

Dietary acrylamide exposure in chosen population of South Poland

Joanna Zając¹, Iwona Bojar², Jadwiga Helbin¹, Emilia Kolarzyk¹, Artur Potocki¹,
Joanna Strzemecka^{3,4}, Alfred Owoc⁵

¹ Department of Hygiene and Dietetics, Jagiellonian University, Medical College, Krakow, Poland

² Department for Health Problems of Ageing, Institute of Rural Health in Lublin, Poland

³ Pope John Paul II State School of Higher Education in Biała Podlaska, Institute of Public Health, Poland

⁴ Department of Orthopaedics and Rehabilitation, Medical University of Lublin, Poland

⁵ Higher School of Public Health, Zielona Góra, Poland

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Abstract

Introduction: Acrylamide is used for wide range of industry purposes and it is produced in food during heating process. Foods with high acrylamide concentration include French fries, chips, bread crust, cereal, different baked goods. The electrophilic nature of acrylamide allows to interact with biological molecules. It is easily absorbed via the ingestion, inhalation or through the skin.

Objective: Evaluation of dietary exposure to acrylamide in chosen population with respect to different age groups in South Poland and assessment of health risk.

Material and Methods: Food consumption survey was conducted among 3 southern provinces in Poland. Studies involved 1470 participants. A semi-Quantitative Food Frequency Questionnaire was used. Consumption data of individuals were calculated into $\mu\text{g}/\text{kg}_{\text{bw}}/\text{day}$. Statistics was calculated for both whole group and different age groups. MOE values were calculated.

Results: Average acrylamide intake was $0.85 \pm 0.82 \mu\text{g}_{\text{acrylamide}}/\text{kg}_{\text{bw}}$ per day and calculated 95th percentile was $1.70 \mu\text{g}_{\text{acrylamide}}/\text{kg}_{\text{bw}}/\text{day}$. In general total dietary exposure decreased with age from $1.51 \mu\text{g}_{\text{acrylamide}}/\text{kg}_{\text{bw}}/\text{day}$ for the youngest group (6–12 years old) to $0.67 \mu\text{g}_{\text{acrylamide}}/\text{kg}_{\text{bw}}/\text{day}$ for the oldest one (42–60 years old). The main contributor of acrylamide in diet in all age groups are bakery products. The MOE values calculated for average acrylamide exposure in diet was 212 and 365 for BMDL_{10} 0.18 and 0.31 $\text{mg}/\text{kg}_{\text{bw}}/\text{day}$.

Conclusions: Young population consume the highest amount of acrylamide thus any efforts should be done to rise their nutritional knowledge and to decrease intake of high acrylamide products (crisps and French fries). The need for promotion of knowledge how to decrease acrylamide level especially in home-made food regardless of age is necessary.

Key words

semi-quantitative food frequency questionnaire, acrylamide, margin of exposure

INTRODUCTION

Acrylamide ($\text{CH}_2=\text{CH}-\text{CO}-\text{NH}_2$) is odourless, colourless, crystalline substance, highly water soluble. It polymerizes easily and forms another molecule—polyacrylamide with new properties. Polymers of acrylamide are used for wide range of purposes (wastewater treatment processes, pulp and paper processing, mining and mineral processing or biotechnology) [1, 2, 3, 4]. High activity of acrylamide is caused by vinyl group, which is easily prone to nucleophilic attack. The electrophilic nature of acrylamide allows to interact with biological molecules. The major targets seem to be the -SH and - NH_2 groups of proteins as well as nitrogen in nucleic acid [5]. Low molecular weight and water solubility of acrylamide enable this molecule to pass through biological membranes. *In vitro* acrylamide can cross the blood/placenta barrier and *in vivo* blood/breast milk barrier [6, 7]. Its structure and compounds created during metabolic transformation enable acrylamide to react with subcellular targets. It is quickly absorbed via the ingestion, inhalation or through the skin [8].

Acrylamide is metabolised on two competing pathways: conjugation with glutathione and epoxidation to glycidiamine [7]. Acrylamide can also bind to plasma proteins, mainly hemoglobin but epoxide group of glycidiamine reacts easier with haemoglobin [9]. This adduct is considered as internal dose marker of acrylamide exposure [2]. Epoxide hydrolase-1 represents the most sensitive biomarker for glycidamide exposure (induction was observed at concentration as low as 0.1 μM) and it shows dose-dependent changes in gene expression [10].

The tragedy that took place in Sweden during tunnel construction, where acrylamide was used as sealing adjuvant (1997), was the cause of many adverse health effects in exposed humans and animals. The observation and researches led to acrylamide as a cause of health problems [11]. The influence of acrylamide on peoples' health was stated first in case of studies conducted on animals and showed its carcinogenic properties [12]. Data gathered in human studies are more ambiguous and correlation between dietary acrylamide uptake and cancer were found only in some groups [13, 14]. Because of reports International Agency for Research on Cancer in 1994 considered acrylamide as “probably carcinogenic to humans” 2A group carcinogen [15, 16]. The Joint FAO/WHO Expert Committee on Food Additives mentioned 0.2 $\text{mg}/\text{kg}_{\text{bw}}/\text{day}$

Address for correspondence: Joanna Zając, Kopernika 7 Street, Krakow, Poland
E-mail: joanna.jankowska@interia.eu

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as NOAEL (non-observed adverse effect level) of acrylamide for morphological changes in rat nerves [17]. Such high value means that typical dietary exposure is about 200–50 times less than NOAEL. Though acrylamide is described as “non-threshold carcinogen” and adverse neurological effects are improbable (in normal exposure from food), some morphological changes in nerves cannot be excluded, mainly for those who have high dietary exposure [18]. For carcinogenic effect a dose-response relationship was based on animal data and Joint FAO/WHO Expert Committee on Food Additive (JECFA) proposed two different values of BMDL₁₀ (lower limit on the benchmark dose for a 10% response): for induction of mammary tumours in rats – 0.31 mg/kg_{bw}/day and for Harderian gland tumours in mice – 0.18 mg/kg_{bw}/day [17]. For health risk connected with dietary exposure to acrylamide evaluation of margin of exposure (MOE) approach is used, even though it is based on animal data it is a common in risk characterization for many food chemicals [19].

Acrylamide in food is produced during heating process (Maillard reaction) [20]. The highest acrylamide content was found in heated carbohydrate-rich foods: 150–4000 µg/kg, moderate levels of acrylamide: 5–50 µg/kg in protein-rich foods and below 5 µg/kg in unheated or boiled foods [21]. Foods with high acrylamide concentration include French fries, chips, bread crust, cereal, different baked goods. The amount of acrylamide depends on processing conditions like temperature, time, nature of food matrix, oil or usage of microwave [21, 22, 23]. Safe limits of acrylamide have been already determined by The Environmental Protection Agency (EPA) and the U.S. Food and Drug Administration (FDA) in water and food. In water: less than 0.5 ppb, in food: 12 µg of acrylamide per person per day are safe in terms of the nervous system [24]. The complex response of human organism to exposure of acrylamide, including exposure from food is still unclear and correlation between estimated acrylamide intake and internal biomarkers is low [17].

The aim of this study was evaluation of dietary exposure to acrylamide in chosen population with respect to different age groups in South Poland and evaluation of health risk.

MATERIAL AND METHODS

Food consumption survey was conducted between September 2011 and June 2012 in southern region of Poland. Among 3 southern provinces: Lesser Poland, Silesian, Podkarpackie random districts were chosen. Then, random households, and random individuals within were taken under consideration in survey. Information about aims of survey and way of conducting were delivered by phone call (if possible) or sent by post. For those who agreed an appointment was made. Among 1560 individuals who were asked, 1470 agreed to participate. The age of participants extended from 6 and 60 years old. Assessment of diet for a large number of individuals requires quick and simple method like questionnaire. For people from a range of various socioeconomic backgrounds, food frequency methods seems to be the most suitable therefore we adapted and validated a semi-Quantitative Food Frequency Questionnaire, conducted in a face-to-face way by trained interviewers. Individuals were asked particularly about products that are known or potential contributors to acrylamide exposure (164 different food items for which

questioned individuals were choosing proper frequencies from “never” to “n times per day”). Portion sizes were estimated using Photographic Album of Products and Dishes [25]. Consumption data of individuals were calculated into µg/kg_{bw}/day. Concentrations of acrylamide in each group of food were taken from European acrylamide monitoring database from June 2006 [26]. Average, standard deviation, median, percentiles value were calculated for different age groups (children from 6 to 12 years old – 300 individuals; adolescences between 13 and 19 – 296 individuals; adults between 20 and 30 – 296 individuals; between 31 and 41 – 278 individuals; between 42 and 60 years old – 300 individuals). Distributions of consumed amounts of each product are not gaussian, so we present also median values for them.

Risk connected with dietary exposure (MOE values) to acrylamide was calculated. MOE values were obtained by comparison of average and 95th percentile intake of acrylamide to both BMDL₁₀ (lower limit on the benchmark dose for a 10% response) values: 0.31 mg/kg_{bw}/day and 0.18 mg/kg_{bw}/day.

RESULTS

All individuals were exposed to acrylamide through diet. Average value for whole group was $0.85 \pm 0.82 \mu\text{g}_{\text{acrylamide}}/\text{kg}_{\text{bw}}/\text{day}$ per day and calculated 95th percentile was $1.70 \mu\text{g}_{\text{acrylamide}}/\text{kg}_{\text{bw}}/\text{day}$. In general total dietary exposure decreased with age from $1.51 \mu\text{g}_{\text{acrylamide}}/\text{kg}_{\text{bw}}/\text{day}$ for the youngest group (6–12 years old) to $0.67 \mu\text{g}_{\text{acrylamide}}/\text{kg}_{\text{bw}}/\text{day}$ for the oldest one (42–60 years old), data presented in Tables 1–5. Comparison of average values for men and women at different age was presented on Fig. 1. The highest differences were observed for two youngest age groups and it decreased with age. In addition men consumed more acrylamide than women.

The main contributor of acrylamide in diet in all age groups were bakery products. For most age groups second great contributor of acrylamide are different kinds of crisps. With

Table 1. Assessment of acrylamide intake among children (6-12 years old); in µg_{acrylamide}/kg_{bw}/day

age	from 6 to 12							the overall intake
	cereals	baker's goods	crisps	French fries	cookies	coffee	meat	
average	0.14	0.63	0.37	0.13	0.21	0.00	0.03	1.51
SD	0.11	0.29	0.68	0.22	0.31	0.00	0.01	0.86
median	0.13	0.62	0.05	0.08	0.10	0.00	0.03	1.36
25 th	0.05	0.42	0.00	0.00	0.00	0.00	0.03	0.83
75 th	0.22	0.75	0.44	0.10	0.28	0.00	0.04	1.78

Table 2. Assessment of acrylamide intake among children (13-19 years old); in µg_{acrylamide}/kg_{bw}/day

age	from 13 to 19							the overall intake
	cereals	baker's goods	crisps	French fries	cookies	coffee	meat	
average	0.04	0.41	0.04	0.05	0.10	0.04	0.02	0.89
SD	0.07	0.25	0.54	0.10	0.13	0.05	0.02	0.89
median	0.01	0.40	0.01	0.01	0.05	0.01	0.02	0.62
25 th	0.00	0.26	0.00	0.00	0.00	0.00	0.01	0.35
75 th	0.05	0.55	0.13	0.03	0.14	0.06	0.03	0.91

Table 3. Assessment of acrylamide intake among adults (20–30 years old); in $\mu\text{g}_{\text{acrylamide}}/\text{kg}_{\text{bw}}/\text{day}$

age	from 20 to 30							
food category	cereals	baker's goods	crisps	French fries	cookies	coffee	meat	the overall intake
average	0.04	0.33	0.05	0.02	0.09	0.06	0.01	0.61
SD	0.14	0.19	0.08	0.04	0.15	0.08	0.01	0.32
median	0.00	0.30	0.02	0.01	0.05	0.02	0.01	0.56
25 th	0.00	0.22	0.00	0.00	0.00	0.00	0.00	0.41
75 th	0.03	0.42	0.05	0.03	0.11	0.08	0.02	0.77

Table 4. Assessment of acrylamide intake among adults (31–41 years old); in $\mu\text{g}_{\text{acrylamide}}/\text{kg}_{\text{bw}}/\text{day}$

age	from 31 to 41							
food category	cereals	baker's goods	crisps	French fries	cookies	coffee	meat	the overall intake
average	0.03	0.31	0.01	0.03	0.08	0.09	0.01	0.56
SD	0.05	0.19	0.04	0.04	0.12	0.17	0.01	0.26
median	0.00	0.28	0.00	0.00	0.03	0.05	0.01	0.52
25 th	0.00	0.17	0.00	0.00	0.00	0.02	0.01	0.40
75 th	0.03	0.37	0.00	0.04	0.09	0.10	0.02	0.67

Table 5. Assessment of acrylamide intake among adults (42–60 years old); in $\mu\text{g}_{\text{acrylamide}}/\text{kg}_{\text{bw}}/\text{day}$

age	from 42 to 60							
food category	cereals	baker's goods	crisps	French fries	cookies	coffee	meat	the overall intake
average	0.04	0.25	0.15	0.05	0.05	0.11	0.01	0.67
SD	0.14	0.14	0.75	0.07	0.07	0.17	0.01	1.26
median	0.00	0.23	0.00	0.02	0.02	0.09	0.01	0.35
25 th	0.00	0.17	0.00	0.00	0.00	0.00	0.01	0.33
75 th	0.04	0.30	0.00	0.07	0.07	0.12	0.01	0.53

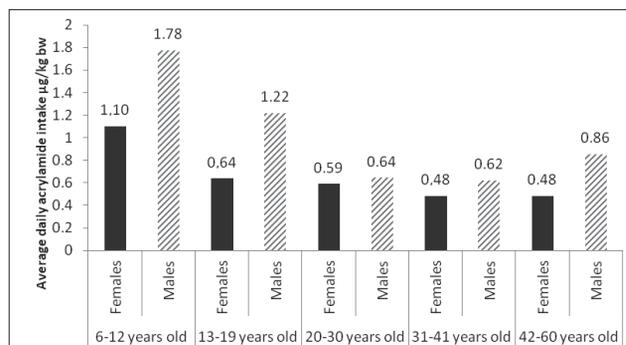
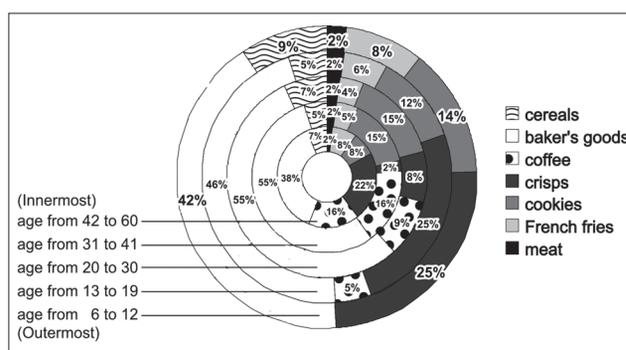
increasing age more intensive uptake of brewed coffee can be observed. Contribution of meat remains on the same level across all groups. More detailed percentage shares for different food categories and different age groups based on average values were presented on Fig. 2.

The MOE values, shown in Table 6, calculated for average acrylamide exposure in diet was 212 for $\text{BMDL}_{10}=0.18 \text{ mg}/\text{kg}_{\text{bw}}/\text{day}$ and 365 for $\text{BMDL}_{10}=0.31 \text{ mg}/\text{kg}_{\text{bw}}/\text{day}$. The lowest values for MOE for both average and 95th percentile were observed among the youngest group. Up to age 31–41 age group MOE values for average exposure as well as MOE values calculated for the 95th percentile were increasing. In the oldest group both MOE values are slightly decreasing.

Table 6. Margins of exposure (MOE) estimated for average and 95th percentile of dietary exposure to acrylamide. in different age groups

Age (years)	6–12		13–19		20–30		31–41		42–60		all	
	\bar{x}	95 th										
Exposure ($\mu\text{g}/\text{kg}_{\text{bw}}/\text{day}$)	1.51	2.86	0.89	3.00	0.61	1.15	0.26	1.10	0.67	1.12	0.85	1.70
MOE ($\text{BMDL}_{10}=0.18 \text{ mg}/\text{kg}_{\text{bw}}/\text{day}$)	119	63	203	60	295	157	702	163	269	161	212	106
MOE ($\text{BMDL}_{10}=0.31 \text{ mg}/\text{kg}_{\text{bw}}/\text{day}$)	206	109	349	103	509	270	1209	281	464	278	365	182

BMDL_{10} values from: JECFA. 2011; \bar{x} – average

**Figure 1.** Average values of overall acrylamide intake in different age groups with sex classification**Figure 2.** Percentage share of acrylamide intake in different age groups based on average values from tables 1–5. The most inner circle represents the oldest group while the other rings. successively younger categories

DISCUSSION

The latest assessment of acrylamide dietary exposure in Poland was published in 2010 [27]. Food consumption data in that study were taken from “Household Food Consumption and Anthropometric Survey in Poland” conducted in 2003 [28]. Comparing with previous studies overall intake was approximately twice bigger: in present study – $0.85 \pm 0.82 \mu\text{g}/\text{kg}_{\text{bw}}/\text{day}$ and $0.43 \pm 0.70 \mu\text{g}/\text{kg}_{\text{bw}}/\text{day}$ in previous one. Probably the main difference in exposure was the result of extrapolation to age from 1 to 99 years old done in former evaluation and the fact that previous one assessed consumption for whole Polish population. Moreover, as mentioned above, consumption data were taken from study conducted in 2003. Its unlike that the differences were due to distinctions in concentrations of acrylamide in food, cause concentrations used in present study were comparable or even lower than those assessed by Mojska et al. [27]. Present assessment of acrylamide intake was about two times higher than other national assessments conducted in such countries as: Belgium [29], France [30], China [31] or Norway [32], about 60%-70% higher than in Australian [33]

or Danish survey [34] but comparable with Hungarian [35] and the US studies data [36]. According to data gathered by The Joint FAO/WHO Expert Committee on Food Additives (JECFA) estimates of average intake of acrylamide among 17 countries ranged from 0.3 to 2.0 $\mu\text{g}/\text{kg}_{\text{bw}}/\text{day}$ and in general values calculated for children were 2–3 times higher than for adults [37]. Probably differences in assessment reflect the fact that presented studies are regarding to population at limited age (6–60 years old). Moreover, methods used in studies, time when the survey was conducted and products which were taken under consideration were different. Information about food consumption was gathered using food frequency questionnaire, 24-hour dietary recall or food record. According to Sirot et al. [30] food frequency questionnaire overestimate consumption which is directly connected with exposure, though Brantsaeter et al. [32] compared results of 4-days food diary, food frequency questionnaire and probabilistic approach concluding that the differences between the methods for estimating dietary acrylamide exposure were small and food frequency questionnaire can be used for epidemiological studies. Time when surveys were conducted was different: like the year 2003 for Australian and Polish studies, or 2005–2007 in case of French survey [30].

Both Polish studies described bakery products as the main source of acrylamide. According to data enclosed in Polish Central Statistical Office report bread in Poland is consumed in amount about 60 kg per inhabitant per year [38], even higher amount (83 kg per inhabitant per year) is consumed in Germany and significant proportion of total intake of acrylamide in Germany came from the intake of bread and other bakery products (18–46%) [39]. Other studies reflect differences in consumption habits. In Norwegian assessment crispbread and coffee are the major contributors (22% and 28%) [32], while in French studies French fries takes the first place (45% for adults and 61% for children) [30]. In the Netherlands crisps are the most important contributor in overall exposure (31%) [40], in Sweden coffee is the main source of acrylamide in food (39%) [41]. In the USA potato crisps were leading among other sources of acrylamide [37].

Level of acrylamide depends on heating process (temperature), kind of fat used for frying and products that are used. Some countries (Germany, Sweden, France) decided to undertake approaches to reduce concentration of acrylamide in foodstuff [42]. Confederation of the Food and Drink Industries of the EU presented an useful approach: The Confederation of the Food and Drink Industries of the European Union (CIAA) Acrylamide “Toolbox”, aimed at finding appropriate and practical solutions to reduce the overall dietary exposure to acrylamide [43].

The importance of acrylamide monitoring is reflected in Recommendations of European Union [44]. The system for supervising food safety covers all food chain and is regulated by many legal acts, both national and those of the European Union. Also the “Rapid Alert System for Food and Feed” (RASFF) is implemented in order to enhance consumers safety [45]. Besides focusing on safety, the risk for health assessment is commonly used (MOE). The lower MOE values are the higher risk indicate. According to JECFA’s report from 2011 MOE values between 45 and 310 may implicate health concern [17]. In present study, the MOE values seem to be low, the lowest for young groups: 63 for 6–12 years old and 60 for 13–19 years old. MOE data obtained in present study extended from 60 to 1209. In JECFA report for 2011,

values of MOE for general population ranged from 50 for 95th percentile to 200 for average intake [17].

It should be pointed out that estimation of MOE value was assessed through experiments conducted on rodents. Different toxicokinetics of rodents may influence on the extrapolation to humans [19]. In addition standard procedure of extrapolating health risk from high-dose effects in rodents (acrylamide causes increase of cancer incidents mainly connected with: brain cancer, lung adenomas, initiated skin tumorigenesis, cancers of the thyroid and other endocrine glands and reproductive organs [7, 46, 47]) to very low-dose level of human exposure may lead to an overestimation of toxicological risk.

Even though years of studies on acrylamide have passed the problem is still raising. Slight correlation between cancer risk and acrylamide exposure cannot be interpreted as a proof of no carcinogenicity of this molecule and it is advisable to reduce dietary exposure to acrylamide [48, 49]. Moreover it is advisable to conduct studies focusing on the effects caused by acrylamide exposure.

CONCLUSIONS

1. Young population consume the highest amount of acrylamide thus any efforts should be done to rise their knowledge about importance of nutrition and problems related with non-appropriate nutrition. The need for promotion of balanced diet and education aiming at selecting proper products is still needed, regardless of age.
2. Efforts aiming at reduction of acrylamide content in food products, both commercial and home-made, must be carried on, because elimination of acrylamide from diet with proper and healthy nutrition is very unlikely.

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