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Quantitative Risk Assessment of Acrylamide in Indonesian Deep Fried Fritters as Street Food Products

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Abstract
Acrylamide, a carcinogenic and neurotoxic compound, is a public health concern in fried food products. This paper demonstrated, for the first time, the exposure assessment and risk characterization of acrylamide through consumption of deep fried fritters, a popular snack of Indonesian population which commonly sold as street food. Acrylamide concentration data were collected from selected monitoring data and laboratory simulated researches, while the consumption data covered 263 respondents (adult, age 16-40). Exposure assessment was conducted with probabilistic approach and followed by Margin of Exposure (MoE) calculation. Estimated mean, median (P50) and P95 acrylamide intake were 14.85, 4.10 and 76.06 µg/kg-bw/week, respectively. Thus, resulted in estimated 17.4% of population exceed the reported tolerable intake value (18.2 µg/kg-bw/week). MoE derived from average exposure was 75, indicating significant risk and need of risk management action. Possible mitigation of 70% acrylamide level reduction was simulated and MoE shifted towards 248. Although the MoE was increased, the value was still lower than 10,000 indicating a public health concern. The risk assessment study can be a valuable input for risk managers such as food safety authorities across Indonesia or neighboring countries consuming fried street foods.

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Exposure;
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Introduction

Toxicological studies have shown that acrylamide is neurotoxicant, reproductive toxicant, genotoxic and carcinogen in animals.[1] In fact, it has been categorized as "probable carcinogen to human" (category 2A) by International Agency for Research

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on Cancer (IARC) in 1994. Although the toxicity of acrylamide has been acknowledged long ago, it was not until the finding of its presence in food by Tareke in 2002 that it gets the attention as it has nowadays.[2] Studies have revealed that acrylamide mostly present in carbohydrate-rich material which is processed by high temperature (> 120°C). It is not found in protein-rich material such as meat and fish. Method of food processing is also an important factor because acrylamide is found in baked, fried, roasted products, but not found in boiled products.[3] Acrylamide formation in food has been associated with Maillard reaction and with the presence of asparagine and reducing sugar in the food materials.[4]

Our previous work has demonstrated that acrylamide is a significant issue in deep fried fritter,[5] hereafter referred simply as fritter, products in Indonesia. The fritter products which have high carbohydrate content are typically fried at 150-180°C for about 5-10 mins.[6] Among several types of fritter, banana fritter and sweet potato fritter have become subject for acrylamide studies. For instance, Tandi *et al.*,[7] have found considerable acrylamide content in banana fritter samples collected from Manado market. This finding is in agreement with studies conducted by Daniali *et al.,*[8] in Malaysia, and Komthong *et al.,*[9] in Thailand for the similar banana based fritter products. Meanwhile, acrylamide in sweet potato fritter samples that collected in Manado has been analyzed by Sengke *et al.,*[10] The findings from monitoring studies were also consistent with banana and sweet potato fritter which were produced in laboratory set up.[8,11]

Occurrence rate of cancer in Indonesia has been estimated to be at least 170-190 new cases per 100.000 people annually.[12] Several factors, including carcinogen exposure, might contribute to this rate. In order to assess if a certain carcinogenic substance (for instance, acrylamide) contributes a risk to population, risk assessment can be performed.

In the case of acrylamide in fritter products in Indonesia, there have been several publications covering the acrylamide level as aforementioned. However, to the best knowledge of author, none has discussed about its exposure and risk assessment. Risk assessment for acrylamide has been subject for several studies such as in Spanish potato crisps,[13] total diets in Hong Kong and Dutch population[14,15] and even total diets at international level.[16] However, Indonesia has typical practices in street food production (e.g. time/temperature conditions during frying and typical carbohydrate-rich foods) which implies different acrylamide concentrations, and obviously different consumption patterns. Therefore, the objective of this paper was to perform a probabilistic exposure assessment and risk characterization of acrylamide in Indonesian fritter products and possible mitigation strategies were also discussed.

Methodology

Model Design

The exposure assessment was carried out with probabilistic approach. Simulation was conducted using Excel spreadsheet (Microsoft Corporation) with @Risk add-in program (version 7, Palisade, Newfield, NY). The software program was widely used in other risk assessment studies (Vinci *et al.,*[17]; Yogendrarajah *et al.,*[18]; Lachenmeier and Rehm[19]; Van de Perre *et al.,*[20]; Imathiu[21]). Acrylamide exposure was modeled as the result of multiplication between concentration and consumption. The exposure model with detailed cell addresses and formula used was tabulated in Table 1. For modeling, first order Monte Carlo simulations using Mersenne Twister generator with 10,000 iterations were applied and run in triplicate to test the stability of the outcomes.

Concentration data were taken from several publications including both monitoring and laboratory set up studies. Only two fritters, namely banana fritter and sweet potato fritter were used in the model due to lack of data for other fritter types, including tempeh fritter which was the most preferred by Indonesian.[5] The values were modeled in PERT or Uniform distribution, depending on the type of data available. Minimum, most likely and maximum values were used to define the PERT distribution while only minimum and maximum values were used for Uniform distribution. Prevalence of acrylamide in the fritters was not put into model as 100% of analyzed samples in cited publications were positive with acrylamide. Meanwhile, the primary consumption data was based on Pratama[5] which covered 263 respondents with the age ranged of 20-40 years old (adult).

Table 1: Exposure model: cell addresses and formula used in the exposure assessment of acrylamide in Indonesian fritter products

Cell	Variable	Value/Function	Unit	Reference/Comment
	Acrylamide in banana fritter			
C3	Banana Fritter 1	=RiskPert(67;204,9;809,2)	µg/kg	Daniali *et al.,* 2013
C4	Banana Fritter 2	=RiskPert(75,6;3410,5;7454,2)	µg/kg	Daniali et al., 2010
C5	Banana Fritter 3	=RiskPert(184,9;192,5;200,7)	µg/kg	Khomtong *et al.,* 2012
C6	Banana Fritter 4	=RiskPert(39,65;170;1789,52)	µg/kg	Tandi *et al.,* 2012
	Acrylamide in sweet potato (SP) fritter			
C9	Sweet potato 1	=RiskUniform(251,1;340,9)	µg/kg	Kim *et al.,* 2014
C10	Sweet potato 2	=RiskUniform(118,54;866,75)	µg/kg	Sengke *et al.,* 2013
C12	Total distribution in banana fritter	=RiskDiscrete(C3:C6;{46, 15\28,85\5,77\19,23})	µg/kg	Calculated
C13	Total distribution in SP fritter	=RiskDiscrete(C9:C10;{36, 36\63,64})	µg/kg	Calculated
	Fritter Consumption			
C16	Frequency of consumption	=RiskDiscrete({7\4,5\2,5\1\0}; {16,35\19,01\34,22\12,55\17,87})	times/ week	Table 3
C17	Amount per consumption	=RiskDiscrete({1\2\3\4\5\6};{5,7 \36,12\32,7\13,69\4,56\7,23})	pcs	Table 4
C18	Consumption per week	=C17*C16*0,1/60	kg/kg-bw/week	Assumption weight: 0.1 kg/pcs, BW: 60 kg
C19	Exposure	=RiskOutput("Original Expo-sure")+RiskDiscrete(C12: C13;{55,5\17,1})*C18	µg/kg-bw /week	Calculated
	If scenario			
C22	70% reduction by dipping in citric acid 1%, 1 hour	=RiskOutput("70% reduction") +RiskDiscrete(C12:C13;{55, 5\17,1})*0,3*C18	µg/kg-bw/week	Jung *et al.,* 2003

Value/Function Input Setting for Acrylamide in Banana Fritter

Four studies were selected to define the distribution of acrylamide content in banana fritter (Table 2). The study by Daniali *et al.,*[8] was the only laboratory set up study used, where fritter's acrylamide content was measured as the effect of banana maturity. Information on the total of sample analyzed and the analysis results were used to produce the minimum, most likely and maximum value of each study. The values were then used to make PERT distribution of each study. The total acrylamide distribution of banana fritter (cell C12) was calculated with Discrete distribution from all 4 PERT distributions by considering the proportion of analyzed samples in each cited studies.

Table 2: Acrylamide content of banana fritter from previous studies

No of sample	% sample from total (n=52)*	Min	Mean	Max	Units	Reference
24	46.15	67	204.9	809.2	µg/kg	Daniali et al., 2013
15	28.85	75.6	3410.5	7454.2	µg/kg	Daniali *et al.,* 2010
3	5.77	184.9	192.5	200.7	µg/kg	Khomtong *et al.,* 2012
10	19.23	39.65	170	1789.52	µg/kg	Tandi *et al.,* 2012

* Total of samples that are included in this table

Value/Function Input Setting for Acrylamide in Sweet Potato Fritter

Only a few studies related to acrylamide content in sweet potato fritter were found from literature. Lim *et al.,*[11] studied the effect of frying oil types and the number of frying sequences toward the acrylamide content. The acrylamide value used in this study was the value taken from the first frying sequence with palm olein frying oil which ranged from 251.1 - 340.9 µg/kg (from 4 analyses). It is in accordance with the typical preparation of fritter in Indonesia which uses palm olein and fried only once. The second study was a monitoring study from 7 samples collected from Manado, Indonesia market, which acrylamide content ranged from 118.54 - 866.75 µg/kg.[10] Due to the type of information available, Uniform distribution was applied for each cited study. Subsequently, a Discrete distribution similar to banana fritter was used to estimate the total sweet potato fritter's acrylamide content (cell C13).

Fritter Consumption and Exposure

The frequency of Indonesian consumer on consuming the fritters product (consumption per week) based on our previous study[5] are shown in Table 3. Answer in a range of certain periods (e.g. 2-3 times/week) was converted into the average value. Amount (in pieces) of fritters consumed in one chance is presented in Table 4 where consumption more than 5 pieces was collectively converted to 6 pieces. Frequency and amount of consumption were modeled using Discrete distribution by taking response proportion into account (Table 1). In order to estimate the consumption per week body weight or Estimated Weekly Intake (EWI), it was assumed that average body weight is 60kg and one piece of fritter weights 100g. It was found that 55.5% of population like banana fritter whereas only 17.1% like sweet potato fritter.[5] This information was incorporated to calculate the exposure of acrylamide from fritters product (cell C19 Table 1). This data was the original exposure or "Scenario 1". Meanwhile, to illustrate the effect of a possible mitigation, an if scenario or "Scenario 2" of 70% reduction was simulated based on study by Jung *et al.,*[22] which achieved 73.1% reduction of acrylamide by immersion in citric acid 1% for 1 hour.

Table 3: Frequency of fritters consumption[5]

Frequency	in value	% of response
Everyday	7	16.35
4-5 times/week	4.5	19.01
2-3 times/week	2.5	34.22
once/week	1	12.55
< once/week	0	17.87

Table 4: Amount of fritter consumed in one occasion[5]

Amount	in value	% of response
1 pcs	1	5.70
2 pcs	2	36.12
3 pcs	3	32.70
4 pcs	4	13.69
5 pcs	5	4.56
>5 pcs	6	7.23

Risk Characterization

Risk characterization is the last part of a risk assessment. It combines the information from the previous steps, such as hazard characterization and exposure assessment into advice relevant for decision making.[23] Margin of Exposure (MoE) approach was used in this study. The approach has been preferred for carcinogenic and genotoxic compound such as acrylamide.[24] The MoE is defined as ratio between toxicological threshold (benchmark dose) and estimated human intake, and the value is often used to compare risk among toxic compounds.[19] Lower MoE value indicates a higher risk and according to EFSA,[24] MoE value lower than 10,000 shows a potential public health concern. MoE was calculated as below equation:

MoE = Bench Mark Dose Lower limit ($BMDL_{10}$)/ estimated dietary exposure

Estimated acrylamide $BMDL_{10}$ for mammary tumor of 0.16 mg/kg-bw/day or 1120 µg/kg-bw/week[16] was used in this study. Meanwhile, dietary exposure was taken from mean and percentiles of simulated probabilistic model. As a second type of risk characterization, the estimated weekly intake was also compared with Tolerable Weekly Intake (TWI) of acrylamide according to Tardiff *et al.,*[25] which was 18.2 µg/kw-bw/week.

Results and Discussion

Estimated Acrylamide Intake

The Monte Carlo simulation of two scenarios (original exposure and 70% reduction) resulted in probabilistic distribution of acrylamide intake shown in Figure 1 and summarized in Table 5. It was estimated that 90% of acrylamide intake from fritter consumption was between 0 – 76.1 µg/kw-bw/week (Scenario 1), while the simulated scenario of 70% acrylamide reduction resulted in intake of 0 – 23.4 µg/kg-bw/week (Scenario 2). The median (P50) of the *Scenario 1* was 4.10 µg/kw-bw/week (P95 = 76.06 µg/kg-bw/week). These results showed that 50% (P50) of the Indonesian population had an acrylamide intake at or below 4.10 µg/kw-bw/week from fritter products, while 95% had an acrylamide intake at or below 76.06 µg/kw-bw/week.

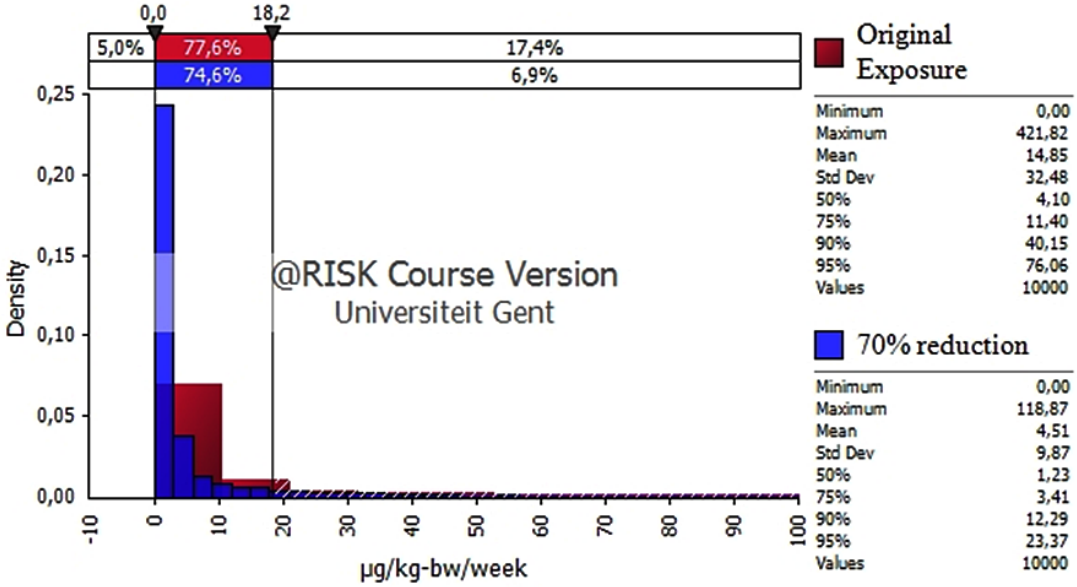

Fig. 1 : Probabilistic density of estimated acrylamide intake from fritter by Indonesian population. Cut off by TWI = 18.2 µg/kw-bw/week, X-axis value was truncated to give better visualization

The result was higher than the similar study which actually covered a range of products (including bakery, cereals, potato, etc) in Dutch population which had P50 of 3.5 µg/kw-bw/week and P95 of 8.4 µg/kw-bw/week15. Therefore, if the total diet is concerned, the acrylamide intake in Indonesian population would be even higher compared to that of Dutch population. Furthermore, the simulated average intake in this study was 14.85 μg/kg-bw/week which could be considered as high level due to a single food group, while the estimated international mean dietary exposures for total diet ranged between 7.7 – 33.6 μg/kw-bw/week.[26] Comparing the exposure with TWI, it was estimated that 17.4% of population exceed the tolerable intake value.

Table 5: Estimated acrylamide intake (μg/kg-bw/week) and MoE at mean and percentiles from fritter products by Indonesian population in original situation and after presumed 70% reduction in acrylamide concentration as potential mitigation strategy

Scenario	Estimated Acrylamide Intake (μg/kg-bw/week)									
	Min	Max	Mean	SD	P50	P75	P90	P95	P99	>TWI
1 - Original	0	421.82	14.85	32.48	4.10	11.40	40.15	76.06	159.4	17.4%
MoE			75		273	98	28	15	7	
2 - 70% reduction	0	118.87	4.51	9.87	1.23	3.41	12.29	23.37	50.33	6.9%
MoE			248		913	328	91	48	22	

The second scenario was to illustrate the impact of possible mitigation to decrease the acrylamide content in the fritters product. The usage of citric acid 1% immersion method was chosen due to its simplicity, and the citric acid is also commercially available with affordable price in Indonesia. Considering the fritters are mainly sold as street food,[5] cost and simplicity of method would play an important factor for mitigation success. Furthermore, the nature of banana as raw material has sour taste, so that the method was expected to not greatly impact the sensory of the product. However, this issue needs to be confirmed, especially for the second product (sweet potato fritter) in this study. With the addition of acid, product had a lower pH which led to the conversion of nonprotonated amine ($-NH_2$) into protonated amine ($-NH^{3+}$) of free asparagine (acrylamide precursor). This phenomenon was effective in blocking its reaction with carbonyl group from reducing sugar and eventually reduced the acrylamide formation in the product.[22]

With the 70% reduction of acrylamide concentration (Scenario 2), the estimated average intake was reduced to 4.51 μg/kw-bw/week. P90 was 12.29 μg/kw-bw/week, which was lower than the estimated TWI 18.2 μg/kw-bw/week. It showed that 90% of the population had an exposure less than tolerable limit if the scenario was carried out successfully. Thus, the remaining population who still exceed the TWI was estimated to be 6.9%.

Risk Characterization

The MoE estimation based on simulated dietary exposure of acrylamide is shown in Table 5. The MoE derived from average exposure estimate for Scenario 1 was 75, while high level estimate from 90% percentile (P90) was 28. Bolger *et al.,*[16] estimated the MoE using international mean intakes (total diet) of acrylamide and several toxicological baselines as point of departure (POD). When the same POD was used (i.e. mammary tumor's $BMDL_{10}$), the current study had lower values than the study by Bolger *et al.,*[16] which estimated MoE were 160 and 40 for mean and P90, respectively. Lower MOE indicates higher risk posed by the substance and by using the same POD means that estimated exposure in current study was higher compared to the study by Bolger *et al.,*[16]. Consequently, by lowering the exposure intake in Scenario 2, estimated MoE increased (lower risk) to 248 and 48 for mean and P90, respectively.

Based on EFSA,[24] MoE of 10,000 or higher, if it is calculated using $BMDL_{10}$, would be a low concern from public health point of view, and thus could be low prioritized in a risk management action. Further categorization was used by Lachenmeier and Rehm,[19] where MoE < 100 fall into 'risk' category, and 'high risk' category is given when MoE < 10. According to the mentioned classification, acrylamide exposure from fritter consumption possess concern for Indonesian public health and hence needs a risk management.

Using the average MoE of 75, acrylamide in Indonesian fritter falls into 'risk' category and would be excluded from the category if the mitigation scenario was in place (MoE 248). However the value was still below 10,000 which indicated public health concern persists, most likely due to the high consumption level. Therefore, the reduction on acrylamide level should be followed by the moderation on consumption to successfully lower the exposure. Nevertheless, using the MoE estimate will help risk managers (e.g. food safety authorities) to prioritize actions, especially when dealing with multiple toxic substances.

Conclusion

The dietary exposure model in this study has demonstrated the probabilistic acrylamide intake from fritter products in Indonesian population. Margin of exposure was calculated from the estimated intake and showed a potential food safety concern among Indonesian population. Therefore, this quantitative risk analysis could be used as an advice for risk managers (Food Safety Authorities) to mitigate the problem. Potential impact of mitigation act in reducing the risk level associated with acrylamide intake from fritter has been shown by the scenario study. As with any risk assessment studies, the quality of the data and assumptions used are the defining factors of the estimate accuracy. Thus, uncertainties for this study arise from lack of concentration data and large scale consumption survey. Addressing the issues is expected to improve the accuracy of the risk assessment study in the future.

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Conflict of Interest

The authors do not have any conflict of interest.

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