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Research Article

Premised research on dietary exposure to benzo[a]pyrene, acrylamide, and N-nitrosodimethylamine from common fried and grilled dishes in North Vietnam

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Abstract

Fried and grilled cooking methods and the widespread consumption of certain dishes may expose the population to elevated levels of potentially carcinogenic compounds, such as benzo[a]pyrene (BaP), acrylamide, and N-nitrosodimethylamine (NDMA). This study aims to quickly estimate dietary exposure to these contaminants and assess the associated carcinogenic risk for several common Vietnamese fried and grilled dishes. The concentrations of the target compounds were obtained from the study showed that BaP, NDMA, and acrylamide are the groups of substances of greatest concern. The analytical results of 235 samples of meat and meat products (grilled/fried/smoked), seafood and seafood products (grilled/fried/smoked), processed oils, and potatoes showed that 12 samples detected acrylamide in the range of 5.0 – 162.0 µg/kg found in grilled/fried dishes and 5.0 – 4605 µg/kg for fried potatoes. Additionally, 204 samples detected NDMA in all groups in the range of 0.20 – 15.0 µg/kg, and 27 samples detected BaP in the range of 5.2 – 88 µg/kg in grilled/roasted food. Combined with information on food consumption patterns to estimate dietary exposure, four age groups were divided into under 6 years old, 6 – 18 years old, 18 – 50 years old, and over 50 years old, which showed that the consumption of processed foods by age groups was very different. In particular, the age group from 6 to 50 years old was the group that consumed the most of these foods (14.1 – 140 g/day). Specifically, up to 94.4% of people interviewed ate fried meat, 88.8% ate fried seafood and 85% ate fried potatoes. Risk characterization using the margin of exposure (MOE) and Cancer Slope Factor approaches indicate that certain dishes, such as grilled/smoked meat and fish, and deep-fried foods, may pose a significant cancer risk to Vietnamese consumers.

Keywords: *food processed contaminants, chemical hazards, dietary intake, dietary exposure, carcinogenic risk.*

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1. INTRODUCTION

Nowadays, the development of the economy and technology along with the opening of trade and cultural exchange has made Vietnamese cuisine increasingly diverse, especially in the industrial age, where processed food is becoming more popular. Fast food, which is often fried and grilled, although convenient and delicious, has a great impact on consumers' health, not only changing eating habits, increasing overweight and obesity [1] but also increasing the risk of cancer from new substances produced during food processing [2-5]. These substances are created during the processing of foods containing a lot of protein, sugar, and fat at high temperatures, and are almost absent in unprocessed foods. Thus, the habit of eating grilled, fried, and smoked foods, especially deep-fried foods, and fried foods at high temperatures, which are common in all regions of our country, is on the rise and is a risk factor for cancer.

The Maillard reaction, named after the French chemist Louis Camille Maillard, is a chemical reaction between amino acids and reducing sugars that gives foods brown color and flavor. Foods made from high protein sources, fried foods, baked goods, marshmallows, and many other foods undergo this reaction [2]. The reaction is a form of caramelization that occurs rapidly at high temperatures, from about 140°C to 165°C. At higher temperatures, caramelization progresses to pyrolysis (a breakdown that eventually leads to burning). The products of the Maillard reaction include BaP (polycyclic aromatic hydrocarbons (PAHs)), NDMA (N-nitroso-amines), and acrylamides, all of which are newly formed during food processing are potentially carcinogenic.

Fresh ingredients do not pose a risk of new substances, but pre-processed ingredients (dried, smoked, or smoked) have risks related to BaP, which are formed by the pyrolysis of fats and other organic substances in food [6, 7]. Ingredients containing a lot of asparagine have a higher potential to form acrylamide than other ingredients, for example in potatoes (40%) [8], ingredients for making cakes such as wheat flour (14%), rye (18%) ... [9]. Also, the quantity and quality of spices used for marinating are influenced by the processing method and local preferences, which in turn affect the formation of new substances during processing. The reaction to form Nitrosamine depends on the acid pH, and the concentration of nitrite and amine. Foods marinated with acid (sour taste) will have a higher risk of forming NDMA [10, 11]. The amount of sugar used in marinating is one of the factors in the Maillard reaction, also forming acrylamide in food [12]. Sweet marinade usually results in a higher formation of NDMA and acrylamide than non-sweet marinade. And finally, the temperature during processing, the higher the temperature, the more substances are produced. The temperature of food depends on the heat source, water content, fat content, and the number of times it is processed. For example, the same ingredient is meat, if processed for stews, braises, and braised dishes, due to the high-water content, the food temperature usually does not exceed 120°C; unlike fried dishes that have a lower water content, the high-fat content is burned, so the food temperature can reach more than 300°C during processing. In addition, some other processing methods such as frying many times, and reusing used oil, also increase the risk, because the food itself already contains newly generated substances after being processed once. It could be seen that, synthesizing from the stage of using raw materials, marinating methods depending on each region, using temperature as well as the number of processing times, the content of substances with the risk of causing cancer is higher and more diverse as the temperature increases. This depends a lot on the culinary characteristics of the region. Therefore, the potential risk from people's daily habits is real and different according to the processing methods of each region.

In recent years, many studies have been conducted to assess the risks of heat-processed foods to human health, which shows that the consumption of these products affects the risk of cancer of consumers very highly [7, 13, 14]. Until 2019, there hasn’t been any published research assessing the risks of carcinogens produced during food processing in Vietnam. For acrylamide, no research assessing the risks to human health has been published. For BaP, there have only been studies assessing the risks of BaP in the environment to human health, but no assessment of food processing and consumption yet. The National Institute for Food Control (NIFC) cooperated with the Federal Scientific Center for Medical and Preventive Health Risk Management Technologies to conduct a program on "Assessing the risks of nitrosamines in the diet of children under 36 months of age" in 2019. NDMA was detected in samples of canned food, sausages, grilled meat, and fried meat with levels ranging from 0.15 to 2.8 µg/kg. The risk assessment study results showed that for children aged from 6 to 36 months, the total NDMA exposure dose was 8.2 ng/kg bw/day, which is between the lowest and highest recommended TDI levels (4.0 – 9.3 ng/kg bw/day) [15]. Primarily due to concern for the exposure of these substances, the Vietnamese authorities have found it necessary to maintain national provisions imposing stricter regulation.

Therefore, the study’s objective was to estimate the exposure to specific substances from commonly consumed fried and grilled foods in North Vietnam, utilizing recent consumption data for the general Vietnamese population. Risk characterization was conducted by calculating the margin of exposure (MOE) to these chemicals, based on the ratio between the benchmark dose level ($BMDL_{10}$) and the estimated dietary exposures.

2. MATERIALS AND METHOD

2.1. Contaminant concentrations

The study was performed on two hundred and thirty-five samples of processed foods including meat, seafood, cooking oil, and fried potatoes. Samples were analyzed with ISO/IEC 17025:2017 accredited analytical methods from NIFC. The food was chopped and ground until homogeneous with a minimum sample mass of 200 g and stored at –20°C for up to one month before analysis.

For BaP analysis: An exact amount (5.0 g) from the homogenized samples was extracted using the QuEChERS technique, cleaned up with PSA and C18 sorbents, and then enriched and analyzed on a tandem gas chromatography-mass spectrometry system GC-MS/MS. The analysis was performed on an Agilent 7000B GC-MS/MS (Agilent Technologies, United States) with DB5MS 30 m × 0.25 mm, 0.25 µm column (Agilent Technologies, United States) with Helium as mobile gas.

For acrylamide analysis: An exact amount (2.0 g) from the homogenized samples was used. Acrylamide was extracted with acetonitrile and the extract was cleaned up by d-SPE and analyzed using liquid chromatography-tandem mass spectrometry (LC-MS/MS). The analysis was performed on an Agilent 6460 Triple Quad LC/MS (Agilent Technologies, United States) with Symmetry C18 (150 × 4.6 mm, 3.5 µm) (Waters, United States) using water and acetonitrile both with 0.1% formic acid as mobile phase.

For NDMA analysis: An exact amount (5.0 g) from the homogenized samples was used. NDMA was extracted by QuEChERS technique using ammonium chloride, cleaned and defatted with n-hexane and C18 powder, and then analyzed using GC-MS/MS. The analysis was performed on an Agilent 7000B GC-MS/MS (Agilent Technologies, United States) with GC Column DB-1701 30 m × 0.25 mm, 0.25 µm (Agilent Technologies, United States) with Helium as mobile gas.

Therefore, the quantitative and qualitative analyses were performed by external calibration and comparing retention times and confirmed/ quantifier ion ratios obtained by analyzing standard, spiked, and samples.

2.2. Exposure assessment

The analysis presented in this report was based on comprehensive data collected from multiple sources, ensuring a robust and reliable foundation. Intake data was divided into four groups: lower to 6 years old, above 6 to 18 years old, above 18 to 50 years old, and above 50 years old with the types of processed food in the consumption survey were meat (specific recording of either grilled, fried, or smoked), seafood (specific recording of either grilled, fried, or smoked), processed cooking oil, and fried potatoes.

According to the Guidelines for Exposure Assessment of the United States Environmental Protection Agency (US EPA), when a contaminant is ingested, the quantity that enters the body in a biologically available form is referred to as the dose, such as potential dose refers to the quantity of a contaminant ingested (i.e., the amount that enters the mouth), though not all of it is necessarily absorbed. The potential dose of a contaminant is the product of the contaminant concentration, intake rate, exposure duration, and exposure frequency divided by the averaging time and body weight. For exposure assessment, the potential dose may be shortened to the exposure dose. Then, the exposure dose (ED) (or the estimated daily intake (EDI)) of each target contaminant was calculated using the following equation [16, 17]:

$$ED\ (\mu g/kg\ bw/day) = \frac{Contaminant\ Concentration\ (\mu g/kg) \times Intake\ Rate\ (kg/day)}{Body\ Weight\ (kg)}$$

where *Contaminant Concentration* was concentrations obtained from the analysis of food samples in this study using the analytical methods mentioned in section 2.1. The *Intake Rate* was the level of food consumption across different age groups, gathered through a frequency of consumption questionnaire conducted in the localities where food samples were taken. Additionally, this survey collected information on height and weight, comparing it with the average physical condition of Vietnamese people as reported in the national statistical study.

According to the Guidelines for Carcinogen Risk Assessment of the United States Environmental Protection Agency (US EPA), carcinogen risk assessment models are typically based on the premise that risk is proportional to the cumulative lifetime dose. For lifetime human exposure scenarios, therefore, the exposure metric used for carcinogenic risk assessment has been the lifetime average daily dose (LADD) [17], calculated as:

$$\text{LADD } (\mu g/kg\ bw/day) = \frac{\text{Contaminant Concentration } (\mu g/kg) \times \text{Intake Rate } (kg/day) \times \text{Exposure Duration } (year)}{\text{Body Weight } (kg) \times \text{Averaging life expectancy } (year)}$$

where the *Exposure Duration* was determined by the time over which the contact takes place, the *Average life expectancy* was estimated at 73.7 years provided by the latest Statista survey released in December 2023 [18].

Using average daily exposure values (e.g., ED, LADD) in dose-response relationships assumes that equal increments of exposure concentration times time (C × T) have the same potential effect, regardless of exposure pattern. When toxicity depends on dose rate, a more precise determination of exposure duration and sequence is needed [17].

2.3. Risk characterization

To assess the significance of estimated dietary exposure to genotoxic compounds, the exposure is compared with the dose that leads to a specified incidence of tumor formation in experimental animals. The greater the margin between the effect dose level and the actual exposure level (margins of exposure, MOE), the lower the concern. An internationally recognized toxicological reference point is the Benchmark Dose Lower Confidence Limit (BMDL), which represents the exposure level where the increase in incidence of the effect (10% in animal experiments) is less than the specified Benchmark Response with 95% confidence. The $BMDL_{10}$ can be derived from dose-response data from multiple long-term carcinogenicity studies rather than a single extensive study.

$$MOE = \frac{BMDL_{10}}{ED}$$

For genotoxic compounds, the European Food Safety Authority (EFSA) has expressed that it would be of low concern if the $BMDL_{10}$ is 10,000 times higher than the exposure [19].

Additionally, according to EPA guidelines, carcinogenic potential can also be calculated using the formula:

$$\text{Cancer Risk} = \text{LADD} \times \text{Cancer Slope Factor}$$

$$Cancer\ Risk_{total} = \Sigma\ Cancer\ Risk$$

which, the total risk is the total risk of substances in a sample matrix, and the calculated risk is the proportion of the population at risk of developing cancer [17].

3. RESULTS AND DISCUSSION

3.1. Chemical concentrations

All methods were validated and confirmed to be suitable for use in this study. The limit of identification (LOD) and limit of quantification (LOQ) of the analytes in food, including processed meat, processed seafood, cooking oil, and fried potatoes are shown in Table 1.

Table 1. *LOD – LOQ and estimated concentrations*

Analyte	*LOD (µg/kg)*	*Estimated concentrations in non-detected (µg/kg)*	*LOQ (µg/kg)*	*Estimated concentrations below LOQ (µg/kg)*
BaP	1.0	0.5	3.0	2.0
Acrylamide	10	5.0	30	20
NDMA	0.1	0.05	0.30	0.20

Left-censored observations significantly impact management decisions by affecting the estimation of statistical parameters and data distribution characterization. Assigning non-detects a fraction of detection limits leads to inaccurate and irreproducible statistics. Statistically robust procedures for analyzing censored data, which do not rely on arbitrary values, are available. The most common procedure to manage non-detects continues to be the substitution of some fraction of the detection limit [20]. For this study, both the mean of all positive findings as well as the mean of all samples analyzed were presented and the non-detected samples would be counted as half LOD, the detected samples but lower than the LOQ value counted as half of the range of LOD - LOQ [5]. Therefore, the results of the survey were presented as the mean content in Table 2.

Table 2. *Concentrations in selected types of food*

Type of food	**Sample size (n=235)**	**Acrylamide (µg/kg)**				**NDMA (µg/kg)**				**BaP (µg/kg)**			
		Mean	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Grilled/Roasted Meat	40	11.6	11.2	5.0	87.4	3.6	2.4	0.20	11.0	25	17	6.6	88
Fried Meat	36	-	-	-	-	3.2	3.1	0.20	15.0	-	-	-	-
Smoked Meat	34	-	-	-	-	4.2	2.5	1.8	12.0	-	-	-	-
Grilled/Roasted Seafood	20	21.2	36.9	5.0	162	3.9	2.6	1.1	9.8	21	9.0	5.2	40
Fried Seafood	28	-	-	-	-	1.8	1.4	0.20	6.0	-	-	-	-
Smoked Seafood	16	-	-	-	-	4.0	3.5	0.20	11.0	-	-	-	-
Processed Cooking Oil	30	-	-	-	-	1.0	2.2	0.20	12.0	-	-	-	-
Fried Potato	31	480	1,030	5.0	4,605	0.61	0.34	0.20	1.2	-	-	-	-

The analytical results of 235 samples of meat and meat products (grilled/fried/smoked), seafood and seafood products (grilled/fried/smoked), processed oils, and potatoes showed that 12 samples detected acrylamide in the range of 5.0 – 162.0 µg/kg found in grilled/fried dishes and 5.0 – 4605 µg/kg for fried potatoes. Additionally, 204 samples detected NDMA in all groups in the range of 0.20 – 15.0 µg/kg, and 27 samples detected BaP in the range of 5.2 – 88 µg/kg in grilled/roasted food.

The results given in Table 2 showed that acrylamide was detected in meat and grilled meat products, seafood and grilled seafood products, and potatoes, of which the potato group had the highest content, averaging 480 µg/kg, the meat and grilled meat products group had the lowest content, averaging 11.6 µg/kg. NDMA was detected in all types of samples, of which the meat and smoked meat products group had the highest content, averaging 4.2 µg/kg, and the processed oil group had the lowest content, averaging 1.0 µg/kg. BaP was detected in grilled samples, of which the grilled meat group had the highest content, averaging 25 µg/kg, and the grilled seafood group had the lowest content, averaging 21 µg/kg. No acrylamide was detected in samples of fried meat and meat products, smoked meat and meat products, fried seafood and seafood products, smoked seafood, and processed oils. Also, no BaP was detected in samples of fried meat, smoked meat, fried seafood, smoked seafood, processed oils, and fried potatoes. Therefore, these product groups are not meaningful for assessing exposure dose.

3.2. Consumption data

General characteristics

The actual survey sample size in localities met the set sample size, with gender statistics that the number of females accounted for 45.6%, less than males accounted for 54.4%, ensuring the representativeness of the survey subjects.

Table 3. *Average height and weight*

Groups (year) (n = 160)	Height (m)		Weight (kg)	
	Mean	SD	Mean	SD
Lower to 6	1.20	8.20	24.00	21.40
Above 6 to 18	1.49	11.40	45.00	31.70
Above 18 to 50	1.60	4.60	53.90	13.70
Above 50	1.60	4.75	57.70	13.60

The average weight and height of the groups shown in Table 3 showed that the survey participants are consistent with published data from the Vietnam Population Health Census conducted in 2020.

Consumption intake

Food consumption survey for risk analysis using the Semi-Quantitative Food Frequency Questionnaire (SQ-FFQ) method, from which average food consumption data in the study localities were calculated based on information collected from the food consumption survey conducted simultaneously with food sampling. Table 4 summarizes daily food consumption statistics by age group.

Table 4. *Consumption of processed food*

Consumption Mean (g/day)	Lower to 6 years (n = 40)	Above 6 to 18 years (n = 40)	Above 18 to 50 years (n = 40)	Above 50 years (n = 40)
Grilled/Roasted Meat	36.7	58.6	140.1	42.9
Fried Meat	32.0	48.1	80.0	23.1
Smoked Meat	11.6	23.4	51.1	14.1
Grilled/Roasted Seafood	11.9	26.6	36.3	18.0
Fried Seafood	25.9	30.3	42.4	24.6
Smoked Seafood	9.76	11.8	41.1	8.21
Processed Cooking Oil	2.59	21.4	11.5	7.47
Fried Potato	8.37	19.1	26.0	12.5

There was a high daily consumption frequency of grilled, fried, and smoked meat and seafood products, with the highest rates and quantities typically among 18-50-year-olds. On average, all age groups consumed 69.6 g of grilled meat daily, with an average frequency of 82.5%, the highest frequency was among 6-18-year-olds (92.5%), while the highest weekly intake was among 18-50-year-olds (140 g/day). Fried meat products were consumed by 94.4% of respondents, averaging 45.8 g weekly, the highest intake is among 18-50-year-olds (80.0 g/day). Smoked meat products were consumed by 44.4% of respondents, averaging 25.1 g daily, with the highest intake among 18-50-year-olds (51.1 g/day). Grilled seafood was consumed by 72.5% of respondents, averaging 23.2 g weekly, the highest consumption rate is among 6-18-year-olds (92.5%), while the highest weekly intake is among 18-50-year-olds (36.3 g/day). Fried seafood was consumed by 88.8% of respondents, averaging 30.8 g daily, with the highest intake among 18-50-year-olds (42.4 g/day). Smoked seafood was consumed by 11.9% of respondents, averaging 17.7 g daily, with the highest intake among 18-50-year-olds (41.1 g/day).

Processed cooking oil and fried potatoes were also widely consumed, especially by the same age group. Processed cooking oil was used by 41.9% of respondents, averaging 10.8 g weekly, with the highest usage among 6-18-year-olds (21.4 g/day). Fried potatoes were consumed by 74.4% of respondents, averaging 16.5 g weekly, with the highest intake among 18-50-year-olds (26.0 g/day).

The findings revealed significant daily consumption of grilled, fried, and smoked meat and seafood products, especially among individuals aged 18-50, who showed the highest intake rates. Younger individuals (6-18 years) also exhibited high consumption frequencies, particularly for grilled items. The data indicated a preference for fried and grilled foods, with fried meat products being the most commonly consumed. This trend extended to processed foods like cooking oil and fried potatoes, highlighting a shift towards high-fat, processed food consumption. This data was relevant to a previous study such as Husam Alomirah on Kuwaiti eating habits for grilled and smoked foods, which found similarities between children/adolescents and adults. While children/adolescents consumed less of each food type (6.5 g vs. 7.4 g for adults), their total daily intake of meat, bread, and vegetables was higher (138.6 g/day compared to 91.1 g/day for adults) [7]. These dietary patterns posed public health risks due to potential exposure to harmful substances like polycyclic aromatic hydrocarbons, acrylamide, and nitrosamines. The insights suggested a need for targeted nutritional interventions and public health strategies to reduce the consumption of these foods and mitigate associated health risks.

3.3. Exposure assessment

The mean ED was calculated to account for the variability in food consumption data using the formula in section 2.2. Table 5 shows the exposure dose corresponding to each food group, correlated with analyte concentration and consumption. The highest exposures were found for acrylamide on fried potato and NDMA, and BaP on grilled/roasted meat. For cancer risk, LADD values were also calculated in Table 6. LADD was highest for acrylamide in fried potato and NDMA, BaP in grilled meat. The concentrations were not significantly different, but what made the difference would be the consumption level in age groups. For example, the 18-50-year-olds had a much higher consumption of grilled meat than other groups, leading to higher ED and LADD.

Table 5. *Exposure dose and MOE estimation*

Food groups	Acrylamide			NDMA			BaP		
	ED Mean (µg/kg bw/day)	MOE Minimum	MOE Mean	ED Mean (µg/kg bw/day)	MOE Minimum	MOE Mean	ED Mean (µg/kg bw/day)	MOE Minimum	MOE Mean
Grilled/Roasted Meat	0.0336	2,510	5,056	0.0104	1,665	3,354	0.0725	6,850	13,799
Fried Meat				0.0061	3,281	5,729			
Smoked Meat				0.0044	3,911	7,977			
Grilled/Roasted Seafood	0.0205	5,304	8,295	0.0038	5,936	9,284	0.0203	31,496	49,261
Fried Seafood				0.0023	10,999	15,159			
Smoked Seafood				0.0030	5,104	11,848			
Processed Cooking Oil				0.0004	39,200	78,114			
Fried Potato	0.3302	327	515	0.0004	52,963	83,403			
$BMDL_{10}$ (mg/kgbw/day)	0.17 [21]			0.035 [22]			1 [23]		

The result also aligned with findings from previous studies in Asian populations. The review study in 2022 assessing acrylamide exposure in Asian populations found that the primary sources of acrylamide were similar, with fried and baked starchy foods being significant contributors [24]. Studies in China and South Korea showed that traditional cooking methods such as steaming or stir-frying generally result in lower NDMA levels compared to grilling or roasting [25, 26]. Korean studies highlighted that grilling and high-temperature cooking methods can increase BaP levels, traditional cooking methods may contribute differently to levels compared to Western practices, such as charcoal grilling, which is common in some Asian cuisines, can result in higher BaP exposure [26, 27]. Thus, the exact exposure levels could vary widely depending on local dietary habits and food preparation methods

3.4. Risk assessment

For genotoxic compounds, there are two approaches: (1) MOE, through the ratio of $BMDL_{10}$ and ED values , and (2) Cancer risk, calculated through the Cancer Slope Factor and LADD.

For the MOE value in Table 5, with a recommendation of greater than 10,000, many food groups pose a risk. Both grilled meat and seafood food groups have an average MOE of less than 10,000 for acrylamide. For NDMA, all processed meat and grilled seafood groups are at risk. For BaP, although the average MOE is higher than 10,000, the smallest MOE calculated falls in the high meat consumption group. In 2005, EFSA's Scientific Committee recommended the MOE approach for assessing genotoxic and carcinogenic substances, indicating that a MOE of 10,000 or higher, based on animal studies, would pose a low public health concern and be a low priority for risk management, and emphasized that risk management measures to reduce human exposure should still be considered [19].

The cancer risk is a measure of the number of cancer cases in the population, based on the LADD estimate in Table 6. The Cancer Slope Factor values are derived from toxicity studies related to the potential to cause gastrointestinal cancer and are different for each substance. The estimates from this study show that the potential to cause cancer for acrylamide is 1.06×10^{-4} (approximately 1 in 10,000 people), NDMA is 7.27×10^{-4} (about 7 in 10,000 people), and BaP is 5.37×10^{-5} (about 5 in 100,000 people). According to the Public Health Assessment Guidance Manual (PHAGM) of the Agency for Toxic Substances and Disease Registry (ATSDR, United States), substances with cancer risk greater than 1×10^{-6} are recommended to conduct an in-depth toxicological effects analysis [28]. The total cancer risk for all these substances combined is 8.87×10^{-4}, which translates to nearly 9 in 10,000 people.

Table 6. *LADD and Cancer Risk Estimation*

Type of food	LADD (µg/kg bw/day)		
	Acrylamide	**NDMA**	**BaP**
Grilled/Roasted Meat	0.0198	0.0061	0.0426
Fried Meat		0.0034	
Smoked Meat		0.0026	
Grilled/Roasted Seafood	0.0112	0.0021	0.0111
Fried Seafood		0.0012	
Smoked Seafood		0.0018	
Processed Cooking Oil		0.0002	
Fried Potato	0.1809	0.0002	
LADD Total	0.2119	0.0176	0.0537
Cancer Slope Factor $(mg/kg\ bw/day)^{-1}$	0.5 [29]	51 [30]	1 [23]
Cancer Risk	1.06×10^{-4}	7.27×10^{-4}	5.37×10^{-5}
Cancer Risk Total		8.87×10^{-4}	

These findings aligned when compared with a study of carcinogenic risk associated with popular Korean dishes [26], including varied types of processed meats and potatoes done in 2019, the pooled MOE range of 1,341 to 53,049 with the lowest potato level being fried, the lowest of processed meat being roasted and the cancer risk range of $10^{-5} – 10^{-4}$. However, this similarity was only for reference due to differences in population customs and regional cooking methods. Additionally, in this study, the LADD method was not applied to estimate cancer risk. Instead, the risk was obtained by summing the risks of individual compounds in a dish, which were calculated by multiplying the oral slope factor values by the concentrations of carcinogens per serving.

Carcinogen risk assessment models have generally been based on the premise that risk is proportional to cumulative lifetime dose. Risk assessment using the Oral Slope Factor approach indicated that the consumption of certain high-risk Vietnamese dishes, such as grilled/smoked meats and fish as well as deep-fried foods, could lead to cancer risk among the Vietnamese population. These findings underscore the urgent need to address the potential public health threat posed by the increased exposure to carcinogenic compounds in these popular Vietnamese culinary practices. The results indicate that certain cooking methods, such as grilling, smoking, and deep-frying, as well as traditional Vietnamese dishes that involve these high-temperature cooking processes, may expose the Vietnamese population to elevated levels of these carcinogenic contaminants, including polycyclic aromatic hydrocarbons, acrylamide, and nitrosamines, thereby posing a significant cancer risk to consumers.

Limitation of the study

The number of food samples and consumption surveys may not be enough to be representative of the entire population. In addition, the results only focus on grilled/fried foods, and these substances may appear in other foods outside the study, such as acrylamide in bakery products, NDMA in fermented products, and BaP in essential oils. Therefore, conducted extensive research to gather comprehensive data and refine risk assessments, contributing to the development of effective strategies for ensuring food safety and protecting public health in Vietnam.

The findings highlight the need for enhanced monitoring, regulation, and consumer education to mitigate the potential health risks associated with the consumption of these popular Vietnamese dishes.

4. CONCLUSION

This study provides a comprehensive estimation of the dietary exposure to acrylamide, NDMA, and BaP among the Vietnamese population, and evaluates the associated carcinogenic risk for several popular Vietnamese dishes. The research aims to enhance our understanding of the potential health implications posed by the presence of these known or suspected carcinogenic compounds in traditional Vietnamese culinary practices. The analysis food samples identified varying levels of targeted substances, with acrylamide concentrations ranging from 5.0 to 4605 µg/kg, NDMA from 0.20 to 15.0 µg/kg, and BaP from 5.2 to 88 µg/kg. Dietary patterns revealed significant consumption differences across age groups, with individuals aged 6 to 50 consuming the most processed foods, particularly fried items. Risk assessments using MOE and Cancer Slope Factor methods indicated that fried potatoes present the highest acrylamide risk, while grilled/roasted meat has elevated levels of NDMA and BaP. The calculated cancer risk estimates for acrylamide, NDMA, and BaP demonstrate varying potentials to cause cancer, with combined risks indicating a notable public health concern and underscoring the necessity for ongoing monitoring and risk management to mitigate these health risks after recommendations from EFSA and ATSDR.

For exposure characterization uncertainties, due to the current data was not representative of exposures occurring within a regional or local population, the usage of short-term data to estimate long-term exposures would under or over-estimate the distribution, further research is necessary to gather more comprehensive data on the levels of BaP, acrylamide, and NDMA in popular Vietnamese dishes, and to refine the associated risk assessment. This would provide a more detailed understanding of the potential health risks associated with the consumption of these dishes, ultimately supporting the development of effective strategies to ensure food safety and protect public health in Vietnam. Therefore, by gaining a deeper insight into the contaminant levels and their impact on the Vietnamese population, policymakers and food safety authorities can be better equipped to implement targeted interventions, update regulations, and educate consumers, all to mitigate the carcinogenic risks posed by these contaminants in Vietnamese cuisine.

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