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ABSTRACT

The core-food (CF) approach, first adopted in the United States in the 1980s, has been widely used by many countries to assess the exposure to dietary hazards at a population level. However, the reliability of exposure estimates ($C \times CR$) depends critically on sampling methods designed for the detected chemical concentrations (C) of each CF to match with the corresponding consumption rate (CR) estimated from the surveyed intake data. In order to reduce the uncertainty of food matching, this study presents a sampling design scheme, namely the subsample method, for the 2016 Taiwan total diet study (TDS) on veterinary drugs. We first combined the four sets of national dietary recall data that covered the entire age strata (1–65+ years), and aggregated them into 307 CFs by their similarity in nutritional values, manufacturing and cooking methods. The 40 CFs pertinent to veterinary drug residues were selected for this study, and 16 subsamples for each CF were designed by weighing their quantities in CR, product brands, manufacturing, processing and cooking methods. The calculated food matching rates of each CF from this study were 84.3–97.3%, which were higher than those obtained from many previous studies using the representative food (RF) method (53.1–57.8%). The subsample method not only considers the variety of food processing and cooking methods, but also it provides better food matching and reduces the uncertainty of exposure assessment.

Introduction

Total diet studies (TDSs) evaluate the health risk of a population group exposed to target hazards from table-ready dietary foods, which is different from pre- or post-market surveillance. In a TDS, lists of table-ready foods that represent the total intake of the studied population are collected from various cities at different seasons. The samples are then harmonised and blended with different scenarios, such as season-composite and/or city-composite prior to laboratory analysis (EFSA/FAO/WHO 2011). While such a pooling is cost-effective to reduce analytical costs, this will cause a dilution effect and mask those samples of potentially high concentration and concern. A TDS is designed to provide a pre-warning at a national or regional level when the risk attributed to a food group exceeds 5–10% of a toxicity reference with chronic effects (CAC 2015). In surveillance, however, individual

samples of each raw commodity are analysed to track the responsible food sources. The analytical results of concentrations are then checked for compliance with regulatory standards, such as the MRL for pesticide or veterinary drug residues (EFSA/FAO/WHO 2011).

As a part of national food safety programmes, TDS is the most effective and reliable method to provide risk assessment on chronic health effects. The WHO requires its members to report their TDS data or outcome accordingly. These data are then compiled in the Global Environmental Monitoring System for Food (GEMS/Food) for regional food safety management (Kim et al. 2015). Currently, there are 17 regional clusters of similar contamination recognised by WHO for TDS reporting, with 62 food groups.

The first TDS that adopted the core-food (CF) approach was conducted by the United States in 1982. A national set of surveyed individual food

intake data were used in 200–300 clusters of similar property food groups. One representative food (RF) with the highest intake in each cluster of CF was then collected from three cities in one region of similar dietary habit, designated the market basket (MB), for a nation (Pennington & Hernandez 2002). While the RF scheme has been widely adopted by many countries, another sampling scheme was adopted in the 2nd French TDS on pesticide residues (Sirot et al. 2009). In the French scheme, 15 subsamples were designed in each CF and collected from two cities in one MB. The design of subsamples considered several strategies, including quantity consumed, manufacturing process, component content and flavour origin. The purposes of this present study are (1) to design the CF list for the 2016 Taiwan TDS (TTDS) on veterinary drugs (Chiang 2016), (2) to design the sampling list based on CF, and (3) to analyse the sampling strategy of this TTDS in the light of the US and French scheme.

Materials and methods

The national dietary survey

The data of the Nutrition and Health Survey in Taiwan (NAHSIT) were obtained from the Taiwan National Health Research Institute (NHRI). This survey adopted a stratified sampling scheme consisting of five geographical and three ethnic-minority regions in Taiwan: North 1, North 2, Central, South, East, Hakka, Mountainous and Penghu Islands. According to Tu et al. (2011) 48 townships or city districts were selected within eight regions. The usual intakes of neighbouring households within two sampling blocks from each township or city district were obtained; approximately 32 subjects for each gender in each sampling block. The survey data were collected using a 24-h household recall technique by face-to-face interviews. Seasonal variation, which might affect dietary characteristics, was taken into consideration by rotating 16 towns for data collection in three periods in a year. Individuals who have a serious illness or unusual dietary intake were excluded from the survey, such as diabetes, renal dialysis, vegetarian status etc (Tu et al. 2011).

In this study, four sets of data were combined. The major one, conducted in 2005–08, covers preschool children (0–6 years) and adults (19–65+ years). The age gaps for 6–12 and 13–18 years were fulfilled with the rest of three surveys conducted in 2001–02 for elementary school students, 2010–11 for junior high students, and May–December 2011 for senior high students, respectively. The effective respondents were 9125 for the four combined datasets. As shown in Figure 1 for the data pretreatment
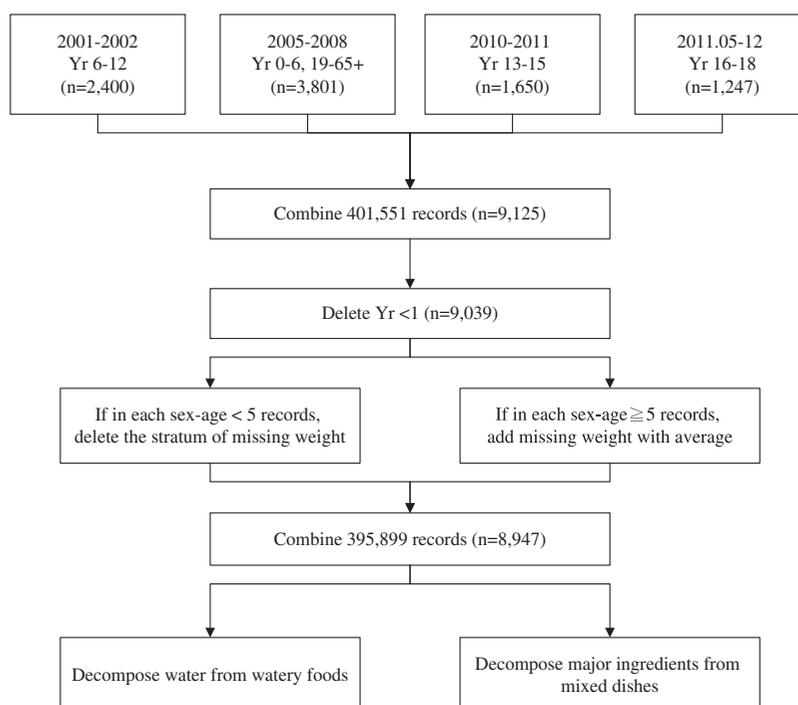

Figure 1. Pretreatment of Taiwan dietary surveys data for total diet studies.

process, individuals less than 1 year old (n = 86) were excluded (WHO 2014). Individuals missing body weights (BW) were allotted the average BW of the sex–age stratum. If there were fewer than five records of BW data in the sex–age stratum, the individuals (n = 92) were excluded. The foods with a high moisture content were adjusted into their regular foods for intake data, such as 10.0 g day^{-1} of congee into 2.0 g day^{-1} of steamed rice. Water was segregated from soupy foods into a separate CF category. Mixed dishes were disassembled into their major ingredients according to the major food recipe available, such as 10.0 g day^{-1} beef noodle soup into 2.5 g day^{-1} of beef, 1.5 g day^{-1} of noodle, 1.5 g day^{-1} of vegetable, 1.0 g day^{-1} of condiment and 3.5 g day^{-1} of meat soup. The consumption rate (CR) of each ingredient was assigned as that of its own CF category.

Food aggregation

The goal of the aggregation is to place the survey foods (SFs) into a reasonable number of CFs for laboratory analysis (Pennington & Hernandez 2002). In this study, a total of 18,837 SFs were obtained after the data pretreatment of the combined NAHSIT data. These SFs were then aggregated into CF categories of similar characteristic according to their nutritional values, composite attribute, processed method, cooking method and consumption habits. Each CF was given its own corresponding code. The code system was divided into six digits: the first digit represents the food category, the second and third digits represent the food group, and the last three digits represent the CF serial number. For instance, the code A01-001 indicates the first CF in group 01 of category A. After the aggregation and coding, 'the consumption rate of whole group' (WG) and 'the consumption rate of consumer only' (CO) for each population, such as general population, women of child-bearing age, and children (0–6 years), were calculated by the summation of all the CRs of the SFs in each appropriate CF divided by all respondents (n) of the combined NAHSIT data in this study and by the number of eaters (m), respectively. The WG can be converted from CO by multiplying the ratio of m to n (WG = CO*m/n). The naming of each CF must completely cover its corresponding SF. According to the nomenclature of Pennington and Hernandez (2002) and Sirot et al. (2009), each CF was named after its RF, which is the SF with the highest CR in that CF. However, the RF method might not be suitable in some situations, e.g., white rice represents all food in A01-001 – this includes rice, congee and sushi rice. It might be misleading in this case that the CR of A01-001 only represent steamed rice.

In this study, the common name of an SF with high purity and homogeneity was used to name the CF, thus A01-001 was named 'Rice and congee'. Furthermore, if the food type was very complicated, descriptors were added for a brief explanation of its characteristic that includes composition, degree of cooking, cooking and processed methods etc., e.g., 'Rice and congee, plain' (A01-001), 'Onigiri, stuffed' (A01-005) and 'Noodles with various ingredients' (A02-032).

Shortened CF list and subsample planning

The CF list produced from the previous section would consist of many complex food types. There was a need to customise and simplify the list suitably for this study. Therefore, a shortened CF list was created by selecting certain CFs mostly associated with the foods listed in the standards of veterinary drug residue limits published in 2015 by Taiwan's Food and Drug Administration (TFDA). Non-animal derived foods, such as vegetables and fruit, were excluded from this study. Furthermore, those CF were selected for the shortened list using the following criteria: (1) WG of general population > 5 g day^{-1} and (2) eater ratio (ER) > 1%. According to Sirot et al. (2009), each seasonal composite sample was composed of 15 subsamples representing the individual CF in the French TDS2. The subsamples were chosen on the basis of five levels of composition that included (1) the quantity consumed, (2) the manufacturing process, (3) the specific component content, (4) the flavour/origin and (5) the product specification. Figure 2 shows the procedure of sampling design of this present study. Before the city allocation of subsamples, it is necessary for all the SFs in each CF: (1) to combine the CR of similar foods with different food codes, (2) to distribute the CR of unknown SF to the selected SFs by WG weights, (3) to narrow down the top four SF with the highest WG weight, and (4) to include those SF
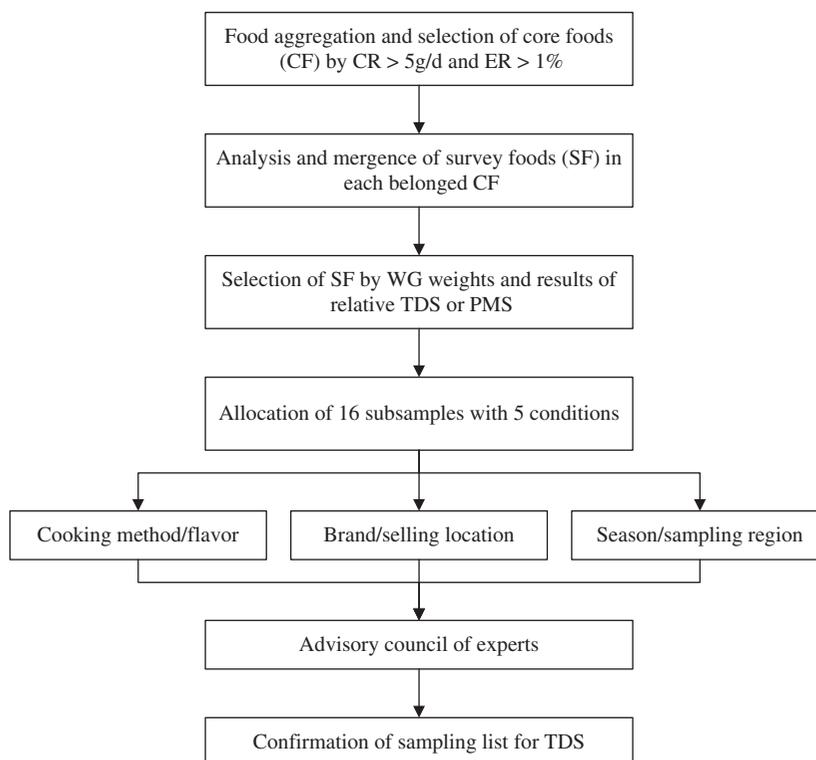
Figure 2. Flowchart of sampling design.

identified as posing potential risk from previous TDS or post-market surveillance (PMS). The matching rate is then calculated for each selected CF as the ratio of the sum WG of these selected SF to the sum WG of their belonged CF (Chiang 2015).

After the matching rate reached at least 60%, 16 subsamples were allocated according to the WG weight of each selected SF and three considerations: (1) cooking method/flavour, (2) brand/selling location and (3) season/sampling region. Cooking method/flavour was determined according to NAHSIT database. However, if the method/flavour could not be clearly recognised, the method/flavour was assumed that was in accordance with the majority of Taiwanese consumption habits.

Brand was separated into national and regional foods by channel patterns. Selling location considered the high rate of dining out in the population in Taiwan; national brand foods, such as milk, canned foods and frozen foods, were collected from the top most famous brand products of home delivery or of supermarket/convenient store and chain restaurants in Taichung city. The regional brand foods were collected from local restaurants, bazaars and night markets according to consumption habits.

Season was divided into spring/summer and fall/winter periods due to the seasonal difference of the veterinary drug residual characteristics. Four stratified regions (north, central, south and east) were distinguished for sampling. One city of each region was chosen in each period for sampling, altogether eight sampling cities. After the 16 samples were allocated by WG weights, the strongest attempt possible was made to collect in all eight cities each SF with the highest WG weights in its appropriate CF.

Results

Food classification and consumption rate

After the aggregation of 18,837 SFs, the CF list of 12 categories (A–L), 57 groups and 307 CFs was obtained. The complete food classification and the WG of each food list are shown in Table 1. Among the 12 categories, 'Vegetables' (category G) contained the most clusters with 95 CFs; 'Grains and tubers' (category A) were in second place with 49 CFs.

The summarised WG of 307 CFs is 2128.1 g day^{-1}, and the top three WGs were 'Dessert' (category I) with 552.1 g day^{-1}, 'Grains and tubers' (category A)

Table 1. Consumption rate of Taiwanese total core foods (CFs) and shortened CFs selected in this study on veterinary drug residue.

Food classification			Consumption rate (g day^{-1})		
			Total CFs	Shortened CFs	
Category	Group	CF	307 CF	55 CF	40 CF
Grains and tubers	4	49	462.1	6.0	–
Oils	3	10	20.4	2.0	2.0
Poultry and its products	3	7	34.8	34.8	34.7
Livestock and its products	3	7	78.7	78.7	78.7
Aquatic products	4	12	43.4	43.1	39.5
Other protein sources	3	21	200.7	134.5	132.7
Vegetables	13	95	207.3	–	–
Fruit	9	43	136.7	–	–
Dessert	5	22	552.1	12.1	12.1
Alcoholic beverages	1	7	19.1	–	–
Seasonings	4	15	141.0	97.1	97.1
Others	5	19	231.7	209.0	201.5
Total	57	307	2128.1	617.2	598.4

with 462.1 g day^{-1}, and 'Others' (category L) with 231.7 g day^{-1}. After excluding the non-animal food categories (categories A, G, H and J), there were three composite CFs: 'Glutinous rice dumpling' (A01-011), 'Chinese omelette wrap, pan-fried' (A02-034), and 'Minced patties, pan-fried, stuffed' (A02-035). But they were later excluded from the shortened CF list of 40 CFs due to WG and ER% not reaching the selection criteria. The total WG of the shortened CF lists of 55 and 40 CFs were 617.2 and 598.4 g day^{-1}, respectively, as shown in Table 1. Among the selected categories, the top three WGs were of categories L, F and K of 201.5, 132.7 and 97.1 g day^{-1}, respectively.

Shortened CF list

The general population WG and ER of the 40 CFs and the number of SFs in each belonged CF are displayed in Table 2, altogether eight categories, 18 groups and 40 CFs. The number of SFs was 1117. The top three were 'Saltwater fish, raw or cooked, processed' (E15-075), 'Flavored milk' (F19-090), and 'Milk' (F19-089) with 126, 68 and 65 SFs, respectively. 'Broth, boiled' (L56-302) had the highest WG of 170.76 g day^{-1} after elimination of all the non-animal derived items. 'Gravy, boiled or canned' (K52-283) was the only CF selected in category K and took the second place in WG of 97.08 g day^{-1}. The CFs with the highest ER were 'Pork' (D11-067) of 56.2%, 'Egg, plain or with other ingredients' (F18-086) of 53.4%, and 'Broth, boiled' (L56-302) of 53.4%.

The WG of the meat products such as 'Poultry and its products' (C), 'Livestock and its products'

(D), and 'Aquatic products' (E) were 34.7, 78.7 and 39.5 g day^{-1}, respectively. 'Pork' (D11-067) and 'Chicken' (C08-060) had the highest WGs of 39.12 and 20.69 g day^{-1}, and ERs of 56.2% and 28.6%, respectively. However, 'Processed pork' (D11-071) had 49 SFs which was higher than 'Pork' (D11-067) and 'Chicken' (C08-060). 'Beef and products' (D12-072) had a WG of only 5.79 g day^{-1} and ER of 6.2%. 'Saltwater fish, raw or cooked, processed' (E15-075), 'Surimi products' (E16-078), and 'Freshwater fish' (E14-074) had the highest WGs in category E of 16.00, 10.44 and 5.63 g day^{-1}, respectively.

As for the animal derived non-meat CFs, 'Animal fats' (B06-052) and 'Cream and butter' (B06-053) were the only two CFs included in category B. 'Milk' (F19-089) and 'Egg, plain or with other ingredients' (F18-086) had WGs of 44.75 and 30.96 g day^{-1}, and ERs of 14.7% and 53.4%, respectively. 'Cake' (I43-245) and 'Ice cream, commercial' (I46-263) were included due to containing egg and milk, and their WGs were 6.26 and 5.83 g day^{-1}, respectively. 'Dumpling, freshly prepared or frozen' (L54-291) and 'Gyoza, freshly prepared or frozen' (L54-292) in category L were separated because the different cooking processes of boiled and steamed versus pan-fried. Although certain CFs, such as 'Goose' (C10-063) and 'Roe' (E17-085), did not meet the screening principles for WG and ER, they were included in the shortened CF list after considering the actual consumption habits of Taiwanese.

Sampling list

All SFs in each belonged CF were carefully examined for subsample planning after selection of the 40 CFs meeting the selection criteria. The planning of the CF 'Dumpling, freshly prepared or frozen' (L54-291) is shown in Table 3 as an illustration. This CF was a composite food with 25 SFs. After SF integration, the top four SFs with the highest WG weight were cabbage pork dumplings, chive pork dumplings, pork dumplings and dumplings. However, to our knowledge most dumplings have vegetable ingredients, and some of the responders did not specify its vegetable part during NAHSIT survey. We determined that the stuffing of two SFs of pork dumplings and dumplings in the NAHSIT database were not just plain ground pork. Therefore, their WGs were distributed into the other two SFs by their respective

Table 2. Whole group (WG) consumption rates and eater ratios of the 40 shortened core food list.

Food classification	Number of survey foods	Consumption rate of WG, mean (g day^{-1})	Eater ratio (%, n = 8947)
B. Oil			
B06. Animal oil			
B06-052 Animal fats	9	0.85	22.2
B06-053 Cream and butter	10	1.11	5.6
C. Poultry and its products			
C08. Chicken and its products			
C08-060 Chicken	41	20.69	28.6
C08-061 Fried chicken	25	10.09	9.4
C09. Duck and its products			
C09-062 Duck	11	1.70	3.3
C10. Other poultry and products			
C10-063 Goose	4	0.33	0.7
C10-065 Poultry offal	12	0.44	1.0
C10-066 Additional parts of poultry	19	1.48	2.1
D. Livestock and its products			
D11. Pork and its products			
D11-067 Pork	36	39.12	56.2
D11-068 Pork offal	13	1.42	3.3
D11-069 Additional parts of pig	12	4.52	5.7
D11-070 Flavored pork, processed	40	10.34	21.7
D11-071 Processed Pork	49	15.84	29.8
D12. Beef and its products			
D12-072 Beef and products	26	5.79	6.2
D13. Other meat and products			
D13-073 Lamb and game meat	14	1.71	2.3
E. Aquatic products			
E14. Freshwater fish			
E14-074 Freshwater fish	47	5.63	10.8
E15. Saltwater fish			
E15-075 Saltwater fish, raw or cooked, processed	126	16.00	29.2
E16. Processed Fish			
E16-076 Dried fish	5	0.51	3.1
E16-077 Canned fish	25	0.96	2.4
E16-078 Surimi products	41	10.44	16.7
E17. Other aquatic and its products			
E17-080 Crustaceans and products	28	3.66	12.4
E17-081 Shellfish, fresh, processed	19	2.18	8.0
E17-085 Roe	4	0.15	0.6
F. Other protein sources			
F18. Egg and its products			
F18-086 Egg, plain or with other ingredients	21	30.96	53.4
F18-087 Flavored egg	13	2.33	5.0
F18-088 Egg products	6	0.59	2.6
F19. Dairy foods			
F19-089 Milk	65	44.75	14.7
F19-090 Flavored milk	68	18.63	7.2
F19-091 Powdered milk	55	3.84	8.6
F19-092 Baby formula	29	4.30	4.4
F19-093 Fermented milk	30	20.25	9.0
F19-095 Cheese and condensed milk	10	1.42	4.4
F19-096 Goat milk	10	5.67	2.6
I. Dessert			
I43. Cookies and snacks			
I43-245 Cake	35	6.26	6.5
I46. Ice and beverages			
I46-263 Ice cream, commercial	50	5.83	3.3
K. Seasonings			
K52. Other seasonings			
K52-283 Gravy, boiled or canned	16	97.08	33.1
L. Others			
L54. Wheat and others			
L54-291 Dumpling, freshly prepared or frozen	25	15.62	7.0
L54-292 Gyoza, freshly prepared or frozen	8	6.34	3.0
L54-295 Salted bun, stuffed with meat or vegetable	17	8.86	5.5
L56. Soups			
L56-302 Broth, boiled	43	170.76	53.4
Total	1117	598.45	

WG weights. Altogether their total WG was 13.0 g day^{-1} with matching rate ER of 84.3%. And the WG weights of cabbage pork dumplings and chive pork dumplings were 60% versus 40%. The cooking methods of 'Dumpling, freshly prepared or frozen' (L54-291) were determined by boiling and

Table 3. Example of subsample planning (core food: dumpling, freshly prepared or frozen).

Criteria	Survey food (SF) planning details	Judgements
Food ingredients	Composite food with about 30% of ground pork 25 SF with top four whole group (WG) (84.3%): cabbage pork dumplings, chive pork dumplings, pork dumplings and dumplings Also including vegetarian dumplings, chicken dumplings, curry dumplings, shrimp dumplings, xiao long bao etc.	Pork stuffing usually has vegetable ingredients, therefore pork dumplings and dumplings were incorporated into the top two SF (cabbage pork dumplings and chive pork dumplings) and the WG weights were distributed as 60% cabbage pork dumplings and 40% chive pork dumplings
Cooking methods or flavours	Boiled and steamed	Ratio of 80% boiled and 20% steamed Pan-fried dumplings incorporated into 'Gyoza, freshly prepared or frozen' (L54-292)
Manufactures and brands	National samples collected in common frozen dumpling manufacturers or famous chain restaurants Regional samples collected in local restaurants, which were made from local commodities	60% of national samples (10 items) and 40% of regional samples (6 items)
Collection places and time	Collected in supermarkets, chain restaurants and local restaurants in four regions, two cities in each regions, for a total of eight cities during spring/summer and fall/winter in two sampling periods	There is only one market basket in Taiwan, therefore one city was selected in each region during one seasonal period for sampling

steaming, and the ratio was 80% versus 20%, respectively. The dumplings prepared by pan frying were placed into 'Gyoza, freshly prepared or frozen' (L54-292).

After carefully examining the SFs from the NAHSIT database and considering the consumption habit of Taiwanese, we determined that 60% of the dumplings consumed were from chain restaurants and frozen food products. The remaining 40% were freshly made by the regional restaurants. Furthermore, the 16 subsamples were distributed evenly in two seasonal periods due to the characteristic that the veterinary drug residues within the pork stuffing might be affected by seasonal variations. Therefore, the regional samples were allocated in eight cities to consider the regional variations, and altogether 16 subsamples with the national samples. In order to reflect the actual dietary exposure of the public, each sample was first homogenised separately without disassembling, and later blended together by an equal amount for laboratory analysis. The resulted concentrations were matched with the CR of that specific CF to calculate estimated daily intake (EDI) for exposure assessment.

The sampling list of 'Dumpling, freshly prepared or frozen' (L54-291) is presented in Table 4. Cabbage pork dumplings and chive pork dumplings were distributed into 10 and six subsamples, respectively. Among the 16 subsamples, six were from the three most famous chain restaurants, four were from the two most famous brands in supermarkets and six were from different regional restaurants. The boiled and steamed items were distributed into 12 and four subsamples, respectively. The subsamples from chain restaurants and supermarkets were collected in

Taichung city in the central region; others were from regional restaurants in the cities of the north, south and east regions.

Discussion and conclusions

Food aggregation

Certain composite food items were also included in the NAHSIT database. Their aggregation principles were similar to the methods used by the US TDS, which placed the nearly identical composite food items together into their own separated CF without disassembling (USFDA 2016). The advantage was to reflect the real-life situation when people consume those composite food items. Furthermore, their detected chemical concentration can directly match with their WG or CO, which can reduce the uncertainty of the exposure assessment. However, if we want to explore the dietary exposure of a specific food ingredient, we can calculate it by the ingredient ratio from the most common recipes. Currently, a few composite food items remained to be un-disassembled, which was one of the uncertainties of this study. Future study using a computer-aided disassembling technique is required in this area.

In addition, some cooking methods resulting in a high oil content might affect the pretreatment process of laboratory analyses, therefore the deep-frying CF like 'Fried chicken' (C08-061) was separated from 'Chicken' (C08-060) for better analytical results. On the same basis, the pan-fried dumplings were incorporated into 'Gyoza, freshly prepared or frozen' (L54-292) also due to the higher oil content of the pan-fried method than the boiled and steamed

Table 4. Final sampling list of 'dumpling, freshly prepared or frozen' (L54-291).

Core food (CF)	Serial number	Subsamples	Cooking methods/ flavours	Brands/ manufactures	Locations	Seasonal periods[a]	Cities[b]
Dumpling, freshly prepared or frozen	1	Cabbage pork dumplings (freshly made)	Steamed	–	Local restaurant	SS	N1
	2	Chive pork dumplings (freshly made)	Boiled	–	Local restaurant	SS	S1
	3	Cabbage pork dumplings (freshly made)	Steamed	–	Local restaurant	SS	E1
	4	Cabbage pork dumplings (frozen)	Boiled	Brand I	Chain restaurant	SS	C1
	5	Cabbage pork dumplings (frozen)	Boiled	Brand II	Chain restaurant	SS	C1
	6	Chive pork dumplings (frozen)	Boiled	Brand III	Chain restaurant	SS	C1
	7	Cabbage pork dumplings (frozen)	Boiled	Manufacturer I	Supermarket	SS	C1
	8	Chive pork dumplings (frozen)	Boiled	Manufacturer II	Supermarket	SS	C1
	9	Cabbage pork dumplings (freshly made)	Boiled	–	Local restaurant	FW	N2
	10	Chive pork dumplings (freshly made)	Steamed	–	Local restaurant	FW	S2
	11	Cabbage pork dumplings (freshly made)	Steamed	–	Local restaurant	FW	E2
	12	Cabbage pork dumplings (frozen)	Boiled	Brand I	Chain restaurant	FW	C1
	13	Cabbage pork dumplings (frozen)	Boiled	Brand II	Chain restaurant	FW	C1
	14	Chive pork dumplings (frozen)	Boiled	Brand III	Chain restaurant	FW	C1
	15	Cabbage pork dumplings (frozen)	Boiled	Manufacturer I	Supermarket	FW	C1
	16	Chive pork dumplings (frozen)	Boiled	Manufacturer II	Supermarket	FW	C1

Notes: [a]SS, spring/summer; FW, fall/winter.
[b]N, north region; C, central region; S, south region; E, east region.

dumplings. However, deep-fried pork was not separated from 'Flavored pork, processed' (D11-070) due to WG < 0.1 g day^{-1} according to the NAHSIT database.

Sampling design method comparison

The EFSA and the French second TDS both recommended that the food list should cover at least 90% of the total food intake (Sirot et al. 2009; EFSA/FAO/WHO 2011). In this study, the diet coverage of the shortened CF list was 95.9%, which was calculated by the WG of the 40 filtered CFs divided by the WG of the 55 animal-derived CFs. However, high diet coverage may not permit fair food matching. To illustrate the merit of the subsample design method proposed in this study, the 2014 TTDS done by Chiang (2014) on pesticide residues which covered the majority of the CF list was used for comparison with the US and French models.

The United States was one of the very first countries to conduct a TDS (Pennington & Gunderson 1987; Pennington et al. 1996). After their SF aggregation, the SFs with the highest CR in each food

group were selected as RFs and were collected in different cities and pooled for laboratory analysis (Pennington & Hernandez 2002; Egan et al. 2007). This RF method has been the major sampling strategy for TDS internationally (Egan et al. 2007; Lee et al. 2015). The United States is divided into four MBs. Sampling took place in three random cities within one MB every season and alternated to another MB in the next season. Each city collected 280 individual samples, altogether 3360 individual samples per MB (Sirot et al. 2009; USFDA 2016). Taiwan is only about 1/68 of the United States in land area with only one MB. During the 2014 TTDS on pesticide residues, the similar RF method was used as the sampling strategy. Each year was divided into two periods of spring/summer and fall/winter, and each MB consisted of two cities. A total of 250 individual samples were collected in each city during each seasonal period, altogether 4000 individual samples per MB (Chiang 2014). As shown in Table 5, on the basis of individual samples per 1000 km^2, Taiwan was sampled by this method 107-fold compared with the United States. This indicated that the sampling density of 2014 TTDS was

Table 5. Comparison of the design parameters of two total diet study (TDS) sampling methods.

	Representative food	Subsample	
	USA, 1961	Taiwan, 2014	France, 2000
Market baskets (MB)	4	1	8
Number of core foods (CF)	280	244	186
Number of sampling periods	4	2	2
Number of cites per MB	3	8	2
Number of individual samples per CF	12	16	30
Number of individual samples per MB (×1000)	3.4	4.0	5.6
Number of composite samples per MB	280	250	186
Average area (km^2) per MB	2,464,250	36,193	80,475
Number of individual samples per area of one MB (1000 km^2)	1	111	69

higher and thus had greater representativeness. However, the RF method may lack food matching between the intake estimate and RF concentration of the CF, especially in food groups having highly composite or heterogeneous SFs.

On the other hand, the French TDS conducted by Sirot et al. used a 'subsample method' that was adopted by this study as the sampling strategy. France was divided into eight MBs by its national consumption survey. Each year was also divided into two sampling periods. A total of 15 subsamples of each CF were collected in two cities within the same MB during one sampling period, altogether 5580 individual samples per MB (Sirot et al. 2009). The individual samples per 1000 km^2 of the French TDS was 69-fold that of the United States. In comparison with the RF method by the United States, the subsample method provided a more multivariate strategy which would result in better food matching.

This study used the subsample method similar to the French TDS, altogether 640 individual samples per MB. Although the number of CFs selected in this study was less, but after the multivariate planning of 16 subsamples, the sampling design indeed provided better food matching and thus reduced the uncertainty of exposure assessment.

Food matching and matching rate

The food items consumed by the public were highly complex and very varied. The numbers of food items analysed in the TDS were quite limited. Therefore, food matching played an important role to ensure the analysed composite samples can closely represent

the entire SF in their appropriate CF (FSANZ 2011, 2014; Boorman et al. 2013). For instance, the CF 'Broth, boiled' (L56-302) includes both vegetable and meat soups. The soup base of many broths may contain animal-derived ingredients. While it was difficult to identify the sources in the NAHSIT database, the elimination of only the sweet and vegetarian items (0.64 g day^{-1}) was determined to be conservative in exposure assessment. The WG of 'Broth, boiled' (L56-302) in Table 2 was the result after elimination.

In order to compare the degree of food matching between the subsample and RF methods, other than the calculation for diet coverage, this study was the first to introduce the matching rate as a better index. Table 6 shows three different CF from this TDS by subsample method and RF method as examples for comparison (Chiang 2015). The RF method did not integrate the SF; it only selected the SF of the top one WG as the RF, and it resulted in matching rates between 53.1% and 57.8%. The subsample method integrated the SF before selecting the top four SFs for the allocation design of 16 subsamples with multivariate criteria, and resulted in a higher matching rate between 84.3% and 97.3% than from the RF method.

Other uncertainties

Currently, the shortened CF list in this study was only designed specifically for veterinary drug residues as an illustration of creating a specific sampling design for the TDS and exposure assessment. Other chemicals such as pesticides, heavy metals etc. were not taken into consideration in this study. Theoretically, veterinary drug residues will not be used on food of plant origin; therefore, only CFs of animal origin were included.

Table 6. Comparison of the matching rate of the subsample and representative food (RF) methods for three illustrated core foods (CFs), showing higher matching rates.

CF	Method	Number of selected SF/ total SF	Matching rate (%)
C08-060 Chicken	Subsample	24/41	97.3
	RF	3/41	54.1
D11-067 Pork	Subsample	18/36	96.1
	RF	3/36	57.8
L54-291 Dumpling, freshly prepared or frozen	Subsample	14/25	84.3
	RF	1/25	53.1

However, the shortened CF list can be modified accordingly to suit the chemical of interest for future studies.

Drug residues in drinking water were another thing to consider. Although the EFSA/FAO/WHO (2011) recommended including drinking water in the sampling list, according to a previous study by Wang (2012) on the risk assessment of pharmaceuticals and personal care products in Taiwan's drinking water, all seven water-purification plants throughout Taiwan detected tetracycline antibiotics as not detected (ND). Therefore, we prioritised the food of animal origin as our current food of interest, and excluded drinking water in this study. Further research might consider drinking water if needed.

Antimicrobial resistance is another issue to consider. It might occur even though the exposure amount is lower than the toxicological guidance level. In order to avoid underestimating residue concentrations, the CAC (2015) and EFSA/FAO/WHO (2011) have both suggested that the LOD of the TDS should be validated to at least 1/10th of the regulated MRL of post-market surveillance. However, residue concentrations below the MRL may be detected for exposure assessment. Furthermore, veterinary drugs and pesticides are compounds intentionally applied by humans, and their occurrence in food should be treated differently from environmental contaminants. If certain veterinary drugs were ND when the LOD is closer to zero, then it is reasonable to assume that they were not present on the food samples under investigation (FSANZ 2011).

Disclosure statement

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