A statistical regression model for estimation of acrylamide concentrations in French fries for excess lifetime cancer risk assessment

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Abstract Human exposure to acrylamide through French fries intake has been recognized as a potential health concern. Preliminary studies of the quantification of acrylamide in French fries have generally been conducted using the approaches of chemical analysis in the laboratory. However, chemical analysis is somewhat time and cost consuming. Therefore, the aim of this study was to establish a statistical regression model based on two most influential factors, cooking temperature and time, to estimate the acrylamide concentration in French fries. Statistical analysis showed that the developed model was significant and valid. The good agreement between model simulation and measured data demonstrated the feasibility for using the model to estimate the concentrations of acrylamide in French fries and perform the health-related risk assessment. Based on the French fries intake survey data conducted in this study and eight frying temperature-time schemes, the results of health risk assessment showed that adolescents in Taichung city with excess lifetime cancer risk higher than the acceptable risk suggested by USEPA. We suggested that the reasonable intake of fries would be no more than one medium packet (105 g) every month for adolescent.

Key Words: Acrylamide, French fry, Carcinogen, Regression model

1. Introduction

In 2002, Swedish National Food Administration announced its initial findings of acrylamide formed in commonly consumed baked and fried foods such as French fries and potato chips (SNFA, 2002). This announcement received a great deal of attention because fried foods such as French fries are consumed daily by millions of people from diverse cultural backgrounds. In addition, the level of acrylamide presented in foods is determined at relatively high concentration (30-2300 mg/kg) comparing with other carcinogens (SNFA, 2002). Acrylamide is known as a carcinogen in experimental animal studies, and is classified by the International Agency for Research on Cancer (IARC) as a probable human carcinogen (IARC, 1994).

At high temperature during food processing, carbohydrate-rich foods can go through a series of reaction, known as Maillard reaction, in which asparagines reacts with glucose or fructose to form acrylamide at μg/kg levels (Tareke et al., 2002; Mottram et al., 2002). Studies have shown that even

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though presence of asparagine is crucial for acrylamide formation, reducing sugars have been identified as the precursor to determine the levels of acrylamide formation in French fries (De Wilde et al., 2006). Other important factors that determine the levels of formation of acrylamide in French fries are cooking temperature and cooking time. Williams (2005) carried out an investigation to examine the effect of several factors such as potato cultivar, presoaking, oil type, and frying time and temperature, on acrylamide formation in fried potato crisps. Data showed that frying time and temperature had the greatest influence on acrylamide formation.

Preliminary studies of the quantification of acrylamide in French fries have generally been conducted using the approaches of chemical analysis in the laboratory (Tareke et al., 2002; Arisseto et al., 2007). However, chemical analysis is somewhat time and cost consuming. The aim of this study was, therefore, to establish a statistical regression model to predict the acrylamide concentration in French fries. The model was based on two most influential parameters, cooking time and temperature. Model validation was performed by comparison of the predicted results with the reported data. Then, it was used to evaluate the health risk associated with exposure to acrylamide for adolescents in Taichung city. Adolescents with age ranged from 13-18 were identified to be with high fast food consumption rate (French et al., 2001). French fries were considered to be one of the 'must order' item at fast food restaurants. The French fries intake rate was based on the questionnaire survey given in this study. Finally, the risk reduction strategy was suggested based on the acceptable risk suggested by US EPA.

2. Material and methods

2.1 Statistical model development for estimation of concentrations of acrylamide in French fries

In this study, we develop a statistical regression model that used the cooking time and temperature as independent variables to predict the concentrations of acrylamide in French fries.

Thanks to Gertz and Klostermann (2002), Matthäus et al. (2004), Granda et al. (2004), and Fiselier et al. (2006) who have provided the valuable dataset related to acrylamide formation as function of cooking time and temperature in frying potato product. These dataset provided us the opportunity to build the prediction model of acrylamide concentration in French fries. We totally collected 41 dataset of acrylamide concentrations that were formed in French fries using different cooking time range from 1 to 10 minutes and cooking temperature ranged from 150 to 190 °C.

Since Matthäus et al. (2004) suggested that as temperature increase, acrylamide concentrations increased exponentially. Therefore, this study adopted a non-linear regression model to carry out its evaluation. That is, after taking the natural log of the acrylamide concentration in French fries, we used a regression analysis of cooking temperature and time to obtain improved explanatory power of the effect on acrylamide concentration in French fries. The multiple regression analysis was conducted using statistical analysis software R version 2.12.1.

2.2 French fries dietary survey for adolescents in Taichung

This study was approved by the Ethics Review Board at China Medical University College of Public Health, Taichung, Taiwan. In order to obtain the French fries intake rate data for adolescent in Taichung city, we recruited 434 adolescents age ranged 13-18 to participate in this study. An individual questionnaires informed consent was obtained before the start of the interview. Participants were interviewed face-to-face by a trained interviewer. Interviewers used a standard questionnaire to collect information with regard to demographic characteristics, frequency of French fries consumption habits during the previous month, and French fries intake. Each study was asked to estimate the average number of times that they had eaten fast food last month. In order to satisfy the differing demands of customers, those in the fast food restaurants in Taiwan, usually offer three sizes of French fries; namely, large (145 g), medium (105 g), and small (75 g). Participants were asked to provide what size of French fries they usually ordered when eating at fast food restaurants.

2.3 Health risk assessment for adolescents exposed to acrylamide in French fries

The assessment of the French fries intake in adolescents is based on the frequency of fry intake and

the intake amount. The intake rate is calculated using the equation below:

$$IR_{ff} = EF \times CF \times W \quad (1)$$

where IRff refers to the French fries intake rate (g/day), EF is the exposure frequency (meal/month), CF is the unit conversion factor (month/day), and W is the amount of French fries eaten per meal (g/meal).

The excess lifetime cancer risk for adolescents exposed to acrylamide through eating French fries can then be calculated as follow:

$$ELCR = \frac{C_{ACM} \cdot IR_{ff} \cdot EF \cdot ED}{BW \cdot AT} \cdot CF \cdot CSF \quad (2)$$

where ELCR is the excess lifetime cancer risk, CACM is the concentration of acrylamide in French fries (μg/kg), EF is the exposure frequency (day/year), ED is the exposure duration (year), BW is the body weight (kg), AT is the averaging time (year), CF is the unit conversion factor (10^{-6} kg-mg/g-μg), and CSF is the oral carcinogenic slope factor for acrylamide (mg/kg bw/day)$^{-1}$.

2.4 Monte-Carlo Simulation

The variability of the predictions of the risk assessment model was carried out by using the Monte Carlo simulation technique. The software program Crystal Ball® (Fusion edition, Oracle Corporation, Redwood Shores, CA, USA) was used to analyze data and to estimate distribution parameters. The distribution type was selected based on statistical criteria. To explicitly account for this variability and its impact on the estimation of cancer risk, a Monte Carlo simulation was adopted. The result of Monte Carlo simulation provides a confidence interval (5th and 95th quartiles) of excess lifetime cancer risk for adolescents exposed to acrylamide through eating French fries.

3. Results and Dicsussion

3.1 A statistical model for the estimation of acrylamide concentrations in French fries

Table 1 showed the results of the parameters yielded from the regression analysis. As seen in the table, the relationships between the values for acrylamide concentrations and both the cooking time (x_1) and frying temperature (x_2) are statistically significant ($p < 0.001$). It indicated that the parameters in the model have explanatory effect. In addition, since the total F criterion has provided evidence for rejecting H_0, the regression model is statistically significant. According to the determination coefficient (R^2) in Table 1, the developed model using cooking temperature and time can account for 91% of the total variation of acrylamide concentrations in French fries. Though other study showed that glucose and fructose have the critical effect on the formation of acrylamide in French fries (Amrein et al., 2004), the results of our analysis indicated that cooking time and temperature can explain the variation of acrylamide in French fries with high value of determination coefficient (0.91).

Table 1. Regression coefficient, standard errors, t-values, and p-values for the multiple regression model of acrylamide concentrations in French fries

Variable	Coefficients regression	Standard errors	t-values	p-values
Intercept	-6.0353	0.8844	-6.8242	< 0.001
x_1	0.0615	0.0053	11.5976	< 0.001
x_2	0.0037	0.00036	10.5283	< 0.001

x_1 = cooking temperature

x_2 = cooking time

$R^2 = 0.91$

$F = 182.67 > F_{2, 38, 0.05} = 3.23$ ($p < 0.0001$)

Based on the results yielded from the multiple regression analysis, the following equation is formulated:

$$Ln(C_{ACM}) = 0.0615 \cdot \theta + 0.0037 \cdot T - 6.0353 \quad (3)$$

where θ is the cooking temperature (°C) and T is the cooking time (sec).

As shown in equation (3), the value for acrylamide concentrations derived from the cooking time and temperature is a natural logarithm. In order to obtain the explanatory effect of this value, a conversion is needed; that is, the estimated value e to the power of $(0.0615 \cdot \theta + 0.0037 \cdot T - 6.0353)$ is computed. As such, the acrylamide concentration in French fries is obtained. The formula is shown below.

$$C_{ACM} = e^{(0.0615 \cdot \theta + 0.0037 \cdot T - 6.0353)} \quad (4)$$

where C_{ACM} is the estimated acrylamide

concentrations in French fries with unit of μg/kg.

3.2 French fries intake survey for adolescents aged between 13 and 18

In this study, a questionnaire survey was carried out which targeted young people aged 13 to 18 in Taichung City. It asked them about their preferences for, and intake of, French fries. A total of 434 valid questionnaires were obtained, of which 213 respondents were male, accounting for 49.08 % of the total; and 221 respondents were female, accounting for 50.92 %. Table 2 showed the demographic characteristics of the respondents and a comparison of their monthly intake of French fries.

Table 2. Demographic characteristics and frequency of French fries consumption of adolescent aged 13-18 in Taichung city, Taiwan

Characteristic	Boys (n = 213)	Girls (n = 221)	p-Value
Age (year)	15.9±1.7	16.2±1.8	0.071
Body weight (kg)	59.2±12.4	49.7±7.8	< 0.001
Like to eat fast food			0.871
Yes	155 (72.8%)	146 (66.1%)	
No	58 (27.2%)	75 (33.9%)	
Frequency of eating fast food			0.122
0 meal/month	20 (9.4%)	29 (13.1%)	
1-2 meals/month	88 (41.3%)	109 (49.3%)	
3-4 meals/month	70 (32.9%)	56 (25.3%)	
5 meals/month	35(16.4%)	27 (12.2%)	
Order French fries when go to fast food			0.588
Yes	176 (82.6%)	189 (85.5%)	
No	37 (17.4%)	32 (14.5%)	
Size of French fries ordered usually			< 0.001
Large (145g)	79 (45.1%)	23 (12.2%)	
Medium (105g)	90 (51.1%)	99 (52.5%)	
Small (75g)	7 (3.8%)	67 (35.3%)	

The results of the questionnaire showed that the average age of male respondents was 15.9 ± 1.7, and female respondent age was 16.2 ± 1.8. There was no statistically significant difference in the ages of male and female respondents. Regarding body weight, the average weight of the male respondents was 59.2 ± 12.4 kg, whereas that of female respondents was 49.7 ± 7.8 kg. The body weight of the males was statistically significantly higher than that of the females ($p < 0.001$). When this group of adolescents were asked whether they enjoyed eating fast food, over 60 % of the respondents answered with a 'yes'. This indicates that at the present time in Taiwan there is a high ratio of adolescents who are fond of Western fast food. Regarding the monthly frequency of fast food consumption, it was found that the most common rate was one to two times every month. Among the male respondents, 41.3 % answered 1-2 times, and 32.9 % answered 3-4 times monthly. Of female respondents, 49.3 % answered 1-2 times monthly, and 25.3 % answered 3-4 times monthly. As for the food orders, more than 82 % of the respondents revealed that they ordered French fries when eating fast food. This means that French fries have become almost a 'must order' item at fast food restaurants for Taichung adolescents.

3.3 Average daily acrylamide exposure dose

Table 4 presented the average daily intake of French fries by adolescents in Taichung city. For comparison purposes, it also provided the results of related studies from other countries. The results of the present study showed that the average daily French fries intake by students aged 13 to 18 in Taichung was 10.1 grams. When looking into the average intake rate by gender, it was found that male students' average intake rate was 12.3 g, and that of the females was 7.9 g. When compared with related findings in other countries, it indicated that Taiwanese adolescents' average fry intake was equivalent with that of Swedish people aged 18 to 74 (Svensson et al., 2003); and very close to that of Brazilian adolescents (Arisseto et al., 2009). When compared with the results on Belgian adolescents aged 13 to 18, (Matthys et al., 2005), it was found that Taiwanese adolescents' average fry intake was clearly lower than that of the Belgians. Regardless, it was believed in the past that Taiwanese culture was based on the custom of eating rice, the

results in this study showed that Taiwanese adolescents' French fry intake rate was already almost the same as that of Brazilians and Swedes. This finding indicated that Taiwan people are becoming more and more inclined to western eating habits.

3.4 Excess lifetime cancer risk estimation and risk reduction strategy

On the basis of the CSF of 0.51 $(mg/kg\ bw/day)^{-1}$, the Monte Carlo simulation using random sampling was run 5,000 times to assess the excess lifetime cancer risk caused by acrylamide exposure.

Table 3. Average daily intake rate of French fries for adolescents in Taichung city and a comparison with reported data worldwide

Reference	Nation	Age	Range of average daily intake rate (g/d)	Mean (g/d)
This study-All	Taiwan	13-18	0-67.67	10.06
This study-Boys	Taiwan	13-18	0-67.67	12.26
This study-Girls	Taiwan	13-18	0-53.17	7.94
Svensson et al., 2003	Sweden	18-74	0-214	12
Matthys et al., 2005-All	Belgium	13-18	0-250	39.88
Matthys et al., 2005-Boys	Belgium	13-18	0-300	45.84
Matthys et al., 2005-Girls	Belgium	13-18	0-200	36.26
Arisseto et al., 2009-All	Brazil	11-17	--	12.53
Arisseto et al., 2009-Boys	Brazil	11-17	--	8.23
Arisseto et al., 2009-Girls	Brazil	11-17	--	17.16

Fig. 2 showed the risk of cancer in a box and whisker diagram. The excess lifetime cancer risk among males at the 5th percentile, the 50th percentile, and 95th percentile was 3.35×10^{-7}, 1.35×10^{-6} and 5.36×10^{-6}, respectively. The cancer risk in females at the 5th percentile, 50th percentile, and 95th percentile was 1.97×10^{-7}, $8.86\times10^{-7}$and 3.81×10^{-6}, respectively. The cancer risk in all the adolescent respondents aged 13 to 18, regardless of gender, at the 5th, 50th, and 9th percentiles was 2.48×10^{-7}, 1.11×10^{-6} and 4.77×10^{-6}, respectively.

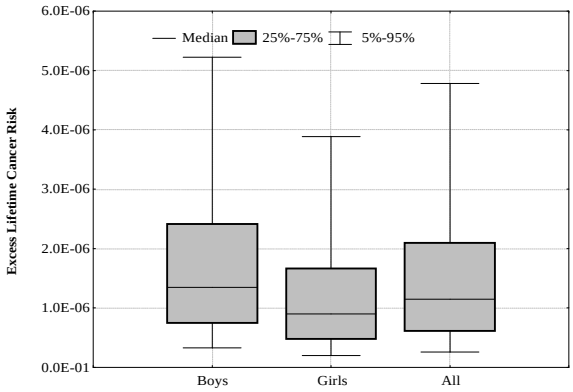

Fig. 2. Box and whisker plot of estimated excess lifetime cancer risk for adolescents who are exposed to acrylamide through eating French fries

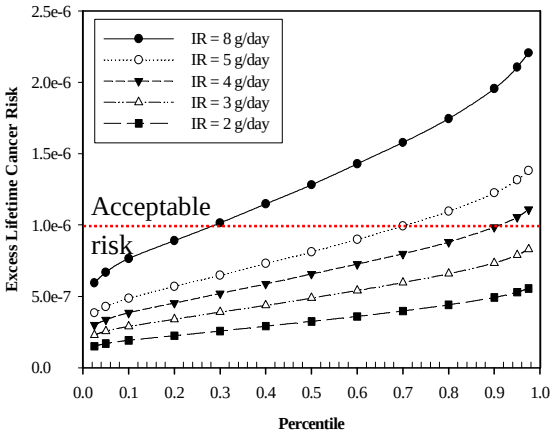

Fig. 3. Daily French fries intake reduction strategies and estimated excess lifetime cancer risk

Fig. 3 presented the results of the Monte Carlo simulation, along with four schemes for the reduction of acrylamide exposure. In the figure, when acrylamide exposure decreases, excess lifetime cancer risk reduced accordingly. For example, when the daily intake of French fries is reduced to 3.0 g/day, all the adolescents would have a excess lifetime cancer risk within the range of acceptable risk. A packet of medium size French fries in Taiwan is approximately 105 grams in weight. It indicated that reasonable

intake of fries would be no more than one medium packet every month. In this way, an appropriate control of French fry intake and acrylamide exposure is achieved, and potential of cancer risk can be reduced.

4. Conclusion

The prediction model developed in this study is an initial attempt to use the cooking temperature and time as independent variables to simulate the concentrations of acrylamide in French fries. Statistical analysis indicated that the developed model using cooking temperature and time can account for 91% of the total variation of acrylamide concentrations in French fries. In addition, the model prediction of acrylamide concentrations in French fries could adequately accounts for the measured data with the same order of magnitude.

We used the developed model and the French fries intake survey data conducted in this study to assess the excess lifetime cancer risk due to exposure to acrylamide for adolescents aged 13-18 in Taichung city. The Monte Carlo simulation results showed that the 95th percentile of excess lifetime cancer risk for boys and girls were 5.36×10^{-6} and 3.81×10^{-6}, respectively. To reduce the risk of acrylamide overexposure, it is therefore recommended that reducing French fries intake should be an alternative. The reasonable intake of fries would be no more than one medium packet every month.

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