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Acrylamide exposure of infants and toddlers through baby foods and current progress on regulations

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Acrylamide is a thermal-process contaminant and found at different levels in various carbohydrate-rich foods processed at high temperatures. Acrylamide poses serious health concerns for babies and children since acrylamide-rich foods comprise an important amount of their diet. Consumption of acrylamide-rich foods results in higher acrylamide-exposure levels of babies and children than adults due to their lower body weight. In recent years, with an increased number of exposure-assessment studies and researches, acrylamide exposure of babies and children is very well defined. In that context, mitigation strategies have been conducted and also, some regulations have been implemented in some countries for baby foods. The aim of this study is to evaluate recent data about acrylamide levels and acrylamide exposure of infants (0–1 years old) and toddlers (1–3 years old) through commonly consumed baby foods in the last decade, and to discuss current progress on regulations.

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Introduction

The first years of life are crucial for healthy development and growth [1]. Proper nutrition containing macro- and micronutrients and free of toxic compounds is a high priority starting from pregnancy and continuing during childhood is among the factors making a big difference to the health of individuals. Therefore, diets of the vulnerable population, including pregnant women, infants, toddlers, and children should be free of unwanted substances, including thermal-process contaminants.

Acrylamide is one of the thermal-process contaminants found in baked or fried carbohydrate-rich foods where raw materials include the precursors, such as cereals and potatoes [2]. Therefore, coffee, potato crisps, potato-fried products, bread, breakfast cereals, crackers, rusks, biscuits, and baby foods contain acrylamide at various levels [3]. The presence of acrylamide in these foods has been attracting considerable attention worldwide for the last two decades because this compound is classified as a Group 2A — probable human carcinogen by the International Agency for Research on Cancer [4]. In that context, many researches have been conducted by researchers and food authorities to investigate the acrylamide formation, levels in different foods, possible toxic effects, as well as exposure of different age groups and mitigation strategies to reduce acrylamide in foods.

Unfortunately, the most sensitive age groups to contaminants including acrylamide are lower age groups [5••]. Acrylamide-exposure studies have been conducted in different countries on various age groups and the highest exposure levels were determined for babies and children [3,5••–9]. Therefore, infants, toddlers, and children are accepted as the most exposed groups [3]. Because they have consumption patterns different from adults and commonly consume acrylamide-detected foods. In addition, due to lower body weight and a higher dietary intake per kilogram of body weight, acrylamide exposure is higher in babies and children compared with adults. Therefore, acrylamide is considered a concern for infants and toddlers since they are the most vulnerable population to acrylamide exposure [10].

In that context, acrylamide monitoring in baby foods and exposure and risk assessment of infants (0–1 years old) and toddlers (1–3 years old) to acrylamide have paramount importance. The aim of this study was to review recent data about acrylamide levels in baby foods and exposure levels of infants and toddlers, as well as progress on current regulations to reduce acrylamide in baby foods.

Acrylamide levels in baby foods

Acrylamide is one of the contaminants that pose a high health risk for infants and toddlers due to the different physiological characteristics, including higher daily food intake per kilogram of body weight, higher ventilation, and also, greater body-surface area compared with adults. Moreover, infants and toddlers have greater sensitivity to potentially toxic compounds as a result of having higher resting metabolic rates [5••]. In that context, infants and toddlers are more vulnerable to toxic compounds and acrylamide exposure of infants and toddlers through baby foods should be the lowest in those age groups. However, according to the exposure studies conducted worldwide, acrylamide exposure of infants, toddlers, and other children is typically higher than adults [3].

Adequate feeding during early childhood is essential and the complementary feeding period for infants and toddlers has lifelong consequences [11,12]. Therefore, besides containing macro- and micronutrients, the commercial complementary foods, baby foods, should be free of toxic compounds. Baby foods, including infant formula, baby biscuits, biscuits, purees, crackers, cakes, breakfast cereals, and bread, constitute an important portion of infants' and toddlers' diet and contain acrylamide at various levels. Table 1 shows the acrylamide contents of baby foods consumed by infants and toddlers based on the worldwide acrylamide studies conducted in baby foods during the last decade.

Acrylamide levels in baby foods showed a great variation due to the different food types, formulations and compositions, production and processing methods, and also, acrylamide analysis techniques conducted worldwide. Especially, cereal-based baby foods are commonly consumed by toddlers and could contain high amounts of acrylamide, resulting in considerably high acrylamide exposure. Abt et al. [19•] investigated the acrylamide levels in foods and exposure assessment between 2011 and 2015 in the United States and reported that infant snack foods, such as teething biscuits, puffs, crackers, and rusks, are an important contributor to acrylamide intake relative to infant jarred foods. Acrylamide concentration in infant foods was in the range of 5–1788 with a mean value of 165.1 μg/kg. The highest mean acrylamide concentrations were determined in infant crackers (826.9 μg/kg) and teething biscuits (414.5 μg/kg) [19•].

Similar results were obtained in other studies in different countries. Mojska et al. [7] found the highest mean acrylamide content among commercially produced baby foods in Poland in infant biscuits (219 μg/kg) and reported that infant biscuits might provide as much as one-fifth of the total amount of acrylamide daily dietary intake for infants above eight months old [7]. Similar acrylamide levels were measured in baby biscuits collected in Turkey [9,20]. In a previous work of our group, mean acrylamide concentrations were determined as 153 μg/kg in baby biscuits and the highest mean acrylamide concentrations were determined in crackers (604 μg/kg) and biscuits (495 μg/kg) among the collected baby foods in Turkey [9]. According to the European Food Safety Authority Panel on Contaminants in the Food Chain report, mean acrylamide concentrations in European countries for baby biscuits–rusks, crackers and biscuits, and wafers were reported as 111, 231, and 201 μg/kg, respectively [3]. Pacetti et al. [15] determined very high acrylamide levels in Colombian foods and reported that the highest mean acrylamide content was found in bakery products, such as biscuit (1104 μg/kg) and wafer (1449 μg/kg). Besides baby biscuits produced with the purposes of infant and toddler nutrition, other food categories such as biscuits and crackers are also commonly consumed by toddlers. Kafouris et al. [23] determined acrylamide levels of the food products in Cyprus as 286 and 353 μg/kg for crispbread, crackers and biscuits, and cookies, respectively. Nematollahi et al. [24] reported acrylamide levels for wafers, biscuits, crackers, cakes, and cookies in Iran as 234, 211, 191, 177, and 156 μg/kg, respectively.

A recent study was conducted in Italy for assessment of the acrylamide exposure through baby foods, including ground and whole biscuits, savory and sweet snacks, baby cereal meal and baby food with plum puree are consumed particularly for infants and toddlers of 4–36 months old, and acrylamide levels found in biscuits (61 μg/kg) and ground biscuits (39 μg/kg) were lower than previously reported studies [8••]. Moreover, none of the samples showed acrylamide levels above the benchmark level of the European Regulation 2017/2158 [2]. In addition, acrylamide levels for plum puree were detected in the range of < LOD — 32 μg/kg, which was lower compared with baby foods containing prunes in the report of European Food Safety Authority (EFSA) [3]. EFSA reported higher levels of acrylamide in baby foods containing prunes (101 μg/kg) than in baby foods not containing prunes (20 μg/kg) due to containing considerable amounts of precursors and the applied thermal treatment [3].

Infant cereals are categorized in the processed cereal-based food and infant cereal porridges constitute the basis of complementary feeding from the age of 4 to 6 months [22••,25]. Infant cereal samples were collected in Spain to evaluate the effects of formulation on Maillard reaction products and mean acrylamide contents were determined as 70.5 μg/kg in the collected samples [22••]. It was reported that the infant cereal sample containing honey and grape juice concentrate resulted in more acrylamide, which shows the importance of some

Table 1

Acrylamide levels in baby foods commonly consumed by infants and toddlers according to the studies published worldwide in the last decade.

Year	Country	Food product	Mean acrylamide levels (μg/kg)	Range of acrylamide levels (μg/kg) Min–Max	Reference
2007–2011	Poland	Follow-on formula	73	32–312	[7]
		Follow-on formula ready-to-eat	10.50	4.35–45.8	
		Jarred baby foods	55	2–162	
		Infant cereals (powder)	148	65–296	
		Infant cereals (ready-to-eat)	26.02	11.43–52.06	
		Infant cereals with follow-on formula in powder	129	17–260	
		Infant cereals with follow-on formula ready-to-eat	22.68	2.99–45.73	
		Infant biscuits	219	37–516	
2012	Turkey	Baby biscuits	153	< LOQ — 588	[9]
		Powdered baby foods	36	< LOQ — 174	
		Rusks	121	< LOQ — 660	
		Crackers	604	< LOQ —2666	
		Biscuits	495	< LOQ — 1177	
		Breakfast cereals	290	< LOQ — 762	
		Bread	225	< LOQ — 695	
2011–2012	France	Milk-based beverage	2.6–5.3	2.0–7.1	[13]
		Milk-based dessert	2.0–5.0	2.0–5.0	
		Cereal-based food	11–17	0.0–99	
		Soup, puree	14.0–15.0	2.0–32.0	
		Fruit puree	5.7–7.3	0.0–15.0	
		Ready-to-eat meal (vegetable-based)	19.0–20.0	2.0–67.0	
		Ready-to-eat meal (meat/fish-based)	14.0	2.0–39.0	
		Infant formula	0.60–2.9	0.0–5.0	
		Follow-on formula	0.14–2.2	0.0–5.0	
		Sweet and savory biscuits and bars	102	–	
2013	Poland	Cereal-based (ready-to-eat)	13.4	10.8–15.7	[14]
		Instant cereal-based	34.7	19.2–59.9	
		Candy-bars	53.5	39.0–61.2	
		Cakes	28.9	13.3–49.5	
2015	Colombia	Infant-powdered formula	1019	< LOQ —1821	[15]
		Wafer	1449	687–2497	
		Biscuits	1104	< LOQ — 3180	
		Crackers	758	194–1271	
		Breakfast cereals	726	< LOQ — 2288	
		Soft bread	231	102–594	
		Toasted bread	< LOD	< LOQ	
		Crispbread	< LOD	< LOQ	
2008–2013	Belgium	Baby biscuits	117	< LOQ — 1200	[16]
		Biscuits	142	< LOQ — 1113	
		Breakfast cereals	145	< LOQ — 670	
2016	Brazil	Fruit-based baby foods	nd-35	–	[17]
2017	Estonia	Biscuits and rusks for infants and young children	< 30	< 30–36	[18]
		Processed cereal-based foods for infants, exclusively biscuits and rusks	42	< 30–353	
		Baby foods, mainly vegetable-based, noncereals	65	< 30–180	
		Baby foods, mainly fruit-based, noncereals	< 30	< 30	
		Bread	< 30–108	< 30–637	
		Breakfast cereals	41–326	< 50–660	
		Biscuits and wafers	242	< 50–885	
2011–2015	United States	Infant formula	nd	–	[19•]
		Infant foods (jarred vegetables and fruits, jarred mixtures, and infant snack foods — teething biscuits, puffs, cracker, and rusks)	165.1	5–1788	
		Breads and bakery products	14.7	5–102	
		Breakfast cereals	207.3	5–1354	
		Cookies	181.8	5–1796	
		Crackers	200.3	5–2110	

Table 1 (*continued*)

Year	Country	Food product	Mean acrylamide levels (μg/kg)	Range of acrylamide levels (μg/kg) Min–Max	Reference
2021	Italy	Biscuits	61	LOQ — 109	[8••]
		Ground biscuits	39	LOQ — 55	
		Multigrain meal	< LOD	< LOD– < LOD	
		Sweet snacks	< LOQ	< LOD– < LOQ	
		Savory snacks	< LOQ	< LOQ– < LOQ	
		Plum puree	< LOQ	< LOD — 32	
		Biscuits	61	LOQ —109	
2021	Turkey	Infant formulas			[20]
		• 0–6 months	45.1	< LOQ — 162	
		• 6–12 months	62.5	< LOQ — 228	
		• > 12 months	88.6	< LOQ — 578	
		Baby biscuits	233	12.3–1270	
2021	Iran	Powder infant formulas for			[21]
		• 0–6 months	992	48–3191	
		• 6–12 months	2349	918–5835	
		• 12–24 months	2372	1290–4400	
2021	Spain	Infant cereals	70.5	< LOQ — 92.4	[22••]

ingredients during the production and processing of the baby foods.

Acrylamide levels in infant and follow-up formulas showed a great variation in different countries as a result of the different chemical compositions and production processing. A recent study conducted in Iran on the risk evaluation of acrylamide in powder infant formulas found very high acrylamide levels in the range of 48–5835 μg/kg [21]. The authors concluded that the formulation and ingredients of powder infant formula have a considerable effect to generate acrylamide, and stated that the role of protein was greater than other factors to form acrylamide in powder infant formulas [21]. Similar results were obtained in the infant-powdered formula samples collected in Colombia [15]. On the other hand, acrylamide levels in infant and follow-up formulas were lower compared with other baby foods in many studies [7,9,13,19•,20]. EFSA [3] reported acrylamide levels in infant formula in the range of 3–26 μg/kg with a mean value of 14 μg/kg according to the scientific opinion on acrylamide. Infant formula and follow-on formula are the foods intended for use by infants during the first months of life [25] and should be free of potentially toxic compounds from a food-safety point of view, which is critically important during the early months of life. The acrylamide concentration in baby foods could be affected by the levels of free asparagine and reducing sugars, as well as the thermal-processing temperatures and times. Therefore, acrylamide levels in baby foods should be a high safety priority and samples containing acrylamide higher than the benchmark levels for the presence of acrylamide in processed cereal-based foods for infants and toddlers [2] should be reduced by various mitigation strategies to decrease higher exposure levels of infants.

Acrylamide exposure of infants and toddlers through baby foods

Following acrylamide detection in foods, acrylamide exposure of different age groups was determined with various studies and reports conducted in different countries to evaluate if acrylamide represents a risk for the population. Daily acrylamide intake of the populations was calculated based on the acrylamide concentration in the food products and the consumption levels. For the estimation of the exposure levels for the different age groups, the daily dietary-intake data should be combined with the bodyweight (bw) parameters.

Table 2 summarizes the acrylamide-exposure levels of infants and toddlers through baby foods based on the studies conducted in the last decade. Different age groups were exposed to acrylamide at different levels due to the different consumption patterns and body weights. In the report of EFSA [3], the mean and 95th percentile exposure levels were in the range of 0.5–1.9 and 1.4–3.4 μg/kg bw/day, and infants, toddlers, and other children were the most exposed groups. The acrylamide exposure of infants and toddlers was higher than adults in many students. Recently, Lee et al. [29] reported that the dietary exposure to acrylamide in different age groups in Korea and the mean acrylamide dietary exposure levels for toddlers (≤2 years) were the highest (0.15 μg/kg bw/day) compared with other age groups, and biscuits (40%) were the primary processed food sources contributing to acrylamide exposure for ≤2-years-old babies. In the United States, the mean-estimated dietary exposure for < 2 years-of-age babies was 1.42 μg/kg bw/day, with a 90th percentile of 3.02 μg/kg bw/day [19•]. It was reported that infant snack foods, such as teething biscuits, puffs, rusks, and crackers, were the main contributors to acrylamide intake compared with infant jarred foods. According to the exposure

Table 2

Acrylamide-exposure levels of infants and toddlers through baby foods in the last decade.

Country	Age groups	Dietary survey method	Mean acrylamide exposure[a] (µg/kg bw/day)		Year[b]	Reference
Poland	Infants (6–12 months)	Theoretical daily intake	2.10–4.32 0.41–12.35 (min–max)		2012	[7]
Turkey	Toddlers (1–3 years old)	24-h dietary recall	1.43 0.06–6.41 (min–max) 3.76 (P95)		2013	[9]
			1 year	1.68		
			1.5 years	1.61		
			2 years	1.19		
			2.5 years	1.28		
			3 years	1.16		
EU	Infants and toddlers (0–3 years old)	The EFSA Comprehensive European Food Consumption Database Dietary recalls dietary records	< 1 year	0.8–1.0 0.5–1.6 (min LB–max UB) 1.8–2.1 (P95) 1.4–2.5 (P95 min LB–max UB)	2015	[3]
			1–3 years	1.3–1.4 0.9–1.9 (min LB–max UB) 2.3–2.4 (P95) 1.4–3.4 (P95 min LB–max UB)		
United Kingdom	Infants and toddlers (0–24 months)	Diet and Nutrition Survey of Infants Young Children and the National Diet and Nutrition Survey Rolling Programme	0–6 months through infant formula	0.046–0.53 0.069–0.79 (high level)	2016	[26]
			0–12 months	0.30–0.95 1.4–2.7 (P97.5)		
			12–24 months	1.2–1.3 2.3–3.2 (P97.5)		
Estonia	Infants (4–12 months)	Estonian National Dietary Survey 24-h food consumption Food diary	4–5 months	0.12–0.20 0.66–0.95 (P95)	2017	[18]
			6–11 months	0.58–0.80 1.87–2.34 (P95)		
Japan	Toddlers and children (1–6 years)	National Health and Nutrition Survey 1-day dietary records	0.41		2018	[27]
France	Infants and toddlers (1–36 months old)	Consumption record 3 consecutive days	1–4 months	0.14–0.51 (LB–UB) 0.37–0.88 (P90 LB–UB)	2019	[28•]
			5–6 months	0.30–0.51 (LB–UB) 0.57–0.81 (P90 LB–UB)		
			7–12 months	0.40–0.53 (LB–UB) 0.78–0.92 (P90 LB–UB)		
			13–36 months	0.71–0.74 (LB–UB) 1.60–1.66 (P90 LB–UB)		
United States	Infants and toddlers (< 2 years of age)	2-days consumption estimate Centers for Disease Control National Health	1.42 3.02 (P90)		2019	[19•]
Korea	Infants and toddlers (≤2 years)	Korea National Health and Nutrition Examination Survey Nutrition Examination Survey	0.15 µg/kg bw/day 0.37 (P95) 0.66 (max)		2020	[29]
Spain	Infants (6–12 months)	Labeling information	6–12 months through infant cereals	0.291–0.446	2021	[22••]
			6 months	0–0.432 (min–max)		
			12 months	0–0.663 (min–max)		

[a] Exposure assessments of different studies are given as mean and also as *min: minimum, max: maximum, P: percentile, LB: lower bound, UB: upper bound* in parenthesis.
[b] Studies were aligned according to the published year.

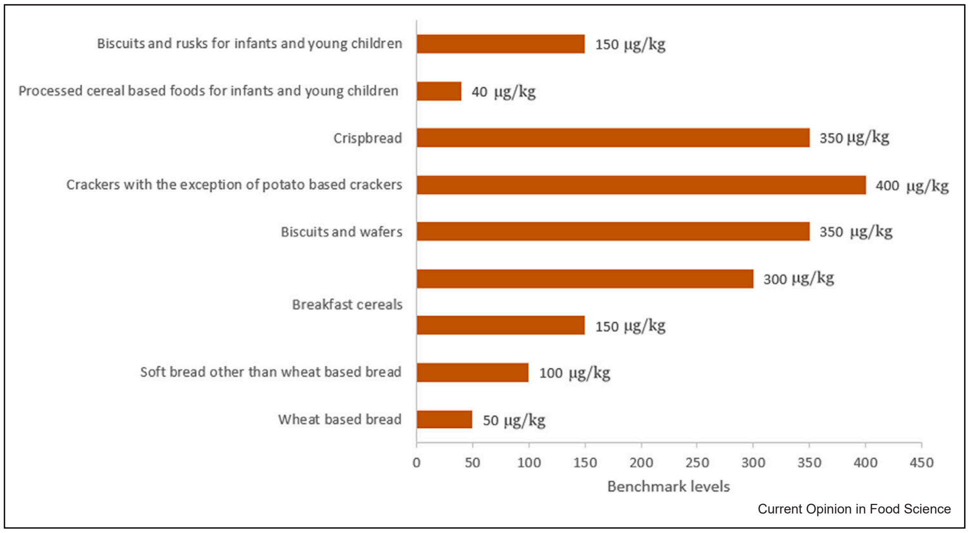
estimates, grain-based infant cereals and infant cookies contribute 27% of acrylamide intake of < 2 years-of-age babies. In addition, the study modeled removal of all infant snack foods that reduced the mean dietary exposure to 0.078 µg/kg bw/day with an 83% reduction [19•]. Another study was conducted to assess the risk associated with chemicals, including acrylamide for 1–36-months infants and toddlers living in France, and reported that the main contributors to the acrylamide exposure in infants were jarred foods, and especially for

1–4-months-old infants, infant formula. On the other hand, potato-based products and biscuits were the main contributors in toddlers [28•]. EFSA [3] reported the relative contributions of each food-product commodity to overall acrylamide exposure and the main contributors to the total lower bound average acrylamide exposure were baby foods — other than processed cereal-based (60%), other products based on potatoes (48%), and processed cereal-based baby foods (30%) in some infant groups. In addition, biscuits, crackers, and crispbread contributed around 20% of the total average exposure level. For toddlers, the contribution of baby-food category was lower than many other categories, including bread, potato-based, and other cereal-based products. In our previous work, the contributions of crackers (25%), biscuits (19%), and baby biscuits (11%) to overall acrylamide exposure of infants and toddlers were significant [9]. Especially, contributions of these food products were higher than specific food categories produced for babies, such as baby biscuits and baby bread for each age group. In that context, the baby-food category should be widened for acrylamide evaluation to the commonly consumed foods by infants and toddlers. In particular, toddlers consume different food products due to starting to explore the environment and this results in dietary diversity. In that context, regulations and mitigation strategies for baby foods should include bread, crackers, biscuits, and cookies that are commonly consumed by infants and toddlers. Mesías et al. [30•] determined acrylamide levels of commercial biscuits in Spain and the results showed a great variation (20–2144 μg/kg) with 30% of the biscuit samples that were above the benchmark level of the European Regulation 2017/2158 [2]. The study calculated acrylamide exposure for a standard adult weight of 70 kg as 0.071 μg/kg bw/day. When considering the high consumption of biscuits by toddlers together with their lower body weights, daily exposure from biscuits will increase at least 2–3 times [30•]. On the other hand, consumption patterns could be different among infants and toddlers in different regions [19•]. A meta-analysis study of conducted researches on acrylamide levels declared that the concentration of acrylamide in diverse food categories is different and the authors reported that the main contributor foods in dietary acrylamide exposure could be different due to the differences in food-preparation methods and consumption patterns in different countries [31]. In that context, specific local foods should also be taken into consideration during exposure-assessment studies. In addition, increasing the number of food categories could prevent underestimation. For example, Kawahara et al. [27] estimated probabilistic acrylamide exposure as the 0.41 μg/kg bw/day for the population in Japan and reported that major sources of acrylamide exposure were potato (40%), confectioneries (19%), and vegetables (15%) between one and six years old. However, the authors emphasized that due to the lack of some food items that might contain acrylamide, exposure levels could be underestimated to the actual dietary intake of acrylamide.

Elias et al. [18] determined the acrylamide levels in baby foods and dietary acrylamide exposure of infants in Estonia, and reported that the mean acrylamide intakes were between 0.12 and 0.80 μg/kg bw/day (P95, 0.66–2.34 μg/kg bw/day) in 4–12-months infants. In the case of excluding the commercial baby-food non-consumers, the acrylamide intake increased to 0.27–0.44 μg/kg bw/day and 0.67–0.92 μg/kg bw/day among infants aged 4–5 months and 6–11 months, respectively. The study conducted the risk assessment taking into consideration the benchmark-dose levels ($BMDL_{10}$) 0.17 mg/kg bw/day and 0.43 mg/kg bw/day and the acrylamide margins of exposure were calculated. The results showed the need to reduce acrylamide exposure among infants [18]. Based on another recent probabilistic exposure-assessment study conducted in Italy by Esposito et al. [8••], the probability of a carcinogenic exposure was determined considering the $BMDL_{10}$ of 0.17 mg/kg bw/day for carcinogenicity as 94%, 92%, and 87% for 6-, 12-, and 18-months infants, respectively. Biscuits were the main contributor in the study, and the authors stated that despite none of the samples showing acrylamide levels above the benchmark level of the European Regulation 2017/2158 [2], acrylamide exposure still is a matter for infants due to the significant probability of carcinogenic exposure. In the United Kingdom, the Committee on Toxicity in Food, Consumer Products and the Environment, COT [26], estimated exposure to acrylamide from exclusive feeding on infant formula in the range of 0.046–0.79 μg/kg bw/day for 0–6-months-old infants. The total mean exposure to acrylamide from foods was in the range of 0.30–0.95 μg/kg bw/day in infants, and from 1.2 to 1.3 μg/kg bw/day in young children [26].

In addition, besides acrylamide levels in foods and bw parameters, acrylamide-exposure calculations were affected with the collection of the consumption data. Various food-consumption data-collection methods have been used: dietary-intake calculations, including food-frequency questionnaires, dietary recalls, or records during acrylamide-exposure studies [3]. Methodological differences during the collection of food-consumption data could result in differences [32–34]. Therefore, limitations of the methods should be well defined and detailed food-consumption data specifically collected with the purpose of acrylamide exposure should be used. In addition, it was reported that dietary questionnaires and recalls could be combined with the analysis of validated biomarkers of exposure/internal dose to improve the accuracy of dietary acrylamide-intake assessment [32].

Figure 1



Benchmark levels for baby-food products according to the Regulation 2017/2158 set by European Commission [2].

Current progress on regulations

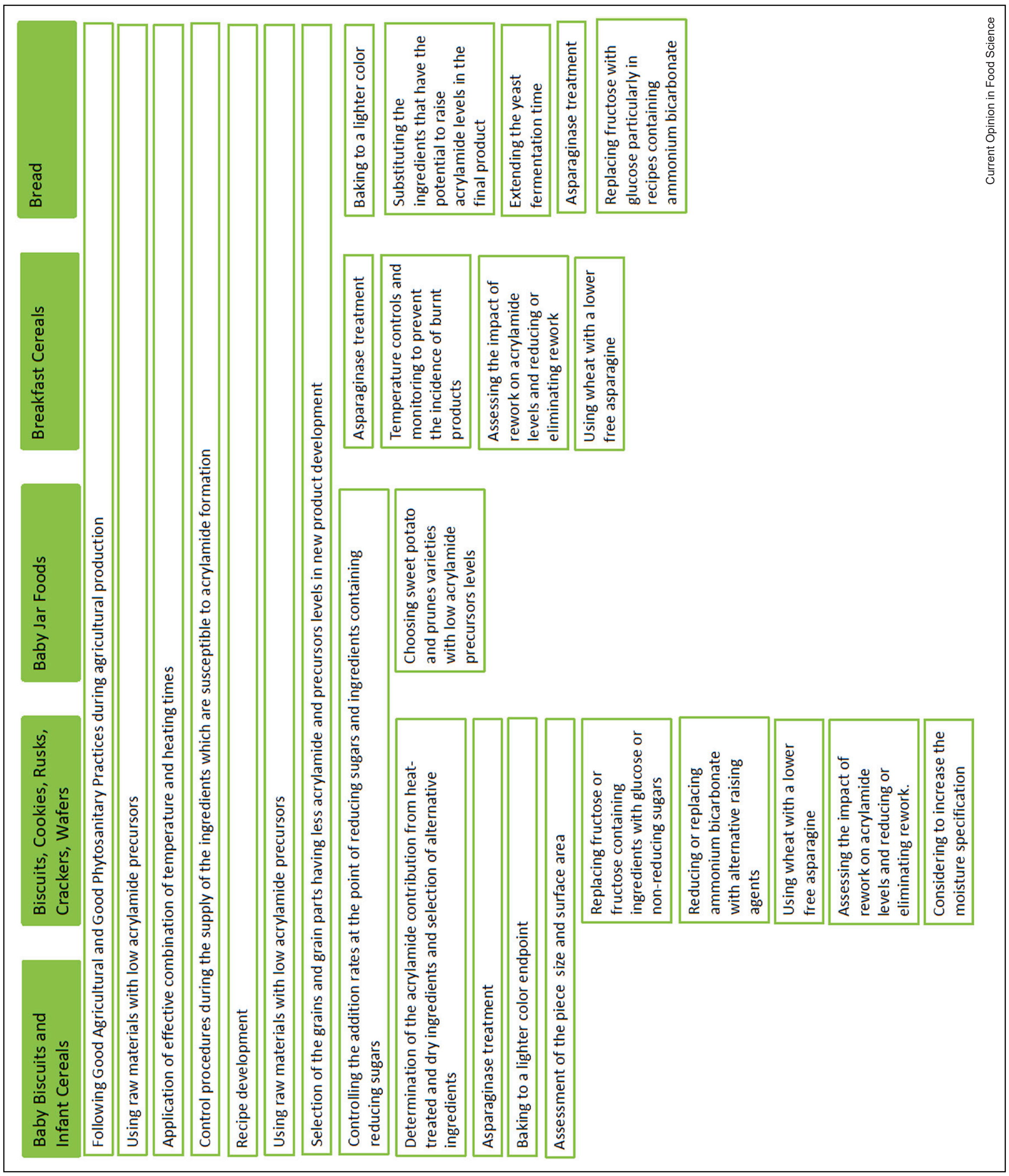
Since acrylamide was detected in foods, many researches were conducted to determine acrylamide levels in foods, to define its health effects from a toxicological point of view, and also, to assess the risk of the population as a result of the exposure to acrylamide. Acrylamide is found at moderate-to-high levels in commonly consumed everyday foods, and infants and toddlers were reported as the most exposed group based on the exposure assessments [3]. As a result, mitigation strategies together with regulatory guides were developed to reduce acrylamide in foods and decrease the exposure of the people.

The European Commission established mitigation measures and set benchmark levels to reduce acrylamide in food products, and the European Commission Regulation 2017/2158 came into force in April 2018 [2]. Science-based mitigation techniques for the best practices, including recipe, agronomy, and processing, were proposed without affecting food quality and food safety to achieve acrylamide levels as low as reasonably achievable below-benchmark levels. Benchmark levels were set for different foodstuffs, including baby foods. Figure 1 shows the benchmark levels for the commonly consumed baby foods by infants and toddlers according to the Regulation 2017/2158 set by European Commission [2]. In addition, the FoodDrinkEurope (FDE) developed the acrylamide toolbox as a guide with possible intervention steps for preventing or reducing acrylamide levels in food products [35].

Mitigation measures should be applied according to the product category based on different parameters during agricultural production, product design, recipe development, processing, and final preparation stages [35]. Figure 2 shows a detailed illustration of the mitigation strategies for commonly consumed baby foods based on the product category and different parameters as reported by the FDE Acrylamide 'Toolbox' and the European Commission Regulation 2017/2158 [2,35]. Current recommended mitigation strategies to reduce acrylamide levels in commonly baby foods include using raw materials with low acrylamide-precursor content, asparaginase treatment, recipe development to achieve low reducing sugars in the final recipe, controlling the added ingredients, and application of the effective combination of temperature and heating times. During the application of mitigation strategies, it is significantly important to avoid compromising the existing chemical and microbiological safety and organoleptic characteristics such as taste, texture, color, and also, shelf life of the product [2,35].

Acrylamide levels should be as low as reasonably achievable below the benchmark levels. It is critically important to reduce acrylamide in commonly consumed baby foods by infants and toddlers. According to the regulations, lower benchmark levels were set for baby foods, 150 μg/kg for infant biscuits and rusks and 40 μg/kg for processed cereal foods. However, some other acrylamide-rich food categories are commonly consumed by toddlers, for example, other biscuits and crackers, which have benchmark levels 350 and 400 μg/kg, respectively. Therefore, taking into consideration the higher acrylamide levels in those kinds of foods, consumption by toddlers should be reduced. In addition, labeling acrylamide on the food packages could increase

Figure 2



Mitigation strategies for commonly consumed baby foods as reported by the FDE Acrylamide 'Toolbox' and the European Commission Regulation 2017/2158 [2,35].

consumer awareness to reduce consumption of other product categories by toddlers. It is important to further control acrylamide levels in other food categories consumed by toddlers and also, to change consumption patterns to ensure lower acrylamide-exposure levels. This regulation should be widened, including not only the European Member States, but also, other countries worldwide.

Conclusion

In conclusion, infants and toddlers are the most exposed group to acrylamide exposure. Lower body weight compared with adults, high consumption of some kinds of baby foods, and their metabolism make them more vulnerable to the effects of the contaminants. For babies, the main route for acrylamide is through diet. On the other hand, some other thermal-process contaminants could be found in the foods and potential cumulative exposure, including all thermal-process contaminants, should be well defined. Acrylamide-exposure and risk-assessment studies should be conducted worldwide for all age groups. It is very important to collect food-consumption data specific to acrylamide-containing foods and their consumption at different ages to prevent underestimation. In addition, consumer awareness should be increased to reduce acrylamide exposure. Since there is not a safe or tolerable daily intake level for acrylamide, acrylamide levels should be as low as reasonably achievable below the benchmark levels in all food-product categories. United States Food and Drug Administration released a new action plan for reducing exposure to toxic elements from foods for babies and young children and developed a closer zero approach [36]. In the future plans, acrylamide could be assessed in that context worldwide and should be aimed to be closer zero to prevent exposure of infants and toddlers.

Conflict of interest statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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