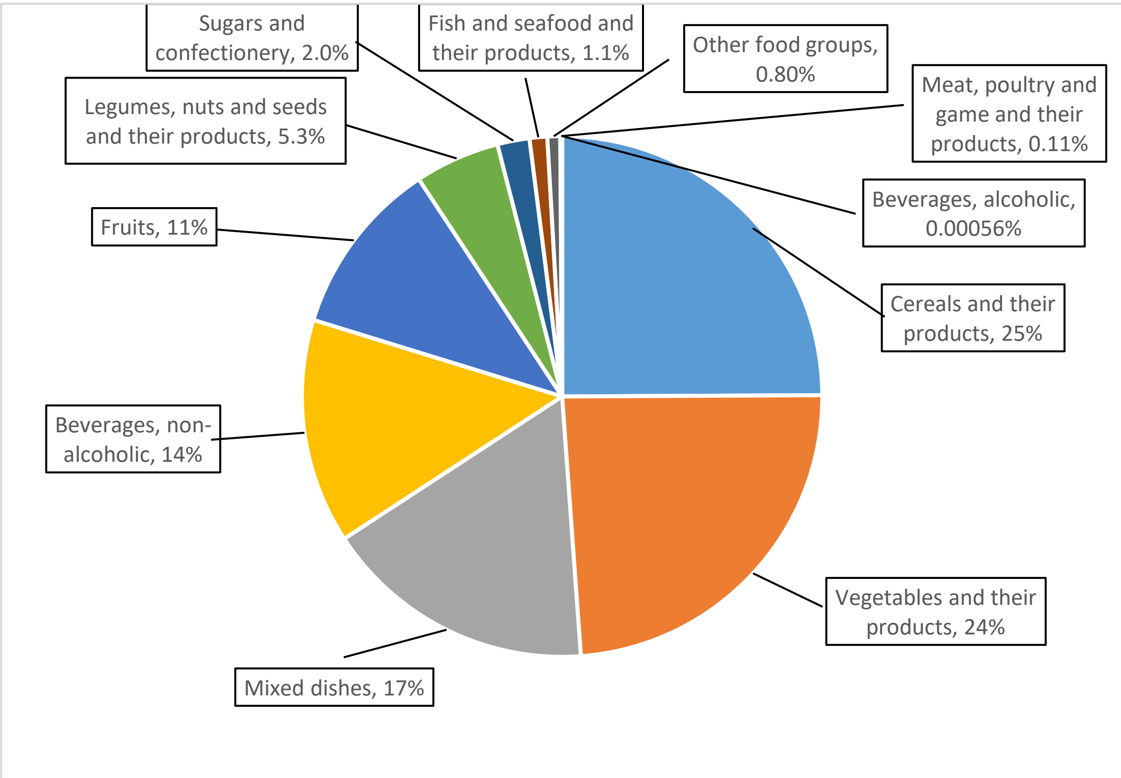

Figure 4: Percentage contribution to dietary exposure to nitrite by TDS food group in the younger population

3.24 For the adult population (Figure 3), the main dietary sources of nitrite were "Vegetables and their products" (30% of the total dietary exposure), followed by "Cereals and their products" (22%), "Mixed dishes" (18%) and "Beverages, non-alcoholic" (16%). For the younger population (Figure 4), the main dietary sources of nitrite were "Cereals and their products" (25%), "Vegetables and their products" (24%) and "Mixed dishes" (17%) and "Beverages, non-alcoholic" (14%). In this study, the top three food subgroups contributing to total daily nitrite exposure were identified as: rice (20% for adults and 23% for younger population), leafy vegetables (20% for adults and 11% for younger population) and Chinese-style clear soup (14% for adults and 13% for younger population).

Comparison with Other Places

3.25 The estimates of dietary exposure to nitrate and nitrite obtained locally were compared with those from other places including Australia, France, Ireland, New Zealand, Portugal, and the region of Taiwan[10, 23, 24, 25, 26, 27, 28] (see Appendix 2). These studies were selected for comparison for two reasons: (i) the sampling approach adopted in these studies covered major food groups, enabling comprehensive dietary exposure estimates; and (ii) food samples were prepared to "as consumed" status before analytical testing, accounting for the changes in nitrate and nitrite concentrations during storage, preparation and cooking. Indeed, nitrate is water soluble, and kitchen processing steps can reduce the nitrate content in vegetables to various extent. According to literature, removing the skin of potatoes, bananas, melons and beetroot can reduce the nitrate content by 20-62%, while washing leafy vegetables (lettuce, endives) can reduce nitrate content by 10-15%.[6] Another research study also remarked that boiling and blanching were more effective than stir-frying and steaming in reducing nitrate content in vegetables.[29]

3.26 Overall, there is a wide range of estimated dietary exposure to nitrate and nitrite among populations from different places. Dietary exposure to nitrate in Hong Kong SAR is comparable to that in the region of Taiwan and is on the upper end of the range compared to other places. This can be attributed to high consumption of vegetables, particularly leafy vegetables, in both the local and Taiwanese diet, and leafy vegetables consistently were found to contain the highest average levels of nitrate in studies conducted both locally and worldwide. Regarding dietary exposure to nitrite from exogenous sources (i.e. food, beverages and drinking water), the dietary exposure estimates for Hong Kong SAR is within the mid-range compared to other places.

3.27 However, caution is advised when comparing the data due to the differences in time when the studies were conducted, approaches to capturing and handling food consumption data, sampling strategies, sample preparation procedures, analytical methods, and the methods adopted for treating analytical results below detection limits, etc.

Other Issues

3.28 Some studies suggest that nitrate/nitrite may have beneficial or protective effects on health. For instance, nitric oxide (NO), formed from nitrite in the stomach, exhibits antimicrobial activity against a wide range of organisms, including gastrointestinal pathogens such as *Yersinia* and *Salmonella*. Nitric oxide has also been shown to have vasodilatory property, contributing to blood pressure reduction, and modulates platelet function in some studies.[16]

3.29 Vegetables and fruits are important components of a healthy diet as they are good sources of dietary fibre, vitamins and minerals. Convincing evidence shows that consuming vegetables and fruits has strong protective effects against chronic diseases and cancers including oral cavity oesophagus, stomach and colorectum.[30] On the other hand, inadequate consumption of vegetable and fruit is linked to poor health and increased risk of non-communicable diseases (NCDs). In 2017, an estimated 3.9 million deaths worldwide were attributed to inadequate consumption of vegetables and fruits.[31] In addition, the IARC 2003 Handbook on Cancer Prevention stated that approximately one in ten cancers in Western populations are due to an insufficient intake of vegetables and fruits.[32]

3.30 Over the past two decades, studies and assessments using risk-benefit analysis approach have been conducted to evaluate the potential risks and benefits of dietary exposure to nitrate/nitrite. In 2008, the EFSA Panel on Contaminants in the Food Chain concluded that the benefits of consuming vegetables (a major source of dietary nitrate) outweigh the potential risks of nitrate exposure.[6] Subsequently, more studies have been conducted using the benefit-risk analysis for foods (BRAFO) framework or toxicokinetic modelling approach, the results further supported that exposure to dietary nitrate/nitrite is unlikely to pose appreciable health risks, and may offer appreciable health benefits particularly cardiovascular benefit.[28, 33] The CFS will keep in view the latest international development/consensus on the application of risk-benefit analysis in the evaluation of dietary nitrate/nitrite exposure.

Limitations of the Study

3.31 In this study, the sampling of a limited number of individual food items where nitrate and nitrite are permitted as food additives, combined with the use of food mapping approach to assign nitrate and nitrite concentration in applicable foods, introduced uncertainties in the dietary exposure assessment of nitrate and nitrite for the local population.

3.32 In addition, due to intrinsic limitations of the TDS approach, such as the pooling of individually prepared food samples before analysis and the resulting loss of information about the variability of substance levels in the respective food items, combined with the use of mean food consumption data of individuals collected over two days of 24-Hour Dietary Recall, the exposure assessment of this study focused more on quantifying long-term average dietary exposure rather than acute dietary exposure.

3.33 Other limitations have been described in the Report on the 2nd HKTDS: Methodology.[21]

Chapter 4
Conclusion and Recommendations

4.1 Out of the 187 TDS food items tested, nitrate was detected in the vast majority (97%) of the food items included in the study. These analytical results indicate that nitrate is widely present in the local diet of Hong Kong, even though the detected levels of nitrate vary significantly across different TDS food groups. Among all TDS food groups, "Vegetables and their products" had the highest mean concentration of nitrate (690-690 mg/kg) (LB-UB).

4.2 For the adult population, the estimated dietary exposure to nitrate was 3.8-3.8 mg/kg bw/day (LB-UB) for the average consumers and 8.0-8.0 mg/kg bw/day (LB-UB) for the high consumers. For the younger population, the estimated dietary exposure to nitrate was 4.1-4.1 mg/kg bw/day (LB-UB) for the average consumers and 8.9-8.9 mg/kg bw/day (LB-UB) for the high consumers. For the average consumers of the adult and younger populations, the vast majority of dietary sources of nitrate came from the food group "Vegetables and their products", contributing to 91% and 87% of the total dietary exposure to nitrate, respectively. Leafy vegetables (such as Chinese flowering cabbage, Chinese pak-choi cabbage, Chinese lettuce) alone amounted to 70-80% of the total daily nitrate exposure. Dietary exposure to nitrate from food additive sources represented less than 4% of the total dietary exposure for the average consumers of both the adult and younger populations.

4.3 The dietary nitrate exposure estimates of the average and high consumers of the overall adult and younger populations fell within the alternative range of ADI values estimated for nitrate (between 1.05 and 9.4 mg/kg bw/day, expressed as nitrate ion) derived by the EFSA Panel in 2017, indicating the general population is unlikely to experience any immediate health risk.

4.4 Regarding nitrite, it was detected in 59 out of the 187 TDS food items tested (32%). The TDS food items detected with the highest mean concentration of nitrite, in descending order, were green string beans (with pod) (12 mg/kg), fruit and/or vegetable juice (9.9 mg/kg), turnip cake (8.2 mg/kg), Chinese kale (6.8 mg/kg), European variety cabbage (6.7 mg/kg) and watermelon (6.4 mg/kg).

4.5 For the adult population, the estimated dietary exposure to nitrite for the average consumers was 0.014-0.018 mg/kg bw/day (LB-UB), representing 19-25% (LB-UB) of the ADI allocated for nitrite. Among the high consumers of the adult population, the estimated dietary exposure to nitrite was 0.025-0.029 mg/kg bw/day (LB-UB), representing 35-42% (LB-UB) of the ADI. For the younger population, the estimated dietary exposure to nitrite of the average consumers was 0.019-0.025 mg/kg bw/day (LB-UB), representing 27-36% (LB-UB) of the ADI. Among the high consumers of the younger population, the estimated dietary exposure to nitrite was 0.038-0.045 mg/kg bw/day (LB-UB), representing 54-65% (LB-UB) of the ADI.

4.6 For the adult population, the main dietary sources of nitrite were "Vegetables and their products" (30% of the total dietary exposure), followed by "Cereals and their products" (22%), "Mixed dishes" (18%) and "Beverages, non-alcoholic" (16%). For the younger population, the main dietary sources of nitrite were "Cereals and their products" (25%), "Vegetables and their products" (24%) and "Mixed dishes" (17%) and "Beverages, non-alcoholic" (14%). As the dietary exposure estimates of nitrite for both populations were below the ADI established by JECFA and EFSA, the health risk is considered low.

4.7 Vegetables are important components of a healthy diet, and there is convincing evidence that their consumption provide strong beneficial effects against chronic diseases and cancers. On the other hand, inadequate consumption of vegetables is linked to poor health and increased risk of non-communicable diseases.

4.8 To maximise the health benefits from vegetable consumption, members of the public are advised to maintain a balanced diet and consume the recommended daily intake of vegetables[§]. They are advised to incorporate a greater variety of vegetables into their diet, such as to consume more flowerhead brassica vegetables (e.g. broccoli, cauliflower), fruiting vegetables (e.g. eggplant, tomato, cucumber, pumpkin), mushrooms and fungus. Additionally, using appropriate preparation methods can further reduce nitrate levels in vegetables. These methods include thorough washing, peeling as appropriate, and boiling vegetables in water instead of stir-frying. Furthermore, if cooked vegetables are meant to be saved for later consumption, e.g. as packed lunch for the following day, it would be advisable to reserve a portion before meal time (to prevent further bacterial contamination) and keep the reserved portion under refrigeration. Besides, vegetables should be stored properly (e.g. keep under refrigeration if they are not consumed or sold immediately) to prolong freshness and minimise nitrite formation.

[§] The Department of Health recommends a daily intake of at least 3 servings of vegetables and 2 servings of fruits (about 80 grams per serving leading to a minimum of 400 grams of vegetables and fruits every day, which is in line with the recommendation of the World Health Organization).

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Appendix 1

Nitrate and nitrite contents (mg/kg) in TDS food items of the 2nd HKTDS

TDS Food Item [a]	Nitrate Contents (mg/kg) [b]			Nitrite Contents (mg/kg) [b]		
	Mean [c]	1st Sampling Occasion	2nd Sampling Occasion	Mean [c]	1st Sampling Occasion	2nd Sampling Occasion
Cereals and their products						
Biscuit / Cookie	2.7	2.4	3.0	0.29-0.39	ND	0.57
Bread, plain	3.2	3.4	3.0	–	ND	ND
Bread, raisin	8.8	8.8	8.8	–	ND	ND
Breakfast cereals	3.9	4.0	3.8	–	ND	ND
Bun, with savoury filling, baked	3.4	4.1	2.7	–	ND	ND
Bun, with savoury filling, steamed	81	78	84	0.39-0.49	0.78	ND
Bun, with sweet filling, steamed	2.8	2.7	2.9	0.18-0.28	ND	0.36
Cake	6.6	6.8	6.3	0.28-0.38	ND	0.56
Corn	0.36-0.46	0.72	ND	–	ND	ND
Corn starch	1.8	2.4	1.2	–	ND	ND
Deep-fried dough, Chinese style	2.6	2.5	2.6	–	ND	ND
Noodles, Chinese / Japanese style	1.7	2.0	1.3	–	ND	ND
Noodles, instant	2.0	2.6	1.3	–	ND	ND
Noodles, rice	1.1	0.46	1.8	–	ND	ND
Oats / Oatmeal	2.1	2.8	1.4	0.47	0.43	0.51
Pasta, Western style	1.8	2.7	0.84	0.22-0.32	0.43	ND
Pastries, Chinese style	5.5	8.8	2.1	–	ND	ND
Pie / Tart	3.1	3.7	2.5	–	ND	ND
Pineapple bun	1.6	1.7	1.5	–	ND	ND
Rice, unpolished	2.5	2.4	2.6	0.47	0.46	0.47
Rice, white	2.7	2.8	2.6	0.74	0.81	0.67
Vegetables and their products						
Bamboo fungus	1.3	1.2	1.4	0.19-0.29	0.37	ND
Bamboo shoot	17	10	24	0.24-0.34	0.47	ND

TDS Food Item [a]	Nitrate Contents (mg/kg) [b]			Nitrite Contents (mg/kg) [b]		
	Mean [c]	1st Sampling Occasion	2nd Sampling Occasion	Mean [c]	1st Sampling Occasion	2nd Sampling Occasion
Beet root	1930	1880	1980	1.2-1.3	ND	2.3
Bitter melon	240	250	220	1.6-1.7	3.2	ND
Blanching chives	420	490	350	–	ND	ND
Broccoli / Cauliflower	370	450	290	–	ND	ND
Cabbage, Chinese (including Pe-tsai / Celery cabbage)	740	640	840	–	ND	ND
Cabbage, Chinese flowering	2080	2260	1900	2.6-2.7	5.1	ND
Cabbage, European variety	950	930	970	6.7	5.2	8.1
Cabbage, Pak-choi Chinese	3630	4410	2850	–	ND	ND
Cabbage, Pak-choi Chinese, dried	81	78	84	1.5	1.4	1.6
Carrot / Radish	310	350	270	–	ND	ND
Celery	1290	1580	1000	–	ND	ND
Chinese amaranth (Chinese spinach)	4880	4700	5060	1.5	1.8	1.2
Chinese kale	1500	1290	1700	6.8	7.8	5.8
Cucumber	240	240	230	0.80-0.90	1.6	ND
Ear fungus	0.54	0.76	0.32	–	ND	ND
Eggplant	260	260	250	1.8-1.9	3.5	ND
Garlic	26	7.2	44	–	ND	ND
Ginger	900	800	1000	–	ND	ND
Hairy gourd / wax gourd	220	200	230	0.90	0.96	0.83
Leaf mustard	1880	1470	2290	3.9	3.7	4.1
Lettuce, Chinese / European / Indian	1050	950	1150	–	ND	ND
Mung bean sprout	3.6	5.3	1.8	–	ND	ND
Mushroom, button	25	31	19	1.1	1.3	0.83
Mushroom, shiitake, dried	0.18-0.28	0.35	ND	–	ND	ND
Onion	14	14	13	–	ND	ND
Pea shoots	190	130	250	–	ND	ND
Peppers (sweet pepper / chili pepper)	54	43	64	–	ND	ND
Potato	83	55	110	1.7-1.8	ND	3.4
Potato, fried	95	120	70	3.3	3.3	3.2
Preserved vegetables	590	670	510	–	ND	ND
Pumpkin	13	9.0	16	0.30-0.40	0.60	ND

TDS Food Item [a]	Nitrate Contents (mg/kg) [b]			Nitrite Contents (mg/kg) [b]		
	Mean [c]	1st Sampling Occasion	2nd Sampling Occasion	Mean [c]	1st Sampling Occasion	2nd Sampling Occasion
Seaweed	300	290	310	–	ND	ND
Spinach	1920	2020	1820	–	ND	ND
Sponge gourd	170	160	180	3.6	4.0	3.2
Spring onion	670	530	810	0.12-0.22	0.23	ND
Sweet potato	29	4.0	54	–	ND	ND
Tomato	7.3	4.9	9.6	–	ND	ND
Water spinach	580	670	490	5.5	5.9	5.1
Watercress	920	420	1410	1.2-1.3	2.3	ND
Zucchini	530	580	480	–	ND	ND
Legumes, nuts and seeds and their products						
Fermented soybean products	3.9	5.3	2.4	–	ND	ND
Green peas	0.85	0.81	0.88	0.57	0.53	0.61
Green string beans (with pod)	270	240	300	12	9.8	14
Peanut	4.0	5.0	2.9	–	ND	ND
Peanut butter	4.1	3.8	4.4	–	ND	ND
Red bean	0.37-0.47	ND	0.74	–	ND	ND
Soybean curd (Tofu)	2.3	2.3	2.2	–	ND	ND
Tree nuts	0.41-0.51	0.81	ND	–	ND	ND
Vermicelli, mung bean	1.7	1.7	1.7	–	ND	ND
Fruits						
Apple	0.36-0.46	0.72	ND	0.39-0.49	0.78	ND
Banana	44	44	44	–	ND	ND
Cherry	0.64	1.0	0.27	–	ND	ND
Dragon fruit	6.5	4.3	8.7	0.47-0.57	0.93	ND
Dried fruits	26	29	22	–	ND	ND
Durian	3.5	4.7	2.2	0.70-0.80	ND	1.4
Grapes	6.3	4.4	8.2	0.37-0.47	ND	0.74
Kiwi	1.7	1.5	1.9	–	ND	ND
Longan / Lychee	5.8	3.6	8.0	–	ND	ND
Mandarin / Tangerine	3.2	3.1	3.3	–	ND	ND
Mango	–	ND	ND	–	ND	ND

TDS Food Item [a]	Nitrate Contents (mg/kg) [b]			Nitrite Contents (mg/kg) [b]		
	Mean [c]	1st Sampling Occasion	2nd Sampling Occasion	Mean [c]	1st Sampling Occasion	2nd Sampling Occasion
Melon	150	150	140	–	ND	ND
Orange	3.0	0.22	5.7	–	ND	ND
Papaya	41	33	48	1.2-1.3	ND	2.4
Peach	0.36-0.46	0.71	ND	–	ND	ND
Pear	0.28-0.38	0.56	ND	–	ND	ND
Pineapple	2.2	0.57	3.9	–	ND	ND
Watermelon	16	10	22	6.4	4.9	7.8
Meat, poultry and game and their products						
Beef	1.3	0.85	1.7	–	ND	ND
Beef tendon	2.8	4.3	1.3	0.91	1.3	0.52
Chicken meat, other than chicken wing	0.60	0.27	0.92	–	ND	ND
Chicken wing	1.7	1.5	1.8	–	ND	ND
Duck / goose, roasted	3.5	3.8	3.1	–	ND	ND
Ham, pork	16	14	17	–	ND	ND
Liver, goose	13	14	11	–	ND	ND
Liver, pig	0.56	0.84	0.28	–	ND	ND
Luncheon meat	13	13	12	–	ND	ND
Meat ball	1.8	2.5	1.1	–	ND	ND
Meat sausage	18	16	20	–	ND	ND
Mutton	0.83	0.92	0.73	–	ND	ND
Pork chop	0.51	0.78	0.23	–	ND	ND
Pork ribs	1.2	1.1	1.3	–	ND	ND
Pork, barbequed	6.5	6.5	6.4	–	ND	ND
Pork, other than pork chop and pork ribs	0.93	1.2	0.66	–	ND	ND
Pork, roasted	2.5	2.6	2.4	–	ND	ND
Egg and their products						
Egg, chicken	1.5	1.1	1.8	–	ND	ND
Egg, lime preserved	2.6	2.1	3.0	0.33-0.43	ND	0.66
Egg, salted	1.5	1.7	1.3	–	ND	ND
Fish, seafood and their products						
Clam	4.1	2.8	5.3	–	ND	ND

TDS Food Item [a]	Nitrate Contents (mg/kg) [b]			Nitrite Contents (mg/kg) [b]		
	Mean [c]	1st Sampling Occasion	2nd Sampling Occasion	Mean [c]	1st Sampling Occasion	2nd Sampling Occasion
Crab	25	42	8.0	–	ND	ND
Cuttlefish	3.4	5.6	1.1	–	ND	ND
Fish ball / fish cake	4.5	3.3	5.6	–	ND	ND
Fish fillet	4.8	6.2	3.4	0.18-0.28	0.36	ND
Fish, Dace, minced	0.89	0.67	1.1	–	ND	ND
Fish, Golden thread	1.1	1.5	0.73	0.55-0.65	1.1	ND
Fish, Grass carp	1.6	2.0	1.1	0.16-0.26	ND	0.31
Fish, Grouper	2.7	2.2	3.1	0.67	0.73	0.6
Fish, Mandarin fish	4.2	4.4	3.9	0.43-0.53	ND	0.86
Fish, Mangrove red snapper	2.7	3.0	2.3	0.62	0.58	0.66
Fish, Pomfret / Pompano	1.7	2.5	0.84	0.85	1.2	0.49
Fish, Salmon	1.9	2.3	1.4	–	ND	ND
Fish, Tuna	2.2	2.7	1.6	–	ND	ND
Fish, Yellow croaker	1.8	2.2	1.3	0.91	1.1	0.71
Lobster	93	16	170	–	ND	ND
Mantis shrimp	30	34	25	–	ND	ND
Mussel	4.2	2.1	6.3	–	ND	ND
Oyster	8.3	11	5.5	–	ND	ND
Salted fish	10	13	7.8	–	ND	ND
Scallop	1.6	1.5	1.7	–	ND	ND
Shrimp / Prawn	4.6	3.5	5.7	–	ND	ND
Shrimp / Prawn, dried	3.0	2.9	3.1	–	ND	ND
Squid	5.1	1.8	8.3	–	ND	ND
Dairy products						
Cheese	7.8	8.9	6.6	–	ND	ND
Fermented / Cultured beverages, dairy based	3.9	3.1	4.6	–	ND	ND
Ice-cream	5.8	7.8	3.7	–	ND	ND
Milk beverages	4.1	6.9	1.2	–	ND	ND
Milk, condensed / evaporated	7.4	6.2	8.6	–	ND	ND
Milk, skim	0.82	1.2	0.43	–	ND	ND
Milk, whole	1.2	1.3	1.0	–	ND	ND

TDS Food Item [a]	Nitrate Contents (mg/kg) [b]			Nitrite Contents (mg/kg) [b]		
	Mean [c]	1st Sampling Occasion	2nd Sampling Occasion	Mean [c]	1st Sampling Occasion	2nd Sampling Occasion
Yoghurt	4.1	3.8	4.3	–	ND	ND
Fats and oils						
Butter	1.1	0.94	1.2	–	ND	ND
Vegetable oil	–	ND	ND	–	ND	ND
Beverages, alcoholic						
Beer	5.7	5.7	5.7	–	ND	ND
Wine, red / white	5.2	5.7	4.7	0.60-0.70	1.2	ND
Beverages, non-alcoholic						
Carbonated drink (including diet version)	4.0	3.8	4.2	–	ND	ND
Coconut water	2.6	1.9	3.3	–	ND	ND
Coffee	6.6	5.7	7.4	1.4-1.5	2.7	ND
Fruit and / or vegetable juice	82	75	88	9.9	9.7	10
Malt drink	4.2	4.0	4.4	–	ND	ND
Soybean drink	3.3	4.2	2.4	–	ND	ND
Tea (including lemon tea)	0.47	0.20	0.73	–	ND	ND
Tea, chrysanthemum	5.0	5.7	4.3	–	ND	ND
Tea, with milk	4.6	4.3	4.8	–	ND	ND
Tea, with milk and tapioca pearls	6.0	4.7	7.2	0.72	0.72	0.71
Water, bottled, distilled / purified	–	ND	ND	–	ND	ND
Water, drinking	6.6	7.5	5.7	–	ND	ND
Mixed dishes						
Dim sum, beef ball, steamed	81	110	51	–	ND	ND
Dim sum, Siu Mai, steamed	4.5	3.7	5.2	–	ND	ND
Dumpling / spring roll, fried	76	67	84	–	ND	ND
Dumpling, boiled (including wonton)	20	8.3	32	0.21-0.31	ND	0.42
Dumpling, steamed	91	52	130	–	ND	ND
Glutinous rice dumpling	4.7	4.8	4.5	0.75-0.85	1.5	ND
Hamburger	29	32	25	–	ND	ND
Pizza	7.7	7.5	7.8	–	ND	ND
Rice-roll, plain, steamed	4.9	6.2	3.6	0.33	0.24	0.42
Soup, Chinese style	21	30	11	1.1-1.2	2.2	ND

TDS Food Item [a]	Nitrate Contents (mg/kg) [b]			Nitrite Contents (mg/kg) [b]		
	Mean [c]	1st Sampling Occasion	2nd Sampling Occasion	Mean [c]	1st Sampling Occasion	2nd Sampling Occasion
Soup, Western style	52	37	67	–	ND	ND
Turnip cake	520	520	510	8.2	1.4	15
Snack foods						
Potato chips	160	130	190	1.7-1.8	3.3	ND
Sugars and confectionery						
Chocolate	7.0	6.2	7.8	–	ND	ND
Honey	4.2	4.7	3.6	–	ND	ND
Jam	29	29	29	–	ND	ND
Sugar, brown / rock	6.2	5.9	6.5	–	ND	ND
Sugar, white, granulated	–	ND	ND	–	ND	ND
Condiments, sauces and herbs						
Chicken powder / cube	–	ND	ND	–	ND	ND
Chinese parsley	3060	3380	2740	1.4-1.5	2.8	ND
Curry sauce	45	20	69	–	ND	ND
Oyster sauce	16	9.4	22	–	ND	ND
Salad dressing	4.5	3.9	5.0	–	ND	ND
Sesame seed oil	0.15-0.25	0.30	ND	–	ND	ND
Soya sauce	15	12	18	–	ND	ND
Table salt	1.1	1.3	0.9	–	ND	ND
Tomato paste / ketchup	18	17	18	–	ND	ND
Vinegar	5.1	6.1	4.0	0.42-0.52	ND	0.83
White pepper	25	6.3	43	–	ND	ND

Notes:

[a] Two composite samples were tested for each TDS food item.

[b] Concentration levels < 1000 mg/kg are rounded to two significant figures while concentration levels ≥ 1000 mg/kg are rounded to three significant figures. ND denotes non-detected, i.e. results less than limit of detection (LOD).

[c] Mean concentrations for those TDS food items detected in both sampling occasions are presented as a single value, whereas those detected only in one of the two sampling occasions are presented as a range (Lower Bound-Upper Bound).

Appendix 2

A comparison of dietary exposure to nitrate and nitrite locally and those reported in other places using total diet study or similar methodology

Nitrate

Country / place	Population subgroups	Average exposure (mg/kg bw/day)	High percentile exposure (mg/kg bw/day)	Percentile used	Reference
Hong Kong SAR*	18+ yrs	3.8-3.8	8.0-8.0	90th	This study
	6-17 yrs	4.1-4.1	8.9-8.9		
Australia	17+ yrs	0.73-0.73	1.5-1.5	90th	FSANZ (2011)
	6-12 yrs	1.0-1.0	1.9-1.9		
	13-16 yrs	0.73-0.73	1.4-1.4		
Ireland*	18+ yrs	0.46-0.86	1.62-2.20	97.5th	FSAI (2016)
	5-12 yrs	0.46-0.91	1.30-1.82		
New Zealand	15+ yrs	0.82	1.64	95th	P. Cressey & B. Cridge (2022)
	5-14 yrs	0.88	1.63		
Portugal	18-74 yrs	1.17	3.33	95th	E. Vasco, M. Dias & L. Oliveira (2022)
The region of Taiwan	19-65 yrs	2.386	9.738	97.5th	Cheng-Jih Cheng et al (2021)
	65+ yrs	2.958	13.006		
	7-12 yrs	2.682	11.788		
	13-18 yrs	1.753	7.441		

Note: * Lower bound-upper bound exposure estimates were presented.

Nitrite (from exogenous sources only)

Country / place	Population subgroups	Average exposure (mg/kg bw/day)	High percentile exposure (mg/kg bw/day)	Percentile used	Reference
Hong Kong SAR*	18+ yrs	0.014-0.018	0.025-0.029	90th	This study
	6-17 yrs	0.019-0.025	0.038-0.045		
Australia*	17+ yrs	0.03-0.07	0.07-0.12	90th	FSANZ (2011)
	6-12 yrs	0.04-0.11	0.08-0.21		
	13-16 yrs	0.02-0.07	0.05-0.14		
France*	18-79 yrs	0.0008-0.002	0.002-0.007	95th	ANSES (2011)
	3-17 yrs	0.0014-0.004	0.004-0.012		
Ireland*	18+ yrs	0.001-0.01	0.004-0.02	97.5th	FSAI (2016)
	5-12 yrs	0.002-0.02	0.01-0.04		
New Zealand	15+ yrs	0.009	0.02	90th	B. Thomson, C. Nokes & P. Cressey (2007)
The region of Taiwan	19-65 yrs	0.037	0.118	97.5th	Cheng-Jih Cheng et al (2021)
	65+ yrs	0.047	0.151		
	7-12 yrs	0.049	0.175		
	13-18 yrs	0.036	0.130		

Note: * Lower bound-upper bound exposure estimates were presented.