The First Hong Kong Total Diet Study Report No. 6

The First Hong Kong Total Diet Study: Acrylamide

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EXECUTIVE SUMMARY

The Centre for Food Safety (CFS) is conducting the First Hong Kong Total Diet Study (the 1st HKTDS) aiming to estimate dietary exposures of the Hong Kong population and various population subgroups to a range of substances, including contaminants and nutrients, and thus assess any associated health risks. This report presents the dietary exposure assessment of acrylamide.

2. Acrylamide is an industrial chemical that has been used since mid-1950s in the production of polyacrylamide and it is also a component of tobacco smoke. The presence of acrylamide in food was first discovered in 2002 by Swedish researchers who revealed that high level of acrylamide was formed in food during frying or baking. Since then, similar findings that acrylamide is formed primarily in carbohydrate-rich foods prepared or cooked at high temperatures have been reported by numerous countries.

3. Acrylamide is a genotoxic carcinogen and may also cause toxic effects on the nervous system, and adverse reproductive and developmental effect in experimental animals. However, epidemiological studies do not provide any consistent evidence to show a positive correlation between the level of dietary exposure to acrylamide and the incidence of cancer in humans.

4. The Joint Food and Agriculture Organization (FAO) / World Health Organization (WHO) Expert Committee on Food Additives (JECFA) evaluated the safety of acrylamide for the first time in 2005 and re-evaluated it in 2010. JECFA considered it appropriate to use the benchmark dose lower confidence limit for a 10% extra risk of tumours ($BMDL_{10}$) in animals for assessing the risk

of acrylamide exposure, in which the end-points in mice and rats with the lowest $BMDL_{10}$, i.e. Harderian gland tumours in male mice ($BMDL_{10}$ of 0.18 mg/kg of body weight (bw)/day) and mammary tumours in female rats ($BMDL_{10}$ of 0.31 mg/kg bw/day), were used.

5. The margin of exposure (MOE) is defined as the ratio of $BMDL_{10}$ from animal study to the estimated dietary exposure to acrylamide of the local population, and can provide an indication of the health concern level without actually quantifying the risk (i.e. the higher the MOE, the lower the health concern, and vice versa). For genotoxic carcinogens, MOE value exceeding 10,000, based on a $BMDL_{10}$ from animal study, would be of low concern from a public health point of view.

Results

6. A total of 532 composite samples were tested for acrylamide. They composed of 133 different foods with 3 purchases collected and prepared on four occasions from March 2010 to February 2011. A total of 1,596 individual samples have been taken. Among the 14 food groups, food group "snack foods" contained the highest acrylamide level (mean: 680 μg/kg), followed by "vegetables and their products" (mean: 53 μg/kg), and "legumes, nuts and seeds and their products" (mean: 40 μg/kg). On the other hand, the majority (95%) of samples for "fish and seafood and their products", and all samples of "eggs and their products" and "beverages, alcoholic" were not detected with acrylamide. At food item level, potato chips, which was the only item in food group "snack foods", was found to contain the highest level (mean: 680 μg/kg), followed by fried potato (mean: 390 μg/kg) and zucchini (mean: 360 μg/kg).

7. The dietary exposures to acrylamide of the average and high consumer of the local population were 0.21 and 0.54 μg/kg bw/day respectively, and their MOEs (847 – 1,459 for the average population, 334 – 576 for the high consumers) were all well below 10,000. It may indicate human health concern because of the relatively low figures for a genotoxic carcinogen.

8. The main dietary source of acrylamide was "vegetables and their products" (52.4% of the total exposure), particularly stir-fried vegetables (44.9%), followed by "cereals and their products", and "mixed dishes". Besides, fried potato products such as fried potato and potato chips, biscuits and breakfast cereals were also significant sources of exposure due to the high acrylamide level found in these food items.

9. The Study findings showed that stir-fried vegetables contained relatively high level of acrylamide and their levels varied among vegetables of the same kinds. In contrast, no acrylamide was detected in any raw or boiled vegetables, and only low level of acrylamide was found in some kinds of stir-fried vegetables such as Chinese spinach, watercress, spinach and Chinese lettuce. The formation of acrylamide may be affected by many factors such as the presence of asparagines and reducing sugars in the vegetables, and the cooking temperature and time. In this Study, the vegetable samples were fried without cooking oil added, which may not truly reflect the situation of domestic cooking on stir-frying vegetables and may introduce bias in the test results.

10. Further investigation on the formation of acrylamide in stir-frying vegetables with and without cooking oil added under different cooking conditions was conducted. Four types of vegetables, namely Chinese

flowering cabbage, water spinach, zucchini and onion, which are found to be the major contributors to dietary acrylamide exposure, were selected for testing. The acrylamide level in stir-fried vegetables prepared by restaurants was also determined.

11. The findings of the experiments revealed that a higher acrylamide level was formed where the vegetables were fried at a higher temperature and for a longer time, and in general, less acrylamide is formed in the two leafy vegetables i.e. Chinese flowering cabbage and water spinach than zucchini and onion, but no obvious associations were observed in acrylamide level for frying with or without cooking oil added. Lower acrylamide levels were found in these experiments and in the vegetables sampled from restaurants as compared with the TDS samples of the same kinds. Therefore, the estimated dietary exposure to acrylamide from fried vegetables in the TDS study might be overestimated. Moreover, it should be noted that many variables may affect the formation of acrylamide, such as the batch to batch variation, food composition (e.g. contents of reducing sugars and amino acid) and processing conditions (e.g. cooking temperature and time), etc.

Conclusions and Recommendations

12. The dietary exposures to acrylamide of the average and high consumer of the local population were 0.21 and 0.54 μg/kg bw/day respectively, and their MOEs were all well below 10,000. It may indicate human health concern because of the relatively low figures for a genotoxic carcinogen. Efforts should continue to be made in the interest of reducing acrylamide levels in food locally.

13. The food trade is advised to seek ways to reduce the level of acrylamide in food. The food trade may make reference to the trade guidelines on reduction in acrylamide level during the selection of raw materials and the formulation of recipes and food processing conditions.

14. The public is advised to have a balanced and varied diet, consume at least three servings of vegetables a day, and moderate the consumption of fried foods such as potato chips and fried potatoes. The public is also advised not to cook food for too long or at too high a temperature, in order to reduce the formation of acrylamide. To reduce the level of exposure to acrylamide from vegetables, the public may consider blanching the vegetables before frying, or cooking them by boiling or steaming. Some vegetables may also be eaten raw after washing.

15. International bodies and many national authorities have endeavoured to explore ways for reducing the acrylamide in foods. CFS will keep in view latest developments on the subject.

The First Hong Kong Total Diet Study:

Acrylamide

BACKGROUND

Total Diet Study (TDS) has been recognised internationally as the most cost effective way to estimate dietary exposures to food chemicals or nutrients for various population groups and to assess their associated health risks. It provides a scientific basis for assessing food safety risks and regulating food supply. Since 1960s, various countries, such as the United Kingdom (UK), the United States of America (USA), Canada, Australia, New Zealand and Mainland China, have been conducting their own TDS.

Introduction of the First Hong Kong Total Diet Study (1st HKTDS)

2. This was the first time carrying out the TDS in Hong Kong by the Centre for Food Safety (CFS). It aims to estimate dietary exposures of the Hong Kong population and various population subgroups to a range of substances, including contaminants and nutrients, and thus assess any associated health risks.

3. The 1st HKTDS is a large and complex project that comprises sampling and food preparation, laboratory analysis and dietary exposure estimation. It covered the majority of food normally consumed by the Hong Kong population with laboratory analysis of over 130 substances, including contaminants and nutrients.

Acrylamide

4. This report focuses on one of the substances covered in the 1st HKTDS, i.e. acrylamide, a processing contaminant. The dietary exposures of the Hong Kong population to acrylamide and its associated potential health risks have been assessed.

5. The presence of acrylamide in food was first discovered in 2002 by Swedish researchers who revealed that high level of acrylamide was formed in food during frying or baking. Due to concerns about the possible public health risks associated with the dietary exposure to acrylamide, the issue has attracted attention in the international arena, and many researches and studies of both toxicity and the occurrence of acrylamide in food have since been conducted around the world.[1,2]

Sources of Acrylamide

6. Acrylamide is an industrial chemical that has been used since mid-1950s in the production of polyacrylamide which has multiple applications in chemical and manufacturing industries, for example, as a flocculant for clarifying drinking-water, as a sealant for construction of dams and tunnels, as a binder in paper and pulp industry, and dye synthesis. Acrylamide is also a component of tobacco smoke.[2] It has been first reported by Swedish researchers in 2002 to be formed in a variety of baked and fried foods cooked at high temperature. Since then, similar findings that acrylamide is formed primarily in carbohydrate-rich foods prepared or cooked at high temperature have been reported by numerous countries such as Norway, Switzerland, the UK and the USA.[3]

7. Acrylamide is formed where foods are cooked or processed in high temperature (usually > 120°C), mainly via the Maillard reactions. Upon heating, the free amino acid asparagine in food, the most important precursor, reacts with reducing sugars or other carbonyl compounds to form acrylamide.[1, 2] Other formation mechanisms have also been identified, for example, formation through pyrolysis of the wheat protein gluten or via enzymatic decarboxylation of asparagines in raw potatoes, but these routes may be of minor importance.[2] In contrast, only trace amounts of acrylamide will be formed by boiling.[1]

8. Potato crisps, French fries, biscuits, crisp bread and crackers and coffee were reported to contain acrylamide in significant levels in many countries, and their ranges of mean acrylamide levels are 399 – 1202 μg/kg, 159 – 963 μg/kg, 169 – 518 μg/kg, 87 – 459 μg/kg and 3 – 68 μg/L, respectively.[2] Vegetables other than potatoes cooked in high temperature, such as baking, grilling, roasting and pan-frying, were also reported to contain acrylamide in some overseas surveys and researches. A Turkish study revealed that the acrylamide level in grilled vegetables can reach 359 μg/kg.[4] A Japanese research revealed that vegetables, such as asparagus, pumpkin, eggplant and green gram sprouts, contained acrylamide at levels of > 100 μg/kg, with the highest at 550 μg/kg (for green gram sprouts) after baking at 220°C for 5 minutes.[5] Pan-fried vegetables as reported by Japan were also found to contain acrylamide ranged from 30 to 393 μg/kg in Japan (393 μg/kg in snow peas, 100 μg/kg in bean sprouts and asparagus, 30 μg/kg in broccoli, cabbage, pumpkin, eggplant, haricot beans and onion).[2]

Toxicity

9. The Joint Food and Agriculture Organization (FAO) / World Health Organization (WHO) Expert Committee on Food Additives (JECFA) evaluated the safety of acrylamide for the first time in 2005 and re-evaluated it in 2010.

10. Orally administered acrylamide is rapidly and extensively absorbed from the gastrointestinal tract, then metabolised and excreted in urine, mainly as metabolites such as glycidamide. Animal studies showed that acrylamide is widely distributed to all tissues and to the fetus in pregnant animals. It has also been found in human milk.[2]

11. Numerous animal studies have shown that the nervous system is a principal target site for the toxic effects of acrylamide and continued dosing with acrylamide has been shown to induce degeneration of nerve terminals in brain areas for learning, memory and other cognitive functions. Epidemiological studies in humans due to occupational or accidental exposure also suggested that the nervous system is a principal target site for toxic effects of acrylamide. Animal studies have also showed adverse reproductive (such as reduced fertility, dominant lethal effects and adverse effect on sperm count and morphology in male rodents) and developmental effects (such as fetotoxic in mice) of acrylamide.[1]

12. Acrylamide and its metabolite glycidamide are mutagenic and clastogenic in mammalian cells in vitro and in vivo.[1] Recent in vitro genotoxicity studies indicated that acrylamide in the absence of activation is

weak mutagen but an effective clastogen.[2] Acrylamide is a multisite carcinogen in rodents and may cause tumours in thyroid and mammary gland and peritesticular mesothelium in rats, and tumours in lung, Harderian gland, forestomach, mammary and ovary in mice.[2]

13. In 1994, the International Agency for Research on Cancer (IARC) considered that there was sufficient evidence of carcinogenicity in experimental animals but inadequate evidence of carcinogenicity in human. IARC has classified acrylamide as Group 2A agent, i.e. probably carcinogenic to humans.[6] However, JECFA commented in the 2010 evaluation that the epidemiological studies do not provide any consistent evidence that occupational exposure or dietary exposure to acrylamide is associated with cancer in humans.[2]

14. As acrylamide is a genotoxic carcinogen, no safe intake level can be established. JECFA considered it appropriate to use the benchmark dose lower confidence limit for a 10% extra risk of tumours ($BMDL_{10}$) in animals for assessing the risk of acrylamide exposure, and that the end-points in mice and rats with the lowest $BMDL_{10}$, i.e. Harderian gland tumours in male mice ($BMDL_{10}$ of 0.18 mg/kg bw/day) and mammary tumours in female rats ($BMDL_{10}$ of 0.31 mg/kg bw/day) were used for assessment.[2] The BMDL is the lower confidence limit of a point on the dose-response curve that characterises adverse effect to account for uncertainty in the data.[7] It should be noted that the significance of the Harderian gland tumours in mice is difficult to interpret with respect to humans as no equivalent organ is available in humans. However, JECFA commented that it was unable to discount the effect in the Harderian gland, having considered acrylamide being a multisite carcinogen in rodents.[2]

15. For risk assessment, the margins of exposure (MOEs) take relative cancer potency and exposure estimates into account for providing an indication of the level of health concern without actually quantifying the risk. The MOE is defined as the ratio of $BMDL_{10}$ from animal study to the estimated dietary exposure to acrylamide of the local population. For genotoxic carcinogens, MOE value exceeding 10,000, based on a $BMDL_{10}$ from animal study, would be of low concern from a public health point of view. The MOEs can be used for priority setting for risk management actions, in which the level of regulatory or non-regulatory intervention can take account of the size of the MOE. The higher the MOE value, the lower the health concern, and vice versa.[7, 8]

The Previous Local Studies

16. The Food and Environmental Hygiene Department (FEHD) conducted several studies on acrylamide levels in local food and the dietary exposures of the local population, as well as the methods for reduction of acrylamide formation, since 2003. These studies found that high level of acrylamide was detected in snack foods such as potato chips and biscuits. The latest 2010 study[9] revealed that the dietary exposures to acrylamide of the average and high consumers (97.5^{th} percentile) of the local population were estimated to be 0.13 μg/kg bw/day and 0.69 μg/kg bw/day, respectively, with MOEs (for Harderian gland tumours in male mice) of 1385 and 261 respectively, and concluded that these low MOE values might indicate human health concern.

17. The studies conducted so far focused on local food products that were reported to have higher acrylamide contents, and in other words, not all

foods that may contain acrylamide were included. Even though the assessment could only reflect the exposures of the local population partially, the findings of the 2010 study suggested that there were possible concerns from the angle of the dietary acrylamide exposure of the local population. Acrylamide was selected in the 1st HKTDS to re-examine the issue with a view to obtaining a more accurate estimate of dietary exposure to acrylamide from the whole diet.

METHODOLOGY AND LABORATORY ANALYSIS

Methodology of the 1st HKTDS

18. The 1st HKTDS involved purchasing samples of food commonly consumed throughout Hong Kong, preparing them as consumed, combining the foods into well-defined food composites, homogenising them, and then analysing them for a range of substances. The analytical results were then combined with food consumption information of various population groups captured from the Hong Kong Population-based Food Consumption Survey (FCS) [10], to estimate the dietary exposures.

19. One hundred and fifty TDS food items were selected for the Study, based on the food consumption data of the FCS. Three samples of each TDS food item were collected and prepared in a form of food normally consumed on four occasions from March 2010 to February 2011. A total of 1,800 samples were collected and combined into 600 composite samples for laboratory analysis.

20. Among the 150 TDS food items, 133 of them (excluding 17 fruit items) were selected for testing of acrylamide with reference to the occurrence in food (i.e. acrylamide is formed in food mainly through high temperature processing). Samples taken from the four occasions (1,596 individual samples) were tested in form of composite samples (532 composite samples).

21. Dietary exposure estimation was performed with the aid of an in-house developed web-based computer system, the EASY (Exposure Assessment System), which involved food mapping and weighting of data. The mean and 95th percentile of the exposure levels were used to represent the dietary exposures of the average and high consumers of the local population respectively.

22. Details of the methodology are given in the same series of reports on Methodology.[11]

Laboratory Analysis of Acrylamide

23. Laboratory analysis of acrylamide was conducted by the Food Research Laboratory (FRL) of the CFS. Two grams of sample portion was extracted with water and defatted by n-hexane. The sample extract was then cleaned up by two solid phase extraction, and the acrylamide was subsequently determined by the liquid chromatography-tandem mass spectrometry (LC-MS/MS) technique. D3-acrylamide was used as an internal reference for the analysis. The test method was validated by single-laboratory validation against certified reference materials. The limit of detection (LOD) and the

limit of quantification (LOQ) were 1 and 3 μg/kg in food, and 0.03 and 0.1 μg/kg in water respectively.

RESULTS AND DISCUSSION

Concentrations of Acrylamide in TDS Foods

24. A total of 532 composite samples on four occasions were tested for acrylamide and the results in 14 TDS food groups are summarised in Table 1 and the results of the 133 TDS food items are shown in Appendix 1. About half of the composite samples (47%) were detected with acrylamide. According to the recommendation of WHO on evaluation of low-level contamination of food in treatment for those non-detected results,[12] all non-detected results were assigned with levels at half of LOD for expressing the acrylamide contents as well as estimating the dietary exposures throughout the report.

Table 1: Acrylamide Contents (μg/kg) in TDS Food Groups of the 1st HKTDS

Food group	Number of composite samples	% of composite samples < LOD	Mean [range] (μg/kg)#	
Cereals and their products	76	30	26	[ND – 220]
Vegetables and their products	140	31	53	[ND – 490]
Legumes, nuts and seeds and their products	24	50	40	[ND – 250]
Meat, poultry and game and their products	48	63	2	[ND – 14]
Eggs and their products	12	100	0.5	[ND]
Fish and seafood and their products	76	95	1	[ND – 3]
Dairy products	20	75	1	[ND – 8]
Fats and oils	8	88	1	[ND – 2]
Beverages, alcoholic	8	100	0.5	[ND]
Beverages, non-alcoholic	40	63	2	[ND – 27]
Mixed dishes	48	42	5	[ND – 43]
Snack foods	4	0	680	[430 – 1100]
Sugars and confectionery	8	50	19	[ND – 53]
Condiments, sauces and herbs	20	60	2	[ND – 14]
Total	532	53		

Notes:

\# As only 53% of results are below limit of detection (LOD), half of LOD is used for all results less than LOD in calculating the mean concentration.

ND denotes non-detected, i.e. results less than LOD.

25. The highest acrylamide level was detected in food group "snack foods" (mean: 680 μg/kg), followed by "vegetables and their products" (mean: 53 μg/kg) and "legumes, nuts and seeds and their products" (mean: 40 μg/kg). However, the majority (95%) of samples for "fish and seafood and their products", and all samples of "eggs and their products" and "beverages, alcoholic" were not detected with acrylamide.

Snack foods

26. Potato chips item, which is the only item in the food group “snack foods”, was found to contain the highest level (mean: 680 μg/kg, ranged from 430 to 1100 μg/kg) among all the 133 TDS food items. The acrylamide levels found in potato chips samples were similar to those reported in other places (mean: 399 – 1202 μg/kg) [2] and our 2010 study (mean: 788 μg/kg) [9].

Vegetables and their products

27. In the food group “vegetables and their products”, the mean levels of the 35 TDS food items ranged from 0.5 to 390 μg/kg, with the highest detected in fried potato (mean: 390 μg/kg), followed by zucchini (mean: 360 μg/kg) and garlic (mean: 200 μg/kg). The acrylamide levels found in fried potato samples were similar to those reported in other places (mean: 159 – 963 μg/kg) [2] and our 2010 study (mean: 382 μg/kg) [9]. Zucchini and garlic, which were cooked by stir-frying, as well as the other stir-fried vegetables, were found to contain acrylamide at relatively high level.

Legumes, nuts and seeds and their products

28. In the food group “legumes, nuts and seeds and their products, the mean levels of the 6 TDS food items ranged from 0.5 to 150 μg/kg, with the highest detected in green string beans, with pod (mean: 150 μg/kg), followed by peanut butter (mean: 64 μg/kg) and peanut (mean: 25 μg/kg). The remaining 3 items (mung bean vermicelli, beancurd and fermented bean products) were not detected with acrylamide.

Dietary Exposure to Acrylamide

29. Dietary exposures to acrylamide of the average and high consumer of the local population were 0.21 μg/kg bw/day and 0.54 μg/kg bw/day respectively. Further analysis of dietary exposures of the individual age-gender population subgroups was performed and the results are shown in Figure 1 and Appendix 2. Overall, the dietary exposures to acrylamide of females were higher than those of males within most age groups, and the highest dietary exposure among all age-gender population subgroups was found in females aged 20 – 29 (0.25 μg/kg bw/day for the average consumer, 0.71 μg/kg bw/day for the high consumer).

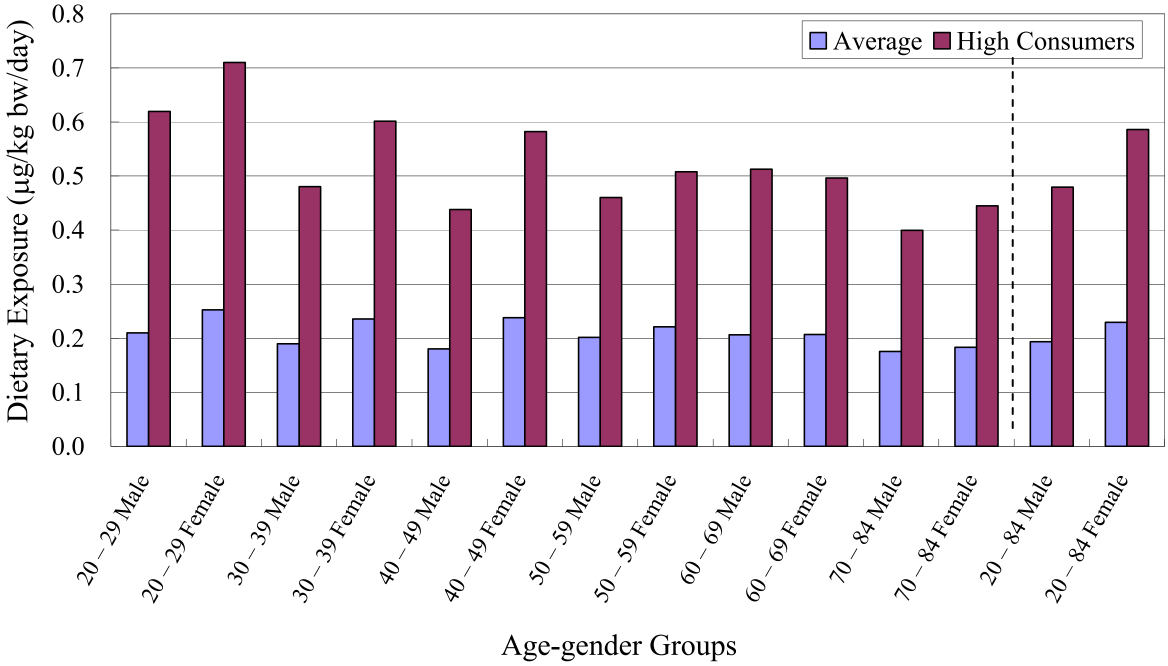

Figure 1: Dietary Exposures to Acrylamide for the Average and High Consumers of Individual Age-gender Groups of the 1st HKTDS

30. The MOEs of acrylamide for the average and high consumer of the local population were determined by using the two $BMDL_{10}$ values. The

dietary exposures to acrylamide and their MOEs are shown in Table 2. All the MOEs (847 – 1,459 for the average population, 334 – 576 for the high consumers), determined from the increase in cancer risk of animals, were found to be well below 10,000, which may indicate human health concern because of the relatively low figures for a genotoxic carcinogen.

Table 2: Dietary Exposures (μg/kg bw/day) to Acrylamide for the Average and High Consumer of the Local Population and their Margin of Exposures (MOEs)

	Average	High consumer
Dietary exposure (μg/kg bw/day)	0.21	0.54
MOEs		
♦ based on $BMDL_{10}$ of 0.18 mg/kg bw/day for Harderian gland tumours in male mice	847	334
♦ based on $BMDL_{10}$ of 0.31 mg/kg bw/day for mammary tumours in female rats	1459	576

Major Food Contributors

31. Dietary exposures to acrylamide for the average population from the 14 TDS food groups are shown in Table 3 and their contributions to total dietary exposure are shown in Figure 2.

Table 3: Dietary Exposure (μg/kg bw/day) to Acrylamide for the Average Individual of the Local Population by TDS Food Group

TDS Food Group	Dietary Exposure in μg/kg bw/day #	% contribution of total exposure
Cereals and their products	0.03	14.7
Vegetables and their products	0.11	52.4
Legumes, nuts and seeds and their products	0.02	7.4
Meat, poultry and game and their products	0.00	2.0
Fish and seafood and their products	0.00	0.3
Dairy products	0.00	0.3
Beverages, non-alcoholic	0.01	6.9
Mixed dishes	0.02	9.4
Snack foods	0.01	4.7
Sugars and confectionery	0.00	0.2
Condiments, sauces and herbs	0.00	1.4
Other food groups (including eggs and their products, fats and oils, and beverages, alcoholic)	0.00	0.2
Total	0.21†	100.0†

Notes:

\# As only 53% of results are below limit of detection (LOD), half of LOD is used for all results less than LOD in calculating the exposure estimates.

† Figures may not add up to total due to rounding.

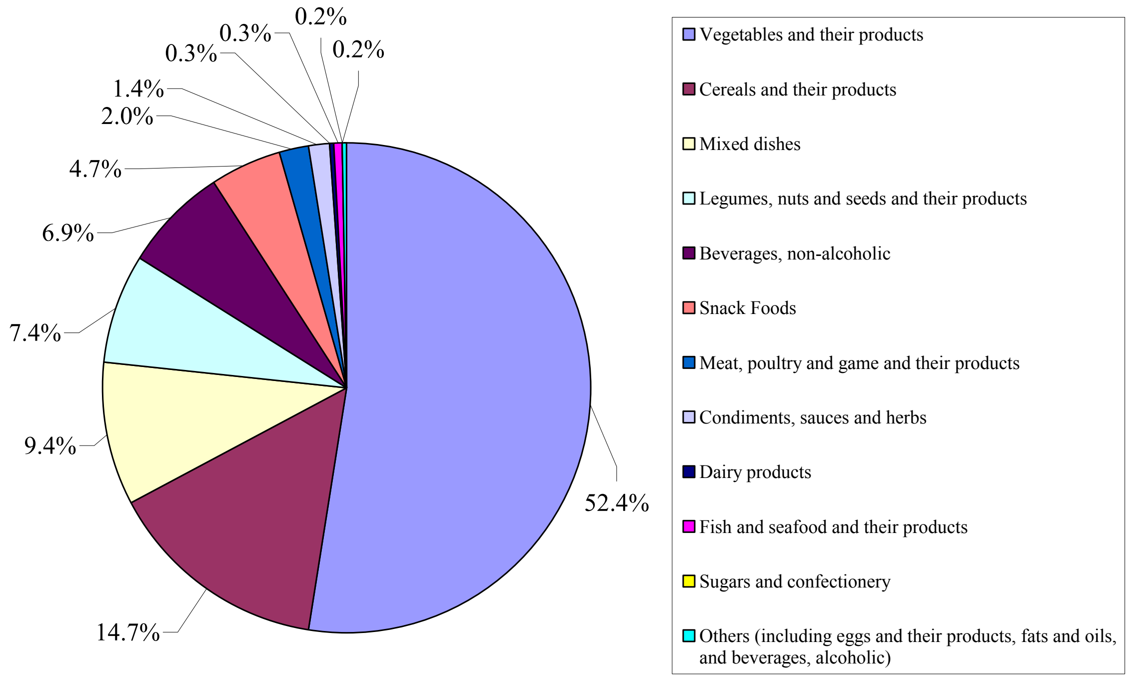

Figure 2: Percentage Contribution to Dietary Exposure to Acrylamide by Food Group

32. In our findings, the main dietary source of acrylamide was "vegetables and their products" (52.4% of the total exposure), followed by "cereals and their products" (14.7%), and "mixed dishes" (9.4%). Our findings are similar to that in Mainland China, in which the major contributor was found to be vegetables (48.4%).[13] In contrast, the major food contributors to acrylamide dietary exposure were reported to be French fries (10 – 60%), potato chips (10 – 22%), bread and rolls /toast (13 – 34%), and pastry and sweet biscuits (or cookies) (10 – 15%) in most countries.[2]

<u>Stir-fried vegetables</u>

33. In the food group "vegetables and their products", stir-fried vegetables amounted to 44.9%. Among them, the Chinese flowering cabbage was the major contributor (16.2% of total exposure), followed by water spinach

(5.8%), zucchini (3.9%) and onion (3.4%). The high contribution to acrylamide exposure from vegetables and their products in this Study is likely because most leafy vegetables were prepared by stir-frying which may incur the formation of acrylamide and also they are consumed in a large amount among the local population. However, in this Study, the vegetables were stir-fried without cooking oil added, which was consistent with the general food preparation procedures in the TDS conducted by overseas countries such as Australia[14] and New Zealand[15], and it may not truly reflect the situation of domestic cooking and may introduce bias in the test results. The influence in acrylamide level by stir-frying vegetables was further analysed in para 37.

<u>Fried potato and potato chips</u>

34. Due to the high level of acrylamide, fried potato (mean: 390 μg/kg) and potato chips (mean: 680 μg/kg) together amounted to 10.6% of the total exposure (fried potato: 7.2%, potato chips: 3.4%).

<u>Biscuits and breakfast cereals</u>

35. In food group "cereals and their products", biscuits (5.3 % of the total exposure) and breakfast cereals (2.3%) were found to be the major contributor of this food group due to the high acrylamide level (mean: 150 μg/kg, biscuits; 160 μg/kg, breakfast cereals) among the other cereals.

<u>Chinese soup</u>

36. Among the food items in the "mixed dishes", the Chinese soup was found to be the major contributor of this food group (6.3% of the total exposure) although the samples contained very low acrylamide level (mean: 5 μg/kg). Its

contribution is largely due to the high consumption amount (mean: 152 ml/person/day).

Influence in Acrylamide Level by Stir-Frying Vegetables

37. The influence in acrylamide level by stir-frying vegetables was further analysed. The acrylamide levels among 22 stir-fried vegetable items are compared. All the 22 stir-fried items were detected with acrylamide in at least one sample of the individual items, with the mean levels ranged from 1 μg/kg to 360 μg/kg and their levels in composite samples of the same items varied (Appendix 1). The distribution of the acrylamide contents among the 22 stir-fried vegetable items is provided in Table 4. On the other hand, 8 non-fried vegetable items (i.e. non-cooked, boiled or steamed) were not detected with acrylamide. The Study findings showed that stir-fried vegetables were found to contain relatively high level of acrylamide and their levels varied among vegetables of the same kinds, in contrast, no acrylamide was detected in any raw or boiled vegetables, and only low levels of acrylamide were found in some kinds of stir-fried vegetables such as Chinese spinach, watercress, spinach and Chinese lettuce. The formation of acrylamide may be affected by many factors such as the presence of asparagine and reducing sugars in the vegetables, and the frying temperature and time.

Table 4: Acrylamide Contents (μg/kg) among the 22 Stir-fried Vegetable Items

Mean acrylamide contents (μg/kg)	No. of items	Food items
< 10	5	Bitter melon, Chinese lettuce, Chinese spinach, spinach, watercress
11 – 50	7	Broccoli, Chinese cabbage, Chinese flowering cabbage, European variety cabbage, mung bean sprout, petiole Chinese cabbage, tomato
51 – 100	5	Celery, Chinese kale, eggplant, leaf mustard, sponge gourd
101 – 360	5	Garlic, onion, sweet pepper, water spinach, zucchini

38. Further investigation on the formation of acrylamide in stir-frying vegetables was conducted. Four types of vegetables, which are found to be the major contributors to dietary acrylamide exposure, were selected for testing and they are Chinese flowering cabbage, water spinach, zucchini and onion. They were stir-fried with and without cooking oil added under different combination of cooking power (i.e. medium (induction cooker at 1200 W) and medium-high (induction cooker at 1600 W)) and cooking time (i.e. 3 and 6 minutes). In addition, three samples each of the three vegetable types (i.e. Chinese flowering cabbage, water spinach and zucchini) prepared by restaurants were taken for testing of acrylamide.

39. The findings on acrylamide levels in stir-frying vegetables under different conditions are shown in Figures 3 and 4. The findings revealed that a higher acrylamide level was formed where the vegetables were fried at a higher temperature and for a longer time, and in general, less acrylamide was formed in the two leafy vegetables, i.e. Chinese flowering cabbage and water

spinach, than zucchini and onion. No obvious associations were observed in acrylamide level for frying with or without cooking oil added. Lower acrylamide levels were found in these experiments and in the vegetables sampled from restaurants as compared with the TDS samples of the same kinds (Figure 5).

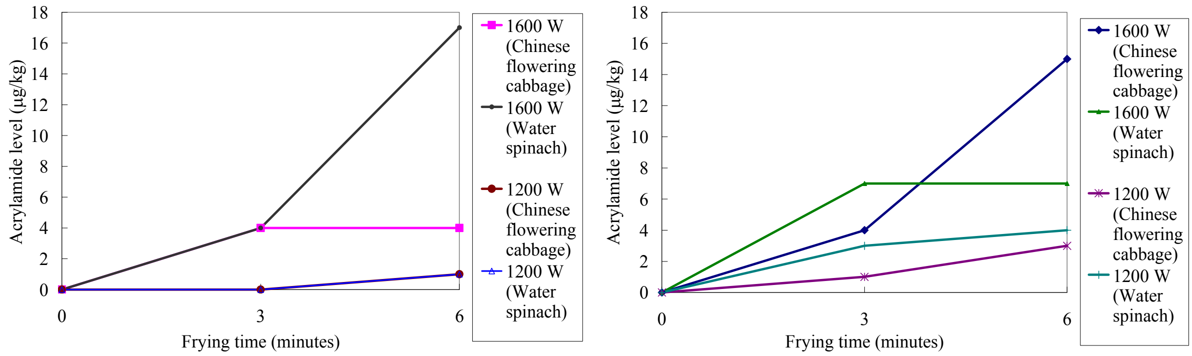

Figure 3: Acrylamide Levels in Stir-frying Chinese Flowering Cabbage and Water Spinach under Different Conditions (*Left*: Without cooking oil; *Right*: With cooking oil)

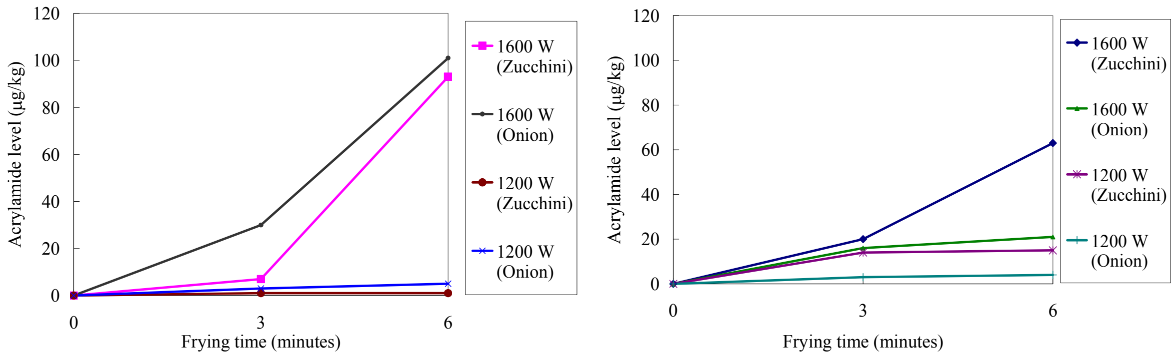

Figure 4: Acrylamide Levels in Stir-frying Zucchini and Onion under Different Conditions (*Left*: Without cooking oil; *Right*: With cooking oil)

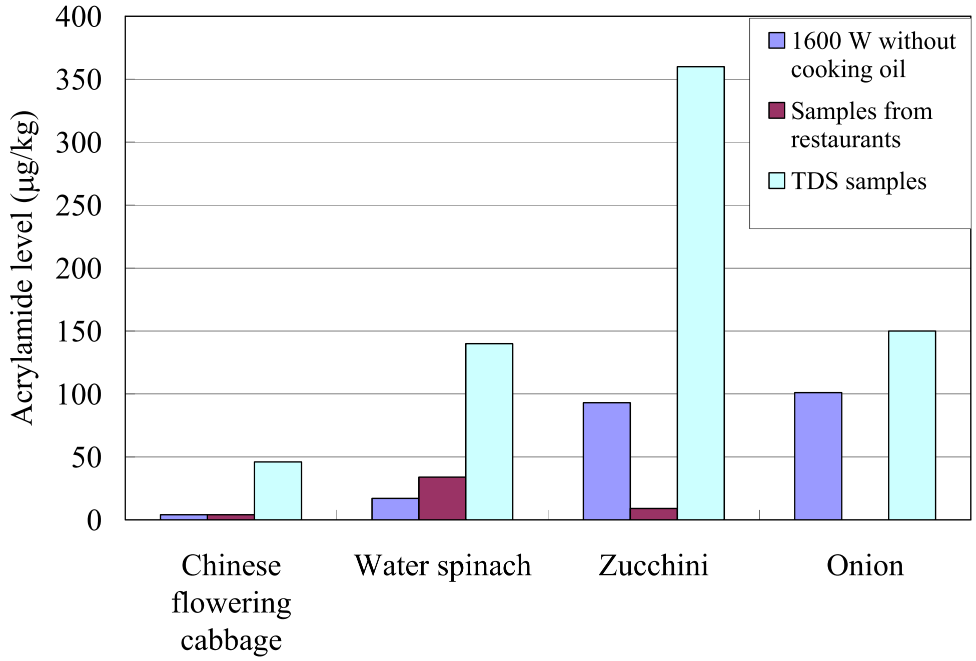

Figure 5: Comparison of Acrylamide Level in Stir-fried Vegetables with TDS Results

40. Since lower acrylamide level was detected in fried vegetables from restaurants, further investigation was carried out. It was found that it was common to blanch leafy vegetables for about 1 minute or less before frying. Based on these findings, blanching vegetables may help to reduce the formation of acrylamide.

41. The estimated dietary exposure to acrylamide from fried vegetables in the TDS study might be overestimated. Moreover, it should be noted that many variables may affect the formation of acrylamide, such as batch to batch variation, food composition (e.g. contents of reducing sugars and amino acid) and processing conditions (e.g. cooking temperature and time), etc.[1,16]

Comparison with the Previous Local Studies

42. The average dietary exposure estimated in our current Study (0.21 μg/kg bw/day) was higher than that in the 2010 study (0.13 μg/kg bw/day)[9] and the MOE values of both studies were well below 10,000. Both studies suggested that there is health concern among the local population because of the relatively low MOE values. It should be noted that as only limited food items were covered in the previous study, our current findings are more comprehensive than the previous study.

International Comparison

43. Table 5 presents the data on the local and reported overseas dietary exposures to acrylamide. It can be seen that the dietary exposure estimated in our Study is around the lower end of the range of the exposure estimates obtained from other places.

Table 5: A Comparison of the Local and Overseas Dietary Exposures to Acrylamide

Places	Dietary exposure of adult (μg/kg bw/day)	
	Average	High consumer
Hong Kong*	0.21	0.54 (95th percentile)
China (2013) [13]	0.286	0.490 (95th percentile)
UK (2005) [17]	0.3	0.6 (97.5th percentile)
Canada (2012) [18]	0.3 – 0.4	
Europe (2011) [19]	0.31 – 1.1	0.58 – 2.3 (95th percentile)
USA (2006)[20]	0.4 (age 2+)	
France (2012) [21]	0.43	1.02 (95th percentile)
Ireland (2011) [22]	0.59	1.75 (97.5th percentile)
New Zealand (2012) [23]	0.84 (Male 25+) 0.66 (Female 25+)	1.39 (Male 25+) (95th percentile) 1.15 (Female 25+) (95th percentile)

* Data are extracted from the current Study.

44. However, caution should be exercised in making any direct comparison of the data due to the difference in time the reported studies were carried out, the methods of collection of consumption data, the methods of contaminant analysis and the methods of treating results below detection limits.

Risk Reduction

45. Subsequent to the reports on the formation of acrylamide in food, international bodies and many national authorities have made efforts to explore ways to reduce the acrylamide in foods. Authorities in overseas countries, such as the USA, Canada and the European Commission are also implementing monitoring programme on the acrylamide levels in food. In 2009, Codex Alimentarius Commission has adopted a Code of Practice for Reduction of

Acrylamide in Foods. This Code of Practice aims to provide national and local authorities, manufacturers and other relevant bodies with guidance to prevent and reduce formation of acrylamide in potato products and cereal products.[24] CFS has also issued in 2011 and revised in 2013 the trade guidelines on reducing acrylamide in food to provide recommendations to help the trade minimise the formation of acrylamide in food, especially in potato and cereal based products and stir-fried vegetables.[25]

46. JECFA mentioned in its 2010 evaluation that the mitigation after 2003 was reported mainly for food types with comparably high acrylamide levels or single products with acrylamide levels in the high end within their food types and thus the exposure for some individuals or population subgroups might significantly be reduced. However, it would have little effect on the dietary exposure for the general population in most countries. JECFA recommended the pursuit of further efforts on developing and implementing mitigation methods for acrylamide in foods as a subject of major importance for dietary exposure.[2]

Limitations of the Study

47. Some food items such as dried fruits may contain acrylamide are not covered in our current Study. It may lead to underestimation of the dietary exposure to acrylamide. For instance, the additional exposure from dried fruits is estimated to be less than 0.3% of total exposure (mean level in dried fruits: 47 μg/kg [2] and its average consumption amount: 0.62 g/person/day [10]).

48. Besides, other limitations were described in the report on methodology.[11]

CONCLUSIONS AND RECOMMENDATIONS

49. The dietary exposures to acrylamide were 0.21 and 0.54 μg/kg bw/day for the average and high consumer of the local population respectively, and their MOEs were all well below 10,000. It may indicate human health concern because of the relatively low figures for a genotoxic carcinogen. However, there is no consistent evidence on the association between dietary exposure to acrylamide and cancer in humans from epidemiological studies. Nevertheless, efforts should continue to be made in the interest of reducing acrylamide levels in food locally.

50. Frying vegetables would induce the formation of acrylamide and fried vegetables were found to be the major contributor of the exposure due to the relatively high level of acrylamide in most stir-fried vegetables and the high consumption amount. Besides, fried potato products such as fried potato and potato chips, biscuits and breakfast cereals were also significant sources of exposure due to the high acrylamide level found in these food items.

51. The food trade is advised to seek ways to reduce the level of acrylamide in food. The food trade may make reference to the said trade guidelines on reduction in acrylamide level during the selection of raw materials and the formulation of recipes and food processing conditions.

52. The public is advised to have a balanced and varied diet, consume at least three servings of vegetables a day, and moderate the consumption of fried foods such as potato chips and fried potatoes. The public is also advised not to cook food for too long or at too high a temperature, in order to reduce the formation of acrylamide. To reduce the level of exposure to acrylamide from vegetables, the public may consider blanching the vegetables before frying vegetables, or cooking them by boiling or steaming. Some vegetables may also be eaten raw after washing.

53. International bodies and many national authorities have endeavoured to explore ways for reducing the acrylamide in foods. CFS will keep in view latest developments on the subject.

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Appendix 1

Acrylamide Contents (μg/kg) in TDS Foods of the 1st HKTDS

TDS food Item	Number of composite samples	% of composite samples < LOD	Mean (μg/kg) * (ND=LOD/2)	[range]
Cereals and their products:	**76**	**30**	**26**	**[ND – 220]**
Rice, white			0.5	[ND]
Rice, unpolished			0.5	[ND]
Corn			1	[ND – 2]
Noodles, Chinese or Japanese style			0.5	[ND]
Pasta, Western style			5	[ND – 16]
Instant noodles			6	[ND – 12]
Noodles, rice			0.5	[ND]
Bread, plain			3	[2 – 5]
Bread, raisin			6	[4 – 8]
"Pineapple" bun			15	[14 – 17]
Sausage/ham/luncheon meat bun			4	[2 – 8]
Chinese steamed bread			6	[2 – 9]
Biscuits			150	[81 – 220]
Cakes			7	[5 – 8]
Pastries			8	[6 – 10]
Pastries, Chinese			39	[11 – 65]
Oatmeal			1	[ND – 2]
Breakfast cereals			160	[97 – 190]
Deep-fried dough			73	[38 – 150]
Vegetables and their products:	**140**	**31**	**53**	**[ND – 490]**
Carrot/ Radish			0.5	[ND]
Potato			0.5	[ND]
Potato, fried			390	[290 – 490]
Broccoli #			20	[4 – 38]
Cabbage, Chinese #			29	[18 – 46]
Cabbage, Chinese flowering #			46	[34 – 70]
Cabbage, European variety #			12	[7 – 19]
Cabbage, Petiole Chinese #			15	[3 – 37]
Celery #			54	[24 – 110]
Chinese kale #			61	[22 – 140]
Chinese spinach #			5	[1 – 10]
Leaf mustard #			52	[4 – 160]
Lettuce, Chinese #			1	[ND – 1]
Lettuce, European			0.5	[ND]

TDS food Item	Number of composite samples	% of composite samples < LOD	Mean (µg/kg) * (ND=LOD/2)	[range]
Mung bean sprout #			19	[1 – 35]
Spinach #			4	[ND – 15]
Water spinach #			140	[50 – 310]
Watercress #			5	[1 – 14]
Bitter melon #			6	[2 – 12]
Cucumber			0.5	[ND]
Hairy gourd			0.5	[ND]
Pumpkin			0.5	[ND]
Sponge gourd #			60	[43 – 88]
Wax gourd			0.5	[ND]
Zucchini #			360	[160 – 480]
Eggplant #			77	[36 – 110]
Sweet pepper #			140	[94 – 180]
Tomato #			24	[3 – 39]
Garlic #			200	[120 – 300]
Onion #			150	[62 – 240]
Spring onion			0.5	[ND]
Preserved vegetables			2	[ND – 3]
Mushroom, dried shiitake			5	[3 – 6]
Mushrooms			2	[ND – 4]
Ear fungus			0.5	[ND]
Legumes, nuts and seeds and their products:	**24**	**50**	**40**	**[ND – 250]**
Green string beans, with pod			150	[92 – 250]
Mung bean vermicelli			0.5	[ND]
Beancurd			0.5	[ND]
Fermented bean products			0.5	[ND]
Peanut			25	[4 – 39]
Peanut butter			64	[51 – 77]
Meat, poultry and game and their products:	**48**	**63**	**2**	**[ND – 14]**
Beef			1	[ND – 2]
Mutton			0.5	[ND]
Pork			3	[ND – 9]
Ham			7	[2 – 14]
Luncheon meat			4	[2 – 6]
Barbequed pork			0.5	[ND]
Roasted pork			0.5	[ND]
Pig liver			0.5	[ND]
Chicken meat			0.5	[ND]
Chicken, soy sauce			1	[ND – 2]
Roasted duck/goose			0.5	[ND]
Meat sausage			7	[2 – 13]

TDS food Item	Number of composite samples	% of composite samples < LOD	Mean (µg/kg) * (ND=LOD/2)	[range]
Eggs and their products:	**12**	**100**	**0.5**	**[ND]**
Egg, chicken			0.5	[ND]
Egg, lime preserved			0.5	[ND]
Egg, salted			0.5	[ND]
Fish and seafood and their products:	**76**	**95**	**1**	**[ND – 3]**
Fish, Big head			0.5	[ND]
Fish, Mandarin fish			0.5	[ND]
Fish, Grass carp			0.5	[ND]
Fish, Golden thread			0.5	[ND]
Fish, Grouper			0.5	[ND]
Fish, Horse head			0.5	[ND]
Fish, Pomfret			0.5	[ND]
Fish, Sole			0.5	[ND]
Fish, Tuna			0.5	[ND]
Fish, Grey mullet			0.5	[ND]
Fish, Salmon			0.5	[ND]
Fish, Yellow croaker			0.5	[ND]
Fish, Dace, minced			2	[2 – 3]
Fish ball/fish cake			0.5	[ND]
Shrimp/ Prawn			0.5	[ND]
Crab			0.5	[ND]
Oyster			0.5	[ND]
Scallop			0.5	[ND]
Squid			0.5	[ND]
Dairy products:	**20**	**75**	**1**	**[ND – 8]**
Milk, whole			1	[ND – 1]
Milk, skim			0.5	[ND]
Cheese			0.5	[ND]
Yoghurt			0.5	[ND]
Ice-cream			4	[ND – 8]
Fats and oils:	**8**	**88**	**1**	**[ND – 2]**
Butter			0.5	[ND]
Oil, vegetable			1	[ND – 2]
Beverages, alcoholic:	**8**	**100**	**0.5**	**[ND]**
Beer			0.5	[ND]
Red wine			0.5	[ND]
Beverages, non-alcoholic:	**40**	**63**	**2**	**[ND – 27]**
Tea, Chinese			0.5	[ND]
Tea, Milk tea			2	[ND – 7]
Coffee			11	[4 – 27]
Malt drink			3	[3 – 3]

TDS food Item	Number of composite samples	% of composite samples < LOD	Mean (μg/kg) * (ND=LOD/2)	[range]
Soybean drink			0.5	[ND]
Fruit and vegetable juice			0.5	[ND]
Carbonated drink			1	[ND – 1]
Tea, chrysanthemum			3	[ND – 4]
Water, bottled, distilled			0.015	[ND]
Water, drinking			0.03	[ND – 0.04]
Mixed dishes:	**48**	**42**	**5**	**[ND – 43]**
Siu Mai			0.5	[ND]
Dumpling, steamed			2	[ND – 5]
Dumpling, pan-fried			16	[7 – 22]
Dumpling, including wonton			0.5	[ND]
Steamed barbecued pork bun			20	[7 – 43]
Turnip cake			6	[3 – 9]
Steamed minced beef ball			0.5	[ND]
Glutinous rice dumpling			4	[2 – 7]
Steamed rice-rolls with filling			1	[ND – 2]
Steamed rice-rolls, plain			0.5	[ND]
Chinese soup			5	[3 – 9]
Hamburger			6	[2 – 10]
Snack foods:	**4**	**0**	**680**	**[430 – 1100]**
Potato chips			680	[430 – 1100]
Sugars and Confectionery:	**8**	**50**	**19**	**[ND – 53]**
Chocolate			38	[18 – 53]
Granulated white sugar			0.5	[ND]
Condiments, Sauces and herbs:	**20**	**60**	**2**	**[ND – 14]**
Table salt			0.5	[ND]
Soya sauce			0.5	[ND]
Oyster sauce			7	[3 – 14]
Tomato paste/ ketchup			2	[ND – 4]
Cornstarch			1	[ND – 1]

Notes:

* As only 53% of results are below limit of detection (LOD), half of LOD is used for all results less than LOD in calculating the mean concentration.

\# Vegetables were stir-fried.

ND denotes non-detected, i.e. results less than LOD.

Appendix 2

Dietary Exposures to Acrylamide by Age-gender Group (The Average and High Consumer of the Local Population)

Age-gender groups	Dietary exposure # (μg/kg bw/day)	
	Average	High consumer@
Male aged 20 – 29	0.21	0.62
Female aged 20 – 29	0.25	0.71
Male aged 30-39	0.19	0.48
Female aged 30 – 39	0.24	0.60
Male aged 40-49	0.18	0.44
Female aged 40 – 49	0.24	0.58
Male aged 50-59	0.20	0.46
Female aged 50 – 59	0.22	0.51
Male aged 60-69	0.21	0.51
Female aged 60 – 69	0.21	0.50
Male aged 70-84	0.18	0.40
Female aged 70 – 84	0.18	0.44
Male aged 20-84	0.19	0.48
Female aged 20 – 84	0.23	0.59
Adult aged 20 – 84	0.21	0.54

\# As only 53% of results are below limit of detection (LOD), half of LOD is used for all results less than LOD in calculating the exposure estimates.

@ Exposures of high consumers refer to the exposures at 95th percentile.