Migration and Safety of Plastic Food Packaging Materials

Subjects: Materials Science, Coatings & Films
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The conventional packaging materials used for the preservation of foods may exhibit many disadvantages that are related to the migration of micromolecular chemical substances incorporated in the packaging material net to the packaged food. There are many chemical substances in the matrix of plastic packaging materials and epoxy-resins that are used in food packaging materials, varnishes, and can coatings. Many migrants have high toxicity, such as acetaldehyde, antimony, antimony (III) oxide, 2,4-di-tert-butylphenol, tris (2,4-di-tert-butylphenol) phosphate, tris(2,4-di-tert-butylphenyl) phosphite, *bisphenol* A, and the plasticizers di(2-ethylhexyl) phthalate), di-n-butyl phthalate, benzyl-butylphthalate, di-isononylphthalate, and di-isododecylphthalate.

plastics migration foods consumers safety natural films and coatings

1. Introduction

A matrix of plastic packaging material, except for macromolecular substances, consists of micromolecular substances such as metals as catalysts, very low amounts of solvent and monomers, and various reaction products that are produced during the manufacturing of plastic materials. Thermal decomposition products and various additives are added for the improvement of plastic materials' disadvantages, such as plasticizers, stabilizers, antioxidants, extinguishers, etc. When a plastic packaging material is in contact with food, the transfer of micromolecular substances from the matrix of the plastic material to the food occurs. This phenomenon is called migration, and the migrating substances are named migrants [1]. Regarding migration, when the migration of a specific substance occurs, it is named specific migration, while when migration concerns all the migrating substances, it is named overall migration. There are migration cases that lead to desirable results, such as the incorporation of antistatic media into packaging materials and the controlled diffusion of medicines from the net of plastics [1]. However, in most cases, migration is undesirable because of the diffusion of harmful chemical substances such as plasticizers from plasticized PVC (in toys and shower curtains), flame retardants (in plastic casings of televisions and computers), and various harmful chemical substances into foods and medicines, which can deteriorate the taste of food and the active compound of the medicine.

The process of migration can be divided into four stages:

(1) Diffusion of the migrants through the polymeric molecules of the plastic packaging material;

(2) The desorption of substances from the surface of the packaging material;

(3)The absorption of substances from the interface between the food and packaging material;

(4)The absorption of substances onto the food [2].

The main factors that are responsible for the migration of these micromolecules are as follows: (a) the presence of attractive forces between the micromolecules and the food constituents, (b) the low dimensions and molecular weight of the micromolecules, and (c) the volatility of the micromolecules. For example, low-size molecules (monomers and debris solvents) have low boiling points and exhibit high migration levels. Some monomers, such as formaldehyde, vinyl chloride, ethylene, and butadiene, present high migration levels even at ambient temperature [3]. Regarding molecular weight, a substance of high molecular weight presents low migration levels on account of its large dimensions. The migration levels are also influenced by the concentration of substances inside the plastic packaging material, the thickness of the packaging material, and the crystallinity and surface structure of the packaging material [3]. Migrants are divided into two categories: (i) IAS and (ii) NIAS [1]. The first type includes substances such as additives, monomers, metals, and various starters, and the second type includes substances such as polymer decomposition products and products from various reactions. The produced degradation products depend on the type of polymer, the degradation mechanisms, and environmental factors, such as temperature and oxygen. During the thermal degradation of plastic materials containing nitrogen (nylons, polyacrylonitrile, and *polyurethane*), HCN is produced, plastic materials containing chloride (PVC, PVdC) produce HCl and dioxins during thermal degradation, and plastic materials containing fluorine (*polytetrafluoroethylene*, *polyvinyl fluoride*) produce HF and perfluoroisobutene. Polymers such as polystyrene, polyesters, polycarbonates, polyamides, and polyurethanes can be depolymerized via chain scission of their initial monomers [4][5][6].

Moreover, regulation of the “limits of specific migration” has been established by the European Safety Food Authority (ESFA) based on data on the toxicity of each substance. For the total quality assurance of plastic packaging materials, the European Commission 2002a [7] established the directive 2002/72/EC, which regulates the application of monomers, additives, and their residual amounts in packaging, as well as their migration limits for the manufacturing of plastics that are intended to come in contact with foods (food-contact materials). As far as coatings are concerned, the resolution AP(96)5 (Council of Europe 1996) was edited [8], adopting a list of approved materials (starting materials) and additives of the directive 90/128/EEC (European Commission 1990, preceding directive of 2002/72/EC).

The use of food simulants to imitate real food samples was introduced for migration tests of all food-contact materials, in particular, plastic food -ontact materials in the European Council Directive 85/572/ECC in 1985 [9]. This directive was then replaced in 2011 by the regulation EC 10/2011 issued by the European Commission [10], which specifies further migration test conditions, again focusing on migration from plastic food-contact materials. To ensure the suitability of the presented food simulants, the associations between real food, food simulants, and migration conditions were thoroughly established [11], even though, in 2016, this directive was amended and corrected [12].

The limit of overall migration should not exceed 60 mg/Kg in food or 10 mg/dm^2 in food-contact material. This regulation also sets out the use of representative simulants for each food category [9]. The reasons for the substitution of real foods with food simulants in migration studies are the complexity of foods, the presence of difficulties during analysis, and the increase in the reproductivity of the results. Indeed, the selection of simulants depends on the food matrix to be imitated. More specifically, a mixture of ethanol/water (50:50, *v*:*v*) should be applied to imitate food with lipophilic properties, alcoholic food (alcohol content > 20%), and oil-in-water emulsions. Furthermore, a mixture of ethanol/water (10:90, *v*:*v*) is recommended by the European Union for the simulation of food with hydrophilic properties [10]. Real food samples typically consist of a complex composition of multiple components in equilibrium that interact and define the properties of each food. Therefore, the selection of suitable food simulants is of great interest and might require a general hypothesis [11]. According to the FDA [13], the food simulant contents that are recommended are as follows: for aqueous and acidic foods, 10% ethanol is recommended; for low- and high-alcoholic foods, 10% or 50% ethanol is proposed; and for fatty foods, food oils such as corn oil, synthetic glycerides (HB307), and miglyol 812 derived from coconut oil have been proposed.

2. Food Simulants

The basic food simulants that are proposed by the Commission Regulation (EU) 2016/416 [12] represent five different food categories and are listed in **Table 1**.

Table 1. Simulants according to Commission Regulation (EU) 2016/416 [12].

Simulant	Food Category	Shortcut
10% ethanol (*v*/*v*)	Hydrophilic foods	A
3% acetic acid (*w*/*v*)	Acidic foods with pH below 4.5	B
20% ethanol (*v*/*v*)	Alcoholic foods with an alcohol content of up to 20%	C
50% ethanol (*v*/*v*)	Alcoholic foods with an alcohol content of above 20%	D1
Vegetable oil	Fatty foods	D2
Poly(2,6-diphenyl-p-phenylene oxide),	Dry foods	E

Simulant	Food Category	Shortcut
particle size: 60–80 mesh, pore size: 200 nm, commonly named Tenax)		

Regarding the specific migration of starting materials and the products of the reactions that happen in can coatings, the 10 derivatives of BADGE and Bisphenol F diglycidyl ether (BFDGE) are limited to 1 mg/Kg of food according to the directive 2002/16/EC (European Commission 2002b) [14]. However, most of the starting materials for the coatings are a mixture of substances or prepolymers that react with other substances in the coating. The migrating substances from the coatings are monomers that belong to a positive list. The Scientific Committee on Food (SCF, European Commission 2001) [15] emphasized the importance of the identification of migrating substances, and their quantity and toxicity. Therefore, only substances with a molecular weight below 1000 Da are cause for concern because these can be absorbed so easily by the gastro-intestinal tract.

The most common chemical substances that migrate to foods are the following: acetaldehyde, methanal, antimony, Sb_2O_3, 2,4-di-tert-butylphenol, tris (2,4-di-tert-butylphenol) phosphate, Irgafos 168, BPA, and the plasticizers DEHP, DBP, BBP, DINP, and DIDP.

Table 2 lists the migrant substances and their toxic effects on human health.

Table 2. List of migrant substances and their toxic effects on human health.

Migrant Name	Toxic Effects and Health Issues	References
Acetaldehyde	Facial flushing, nausea, vomiting, tachycardia, hypotension, hepatitis, liver cirrhosis, and in extreme cases, even death.	[16][17][18][19]
Antimony and Antimony(III) oxide	Carcinogenic potential for humans.	[20][21]
Irgafos 168	Not any significant toxicological effects.	-
BPA	Negative effect on estrogen, great inhibitor of endocrine gland,	[22][23][24][25][26][27]

Migrant Name	Toxic Effects and Health Issues	References
	Negative effect on the metabolic homeostasis of the progeny, sex steroids, and thyroid hormones levels during pregnancy. Epigenetic effects and developmental neurotoxicity.	
Derivatives of BPA and other bisphenols	Negative effect on the regulation of metabolic homeostasis of the progeny, sex steroids, and thyroid hormone levels during pregnancy. Epigenetic effects and developmental neurotoxicity in zebrafish.	-
Melamine	Increase in urea content, increase in nephrotoxicity, i.e., kidney stones. Cannot be decomposed in activated sludge treatment systems.	[28][29]
PFOA PFOS	Liver dysfunction, testicular and liver cancers, high levels of cholesterol, ulcerative colitis, and low response of immune system to vaccines.	[30][31][32][33][34][35][36][37][38][39][40][41]
Phthalates	Endocrine disruption, various cancer forms, immune and metabolic diseases, abnormalities. In new-born babies, preterm birth, abnormal birth length and weight and head circumference,	[42]

Migrant Name	Toxic Effects and Health Issues	References
	and altered reproductive hormone levels. During childhood, asthma and allergic symptoms, obesity, anti-androgen effects, delay in growth and puberty, and changes in systolic blood pressure.	

2. Ferrara, G.; Bertoldo, M.; Scoponi, M.; Ciardelli, F. Diffusion coefficient and activation energy of Irganox 1010 in poly(propylene-co-ethylene) copolymers. Polym. Degrad. Stab. 2001, 73, 411–416.
3. Hansen, E.; Nillson, N.; Lithner, D.; Lassen, C. Hazardous Substances in Plastic Materials; COWI in cooperation with Danish Technological Institute: Taastrup, Denmark, 2013.
4. Ravve, A. Principles of Polymer Chemistry, 2nd ed.; Kluwer Academic, Plenum Publishers: New York, NY, USA, 2000.
5. La Mantia, F. Handbook of Plastics Recycling; iSmithersRapra Publishing: Shrewsbury, UK, 2002.
6. Lokensgard, T.L.E. Richardson, Industrial Plastics: Theory and Applications; Delmar Learning: New York, NY, USA, 2004.
7. European Commission. Commission Directive No. 2002/72/EC of 6 August 2002 relating to plastic materials and articles indented to come into contact with foodstuffs. Off. J. Eur. Communities 2002, 220, 18–58.
8. Council of Europe Resolution AP (96) 5 on Surface Coatings Intended to Come into Contact with Foodstuffs. Adopted by the Committee of Ministers on 2 October 1996 at the 574th Meeting of the Ministers’ Deputies, 1–128. Available online: https://rm.coe.int/16804e230f (accessed on 7 December 2023).
9. Council directive 85/572/EEC of 19 December 1985: Laying down the list of simulants to be used for testing migration of constituents of plastic materials and articles intended to come into contact with foodstuffs. Off. J. Eur. Communities 1985, L372, 14–21.
10. Commission regulation (EU) No 10/2011 of 14 January 2011 on plastic materials and articles intended to come into contact with food. Off. J. Eur. Union 2011, L12, 1–89.
11. Lerch, M.; Fengler, M.; Mbog, G.-R.; Nguyen, K.H.; Granby, K. Food simulants and real food–What do we know about the migration of PFAS from paper based food contact materials? Food Pack. Shelf Life 2023, 35, 10099.

12. Commission Regulation (EU) 2016/1416 of 24 August 2016 amending and correcting Regulation (EU) No 10/2011 on plastic materials and articles intended to come into contact with food. Off. J. Eur. Union 2016, L230, 22–40.
13. U.S. Food and Drug Administration (FDA). Guidance for Industry: Preparation of Premarket Submissions for Food Contact Substances (Chemistry Recommendations), 2007, Center for Food Safety and Nutrition. Available online: https://www.fda.gov (accessed on 9 January 2024).
14. European Commission. Commission Directive No. 2002/16/EC of 20 February 2002 on the use of certain epoxy derivatives in materials and articles indented to come into contact with foodstuffs. Off. J. Eur. Communities 2002, L51, 27–31.
15. European Commission, Health and Consumer Protection Directorate-General. Guidelines of the Scientific Committee on Food for the Presentation of an Application for Safety Assessments of Substances to be Used in Food Contact Materials Prior to Its Authorization; European Commission: Brussels, Belgium, 2001; pp. 1–6.
16. Paine, A.J.; Dayan, A.D. Defining a tolerable concentration of methanol in alcoholic drinks. Hum. Exp. Toxicol. 2001, 20, 563–568.
17. Lachenmeier, D.W.; Haupt, S.; Schulz, K. Defining maximum levels of higher alcohols in alcoholic beverages and surrogate alcohol products. Regul. Toxicol. Pharmacol. 2008, 50, 313–321.
18. Lachenmeier, D.W.; Rehm, J. What is the main source of human exposure to higher alcohols and is there a link to immunotoxicity? Immunopharmacol. Immunotoxicol. 2013, 35, 451–453.
19. Park, Y.S.; Lee, Y.J.; Lee, K.T. Analysis of formaldehyde and acetaldehyde in alcoholic beverage. J. Korean Soc. Food Sci. Nutr. 2006, 35, 1412–1419.
20. Fang, H.; Wang, J.; Lynch, R.A. Migration of di(2-ethylhexyl)phthalate (DEHP) and di-nbutylphthalate (DBP) from polypropylene food containers. Food Control 2017, 73, 1298–1302.
21. Ohno, K.; Azuma, Y.; Nakano, S.; Kobayashi, T.; Hirano, S.; Nobuhara, Y.; Yamada, T. Assessment of styrene oligomers eluted from polystyrene-made food containers for estrogenic effects in in vitro assays. Food Chem. Toxicol. 2001, 39, 1233–1241.
22. Goodson, A.; Robin, H.; Summerfield, W.; Cooper, I. Migration of bisphenol A from can coatings—Effects of damage, storage conditions and heating. Food Addit. Contam. 2004, 21, 1015–1026.
23. Dodds, E.C.; Lawson, W. Synthetic strogenic agents without the phenanthrene nucleus. Nature 1936, 137, 996.
24. Dodds, E.C.; Lawson, W. 1938 Molecular structure in relation to oestrogenic activity. Compounds without a phenanthrene nucleus. Proc. Royal Soc. B 1938, 125, 222–232.
25. Krishnan, A.V.; Stathis, P.; Permuth, S.F.; Tokes, L. Bisphenol-A: An Estrogenic Substance is Released from Polycarbonate Flasks During Autoclaving. Endocrinology 1993, 132, 2279–2286.

26. Silva, B.S.; Bertasso, I.M.; Pietrobon, C.B.; Lopes, B.P.; Santos, T.R.; Peixoto-Silva, N.; Carvalho, J.C.; Claudio-Neto, S.; Manhaes, A.C.; Cabral, S.S.; et al. Effects of maternal bisphenol A on behavior, sex steroid and thyroid hormones levels in the adult rat offspring. Life Sci. 2019, 218, 253–264.
27. Nesan, D.; Sewell, L.C.; Kurrasch, D.M. Opening the black box of endocrine disruption of brain development: Lessons from the characterization of Bisphenol A. Horm. Behav. 2018, 101, 50–58.
28. Zheng, X.; Zhao, A.; Xie, G.; Chi, Y.; Zhao, L.; Li, H.; Wang, C.; Bao, Y.; Jia, W.; Luther, M.; et al. Melamine-induced renal toxicity is mediated by the gut microbiota. Sci. Transl. Med. 2013, 5, 172ra22.
29. Xu, S.; Zhang, Y.; Sims, A.; Bernards, M.; Hu, Z. Fate and toxicity of melamine in activated sludge treatment systems after a long-term sludge adaptation. Water Res. 2013, 47, 2307–2314.
30. Still, M.; Schlummer, M.; Gruber, L.; Fiedler, D.; Wolz, G. Impact of industrial production and packaging processes on the concentration of per-and polyfluorinated compounds in milk and dairy products. J. Agric. Food Chem. 2013, 61, 9052–9062.
31. Lau, C.; Anitole, K.; Hodes, C.; Lai, D.; Pfahles-Hutchens, A.; Seed, J. Perfluoroalkyl acids: A review of monitoring and toxicological findings. Toxicol. Sci. 2007, 99, 366–394.
32. Lindström, A.B.; Strynar, M.J.; Libelo, E.L. Polyfluorinated compounds: Past, present, and future. Environ. Sci. Technol. 2011, 45, 7954–7961.
33. DeWitt, J.C.; Peden-Adams, M.M.; Keller, J.M.; Germolec, D.R. Immunotoxicity of perfluorinated compounds: Recent developments. Toxicol. Pathol. 2012, 40, 300–311.
34. White, S.S.; Fenton, S.E.; Hines, E.P. Endocrine disrupting properties of perfluorooctanoic acid. J. Steroid Biochem. Mol. Biol. 2011, 127, 16–26.
35. Gallo, V.; Leonardi, G.; Genser, B.; Lopez-Espinosa, M.J.; Frisbee, S.J.; Karlsson, L.; Ducatman, A.M.; Fletcher, T. Serum perfluorooctanoate (PFOA) and perfluorooctane sulfonate (PFOS) concentrations and liver function biomarkers in a population with elevated PFOA exposure. Environ. Health Perspect. 2012, 120, 655–660.
36. Barry, V.; Winquist, A.; Steenland, K. Perfluorooctanoic acid (PFOA) exposures and incident cancers among adults living near a chemical plant. Environ. Health Perspect. 2013, 121, 1313–1318.
37. Benbrahim-Tallaa, L.; Lauby-Secretan, B.; Loomis, D.; Guyton, K.Z.; Grosse, Y.; El Ghissassi, F.; Bouvard, V.; Guha, N.; Mattock, H.; Straif, K. Carcinogenicity of perfluorooctanoic acid, tetrafluoroethylene, dichloromethane, 1, 2-dichloropropane, and 1, 3-propane sultone. Lancet Oncol. 2014, 15, 924–925.

38. Fitz-Simon, N.; Fletcher, T.; Luster, M.I.; Steenland, K.; Calafat, A.M.; Kato, K.; Armstrong, B. Reductions in serum lipids with a 4-year decline in serum perfluorooctanoic acid and perfluorooctanesulfonic acid. Epidemiology 2013, 24, 569–576.

39. Steenland, K.; Zhao, L.; Winquist, A.; Parks, C. Ulcerative colitis and perfluorooctanoic acid (PFOA) in a highly exposed population of community residents and workers in the mid-Ohio valley. Environ. Health Perspect. 2013, 121, 900–905.

40. Grandjean, P.; Andersen, E.W.; Budtz-Jørgensen, E.; Nielsen, F.; Mølbak, K.; Weihe, P.; Heilmann, C. Serum vaccine antibody concentrations in children exposed to perfluorinated compounds. JAMA 2012, 307, 391–397.

41. Sunderland, E.M.; Hu, X.C.; Dassuncao, C.; Tokranov, A.K.; Wagner, C.C.; Allen, J.G. A review of the pathways of human exposure to poly-and perfluoroalkyl substances (PFASs) and present understanding of health effects. J. Expo. Sci. Environ. Epidemiol. 2018, 29, 131–147.

42. Benjamin, S.; Masai, E.; Kamimura, N.; Takahashi, K.; Anderson, R.C.; Faisal, P.A. Phthalates impact human health: Epidemiological evidences and plausible mechanism of action. J. Hazard. Mater. 2017, 340, 360–383.