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Intake and risk assessment of nine priority food additives in Turkish adults

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A R T I C L E I N F O

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A B S T R A C T

Exposure to excess food additives is a potential health risk for humans. This study aimed to assess the dietary exposure to nine priority food additives in Turkey. The study took a conservative approach (based on individual consumption data combined with maximum permitted levels). The dietary exposure was estimated using a food frequency questionnaire and food additives maximum permitted levels in various foodstuffs. The study had 433 participants (72.3% female, 27.7% male) who completed the study. None of the food additives included in the study exceeded the acceptable daily intake (ADI) on average. Intake of nitrite and nitrate, especially in frozen meat/chicken/fish was higher compared to ADI by 215% and sulfites were higher than the ADI in some food groups ("pickled fruit and vegetables", "dried tomatoes", and "apricots, peaches, grapes, plums, and figs") at P95. There is a growing concern about food additives in the food supply. Their exposure should be the responsibility of both the producer and the consumer. Therefore, it is necessary to monitor both the use of food additives and their consumption.

1. Introduction

Food additives are the common component of the modern food industry and are typically added to foods to extend shelf life or improve their flavor, taste, or appearance (Zhang et al., 2014). Since the early 1800 s, the use of food additives has increased significantly (Partridge et al., 2019). In recent times, it has become nearly impossible to avoid processed foods when shopping for groceries, particularly when following a Western-style diet - a modern dietary pattern that is characterized by lower consumption of vegetables, fruits, and legumes; and higher consumption of eggs, red meats, dairies, refined grains, saturated fats, sugars and sodium with increased exposure to food additives due to their use in processed foods (Partridge et al., 2019).

There are, currently, approximately 25,000 authorized food additives in use in foods (Carocho et al., 2014; Partridge et al., 2019). Only food additives that have been evaluated and deemed safe by Joint Expert Committee on Food Additives (JECFA), a committee established jointly by two United Nations bodies, the Food and Agriculture Organization (FAO) and the World Health Organization (WHO), based on which maximum use levels have been established by the Codex Alimentarius Commission, can be used in foods that are traded internationally. The ADI value is a numerical value calculated using a safety factor that ensures that if the additive is consumed daily at this level for the remainder of a person's life, there will be no "significant health risk" (Galli et al., 2008). However, the consumption of processed foods is increasing annually, and the ADI values of food additives may be exceeded. According to the studies, the consumption of processed foods containing additives can account for 25–50% of the total daily energy intake (Moubarac et al., 2013; Adams and White, 2015; da Costa Louzada et al., 2015; Steele et al., 2016; Cediel et al., 2018; Zhong et al., 2018). Furthermore, the European Food Safety Authority (EFSA) re-evaluated the safety of dietary glutamates in June 2017, findings that the ADI dose of glutamates had been exceeded in all age groups (Zanfirescu et al., 2019). Adults' intakes of nitrites, sulfites, and annatto in France were found to be above the ADI values (Bemrah et al., 2008). In Australia, the ADI was exceeded for sulfites among adults (Mischek and Krapfenbauer-Cermak, 2012). In Turkey, nitrites consumption was found to be above the ADI value, especially intake in sausages and frozen meats (Kaya Cebioğlu and Önal, 2017).

Excessive consumption of food additives is associated with adverse health outcomes. Studies showed that high-dose monosodium glutamate (MSG) consumption causes changes in taste perception in humans, and can lead to obesity by changing food intake, and increasing appetite (Pepino et al., 2010; He et al., 2011; Insawang et al., 2012; Masic and Yeomans, 2014). Nitrite and nitrate were found to be potential sources of nitrosamine, which is thought to have a carcinogenic effect; they are precursors of N-nitroso compounds, which are linked to cancers of liver, esophagus, kidney, stomach, intestine, central nervous system, and

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lymphoid system (Xie et al., 2016; Barry et al., 2020). Excessive sweetener consumption has comparable effects to sugars consumption including weight gain (Pearlman et al., 2017; Cabral et al., 2018), glucose intolerance (Cabral et al., 2018), diabetes (Sanyaolu et al., 2018; Hirahatake et al., 2019), cardiovascular diseases (Mulligan, 2019), and metabolic syndrome (Pearlman et al., 2017). Higher consumption of benzoates and their derivatives causes urticaria, asthma, rhinitis, or anaphylactic shock (Bilau et al., 2008). Additionally, the excess sulfite consumption may irritate the mucosal system of the respiratory tract. It may also include stomach and digestive system problems, such as vomiting and diarrhea (Mu et al., 2022), as well as asthma in susceptible populations (Zhang et al., 2014).

Risk analysis is a powerful tool for estimating the threats to human health and safety. Identifying and implementing suitable risk control measures, and communicating the risks and measures to stakeholders are essential. Risk analysis is comprised of three components: risk management, risk assessment, and risk communication. Risk assessment is the central scientific component of risk analysis which aims to quantify chemical exposures from relevant sources and routes of exposure (inhalation, oral, dermal through the air, water/food, skin) for a given population or species (exposure assessment) (Ingenbleek et al., 2020). Risk assessment primarily defines the potential risk, determines the nature and magnitude of the risk, the exposure to the defined risk, the effect of the consequences of the risk on human health and includes the steps of organizing the priorities among the risks (Kaya Cebioğlu and Önal, 2017). With the risk assessment method, the exposure dose of people can be partially determined and it can be a guide in raising public awareness by determining whether doses exceed the ADI values.

Since the beginning of the 20th century, especially due to the increase in the Western-style diet, significant changes have been observed in people's diets, and the consumption of food additives has increased as a result of being added to almost all processed foods (Bayram and Ozturkcan, 2020). Although research has indicated the hazards associated with excessive use of food additives, clinical trials on the subject are limited. Additionally, there is little information in studies about the amount of food additives typically consumed by humans. This study aimed to assess the dietary exposure of nine priority food additives (nitrite, nitrate, sulfite, benzoate, MSG, sucralose, acesulfame-K, aspartame, and saccharine) in Turkey.

2. Methods

2.1. Study design and participants

This study used a conservative approach (based on individual consumption data combined with maximum permitted levels). Between April and November 2021, an online survey method was conducted. The survey included: demographic characteristics (age, sex, dieting, profession, physical activity, educational status, medical condition) and a food frequency questionnaire (FFQ). Additionally, anthropometric measurements (height and body weight) were taken by participants' statements.

The study comprised a total of 433 adults (72.3% female, 27.7% male, mean age 25.83 ± 9.48 years). The subjects were all from Istanbul, Turkey. The majority of the participants (80.0%) led sedentary lives and had normal body mass index (BMI) (61.2%). Additionally, the majority of the participants had a higher educational status with, 50.8% of participants graduating from university, and 48.3% graduating from high school. Inclusion criteria were individuals over the age of 18, not on any specific diet (such as medical condition or personal preference), not using any medication or supplement, and having any medical condition that would limit some food intake. Exclusion criteria included age under 18, more than one individual from the same household, pregnant or breastfeeding women, practicing a specific diet, using a medication or supplement, or having a medical condition that would limit some food intake.

Written approval to use the document was secured, and ethical approval was obtained from the Noninvasive Clinical Research Ethics Committee (Approval number: E-77366270-302.08.01-2570) at Istanbul Gelisim University. Informed consent was obtained from all participants.

2.2. Dietary intake

A validated FFQ was used for evaluating the dietary intake of food additives. The FFQ included 40 food items organized into nine specified food groups: meats and meats products, snack foods, dried fruits, breakfast products, low-calorie products, sauces, spices, non-alcoholic beverages, and miscellaneous foods. Food categories were defined and classified according to the Turkish Food Codex (2013). Participants reported how many times per day, week, or month they consumed specific food items and the approximate serving sizes of each food item during the last month. The frequency of food consumption was classified and recorded in seven categories: never, once a month, once every 15 days, 1–2 times a week, 3–4 times a week, 5–6 times a week, and every day.

Each food or beverage item's portion size was defined in terms of units or common portions (e.g., 1 slice, 1 packet, or 1 average portion) or household measures (e.g., glass, cup, or teaspoon). The size of the portion (e.g., 1 slice, 1 packet, 1 average portion) for each food category was established using a validated picture booklet called "the Food and Nutrition Photograph Catalog" (Rakıcıoğlu et al., 2017). The intake of foods was calculated as the frequency and the portion size of the product.

The mean daily food intake was calculated according to the following equations:

If the frequency of food consumption was never: the portion size of food x 0.

If the frequency of food consumption was once a month: the portion size of food x 0.033.

If the frequency of food consumption was once every 15 days: the portion size of food x 0.067.

If the frequency of food consumption was 1–2 times a week: the portion size of food x 0.2145.

If the frequency of food consumption was 3–4 times a week: the portion size of food x 0.4980.

If the frequency of food consumption was 5–6 times a week: the portion size of food x 0.7855.

If the frequency of food consumption was every day: the portion size of food x 1.

The following equation was used for calculating food additives consumption:

The mean individual daily food consumption x the maximum permitted levels (MPL) of food additives added to the relevant food.

2.3. Risk assessment method

Risk assessment is a component of the process of risk analysis. The risk assessment method is divided into four stages: hazard identification, hazard characterization, exposure assessment, and risk characterization (Ingenbleek et al., 2020).

2.3.1. Step 1. Hazard identification

Hazard identification has been defined as "the identification of biological, chemical and physical agents capable of causing adverse health effects and which may be present in a particular food or group of foods'' (FAO and WHO, 2009). As stated in the introduction, a large broad of literature exists evaluating the detrimental health effects of the selected food additives (MSG, nitrite, nitrate, benzoates, artificial sweeteners, sulfites) on humans.

2.3.2. Step 2. Hazard characterization

Hazard characterization has been defined as "the qualitative and/or quantitative evaluation of the nature of the adverse health effects

Table 1
List of food categories and additives selected and mean consumption of food categories (g/day).

Food groups	Consumption data (g/day)	Nitrite	Nitrate	Sulfite	Benzoate	MSG	Sucralose	Ace-K	Aspartame	Saccharine
Meat and meat products										
Frozen meat/chicken/fish products	15.4 ± 24.9 (0–235.7)	X	X							
Dried smoked meat products	2.2 ± 7.6 (0–64.4)	X	X							
Sausage	2.2 ± 6.6 (0–64.4)	X	X							
Salami	3.4 ± 9.5 (0–80)	X	X							
Pastrami	1.5 ± 7.4 (0–100)		X							
Ham	0.2 ± 0.8 (0–10.7)		X							
Canned meat/chicken/fish products	3.3 ± 12.4 (0–149.4)	X	X							
Miscellaneous										
Package soup	12.5 ± 38.6 (0–298.8)					X				
Pickled fruit and vegetables	15.3 ± 51.1 (0–471.3)			X						
Frozen potatoes	7.2 ± 30.7 (0–400)			X						
Dried tomatoes	6.3 ± 18.7 (0–125.7)			X						
Snack foods										
Chips	8.9 ± 17.8 (0–185)					X				
Cakes	22.7 ± 56.6 (0–500)					X				
Chocolate / Wafer	23 ± 47.9 (0–500)					X	X	X	X	
Biscuits	12.7 ± 26.5 (0–249)			X		X				
Ice cream (packaged)	17.3 ± 89 (0–393.8)						X	X	X	
Dried fruits										
Apricots, peaches, grapes, plums, and figs	11.1 ± 40.2 (0–500)			X						
Banana	3 ± 31 (0–500)			X						
Apple and pear	6 ± 33 (0–500)			X						
Others (including nuts)	8.3 ± 13.4 (0–80)			X						
Breakfast products										
Instant jelly	0.2 ± 1.5 (0–30)			X	X		X		X	
Jam	1 ± 4.8 (0–90)			X	X		X			
Marmalade	0.5 ± 4.5 (0–90)			X	X		X			
Low-calorie products										
Light Ice cream (packaged)	2 ± 13.1 (0–200)						X	X	X	X
Light jelly	1 ± 8.7 (0–157.1)			X	X		X			
Light jam	1.4 ± 9.4 (0–99.6)			X	X		X			
Light marmalade	0.4 ± 3.3 (0–49.8)			X	X		X			
Light chocolate spread	1.1 ± 5.6 (0–78.6)						X	X	X	X
Wholegrain breakfast cereals	2 ± 5 (0–35)						X	X	X	X
Non-alcoholic beverages										
Soda + energy drinks	103.1 ± 309 (0–2500)						X			X
Fruit juice	46.6 ± 180.3 (0–2500)						X			
Low-calorie drinks	41.5 ± 188.5 (0–2500)						X	X	X	X
Mineral waters	115.8 ± 256.2 (0–1000)									X
Lemonade							X			

(*continued on next page*)

Table 1 (*continued*)

Food groups	Consumption data (g/day)	Nitrite	Nitrate	Sulfite	Benzoate	MSG	Sucralose	Ace-K	Aspartame	Saccharine
	49.2 ± 250 (0–2500)									
Flavored waters	48.3 ± 182.2 (0–1963.8)						X	X	X	
Turnip	15 ± 50.6 (0–498)				X					
Flavored kefir	16 ± 54.5 (0–500)				X					
Sauces										
Ready-made salad dressings	0.5 ± 2 (0–15.6)					X	X	X	X	
Spices										
Bouillons	0.8 ± 4.7 (0–90)					X				
Mustard	0.3 ± 1.2 (0–10)							X	X	

Ace-K: Acesulfame-K, g: gram.

associated with biological, chemical and physical agents, which may be present in food. For chemical risk assessments, a dose-response assessment is performed'' (FAO and WHO, 2009). The ADI is established from the "no observed adverse effect level" (NOAEL) by dividing it by a safety factor, which takes into account species differences between humans and test animals, and variation among humans. The JECFA-reported hazard characterization of nitrite, nitrate, benzoates, artificial sweeteners, and sulfites, and EFSA reported hazard characterization of MSG was utilized in this study.

2.3.3. Step 3. Exposure assessment

Exposure assessment has been defined as "the qualitative and/or quantitative evaluation of the likely intake of biological, chemical or physical agents via food, as well as exposures from other sources if relevant'' (FAO and WHO, 2009). Although hazard identification and characterization are associated with universal properties of the substance, exposure assessment varies between populations and subpopulations. It is dependent on the levels of substance present and the quantities of substance food consumed by individuals. In this step, we used the MPL of food additives in foods to determine exposure. Only the name of the food additive, not the amount, is printed on food labels in Turkey. As a result, a search for food additives added to foods was conducted by doing market research. Food items were selected that had the most commonly used food additives. The MPLs of food additives were obtained according to the Turkish Food Codex (2013).

In accordance with EFSA standards, the 95th percentile was chosen as the high percentile (EFSA, 2011).

The exposure values to food additives were calculated according to the following formula:

$$E_i = \sum_{k=1}^{n} \frac{C_{i,k} \times L_k}{W_i}$$

Ei: is the daily exposure of a household normalized by consumption units (mg/kg *bw*/day).*Ci,k:* is the daily consumption of food.*Lk:* is the maximum permitted level of food additives in that food item.*Wi:* is the body weight of the individual.

2.3.4. Step 4. Risk characterization

Risk characterization has been defined as "the qualitative and/or quantitative estimation, including attendant uncertainties, of the probability of occurrence and severity of known or potential adverse health effects in a given population based on hazard identification, hazard characterization and exposure assessment'' (FAO and WHO, 2009). At this step, ADI levels of food additives were compared with participant exposure levels. We used Hazard Index (HI) for characterizing risk. HI is calculated by the average daily dose (ADD) for an additive from the diet expressed as a percentage of ADI. According to the HI, if it is less than 100% exposure to that food additive is not harmful.

Table 2

The exposure levels of nitrite and nitrate using MPL, reported maximum use level and compared with ADI.

Food groups	Nitrite Estimation of mean intake (mg/kg bw/day)	P95 (mg/kg bw/day)	MPL (mg/kg)	% ADI (mean)	% ADI (P95)	Nitrate Estimation of mean intake (mg/kg bw/day)	P95 (mg mg/kg bw/day)	MPL (mg/kg)	% ADI (mean)	% ADI (P95)
Meat and meat products										
Frozen meat/chicken/fish products	0.038 ± 0.062	0.151	150	54	**215**	0.038 ± 0.062	0.151	150	54	**215**
Dried smoked meat products	0.005 ± 0.016	0.027	150	7	39	0.005 ± 0.016	0.027	150	7	39
Sausage	0.008 ± 0.014	0.035	150	11	50	0.008 ± 0.014	0.035	150	11	50
Salami	0.008 ± 0.022	0.039	150	11	56	0.008 ± 0.022	0.039	150	11	56
Pastrami			–	–		0.003 ± 0.017	0.014	150	5	20
Ham			–	–		0.000 ± 0.002	0.003	150	0	0.1
Canned meat/chicken/fish products	0.007 ± 0.026	0.034	150	10	48	0.007 ± 0.026	0.034	150	10	48
TOTAL[a]	**0.013 ± 0.035**	**0.064**		**19**	**91**	**0.009 ± 0.029**	**0.046**		**13**	**66**

[a] TOTAL: the mean intake of food groups. P95 was the high percentile, which is used according to JECFA. MPL: Maximum permitted level, which was obtained according to the Turkish Food Codex (2013). ADI: acceptable daily intake, which was obtained according to JECFA. ADI value: 0.07 mg kg^{-1} *bw* day^{-1} for nitrite and nitrate.

Table 3
The exposure levels of sulfites and benzoates using MPL, reported maximum use level and compared with ADI.

Food groups	Sulfite Estimation of mean intake (mg/kg bw/day)	P95 (mg/kg bw/day)	MPL (mg/kg)	% ADI (mean)	% ADI (P95)	Benzoate Estimation of mean intake (mg/kg bw/day)	P95 (mg mg/kg bw/day)	MPL (mg/kg)	% ADI (mean)	% ADI (P95)
Miscellaneous										
Pickled fruit and vegetables	0.025 ± 0.087	0.114	100	36	**163**					
Frozen potatoes	0.011 ± 0.045	0.043	100	16	61					
Dried tomatoes	0.019 ± 0.059	0.122	200	28	**174**					
Snack foods										
Biscuits	0.010 ± 0.019	0.042	50	1	6					
Dried fruits										
Apricots, peaches, grapes, plums, and figs	0.364 ± 1.446	1.167	2000	52	**167**					
Banana	0.042 ± 0.418	0.042	1000	6	6					
Apple and pear	0.056 ± 0.287	0.282	600	8	40					
Others (including nuts)	0.067 ± 0.111	0.290	500	10	41					
Breakfast products										
Instant jelly	0.000 ± 0.001	0.000	50	0	0					
Jam	0.001 ± 0.005	0.003	50	0.1	0.4	0.007 ± 0.048	0.028	500	0.1	1
Marmalade	0.000 ± 0.005	0.001	50	0	0.1	0.004 ± 0.047	0.008	500	0.1	0.2
Low-calorie products										
Light jelly	0.001 ± 0.006	0.001	50	0.1	0.2	0.006 ± 0.058	0.013	500	0.1	0.3
Light jam	0.001 ± 0.007	0.001	50	0.1	0.2	0.009 ± 0.069	0.011	500	0.2	0.2
Light marmalade	0.000 ± 0.002	0.001	50	0	0.1	0.003 ± 0.023	0.006	500	0.1	0.1
Non-alcoholic beverages										
Turnip						0.053 ± 0.317	0.192	200	1	4
Flavored kefir						0.075 ± 0.288	0.354	300	2	7
TOTAL[a]	**0.043 ± 0.421**	**0.159**		**6**	**23**	**0.022 ± 0.170**	**0.071**		**1**	**1**

[a] TOTAL: the mean intake of food groups. P95 was the high percentile, which is used according to JECFA. MPL: Maximum permitted level, which was obtained according to the Turkish Food Codex (2013). ADI: acceptable daily intake, which was obtained according to JECFA. ADI value: 0.7 mg kg^{-1} *bw* day^{-1} for sulfite, and 5 mg kg^{-1} *bw* day^{-1} for benzoate.

Table 4
The exposure levels of MSG using MPL, reported maximum use level and compared with ADI.

Food groups	MSG Estimation of mean intake (mg/kg bw/day)	P95 (mg/kg bw/day)	MPL (mg/kg)	% ADI (mean)	% ADI (P95)
Miscellaneous					
Package soup	0.002 ± 0.006	0.012	10	0	0.04
Snack foods					
Chips	0.001 ± 0.003	0.006	10	0	0.02
Cakes	0.004 ± 0.009	0.017	10	0	0.06
Chocolate / Wafer	0.004 ± 0.008	0.015	10	0	0.1
Biscuits	0.002 ± 0.004	0.008	10	0.01	0.03
Sauces					
Ready-made salad dressings	0.000 ± 0.000	0	10	0	0
Spices					
Bouillons	0.000 ± 0.001	0.001	10	0	0
TOTAL[a]	**0.002 ± 0.006**	**0.01**		**0.01**	**0.03**

[a] TOTAL: the mean intake of food groups. P95 was the high percentile, which is used according to EFSA. MPL: Maximum permitted level, which was obtained according to the Turkish Food Codex (2013). ADI: acceptable daily intake, which was obtained according to EFSA. ADI value: 30 mg kg^{-1} *bw* day^{-1} for MSG.

2.4. Statistical analysis

All statistical analyses were conducted using SPSS Statistics 24.0 (Statistical Package for the Social Sciences, Inc.; Chicago, Illinois, United States). This study made use of descriptive statistics. The nine food additives' mean daily intakes were represented as mg/kg *bw*. For each additive, the mean, standard deviation of the mean (SD), and P95 value were calculated for the entire group of individuals.

3. Results

Table 1 shows the food additives used for the survey on food composition and the mean intake of food categories. Table 2 shows the amounts consumed by the major food categories in which nitrites and nitrates are permitted as well as the MPL of nitrites and nitrates for each of these food groups. The mean intake of nitrite was 0.113 ± 0.035 mg/kg *bw*/day (19% of the ADI), and nitrate was 0.009 ± 0.029 mg/kg *bw*/day (13% of the ADI), both of which did not exceed ADI, whereas intake at P95 accounting for 91% and 66% of the ADI, respectively.

The results of the exposure assessment of sulfites are presented in Table 3. The mean intake of sulfite was below established ADI with 6% (0.043 ± 0.421 mg/kg *bw*/day). However, at P95 intakes for "pickled fruit and vegetables", "dried tomatoes", and "apricots, peaches, grapes, plums, and figs" groups were higher than ADI (accounting for 163%, 174%, and 167% of the ADI, respectively). The mean intake of benzoates was 0.022 ± 0.170 mg/kg *bw*/day, which was negligible in comparison to the established ADI. There was no excess in ADI value in any of the benzoate-containing subgroups.

Similarly, the mean intake of MSG did not exceed ADI for each food group containing MSG (Table 4).

According to Table 5, the mean intake of sucralose was 0.103 ± 0.612 mg/kg *bw*/day and did not exceed ADI (1% of the ADI). The groups that contributed the most to sucralose intake were "soda + energy drinks", "flavored water", and "chocolate/wafer". The mean intake of acesulfame-K (Ace-K) for food groups did not exceed ADI. The major foods contributing to the intake of Ace-K were "flavored water", "chocolate/wafer", "ice cream", and "low-calorie drinks" groups (3, 2, 2, 2% of the ADI, respectively).

The exposure levels of aspartame and saccharine are presented in Table 6. All estimated intakes of aspartame for food groups were below the ADI. The "chocolate/wafer" group contributed 2% of the ADI, and the "ice cream" group contributed 1% of the ADI. The exposure levels of

Table 5
The exposure levels of sucralose and Acesulfame-K using MPL, reported maximum use level and compared with ADI.

Food groups	Sucralose Estimation of mean intake (mg/kg bw/day)	P95 (mg/kg bw/day)	MPL (mg/kg)	% ADI (mean)	% ADI (P95)	Ace-K Estimation of mean intake (mg/kg bw/day)	P95 (mg/kg bw/day)	MPL (mg/kg)	% ADI (mean)	% ADI (P95)
Snack foods										
Chocolate / Wafer	0.301 ± 0.659	1.172	800	2	8	0.188 ± 0.412	0.732	500	2	8
Ice cream (packaged)	0.086 ± 0.144	0.341	320	1	2	0.215 ± 0.359	0.852	800	2	10
Breakfast products										
Instant jelly	0.001 ± 0.008	0.004	400	0.01	0.03	0.002 ± 0.020	0.010	1000	0.02	0.1
Jam	0.002 ± 0.012	0.007	400	0.01	0.1					
Marmalade	0.003 ± 0.037	0.007	400	0.02	0.04					
Sauces										
Ready-made salad dressings	0.004 ± 0.016	0.016	450	0.02	0.1	0.003 ± 0.012	0.012	350	0.03	0.1
Spices										
Mustard						0.002 ± 0.007	0010.	350	0.02	0.1
Non-alcoholic beverages										
Soda + energy drinks	0.478 ± 1.492	1.960	300	3	13					
Fruit juice	0.210 ± 0.783	0.800	300	1	5					
Low-calorie drinks	0.183 ± 0.857	0.832	300	1	6	0.214 ± 0.999	0.971	350	2	11
Lemonade	0.223 ± 1.142	0.756	300	1	0.1					
Flavored waters	0.217 ± 0.840	0.964	300	2	6	0.254 ± 0.980	1.124	350	3	13
Low-calorie products										
Light Ice cream (packaged)	0.008 ± 0.056	0.032	320	0.1	0.2	0.021 ± 0.141	0.058	800	0.2	1
Light jelly	0.005 ± 0.046	0.011	400	0.03	0.1					
Light jam	0.008 ± 0.055	0.009	400	0.05	0.06					
Light marmalade	0.002 ± 0.018	0.005	400	0.01	0.03					
Light chocolate spread	0.007 ± 0.040	0.029	400	0.1	0.2	0.018 ± 0.100	0.072	1000	0.2	0.8
Wholegrain breakfast cereals	0.012 ± 0.029	0.071	400	0.1	0.5	0.036 ± 0.087	0.214	1200	0.4	2
TOTAL[a]	**0.103 ± 0.612**	**0.379**		**1**	**3**	**0.095 ± 0.489**	**0.400**		**1**	**4**

[a] TOTAL: the mean intake of food groups. Ace-K: Acesulfame-K. P95 was the high percentile, which is used according to JECFA. MPL: Maximum permitted level, which was obtained according to the Turkish Food Codex (2013). ADI: acceptable daily intake, which was obtained according to JECFA. ADI value:15 mg kg^{-1} *bw* day^{-1} for sucralose, and 9 mg kg^{-1} *bw* day^{-1}Ace-K.

saccharine were below the corresponding ADIs at both mean levels (intake accounting for 4% of the ADI) and at P95 (accounting for 13% of the ADI).

4. Discussion

Food additives are substances to which individuals are exposed from birth to death. Additionally, from the beginning of the twentieth century, the use of food additives has grown in tandem with the rising consumption of processed foods. Although many food additives have upper limits, surpassing the ADI levels may have a detrimental impact on health when individuals consume excessive quantities of processed foods (Bayram and Ozturkcan, 2020). Exceeding the ADI occasionally does not pose an additional health risk. If there is evidence that the ADI is chronically exceeded, a case-by-case assessment should be carried out. Considering that the margin of safety between the ADI and the dose that causes some adverse effects is quite large, the extent to which the ADI is exceeded needs to be critically evaluated. The study showed that none of the food additives included in the study exceeded the ADI according to the mean and P95 intake of total participants. Turkish adults were, therefore, not presently at risk of overexposure to these food additives.

Due to their preservative, antimicrobial, flavorful, and color fixative properties, nitrite (E249–250) and nitrate (E251–252) are commonly used as food additives in meat and meat products (Ozturkcan and Acar, 2017). The mean intakes for nitrites were 0.038 mg/kg *bw*/day in Italy, 0.046 mg/kg *bw*/day in the United Kingdom (UK), 0.054 mg/kg *bw*/day in France, 0.059 mg/kg *bw*/day in Ireland, with mean ADIs of 54%, 66%, 77%, and 84%, respectively (Vin et al., 2013). In the present study, the mean intake of nitrite was 0.113 ± 0.035 mg/kg *bw*/day and nitrate was 0.009 ± 0.029 mg/kg *bw*/day; both did not exceed ADI (19% and 13% of the ADI, respectively). However, the intake of nitrite at P95 was close to the ADI at 91%, whereas nitrate was 66% of the ADI. In an Australian adult study using the MPL scenario, the mean nitrate intake contributed 103% of the ADI, and 252% of the ADI at P95 (Vlachou et al., 2020). Our findings revealed that nitrate and nitrite contributions were lower in the UK, France, Ireland, and Austria. In these studies, nitrate sources included not only those used as food additives, but also natural presence and contamination (Vin et al., 2013; Vlachou et al., 2020). Accordingly, nitrite and nitrate consumption may have contributed less to ADI in our study. Additionally, food additives were shown to contribute 8–9% of ADI to nitrate and nitrite exposure in the Dutch population (van den Brand et al., 2020). In comparison to the Dutch study, our data indicated that the contribution of nitrate and nitrite from food additives was higher. According to a Turkey market research, sodium nitrite was the third most commonly used salt-containing food ingredient, accounting for 10.7% (Bayram and Ozturkcan, 2021). Furthermore, because nitrate and nitrite are prevalent in foods other than processed foods, their intake of additional sources such as natural presence, contamination, and food additives may have exceeded the ADI threshold in Turkish adults.

Benzoates are a group of food additives that include benzoic acid (E210) and its sodium (E211), potassium (E212), and calcium (E213) salts. They are used as preservatives in foods and to protect the consumer from microbiological risks of various bacteria, yeasts and fungi that can be involved in food poisoning (Bilau et al., 2008; Ozturkcan and Acar, 2017). In our study, the mean intake of benzoates in food groups

Table 6
The exposure levels of aspartame and saccharine using MPL, reported maximum use level and compared with ADI.

Food groups	Aspartame Estimation of mean intake (mg/kg bw/day)	P95 (mg/kg bw/day)	MPL (mg/kg)	% ADI (mean)	% ADI (P95)	Saccharine Estimation of mean intake (mg/kg bw/day)	P95 (mg/kg bw/day)	MPL (mg/kg)	% ADI (mean)	% ADI (P95)
Snack foods										
Chocolate / Wafer	0.754 ± 1.647	2.929	2000	2	7					
Ice cream (packaged)	0.215 ± 0.359	0.852	800	1	2					
Breakfast products										
Instant jelly	0.002 ± 0.020	0.010	1000	0.0.1	0.03					
Sauces										
Ready-made salad dressings	0.003 ± 0.012	0.012	350	0.01	0.03					
Spices										
Mustard	0.002 ± 0.007	0.010	350	0	0.02					
Non-alcoholic beverages										
Soda + energy drinks						0.478 ± 1.492	1.960	300	10	39
Low-calorie drinks	0.367 ± 1.713	1.664	600	1	4	0.049 ± 0.228	0.222	80	1	4
Flavored waters	0.435 ± 1.680	1.928	600	1	5					
Mineral waters						0.177 ± 0.429	0.604	100	4	12
Low-calorie products										
Light Ice cream (packaged)	0.021 ± 0.141	0.058	800	0.1	0.2					
Light chocolate spread	0.018 ± 0.100	0.072	1000	0.04	0.2	0.04 ± 0.020	0.014	200	0.1	0.3
Wholegrain breakfast cereals	0.030 ± 0.072	0.178	1000	0.1	0.5					
TOTAL[a]	**0.185 ± 0.960**	**0.830**		**1**	**2**	**0.177 ± 0.805**	**0.653**		**4**	**13**

[a] TOTAL: the mean intake of food groups. P95 was the high percentile, which is used according to JECFA. MPL: Maximum permitted level, which was obtained according to the Turkish Food Codex (2013). ADI: acceptable daily intake, which was obtained according to JECFA. ADI value: 40 mg kg^{-1} *bw* day^{-1} for aspartame, and 5 mg kg^{-1} *bw* day^{-1} for saccharine.

was 0.022 ± 0.170 mg/kg *bw*/day and this was below ADI with 1%. Across the countries, the mean intake was 2.3 mg/kg *bw*/day (45.7% of the ADI) in Flemish adult women (Bilau et al., 2008); 0.630 mg/kg *bw*/day (13% of the ADI) in Italy; 1.320 mg/kg *bw*/day (26% of the ADI) in UK; 1.070 mg/kg *bw*/day (74% of the ADI) in France, and 1.837 mg/kg *bw*/day (128% of the ADI) in Ireland (Vin et al., 2013). In a study conducted on European market research, maximum total benzoate high-level intakes ranged from 2.5 to 8.6 mg/kg *bw*/day in the brand-loyal model and 1.3–5.6 mg/kg *bw*/day in the non-brand-loyal model (Tennant and Vlachou, 2019). In comparison to the other nations, Turkish adults had a lower mean consumption of benzoates. Depending on the country, several major foods contribute to benzoate consumption. The primary contributors were meat products for Italy; soups and sauces for France, the UK, and Ireland, non-alcoholic beverages for the UK and Ireland (Vin et al., 2013), and beer for European (Tennant and Vlachou, 2019). In Turkey, benzoates are added to fewer foods, including jam, marmalade, light jelly, light jam, light marmalade, and non-alcoholic beverages such as turnip and flavored kefir, according to the current study. Benzoate use in this study may have been lower in contrast to other nations since they are not high-consumption items.

MSG (E620–625), is a commonly used flavor enhancer, derived from L-glutamic acid, a naturally occurring amino acid in various food products (Zanfirescu et al., 2019). In a study conducted in Turkey similar approach was performed and the intake of MSG did not exceed the ADI (Kaya Cebioğlu and Önal, 2017). The mean intake of MSG was very low with 0.002 ± 0.006 mg/kg *bw*/day in this study. The major contributors' foods of the MSG were packaged soups, snack foods, and sauces. However, these products were not widely consumed on a daily basis, and consumption was found to be low among the adults in this study.

Sulfites (E220–228), a group of food additives that includes sodium or potassium bisulfite, sodium or potassium sulfite, and sulfite, have been used as food additives since ancient times due to their antimicrobial activity (Ozturkcan and Acar, 2017). The mean intakes for sulfites were 0.560 mg/kg *bw*/day in Italy, 0.578 mg/kg *bw*/day in the UK, 0.620 mg/kg *bw*/day in France, 0.509 mg/kg *bw*/day in Ireland, 0.27 mg/kg *bw*/day in Indonesia, accounting for 80%, 42%, 83%, 73%, and 38,6% of the ADI respectively (Vin et al., 2013; Fanaike et al., 2019). In the present study, the mean intake of sulfites was 0.043 ± 0.421 mg/kg *bw*/day with 6% of the ADI. Additionally, because sulfites are added to wines and alcoholic beverages, consumption was not recorded in this study, thus the intake of sulfites may have been marginal.

In the food industry, there is a growing interest in sweeteners as an alternative to sugars substitute (Bayram and Ozturkcan, 2022). An exposure study to sweeteners was seen in the literature in several countries using an approach similar to the one used in this study (Huvaere et al., 2012; Le Donne et al., 2017; Buffini et al., 2018). Sweeteners were ascertained in Belgium, resulting in relative mean intakes of 10% for Ace-K, 4% for aspartame, 6% for saccharin, and 5% for sucralose related to the corresponding ADIs (Huvaere et al., 2012). In Italy, these results were lower than in Belgium (0.59% for Ace-K, 0.03% for aspartame, 0.14% for saccharine, and 0.44% for sucralose, respectively) (Le Donne et al., 2017). In another study, the mean intakes of Ace-K were 6% of the ADI in Italy, 18% in the UK, 8% in France, and 28% in Ireland, respectively; for aspartame was 2% in Italy, 7% in the UK, 3% in France and 12% in Ireland (Vin et al., 2013). In Ireland, exposure to Ace-K was 34.05% of ADI, aspartame 12.94% of ADI, saccharine 20.50% of ADI, and sucralose 13.89% of ADI (Buffini et al., 2018). The current study found that none of the sweeteners exceeded ADI. According to our results, the exposure to sucralose was 1% of the ADI which was lower than Belgium, and Ireland, but greater than Italy (Huvaere et al., 2012; Le Donne et al., 2017). Ace-K was found at 1% of the ADI which was lower than in Belgium, Ireland, Italy, the UK, and France (Huvaere et al., 2012; Vin et al., 2013), but similar to another Italy study (Le Donne et al., 2017). Exposure to aspartame did not exceed the ADI with 1% in this study. Comparing countries, Ireland had 12% of the ADI, compared to the UK (7%), Belgium (4%), France (3%), Italy (2%), Ireland (12.94%) (Huvaere et al., 2012; Vin et al., 2013; Buffini et al., 2018). Additionally, another Italian study found that exposure to aspartame was 0.03% of the ADI and these results were lower than our exposure level in this study (Le Donne et al., 2017). The estimated exposure of sweeteners in Nanjing was well below the ADIs, as relative intakes at the P95 were 29.7% for saccharin, and 35.9% for Ace-K of the respective ADIs (Wang et al., 2021). The results in this study were lower compared with Nanjing with 13% for saccharin, and 4% for Ace-K of the respective ADIs at P95. It was concluded that adults were not at risk of exceeding ADIs for these sweeteners.

The present study has some limitations. Firstly, the study only included individuals from the province of Istanbul, the results may not reflect nationwide consumption averages. Second, the study only included adults. As a result, it did not accurately represent various population segments such as infants, children, elderly individuals, or pregnant, and breastfeeding women. Third, the FFQ questioned about processed foods containing specific food additives. Because the precise value of the food additive values present in these food groups is unknown, the MPL was used to calculate it. Therefore, the estimated intake value of food additives may be exceed the identified intake. Fourth, while the average measurement values were given for the analysis of the amount of food consumed by the participants in the FFQ, incorrect measurement amounts may have been recorded. Fifth, the FFQ only covered items consumed in the previous month. A long-term and more credible food intake record can be used to assess long-term exposure. Sixth, since the study was done between April and November, seasonal differences in food consumption may exist. As a result, some nutrients may be less or more than the amounts reported.

5. Conclusion

The present study examined the risk assessment of various food additives that are widely used in Turkey's food supply. The exposure assessment approach is commonly used as an early stage for food additives under study and may be used to guide more accurate assessments. The estimated mean exposure of additives included in this study was below the ADIs among consumers. However, exposures of nitrite, nitrate, and sulfites (for some subgroups) at P95 were greater than the estimated ADIs. Given the increased concern over food additives in the food supply, the consequences for health should be the responsibility of both the producer and the consumer and monitored more closely. Furthermore, monitoring potential exposures for high-risk individuals, such as children, adolescents, and chronic diseases (obesity, diabetics, hypertension, etc.) with special dietary needs, is critical, as is ensuring risk management decisions are based on quality intake analyses.

CRediT authorship contribution statement

Hatice Merve Bayram: Data curation, Writing – original draft, Visualization, Software, Validation. **Arda Ozturkcan:** Supervision, Conceptualization, Methodology, Software Writing – review & editing.

Declaration of Competing Interest

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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