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The amount and detection method of styrene in foods: A systematic review and *meta*-analysis

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ABSTRACT

The ingredients in food packaging migrate to the food inside. One of the most common compounds used for packaging of food is polystyrene. This systematic review aimed to investigate the level of styrene's pollution in food packed with polystyrene. The original articles include keywords styrene, polystyrene, food, contamination, pollution, "food packaging" were searched in Web of science, Medline, Scopus, and Science Direct. A total of 227 studies were achieved. The articles that did not meet the inclusion criteria were excluded with the initial evaluation. The quality assessment was conducted for full paper and finally data were extracted from 8 selected articles. Mata analysis, *meta*-regression, subgroup analysis, and publication bias was also conducted with comprehensive *meta*-analysis (CMA) software. Most of the examined samples were dairy products. The amount of fat in dairy products is an important factor in increasing the migration of styrene. The shelf life of product also had effect on migration of styrene. The overall average was estimated as 91.53 ± 26.18 μg/kg in food matrix. This amount is less than the permissible level. The results of meta regression showed that the type of food affects the pooled mean of styrene in the food. There was no publication bias for the selected articles.

1. Introduction

The safety of materials in polymers is very important (Guart, Bono-Blay, Borrell, & Lacorte, 2011, Peivasteh-Roudsari et al., 2020). Polystyrene is one of the most commonly used compounds for packaging of food (Brandsch & Schuster, 2020, Cao, Sparling, Pelletier, & Dabeka, 2018). Styrene is used in polystyrene, polyamide, and acrylonitrile–butadiene–styrene (Chung et al., 2013, Marć, Formela, Klein, Namieśnik, & Zabiegała, 2015). In humans, exposure with styrene occurs through food and respiration (Tang, Hemm, & Eisenbrand, 2000). Styrene in Polystyrene has the ability to migrate to food (Cao, Sparling, & Dabeka, 2016). Polystyrene are used in beverage cups, meat, egg, yogurt and cheese containers and ready-to-eat foods (Cao et al., 2018, Duffy & Gibney, 2007). Styrene is often detected in ready-to-eat foods (Cao et al., 2016). In some cases, food is heated in microwave with polystyrene packaging (Choi, Jitsunari, Asakawa, & Lee, 2005). In these conditions, styrene will enter the food packed with polystyrene. Therefore, one of the major exposures of styrene is through food. Metabolites resulting from styrene metabolism are mutagenic and carcinogenic (Bendall, 2007, Tang et al., 2000). The developmental toxicity in rat has also been confirmed (Gelbke et al., 2014). It also changes the flavor of food (Choi et al., 2005). Apart from contamination through packaging, styrene has also been reported in some spice and herb. This component is probably produced by the breakdown of some molecules in spices, such as cinnamon acid (Cao et al., 2016, Cao et al., 2018). Therefore, high levels of styrene are usually found in cinnamon (Tang et al., 2000).

According to the Food and Drug Administration (FDA), the maximum allowable styrene in bottled water is 0.1 mg/L. The European food safety authority, has announced the maximum permissible limit for styrene in food as 0.6 mg/kg (Chiesa, Soncin, Panseri, & Cantoni, 2008). The Committee of the World Health Organization (WHO) and the World Food Organization have announced a Tolerable Daily Intake of 40 mg/kg-body weight per day (Holmes et al., 2005). In order to assess the risk and receive exposure to toxins and chemical compounds, it is necessary to measure the amount of these compounds in food. A comprehensive

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and systematic study of styrene has not yet been performed. Due to the carcinogenicity of this compound, in this systematic study and *meta*-analysis, the amount of styrene and the type of food containing styrene will be studied.

2. Methods

PRISMA guideline was used to perform this systematic review. Evaluations of studies and data extraction were carried out by two authors in order to prevent bias.

2.1. Search strategy

Search was performed on 21 July 2021 in Medline, Science direct, Scopus, Web of science, and Google scholar by two persons (P.S and N. Y), individually. The searched keyword was (Styrene OR Polystyrene) AND (food) AND (contamination OR pollution) AND ("food packaging").

2.2. Inclusion and exclusion criteria

Original studies which analyzed styrene by valid methods in foods were included in the systematic reviews. Papers that examined the rate of styrene migration on food simulators were excluded.

2.3. Data extraction

Study characteristics including name of the first author, time of study, country, type of food, amount of styrene and sample size, method of detection were recorded. Data were extracted by two independent reviewers. When the full text of the articles was not available, we contact the authors of the article.

2.4. Meta-analysis and estimation of the mean of styrene

The levels of styrene in food were converted to μg/kg units. For this estimation, studies were selected that had mean, standard deviation and number of samples. The total mean was estimated with comprehensive *meta*-analysis software. Furthermore, meta- regression, publication bias and subgroup analysis were also carried out.

3. Results

3.1. The search processes

227 articles were obtained through Medline, Scopus, Web of science, Science direct, and Google Scholar. 155 articles were not duplicate. The title and abstracts of the articles were carefully evaluated that lead to exclusion of 100 articles. Moreover, 24 review and conference papers, 28 papers on research on other monomers, 34 laboratory and animal studies, 14 in other samples including environmental samples were excluded from initial screening. Then, the full text of the remaining paper was then read. Those papers that were not measured styrene in food and used a food simulator, were removed from this systematic review. The quality assessment was conducted for full manuscript. The manuscript that the number of samples was only one, were excluded. At end step, 8 articles were remained. Fig. 1 shows the PRISMA guideline for this systematic review.

3.2. The descriptive results of screened manuscript

Of all screened manuscript, 8 were selected for the systematic review. The type of food, sample size, level of styrene and the method used to measure styrene in food matrix are shown in Table 1.

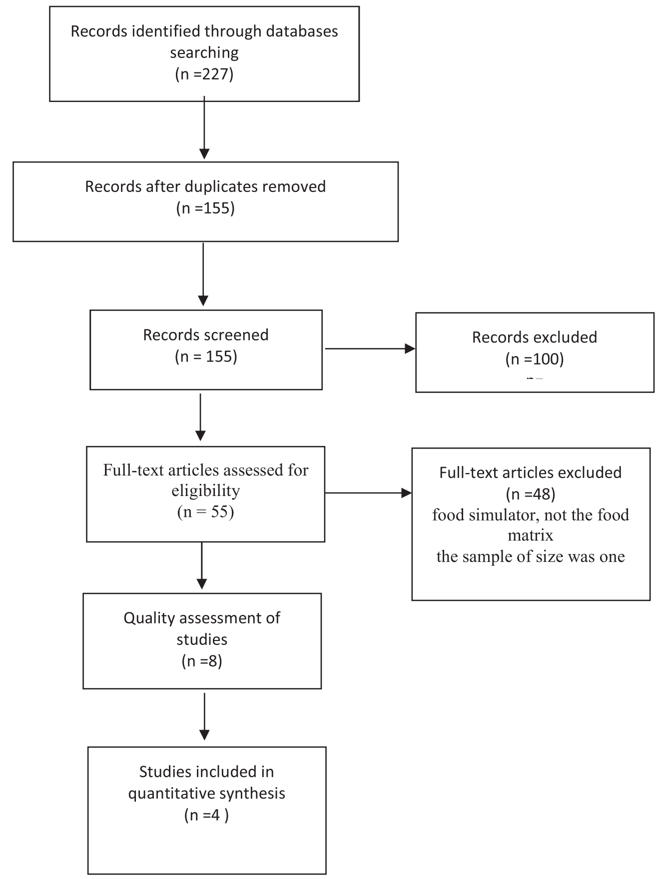

Fig. 1. The diagram of study.

3.3. Meta-analysis and estimation of the mean of styrene in food matrix

Among the selected studies, four studies reported the mean, standard deviation and the number of samples. The overall mean was estimated with CMA software. Heterogeneity was identified by I^2 and Q parameters. The p value was less than 0.05 and I^2 was about 99%, so random effects model was selected. In this calculation, the overall mean of 91.53 ± 26.18 μg/kg was measured. Due to the high heterogeneity, the subgroup analysis was also performed. The studies were divided into two categories: dairy products and non-dairy products. Heterogeneity was still high in these two groups and the p value was less than 0.05.

Publication bias was calculated with the egger test and its value was 0.35. Due to this value is higher than 0.05, so there is no publication bias. Meta regression was also done based on food groups. In this case, the groups were divided into two categories of dairy and non-dairy products. It was observed that the p value was less than 0.05. Therefore, the type of food is effective on the results (Fig. 2).

4. Discussion

The Table 1 shows extracted data from published paper. International agency for research on cancer grouped styrene to 2B as possible human carcinogen (Chung et al., 2013). Therefore, it is necessary to regularly monitor this compound in food. EU regulations determine 0.6 mg/kg as considered level in food. The amount mentioned in all published articles is less than this limit. The samples were mostly in dairy products and the highest amount was reported in cheese samples between dairy products. This is probably due to the higher fat content of these products. In the Bendall study, styrene dibromide was isolated in cheeses. The cheeses had polystyrene packaging. This compound is used as a catalyst in the manufacture of polystyrene. The styrene dibromide

Table 1
The detection method and level of styrene in foods.

Authors/ Year	country	Type of package	Type of food/Level of styrene	Sample size	Analysis method	Ref
Bendall/ 2007	New Zealand	Polystyrene	CheeseThe concentrations ranged from 0 to 70 ppb	20	GC–MS	(Bendall, 2007)
Chiesa/ 2008	Italy	Polystyrene	CheeseThe concentrations ranged from 0.01 to 429 ng/g	7	GC–MS	(Chiesa et al., 2008)
Gilbert/ 1983	UK	Polystyrene	Mean concentration of Cream:8µg/kg Mean concentration of Yoghurt:4 µg/kg Mean concentration of Salad:5 µg/kg Mean concentration of Cheese: 5 µg/kg Mean concentration of Margarine:9 µg/kg	15	GC–MS	(Gilbert & Startin, 1983)
Lopez/ 2008	Spain	Polystyrene	Skimmed milk = 84 ± 11 µg/kg Whole milk = 111 ± 3 µg/kg	3	GC–MS	(López et al., 2008)
Marc/2015	Poland	polyamideacrylonitrile–butadiene–styrene	Chocolate in polyamide toys = 8.2 ± 9.9 ng/g Chocolate in acrylonitrile–butadiene–styrene toys = 36 ± 44 ng/g	For each package 26	GC–MS	(Marć et al., 2015)
Nerin/1998	Spain	Polystyrene	Yoghurt4.7 ± 2.5 µg/kg	5	GC–MS	(Nerín et al., 1998)
Penalver/ 2021	Spain	Polystyrene	Honey310 ± 15 ng/g	2	GC–MS	(Peñalver et al., 2021)
Tawfik/ 1998	Belgium	Polystyrene	Mean concentration of: Yoghurt (3.5% fat) = 0.044 mg/kg Yoghurt (2.6% fat) = 0.039 mg/kg Cheese (13.5%fat) = 0.062 mg/kg Cheese(8.9%fat) = 0.054 mg/kg	Yoghurt = 5 Cheese = 8	HPLC	(Tawfik & Huyghebaert, 1998)

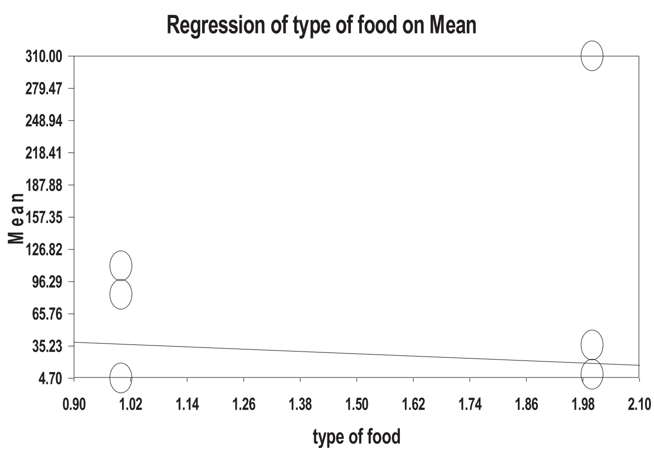

Fig. 2. Meta regression of the relationship between the type food and pooled styrene in food.

changed the color of the cheeses (Bendall, 2007). The rate of migration of this substance in cold is less, so it is recommended to ensure the storage of products in cold conditions. In the study of Chiesa, the amount of styrene in cheeses was also measured. The highest amount 429 ng/g was reported to be related to cheese, the production date of which was more than one year (Chiesa et al., 2008). In a study in the United Kingdom, the amount of styrene in some foods packed with polystyrene was measured. The highest levels were found in cream and margarine. This confirms that styrene is lipophilic (Gilbert & Startin, 1983, Nerín, Rubio, Cacho, & Salafranca, 1998). Therefore, the rate of migration to food products with a higher percentage of fat is higher. In addition, in Tawfik study, the amount of styrene in the cheese and yogurts examined was directly related to the fat content of the products (Tawfik & Huyghebaert, 1998). Furthermore, on studies that use different compounds as food simulators, *n*-heptane is selected as a simulator for fatty foods. It has been observed that in these conditions the rate of styrene migration is significant (Hwang et al., 2019). The Lopez study on skim milk and whole milk, the amount of styrene in whole milk was higher than skim one (López, Batlle, Salafranca, & Nerín, 2008).

The amount of styrene in the packaging is also an important factor. For example, in Marc's study, the amount of chocolate packaged in two type of polymer; polyamide and acrylonitrile–butadiene–styrene was examined(Marć et al., 2015). The amount of styrene in chocolate packed with acrylonitrile–butadiene–styrene was more than polyamide (Table 1). Therefore, it is also recommended not to use acrylonitrile–butadiene–styrene packaging for toys (Marć et al., 2015). In the Penalver study, the amount of styrene in honey samples was investigated and a significant amount of styrene was reported (Peñalver, Arroyo-Manzanares, Campillo, & Viñas, 2021). It probably relates to the shelf life of honey, which usually stays longer in these packages. Therefore, the longer shelf life of the product is directly related to the amount of styrene. In previous studies, the migration of styrene to foods that were stored for a longer period of time was higher (Paraskevopoulou, Achilias, & Paraskevopoulou, 2012).

The result of meta regression showed that the type of food affect on pooled mean. In fact, styrene in foods such as chocolate and honey are higher than in dairy products. This is probably due to the longer shelf life of these products compared to dairy products. By subgroup analysis, heterogeneity was observed within the groups, especially in dairy products. As mentioned, the fat content of dairy products greatly affects the rate of migration.

The second monomer used is styrene, which is found in the environment in addition to food (Tang et al., 2000). As a result of industrial activities and burning of polymers containing styrene, significant amounts are released into the environment (Tang et al., 2000). Therefore, for future studies, the occupational exposure and environmental samples need to be taken to assess.

5. Conclusion

In this systematic review, the amount of styrene in food samples was surveyed. The samples were mostly dairy products. Therefore, there is little information about the amount of styrene in various food categories. Various foods, especially ready-to-eat foods, are available in polystyrene packaging. Therefore, it needs a comprehensive study on the amount of styrene in ready-to-eat foods. The food matrix plays a major role in the rate of styrene migration. Including the fat content is one of the important factors in increasing the migration rate of styrene, which was confirmed in most studies. Styrene is a volatile compound, and in almost all studies, GC/MS was used to identify it in food. By pooling the results of the studies, the overall mean was lower than permissible level.

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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