COMPREHENSIVE REVIEWS IN FOOD SCIENCE AND FOOD SAFETY

# Phthalate Esters in Foods: Sources, Occurrence, and Analytical Methods

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**ABSTRACT: Phthalates are a group of diesters of ortho-phthalic acid (dialkyl or alkyl aryl esters of 1,2-benzenedicarboxylic acid). Higher-molecular-weight phthalates, such as di-2-ethylhexyl phthalate (DEHP), are primarily used as plasticizers to soften polyvinyl chloride (PVC) products, while the lower-molecular-weight phthalates, such as diethyl phthalate (DEP), di-n-butyl phthalate (DBP), and butyl benzyl phthalate (BBzP), are widely used as solvents to hold color and scent in various consumer and personal care products. Phthalates have become ubiquitous environmental contaminants due to volatilization and leaching from their widespread applications, and thus contamination of the environment has become another important source for phthalates in foods in addition to migration from packaging materials. Human exposure to phthalates has been an increased concern due to the findings from toxicology studies in animals. DEHP, one of the important and widely used phthalates, is a rodent liver carcinogen. DEHP, DBP, BBzP, and several phthalate metabolites, such as monobutyl phthalate, monobenzyl phthalate, and mono-(2-ethylhexyl) phthalate, are teratogenic in animals. Since foods are the major source of exposure to phthalates, information on levels of phthalates in foods is important for human exposure assessment. The objective of this review is to identify the knowledge gaps for future investigations by reviewing levels of a wide range of phthalates in a variety of foods, such as bottled water, soft drinks, infant formula, human milk, total diet foods, and others, migration of phthalates from various food-packaging materials, and traditional and new methodologies for the determination of phthalates in foods.**

## Introduction

Phthalates are a group of diesters of ortho-phthalic acid (dialkyl or alkyl aryl esters of 1,2-benzenedicarboxylic acid, Figure 1). The structures and properties of phthalates commonly monitored in foods and food-packaging materials are summarized in Table 1. It should be mentioned that di-isononyl phthalate (DiNP) and di-isodecyl phthalate (DiDP) are commercially available in 2 different mixtures and thus 2 Chemical Abstract Service (CAS) numbers were assigned to each. Higher-molecular-weight phthalates, such as di-2-ethylhexyl phthalate (DEHP), DiNP, and DiDP, are primarily used as plasticizers to soften polyvinyl chloride (PVC) products, while the lower-molecular-weight phthalates, such as diethyl phthalate (DEP), di-n-butyl phthalate (DBP), and butyl benzyl phthalate (BBzP), are widely used as solvents to hold color and scent in various consumer and personal care products. Adipates, such as di-2-ethylhexyl adipate (DEHA) and di-isononyl adipate (DiNA), are also used frequently as plasticizers in PVC products as replacement of phthalates. Thus adipates, especially phthalates, have become ubiquitous environmental contaminants due to volatilization and leaching from their widespread applications, and they have been detected in the environment (Rudel and others 2003; Bornehag and others 2004; Bornehag and others 2005) and in foods.

Human exposure to phthalates has been of an increased concern due to the findings from toxicology studies in animals. DEHP, one of the important and widely used phthalates, is a rodent liver carcinogen. DEHP, DBP, BBzP, and several phthalate metabolites, such as monobutyl phthalate (mBP), monobenzyl phthalate (mBzP), and mono-(2-ethylhexyl) phthalate (mEHP), are teratogenic in animals (Silva and others 2004). A possible association was suggested between phthalates and the cause of premature breast development in young Puerto Rican girls by Colón and others (2000). The study by Bornehag and others (2004) also demonstrated an association between asthma and allergic symptoms in children and phthalates in house dust. Tolerable daily intakes (TDI) have been specified by the European Food Safety Authority (EFSA) for several phthalates, and they are 0.01, 0.5, 0.05, 0.15, and 0.15 mg/kg body weight/day for DBP

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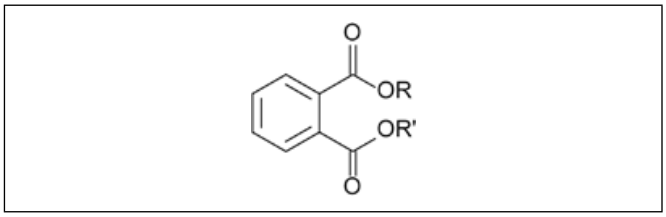


**Figure 1—General structure of phthalates, R and R′ are the same or different alkyl or aryl groups.**

(EFSA 2005a), BBzP (EFSA 2005b), DEHP (EFSA 2005c), DiNP (EFSA 2005d), and DiDP (EFSA 2005e), respectively.

Foods are the major source of human exposure to phthalates, thus it is important to monitor levels of phthalates in various foods to provide data for human exposure assessment. Since phthalates are ubiquitous environmental contaminants, contamination of the environment is one of the sources for phthalates present in foods at various levels. Although use of phthalates in food-packaging materials is decreasing, there are still many products that contain phthalates and adipates as plasticizers and are used for food packaging and processing, and migration of plasticizers from these products is the major path of phthalates and adipates into foods that are in contact with these products.

## Sources of Phthalates in Foods

### PVC tubing

PVC tubing is commonly used in the milking process and in the bulk transfer of milk between tankers and storage tanks in dairy farms and dairy processing plants. Like many other PVC products, plasticizers such as phthalates are used in PVC tubing to make it more flexible, and among which DEHP is the most frequently used with as much as 40% in the tubing (Ruuska and others 1987; Tsumura and others 2002a). Since they are not chemically bonded to the polymer, plasticizers can migrate from the PVC tubing into milk, especially at relatively higher temperature during the milking process. Migration of phthalates from plasticized PVC tubing has been investigated since the early 1970s (Wildbrett 1973); 2 PVC tubings containing different plasticizers were tested for migration of the plasticizers into milk at different temperatures. Migration levels of phthalate from the PVC tubing plasticized with 47.2% of dinonyl phthalate were 46 and 70 mg/L after contacting with milk at 38 and 56°C, respectively, and migration levels of phthalate from the other PVC tubing plasticized with 5.5% of DEHP and 26.8% polyadipate were 20 and 31 mg/L after contacting with milk at 38 and 56°C, respectively. Wildbrett (1973) also observed that previous absorption of moisture by the PVC tubing plasticized with 47.2% of dinonyl phthalate significantly increased the migration of phthalate from the tubing, with migration levels at 46, 73, and 95 mg/L after contacting with milk at 38 °C for 8 h for the tubings contacted with water for 0, 7, and 14 d, respectively.

Similar results were obtained by Ruuska and others (1987); migration levels of DEHP in milk ranged from 1.2 to 2.8 mg/L for PVC tubings plasticized with DEHP at 7% to 8.2% after being soaked in milk for 1 to 6 d at 40 °C, and from 1.9 to 5.0 mg/L for PVC tubings plasticized with DEHP at 37% to 40% after being soaked in milk for 1 to 6 d at 40 °C. The lower migration levels than those from Wildbrett (1973) were due to the short PVC tubing (10 cm compared with 1 m used by Wildbrett) and large volume of milk (500 mL compared with 100 mL used by Wildbrett) used in their migration experiments. However, Mueller and Bradley (1980) demonstrated much lower migration levels of

**Table 1—Properties of phthalates and adipates.**

| Phthalates | CAS number | Formula | FW | Density (g/mL) | b.p.(°C) | m.p.(°C) | Vapor pressure at 25 °C (Pa) | Water solubility (mg/L) at 25 °C | Log $K_{OW}$ at 25 °C |
|---|---|---|---|---|---|---|---|---|---|
| Dimethyl phthalate (DMP) | 131-11-3 | $C_{10}H_{10}O_4$ | 194.2 | 1.191 | 282 | 2 | 0.263 | 5220 | 1.61 |
| Diethyl phthalate (DEP) | 84-66-2 | $C_{12}H_{14}O_4$ | 222.2 | 1.232 | 295 | −40.5 | $6.48 \times 10^{-2}$ | 591 | 2.54 |
| Dipropyl phthalate (DPP) | 131-16-8 | $C_{14}H_{18}O_4$ | 250.3 | 1.078 | 317.5 | | $1.75 \times 10^{-2}$ | 77 | 3.40 |
| Di-iso-butyl phthalate (DiBP) | 84-69-5 | $C_{16}H_{22}O_4$ | 278.3 | 1.039 | 327 | −37 | $4.73 \times 10^{-3}$ | 9.9 | 4.27 |
| Di-n-butyl phthalate (DBP) | 84-74-2 | $C_{16}H_{22}O_4$ | 278.3 | 1.043 | 340 | −35 | $4.73 \times 10^{-3}$ | 9.9 | 4.27 |
| Butyl benzyl phthalate (BBzP) | 85-68-7 | $C_{19}H_{20}O_4$ | 312.4 | 1.119 | 370 | <−35 | $2.49 \times 10^{-3}$ | 3.8 | 4.70 |
| Dicyclohexyl phthalate (DCHP) | 84-61-7 | $C_{20}H_{26}O_4$ | 330.4 | 1.383 | 222 to 228 (0.5 kPa) | 66 | 13.3 (150°C) | 4.0 (24°C) | 3–4 |
| Di-n-hexyl phthalate (DHP) | 84-75-3 | $C_{20}H_{30}O_4$ | 334.5 | 1.011 | 350 | −27.4 | $3.45 \times 10^{-4}$ | 0.159 | 6.00 |
| Di-2-ethylhexyl phthalate (DEHP) | 117-81-7 | $C_{24}H_{38}O_4$ | 390.6 | 0.985 | 384 | −47 | $2.52 \times 10^{-5}$ | $2.49 \times 10^{-3}$ | 7.73 |
| Di-n-octyl phthalate (DOP) | 117-84-0 | $C_{24}H_{38}O_4$ | 390.6 | 0.985 | 390 | −25 | $2.52 \times 10^{-5}$ | $2.49 \times 10^{-3}$ | 7.73 |
| Di-iso-nonyl phthalate (DiNP) | 68515-48-0; 28553-12-0 | $C_{26}H_{42}O_4$ | 419 | 0.972 | 370 | −50 | $6.81 \times 10^{-6}$ | $3.08 \times 10^{-4}$ | 8.60 |
| Di-iso-decyl phthalate (DiDP) | 68515-49-1; 26761-40-0 | $C_{28}H_{46}O_4$ | 446.66 | 0.966 | >400 | −50 | $1.84 \times 10^{-6}$ | $3.81 \times 10^{-5}$ | 9.46 |
| Di-2-ethylhexyl adipate (DEHA) | 103-23-1 | $C_{22}H_{42}O_4$ | 370.57 | 0.927 | 417 | −67.8 | | | |
| Di-isononyl adipate (DiNA) | 33703-08-1 | $C_{24}H_{46}O_4$ | 398.63 | 0.922 | 235 (5 mbar) | −65 | | | |

phthalates from PVC tubing, with total concentrations of DBP and DEHP ranging from 0.12 to 4.33 ppb per day in milk after soaking a 10-cm PVC tubing in 500 mL milk at 38 °C for 4 h each day, and they also claimed that water extracts higher amounts of phthalates from PVC tubing than milk despite the well-known fact that phthalates are lipophilic and can migrate into fatty media much more easily than nonfatty media.

Due to health concerns, some countries have already banned the use of DEHP in PVC tubing for milking purpose. For example, Denmark banned the use of DEHP in milk tubing in August 1989, and DEHP-plasticized milk tubing was also being replaced by other types of plasticizers in Norway (Petersen 1991). The UK dairy industry uses tubing that does not contain plasticizers, except in the bulk transfer between tankers and storage tanks where PVC tubing plasticized with DiDP rather than DEHP is used (Castle and others 1990). However, PVC tubing plasticized with DEHP may still be used in other countries for milking purpose. For example, in a Canadian study conducted recently (Feng and others 2005), DEHP levels in cow milk collected with a machine using PVC tubing plasticized with 28% DEHP ranged from 111.7 to 282.9 ng/g, about 15 times higher on average than those in cow milk manually collected without using PVC tubing (8.4 to 23.7 ng/g), indicating that migration from PVC tubing could be the main source for DEHP in milk and milk products in Canada.

### Food-packaging films

The thin packaging film, also known as the cling film, is widely used for wrapping a variety of foods. Several types of films are available, such as PVC film, polyvinylidene chloride (PVDC) film, polyethylene (PE) film, regenerated cellulose film (RCF), cellulose acetate film, and more. PVC film, the most commonly used, is plasticized mainly with DEHA, although DEHP is also used in some other countries (Freire and others 2006). PVDC is a copolymer of vinylidene chloride (85% to 90%) and vinyl chloride (Lee and others 2008), and PVDC film is plasticized with dibutyl sebacate (DBS) or acetyl tributyl citrate (ATBC) (Castle and others 1988a). PE film is naturally flexible and thus does not contain plasticizers. RCF is coated with plasticized nitrocellulose to provide flexibility and heat sealability, and the plasticizers most commonly used are DBP, dicyclohexyl phthalate (DCHP), BBzP, and diphenyl 2-ethylhexyl phosphate (DPOP) (Castle and others 1988a; Harrison 1988). Cellulose acetate film is plasticized with DEP to form transparent windows in cardboard cartons to display the contents (Castle and others 1988b; Harrison 1988).

Like plasticizers in PVC products, plasticizers in packaging films are also not bonded chemically to the polymer and can migrate when they are in contact with foods, especially fatty foods. Migration of plasticizer from PVC packaging films (plasticized with about 30% DEHA) to meat was investigated by Daun and Gilbert (1977), and they observed that migration levels of DEHA were higher in meat with high fat content, ranging from 14.5 and 15.5 mg/dm$^2$ for beef with 20% fat to 21.0 and 23.5 mg/dm$^2$ for beef fat (90% fat) after being stored at 4 °C for 72 h. They also observed that migration of DEHA into meat increased with longer contact time, with levels of DEHA in beef with 21.1% fat at 4.5, 13.5, and 14.0 mg/dm$^2$ after contacting with the film for 24, 28, and 96 h, respectively.

A series of studies was conducted in the United Kingdom in the 1980s to investigate migration of various plasticizers from different packaging films into foods (Startin and others 1987a; Castle and others 1987, 1988a, 1988b; Harrison 1988). Migration of DEHA from PVC films into various foods during home-use and microwave cooking was investigated by Startin and others (1987a). It was observed that the moisture content of cheese also had an influence on the migration in addition to fat content, DEHA levels in different types of cheese ranged from 3.1 to 22.5 mg/dm$^2$ after being wrapped in PVC film for 5 d at 5 °C. Migration levels of DEHA into purchased ready-cooked meats rewrapped with PVC film at home after storage at 5 °C for 7 d were higher than those after storage at −18 °C for 30 d. A reasonable correlation between the extent of migration and the fat content of the meats was observed; highest levels observed for the fatty skin surfaces of chicken (7 d at 5 °C: 75 mg/kg; 30 d at −18 °C: 29 mg/kg) and the high fat content of salami (7 d at 5 °C: 181 mg/kg; 30 d at −18 °C: 109 mg/kg), while lower levels were observed for minced beef (7 d at 5 °C: 78 mg/kg; 30 d at −18 °C: 23 mg/kg). Migration levels of DEHA into fruits and vegetables wrapped with PVC films were low in general, except for avocado due to its high fat content (22%) with DEHA level at 53 mg/kg after storage at 5 °C for 5 d. They also demonstrated the effect of overwrapping on migration of DEHA into cheese; migration from a single layer reached 15.1 mg/dm$^2$ after 24 h of contact at 5 °C compared with 24.6 mg/dm$^2$ for a double layer.

Castle and others (1988a) proposed and investigated 2 approaches to reduce the migration of plasticizers from PVC films into foods: production of thinner films with a consequent reduction in DEHA levels normally present, and partial or complete replacement of DEHA with a higher-molecular-weight polymeric plasticizer. A 41% to 53% reduction in the mean migration level of DEHA in foods was observed for a thinner film containing 13.3% DEHA compared to the conventional PVC film with 18.3% of DEHA. Levels of plasticizer migrated from PVC film with 23% polymeric plasticizer were 3 to 21 times lower than levels of DEHA migrated from the conventional PVC film plasticized with 18% DEHA.

Migration of various plasticizers from other types of packaging films was also investigated by Castle and others (1988a). Migration levels of ATBC from PVDC films plasticized with 4.3% to 4.6% of ATBC into cheese ranged from 1.3 to 7.7 mg/kg. Migration into cheese and cooked meat products of DBS from PVDC films plasticized with 3.5% to 4.1% of DBS ranged from 2.3 to 137 mg/kg. Levels of DBP, DCHP, BBzP, and DPOP in foods packaged with nitrocellulose-coated RCFs plasticized with DBP alone, with DBP and DCHP, and DBP, DCHP, BBzP, and DPOP were 0.5 to 30.8 mg/kg, 0.05 to 19.8 mg/kg, 0.05 to 9.4 mg/kg, and 0.05 to 9.4 mg/kg, respectively. DEP was also detected in baked foods packaged in cardboard boxes with cellulose acetate windows plasticized with 16% to 17% of DEP at levels ranging from 1.7 to 4.5 mg/kg. It is suggested that a possible route could be volatilization of DEP from the film to the food without a direct contact.

Petersen and others (1997) and Petersen and Breindahl (1998) investigated the migration of DEHA from 44 and 49 PVC films collected in 1990 to 1991 and 1996 in Denmark, respectively. The specific migration of DEHA from thin plasticized PVC films immersed in olive oil at 40 °C for 10 d (7.8 to 41.3 mg/dm$^2$) and isooctane at 40 °C for 2 h (8.1 to 48.1 mg/dm$^2$) correlates well in general, except that the migration to isooctane is slightly higher than to olive oil when the DEHA concentration in the film is high. DBP was detected in 4 PVC films with migration levels ranging from 0.24 to 1.1 mg/dm$^2$, and DEHP was also detected in another 5 PVC films.

Petersen and others (1995) also investigated the migration of DEHA into cheese packaged with PVC film plasticized with 14.4% DEHA. Although higher migration levels of DEHA into cheese were observed with longer contacting time (58, 102, and 196 mg/kg after exposure at 21 °C for 2 h, 1 d, and 5 d, respectively), there were no considerable differences among DEHA levels in cheese exposed for the same period at different temperatures (45, 58, and 49 mg/kg after exposure for 2 h at 5, 21, and 40 °C, respectively). They proposed that this could be due to the dry and hard surfaces of the cheese at 40 °C, which create a

barrier limiting the intimate contact between the film and cheese surface.

Goulas and others (2000) also investigated the migration of DEHA into cheeses with different fat contents (19% to 30%) and moisture contents (38% to 56%) wrapped with food-grade PVC film plasticized with 28.3% DEHA. DEHA levels increased with increasing contacting time for all cheeses, and higher DEHA levels were found in cheese with higher fat content, with 345.4, 222.5, and 133.9 mg/kg in cheeses with 30%, 23%, and 19% fat, respectively, after being stored at 5 °C for 10 d. The degree of DEHA penetration in cheeses contacting with PVC film for 10 d at 5 °C was also investigated, levels of DEHA in the 2nd slices (11.4 to 25.7 mg/kg at depth of 1.2 to 2.4 mm) decreased considerably compared to those in the 1st slices (194.3 to 505.7 mg/kg at depth of 0 to 1.2 mm), and DEHA was not detected in the 3rd (depth of 2.4 to 3.6 mm) or the 4th slices (depth of 3.6 to 4.8 mm).

Over the past 10 y, very low volume of requests have been received by Health Canada from manufacturers of PVC and/or PVDC packaging films, indicating a constant decline of this market in North America (personal communication, Parent 2009). The Canadian food-packaging film market is now strongly dominated by polyolefins such as LDPE, LLDPE (personal communication, Parent 2009).

### PVC gaskets in metallic caps for glass jars

Plasticized PVC is commonly used as a gasket in the metallic caps to provide a seal against the rim of the glass jars. Various plasticizers such as epoxidized soya bean oil (ESBO), phthalates, adipates, and so on, have been used in PVC gaskets by different countries. Hirayama and others (2001) analyzed the gaskets used in 82 bottled food products collected during 1997 to 1999; DEHP was detected in the gaskets used in 7 of the 21 domestic (Japan) bottled food products with levels ranging from 19.6% to 31.2%, DALG (diacetyl lauroyl glycerol) was also detected in the gaskets of 5 products. Among the 61 imported bottled food products, DEHP was detected in the gaskets of 11 products at levels from 19.5% to 31.6%, DiNP was detected in the gaskets of 3 products (24.5% to 37.2%), DiDP in the gaskets of 23 products (13.6% to 40.7%), and DEHA in the gaskets of 2 products (1.9% to 27.4%).

Tsumura and others (2002b) analyzed the cap-sealing for 103 bottled food samples (80 imported and 23 domestic), DEHA was detected in 5 of the samples (0.1% to 25.8%), DCHP in 4 samples (0.1% to 10.5%), DEHP in 33 samples (0.1% to 48.6%), DiNP in 5 samples (28.3% to 52.1%), and DiDP was detected in 26 samples (0.3% to 37.0%). Various plasticizers were also detected in the lids of food products in glass jars during the 2 Swiss market surveys conducted in 2004 (Biedermann-Brem and others 2005) and 2005 (Fankhauser-Noti and others 2006), with ESBO being the most frequently used, followed by DEHP, DiNP, DiDP, and DEHA.

Fankhauser-Noti and Grob (2006) investigated migration of plasticizers from PVC gaskets of lids for glass jars into various oily foods. Levels of ESBO ranged from 10 to 650 mg/kg for foods contained in jars with gaskets plasticized with 5% to 45% of ESBO, levels of DEHP from 20 to 430 mg/kg for foods contained in jars with gaskets plasticized with 1% to 28% of DEHP, levels of DiNP from 15 to 150 mg/kg for foods contained in jars with gaskets plasticized with 1% to 23% of DiNP, and levels of DiDP from 55 to 380 mg/kg for foods in jars with gaskets plasticized with 18% to 24% of DiDP. DEHA, DEHS, and ATBC were also detected in a few oily products at levels from 10 to 225 mg/kg. In a more extensive market survey conducted in 2005 (Fankhauser-Noti and others 2006), migration of plasticizers from PVC gaskets in lids of more than 100 oily food products was investigated, and concentrations in the food reached 1170 mg/kg for ESBO, 825 mg/kg for DEHP, 180 mg/kg for DEHA, 270 mg/kg for DiDP, and 740 mg/kg for DiDP.

In order to reduce the migration of current plasticizers from the PVC gaskets in the lids into foods, especially oily foods, plasticizer with high molecular weight such as polyadipates was investigated recently (Biedermann and others 2008). Although polyadipates have been successfully used in PVC packaging films (Castle and others 1988a), they are not easy to work with since they render the plastisol highly viscous and make it difficult to place a uniform ring into the lid and thus dilution with plasticizers of low viscosity is needed. The preliminary results obtained with 11 packed foods stored and repeatedly shaken for up to 2 y show that migration of polyadipates was below the legal limits.

Recently, Health Canada evaluated a new plasticizer, di(2-ethylhexyl) terephthalate (DEHT, CAS No. 6422-86-2), proposed as a substitute for DEHP in the formulation of PVC-based liners for closure caps intended for bottled beverages (personal communication, Parent 2009). This again indicates the decreasing trend of DEHP in food-packaging materials in North America.

### Printing inks

Plasticizers, such as DBP, DCHP, and DEHP, are part of printing ink formulations (2% to 8%) to improve its adhesion on surfaces and thus its flexibility and wrinkle resistance (Castle and others 1989). Since ink is printed on the outer surfaces of food-packaging materials (film, cardboard, and so on), it will be another source of phthalates in foods in addition to the packaging materials.

Castle and others (1989) investigated migration of plasticizers into foods from printing inks used on the outside of food wrappers. Chocolate confectionery and potato snack products were analyzed after being wrapped for up to 90 to 180 d with printed polypropylene films and stored at 20 °C. Since polypropylene film itself does not contain plasticizers, migration of any plasticizers into the foods will be from the inks. Migration levels of DBP increased from 0.2 to 6.7 mg/kg over the period from 0 to 180 d of storage of a chocolate-coated confectionery product. The presence of one or more plasticizers was also observed in a number of confectionery and snack products wrapped in printed polypropylene film, with levels ranging from 0.02 to 14.1 mg/kg for DBP, less than 0.01 to 18.6 mg/kg for DCHP, and less than 0.01 to 1.8 mg/kg for DEHP.

Balafas and others (1999) investigated phthalates and adipate in various Australian food-packaging materials. DEHP was the most frequently detected in all samples (ranging from 2 to 7058 mg/kg), followed by DBP (up to 4750 mg/kg), DEHA (up to 1728 mg/kg), and BBzP (up to 2716 mg/kg). The highest concentrations of phthalates and adipate were detected in the printed PE materials, thus printing inks may have been the ultimate source.

However, since new technologies have been introduced by printing ink-system designers and manufacturers who focus on the use of less ink and new curing techniques such as fast UV cured systems as a way to reduce bleeding (personal communication, Parent 2009), the various printing inks currently used for food-packaging materials may contain little or no phthalates and should be investigated.

### Paper and board packaging

Phthalates have been detected in various paper and board-packaging materials. For example, Summerfield and Cooper (2001) detected DBP, DiBP, DEHP, and BBzP in various paper towels at levels of 1.9 to 2.9, 3.3 to 10.3, 12.5 to 21.0, and 9.0 mg/kg, respectively. Aurela and others (1999) detected DBP, DEHP, DiBP, and DEP in paper and boxboard-packaging materials at levels of 7 to 130, 8 to 430, 30 to 450, and 41 mg/kg, respectively. Zhang and others (2008) found that 20% of domestic and more than 60% of imported paper box and corrugated

paper board packages tested contained both DBP and DIPN (2,6-diisopropylnaphthalene), with levels of DBP and DIPN ranging from 0.14 to 55 mg/kg and 0.09 to 20 mg/kg, respectively. Phthalates were also detected in foods packaged with paper and board-packaging materials. For example, levels of DiBP and DBP in sugar packed with paper wraps (containing 95 to 98 mg/kg of DiBP and 56 to 64 mg/kg of DBP) were 2.2 to 2.6 mg/kg and 0.5 to 1.0 mg/kg, respectively, after being stored at room temperature for 4 mo (Aurela and others 1999). The principal sources of phthalates in paper and board-packaging materials are the printing inks and adhesives used in the materials. For example, Aurela and others (1999) found that the adhesive used for the bottom joint of a boxboard contained about 0.5% of DiBP and about 0.5% of DBP for that used for the side joint. For paper and board packaging made from recycled materials, phthalates could also be carried over from the inks and adhesives on previous materials due to an incomplete removal during the recycling process.

### PVC gloves

Tsumura and others (2001b) investigated phthalate contamination of retail-packed lunches caused by PVC gloves used in the preparation of foods. The PVC gloves used in the preparation of the foods contained up to 41.0% of DEHP, 60.2% of DEHA, 74.8% of DiNP, and 27.9% of BBzP. Higher levels of phthalates were found in general in the final food products (contacted with PVC gloves) than in the uncooked (not yet contacted with PVC gloves). PVC gloves sterilized with alcohol also increased migration of phthalates from gloves into foods; higher levels of phthalates were found in foods treated with sterilized PVC gloves than in foods treated with nonsterilized PVC gloves. The authors also observed lower phthalate levels in packed lunches at a factory where no PVC gloves were used.

### Aluminum foil-paper laminates

In the early 1990s, samples of Canadian butter and margarine wrapped in aluminum foil-paper laminate were found to contain DBP, BBzP, and DEHP at levels up to 10.6, 47.8, and 11.9 mg/kg, respectively (Page and Lacroix 1992). These phthalates were also detected in the wrappers at levels up to 37.6, 66.0, and 25.5 mg/cm$^2$ for DEP, BBzP, and DEHP, respectively. An analysis of unused wrappers showed 76% to 88% of the total DBP and DEHP to be present on the foil (outer) surface as a component of the protective coating (washcoat). The remainder of the DBP and DEHP was found on the food-contacting paper surface, presumably by transfer from the outer to inner surface during storage in tightly wound rolls. In the typical production of a foil-paper laminate, an adhesive is applied to the foil, the foil and paper are brought together and bonded between rollers. The washcoat can then be applied to the foil surface to increase its abrasion resistance and improve its inking properties. In order to find out the exact sources of the phthalates in butter and margarine, samples of aluminum foil, paper, adhesive, ink, a washcoat, and unprinted coated foil-paper laminate were obtained from a packaging manufacturer and analyzed, and only the washcoat was found to contain the phthalates. However, since this study was conducted in the early 1990s, and the authors did mention that suppliers of the washcoat were replacing the phthalates in their product with other plasticizers having less potential for migration, phthalates in butter and margarine wrapped in aluminum foil-paper should be re-investigated.

### Coatings on cookware

Recently, migration of coating materials from cookware products was investigated (Bradley and others 2007). In addition to many other chemicals, several phthalates were also detected in the solvent extracts of nonstick coatings, such as DEP (0.8 $\mu$g/dm$^2$), DBP (0.6 to 3 $\mu$g/dm$^2$), DiBP (0.6 to 9 $\mu$g/dm$^2$), DEHP (0.5 to 11 $\mu$g/dm$^2$), and DiDP (1.2 to 2.7 $\mu$g/dm$^2$). Since phthalates are not known to be added into the nonstick coatings, it is believed that these phthalates originated from the packaging the nonstick articles were sold in and adsorbed onto the coatings during transportation and storage.

### Polyethylene terephthalate (PET)

PET is the reaction product of terephthalic acid and ethylene glycol. Due to properties such as its strength and clarity, this polymer has been used to make PET bottles for bottled water, soft drinks, and other food products. Comonomers such as isophthalic acid and dimethyl terephthalate could also be incorporated to generate a copolymer that will allow the manufacture of thicker bottle walls for large-volume refillable water carboys (Park and others 2008). Due to an incomplete reaction, residues of monomers (terephthalic acid, ethylene glycol, isophthalic acid, dimethyl terephthalate) in the polymer could migrate from PET into foods. For example, terephthalic acid was detected in vodka and 50% of aqueous ethanol at levels of 0.03 and 0.02 mg/kg after storage in PET bottles at 40 °C for 10 d (Ashby 1988); ethylene glycol migrated from PET into 3% of acetic acid at 0.1 mg/kg after 6 mo at 32 °C (Kashtock and Breder 1980). Degradation products of PET (for example, acetaldehyde) and polymer additives such as Tinuvin P or Tinuvin 234, a UV light stablizer, could also migrate into foods (Monteiro and others 1999; Begley and others 2004; Choodum and others 2007). However, due to the wrong impression left by the name of this polymer on some people, that is, it contains "phthalate" as part of its name, there have been some questionable reports in which migration of phthalates and DEHA from PET bottles into water or food simulants was observed (Biscardi and others 2003; Farhoodi and others 2008; Montuori and others 2008). It should be stressed that the PET polymer has nothing to do, chemically and physically, with the chemical group of phthalates; their chemical structures are different. The phthalates we know are the esters of ortho-phthalic acid, while para-phthalic acid (terephthalic acid) and/or meta-phthalic acid (isophthalic acid) is used in PET. Unlike some PVC products that need to be plasticized with phthalates to make them more flexible, PET bottles should be as strong and rigid as possible and thus phthalates are not used in the PET polymer.

## Levels of Phthalates in Foods

Although the determination of phthalates in foods began more than 4 decades ago (Cerbulis and Ard 1967; Williams 1973b), unlike the other chemical contaminants, information on phthalates in foods is very limited, as summarized in Table 2, probably due to the challenges in the methods or high blank levels of phthalates caused by the contamination of laboratory environments.

### Infant formulas

In the mid-1990s, the UK Ministry of Agriculture, Fisheries, and Food (MAFF) conducted a survey of phthalates in infant formulas (MAFF 1996b). A total of 59 individual samples of 12 different brands of casein-dominant, whey-dominant, or soy-based infant formulas were collected from retail outlets in 5 towns across the United Kingdom, and they were prepared into 12 composite samples (5 casein-dominant, 5 whey-dominant, and 2 soy-based) for analysis. The types (powder, liquid) of the 59 samples were not clear. In addition to the 11 individual phthalates, samples were also analyzed for total phthalates (as DMP) by heating the sample extracts with methanolic potassium hydroxide solution and then with boron trifluoride/diethyl ether complex to convert phthalates to DMP. DEHP was detected in all composite samples

**Table 2—Concentrations of phthalates and adipates in foods.**

| Food | *n** | Unit | Phthalate or adipate | Reference |
|---|---|---|---|---|
| Baby food | 9 | μg/g | DEHP: 0.1 to 0.6 (4) | Page and Lacroix 1995 |
| Baby food | 11 | mg/kg | DBP: 0.04 (1);<br>BBzP: 0.005 (1);<br>DEHP: 0.36 to 0.63 (2) | Petersen and Breindahl 2000 |
| Beef, braising steak | 3 | mg/kg | DEHA: 2.6 to 3.3 | Castle and others 1987 |
| Beef, kidney | 1 | mg/kg | DEHA: 1 | Castle and others 1987 |
| Beef, minced | 6 | mg/kg | DEHA: 4.5 to 8.0 | Castle and others 1987 |
| Beef, steak and kidney | 1 | mg/kg | DEHA: 3.1 | Castle and others 1987 |
| Beef, stewing steak | 3 | mg/kg | DEHA: 2.1 to 7.8 | Castle and others 1987 |
| Beer | 16 | μg/g | DBP: 0.09 (1);<br>DEHP: 0.03 to 0.04 (13) | Page and Lacroix 1995 |
| Beverage | 8 | ng/g | DBP: 7.8 to 105.3 (8);<br>DEHP: 3.3 to 36.3 (8) | Kato and others 2002 |
| Beverage, Japanese | | μg/g | DBP: 0.034;<br>DEHP: 0.032 | Yano and others 2002 |
| Beverage, Korean | | μg/g | DBP: 0.023;<br>DEHP: 0.018 | Yano and others 2002 |
| Bottled water | 16 | μg/g | DEHP: 0.006 to 0.01 (2) | Page and Lacroix 1995 |
| Bottled water | 11 | μg/L | DEP: 0.065 to 0.10 (10);<br>DBP: 0.075 to 1.717 (11);<br>DiBP: 0.133 to 0.481 (11);<br>DEHP: 0.052 to 0.338 (11) | Cao 2008 |
| Bottled water | 6 | μg/L | DMP: 0.02 to 0.10 (4);<br>DEP: 0.02 to 0.35 (5);<br>DBP: 0.02 to 0.52 (6);<br>DiBP: 0.02 to 0.45 (6);<br>DEHP: 0.02 (1) | Montuori and others 2008 |
| Breakfast, duplicate diet | 21 | ng/g | DBP: 4.5 to 27.1 (6);<br>BBzP: 1.0 to 4.9 (9);<br>DEHP: 31 to 185 (20);<br>DEHA: 2.8 to 30.8 (15);<br>DiNA: 25 to 538 (9) | Tsumura and others 2003 |
| Breakfast, duplicate diet | 21 | ng/g | DBP: 4- 12(6);<br>BBzP: 1.9-8.0 (14);<br>DEHP: 22-804 (21);<br>DEHA: 1.9-140.6 (19);<br>DiNP: 11-159 (5) | Tsumura and others 2001a |
| Butter | 12 | μg/g | DBP: 2.4-8.9 (3);<br>BBzP: 3.1-47.8 (8);<br>DEHP: 2.3-11.9 (12) | Page and Lacroix 1992 |
| Butter, UK | 10 | mg/kg | DEHP: 2.5-7.3 | Sharman and others 1994 |
| Candy/chocolate | 5 | mg/kg | DBP: 0.5-30.8;<br>BBzP: <0.05-0.1;<br>DCHP: <0.05-19.8 | Castle and others 1988a, 1988b |
| Carcass meat, total diet | | mg/kg | DPP: 0.04; DBP: 0.09;<br>DiBP: 0.06;<br>BBzP: 0.09;<br>DEHP: 0.7 | MAFF 1996a |
| Cereal, total diet | 19 | μg/g | DEP: 0.04-2.2 (7);<br>DBP: 0.03-1.9 (11);<br>BBzP: 0.48 (1);<br>DEHP: 0.02-3.4 (13);<br>DEHA: 0.1-22 (4) | Page and Lacroix 1995 |
| Cereal, total diet | 12 | ppm | DEHP: 0.01-0.47 (10) | Page 1996 |
| Cheese | 25 | mg/kg | DEHP: 0.2-16.8 | Sharman and others 1994 |
| Cheese | 60 | mg/kg | DEHA: 31-429 (36) | Kozyrod and Ziaziaris 1989 |
| Cheese | 17 | μg/g | DEHP: 0.3-5.5 (16);<br>DEHA: 2.1-310 (17) | Page and Lacroix 1995 |
| Chicken eggs | 7 | ppm | DBP: 0.05-0.15 (6);<br>DEHP: 0.05-0.40 (7) | Ishida and others 1981 |

*Continued*

**Table 2—Continued.**

| Food | *n** | Unit | Phthalate or adipate | Reference |
|---|---|---|---|---|
| Chicken pie | 2 | mg/kg | DBP: 3.2-8.0; BBzP: 1.5-4.5; DCHP: 1.6-9.1 | Castle and others 1988a |
| Chicken, barbequed | 2 | mg/kg | DEHA: 38.4-42.9 | Castle and others 1987 |
| Chicken, barbequed | 3 | $\mu$g/g | DEHA: 18-80 | Page and Lacroix 1995 |
| Chicken, bread crumbed fillets | 1 | mg/kg | DEHA: 72.8 | Castle and others 1987 |
| Chicken, breast | 2 | mg/kg | DEHA: 18.8-53.1 | Castle and others 1987 |
| Chicken, Chinese style | 2 | mg/kg | DEHA: 12.1-13.7 | Castle and others 1987 |
| Chicken, drumsticks | 2 | mg/kg | DEHA: 8.5-24.4 | Castle and others 1987 |
| Chicken, escalope | 1 | mg/kg | DEHA: 18.4 | Castle and others 1987 |
| Chicken, leg quarter | 2 | mg/kg | DEHA: 13.9-39.7 | Castle and others 1987 |
| Chicken, legs | 1 | mg/kg | DEHA: 11 | Castle and others 1987 |
| Chicken, roast breast | 4 | mg/kg | DEHA: 9.4-42.4 | Castle and others 1987 |
| Chicken, roast leg | 1 | mg/kg | DEHA: 33 | Castle and others 1987 |
| Chicken, thighs | 2 | mg/kg | DEHA: 27.2-33.2 | Castle and others 1987 |
| Chicken, turkey-burger | 1 | mg/kg | DEHA: 25.6 | Castle and others 1987 |
| Chicken, wings | 3 | mg/kg | DEHA: 10.5-12.7 | Castle and others 1987 |
| Citrus essential oils | 87 | mg/kg | DBP: 0.14-0.54 (8); DiBP: 0.03-62 (70); DEHP: 0.06-29.9 (75) | Di Bella and others 1999 |
| Cooked meat | 12 | mg/kg | DEHA: 40 (1) | Kozyrod and Ziaziaris 1989 |
| Cream, 31%, Spain | 1 | mg/kg | DEHP: 0.48 | Sharman and others 1994 |
| Cream, 33% fat, Spain | 1 | mg/kg | DEHP: 0.55 | Sharman and others 1994 |
| Cream, 35% fat | 5 | mg/kg | DEHP: 1.06-1.67 | Sharman and others 1994 |
| Cream, pasteurized, homogenized, Norwegian | 2 | $\mu$g/kg | DEHP: 1200, 1400 | Castle and others 1990 |
| Cream, UK | 10 | mg/kg | DEHP: 0.2-2.7 | Sharman and others 1994 |
| Dairy, total diet | 11 | $\mu$g/g | DBP: 1.5 (1); BBzP: 0.6-1.6 (3); DEHP: 0.01-3.4 (11) | Page and Lacroix 1995 |
| Dairy, total diet | 11 | ppm | DEHP: 0.02-3.2 (8) | Page 1996 |
| Eggs, total diet | | mg/kg | DPP: 0.04; DBP: 0.1; DiBP: 0.1; BBzP: 0.09; DEHP: 0.6 | MAFF 1996a |
| Fish | 8 | $\mu$g/g | DEHA: 0.3-220 (7) | Page and Lacroix 1995 |
| Fish, canned | 9 | ppb | DBP: 37-78 (2); DEHP: 40-160 (5) | Williams 1973 |
| Fresh meat | 44 | mg/kg | DEHA: 49-151 (5) | Kozyrod and Ziaziaris 1989 |
| Fruit | 3 | $\mu$g/g | DEHA: 0.3-0.8 | Page and Lacroix 1995 |
| Fruit dinks | 6 | $\mu$g/g | DEHP: 0.06-1.7 (5) | Page and Lacroix 1995 |
| Fruit of *Benincase hispida* | 7 | mg/kg | DEHP: 2.64-75.5 (7) | Du and others 2006 |
| Fruit or vegetable juices | 16 | $\mu$g/g | BBzP: 0.11-0.56 (2); DEHP: 0.053-0.56 (14) | Page and Lacroix 1995 |
| Fruits, total diet | 16 | $\mu$g/g | DEP: 0.04-0.73 (2); DBP: 0.05-0.12 (3); DEHP: 0.04-0.07 (3); DEHA: 0.05-0.34 (2) | Page and Lacroix 1995 |
| Fruits, total diet | 3 | ppm | DEHP: 0.03 (1) | Page 1996 |
| Human milk | 42 | ng/mL | DEP: 0.22-1.45 (8); DBP: 1.5-20 (12); BBzP: 0.06-4.4 (41); DOP: 0.24-11 (10); DEHP: 0.45-305 (39) | Hogberg and others 2008 |
| Human milk | 86 | ng/g | DEP: 0.31; DBP: 0.62-1.2; DEHP: 156-398 | Zhu and others 2006 |
| Infant formula | 12 | mg/kg | DBP: 0.09-0.40; DiBP: 0.06-0.26; BBzP: $<$0.004-0.25; DEHP: 0.33-0.98 | MAFF 1996b |

*Continued*

**Table 2—Continued.**

| Food | *n** | Unit | Phthalate or adipate | Reference |
|---|---|---|---|---|
| Infant formula, liquid | 2 | μg/kg | DBP: <9; BBzP: <4; DEHP: 10-23; DiNP: <5; DiDP: <5 | Sorensen 2006 |
| Infant formula, powdered | 1 | μg/kg | DMP: 1.38; DEP: 76.4; DBP: 18.4; BBzP: 1.18; DEHP: 20.5 | Casajuana and Lacorte 2004 |
| Infant formula, powdered | 27 | ng/g | DEP: 15-77; DEHP: 34-281 | Yano and others 2005 |
| Infant formula, powdered | 6 | μg/kg | DBP: <9; BBzP: <4; DEHP: 37-138; DiNP: <5-12; DiDP: <5 | Sorensen 2006 |
| Infant formula, powdered and liquid | 39 | mg/kg | DBP: 0.007-0.09 (9); BBzP: 0.004-0.012 (8); DEHP: 0.05-0.44 (23) | MAFF 1998 |
| Infant formula, powdered and liquid | 11 | mg/kg | BBzP: 0.004-0.01 (2); DEHP: 0.04-0.06 (2); DEHA: 0.02-0.05 (2) | Petersen and Breindahl 2000 |
| Jams | 16 | μg/g | DEHP: 0.02-1.2 (14) | Page and Lacroix 1995 |
| Jellies | 16 | μg/g | DEHP: 0.015-0.61 (15) | Page and Lacroix 1995 |
| Lamb, breast | 1 | mg/kg | DEHA: 3.9 | Castle and others 1987 |
| Lamb, leg steak | 1 | mg/kg | DEHA: 10.6 | Castle and others 1987 |
| Lamb, stuffed breast | 1 | mg/kg | DEHA: 2.9 | Castle and others 1987 |
| Lunch, duplicate diet | 21 | ng/g | DBP: 5.1-61 (4); BBzP: 1.3-27.1 (9); DEHP: 29-675 (19); DEHA: 3.4-65.4 (10); DiNA: 14-16500 (8); DiNP: 24 (1) | Tsumura and others 2003 |
| Lunch, duplicate diet | 21 | ng/g | DEP: 0.7-1.0 (2); DBP: 5-46 (5); BBzP: 2.0-8.6 (11); DEHP: 18-1820 (19); DEHA: 1.2-370.6 (17); DiNP: 12-626 (5) | Tsumura and others 2001a |
| Margarine | 8 | μg/g | DBP: 4.1-10.6 (4); BBzP: 3.9-16.1 (4); DEHP: 0.7-11.3 (8) | Page and Lacroix 1992 |
| Margarine, soft | 1 | mg/kg | DEHP: 2 | Sharman and others 1994 |
| Margarine, sunflower | 1 | mg/kg | DEHP: 1.2 | Sharman and others 1994 |
| Meat | 7 | μg/g | DEHA: 1.0-9.5 (6) | Page and Lacroix 1995 |
| Meat pasty | 3 | mg/kg | DBP: 1.2-15.6; BBzP: <0.05; DCHP: 1.1-16.9 | Castle and others 1988a |
| Meat pie | 4 | mg/kg | DBP: 3.1-7.8; BBzP: <0.05-1.2; DCHP: 0.2-8.6 | Castle and others 1988a |
| Meat, poultry, and fish, total diet | 12 | μg/g | DBP: 0.5 (1); DEHP: 0.1-2.6 (7); DEHA: 0.3-7.5 (4) | Page and Lacroix 1995 |
| Meat, poultry, and fish, total diet | 7 | ppm | DEHP: 0.03-0.33 (5) | Page 1996 |
| Milk | 5 | μg/kg | DMP: 0.97-1.75; DEP: 36.5-85.3; DBP: 7.30-50.3; BBzP: 1.11-2.93; DEHP: 15.1-27.2 | Casajuana and Lacorte 2004 |

*Continued*

**Table 2—Continued.**

| Food | *n** | Unit | Phthalate or adipate | Reference |
|---|---|---|---|---|
| Milk, <1% fat | 5 | mg/kg | DEHP: 0.02-0.04 | Sharman and others 1994 |
| Milk, 1% fat | 3 | mg/kg | DEHP: 0.05-0.05 | Sharman and others 1994 |
| Milk, 3% fat | 9 | mg/kg | DEHP: 0.20-2.26 | Sharman and others 1994 |
| Milk, Danish | 8 | mg/L | DEHP: 0.05-0.14 | Petersen 1991 |
| Milk, doorstep, UK | 16 | mg/kg | DEHP: <0.01-0.09 | Sharman and others 1994 |
| Milk, fresh, Spain | 5 | mg/kg | DEHP: <0.01-0.05 | Sharman and others 1994 |
| Milk, full, pasteurized, UK | 1 | μg/kg | DEHP: 35 | Castle and others 1990 |
| Milk, pasteurized, homogenized | 4 | μg/kg | DBP: <9;<br>BBzP: <4;<br>DEHP: 13-27;<br>DiNP: <5;<br>DiDP: <5 | Sorensen 2006 |
| Milk, raw | 18 | μg/kg | DBP: <9;<br>BBzP: <4;<br>DEHP: 7-30;<br>DiNP: <5;<br>DiDP: <5 | Sorensen 2006 |
| Milk, skimmed, pasteurized, Norwegian | 2 | μg/kg | DEHP: 20, 25 | Castle and others 1990 |
| Milk, total diet | | mg/kg | DPP: <0.001;<br>DBP: 0.003;<br>DiBP: 0.002;<br>BBzP: 0.002;<br>DEHP: 0.3 | MAFF 1996a |
| Miscellaneous, total diet | 23 | μg/g | DEP: 0.09-5.3 (3);<br>DBP: 0.09-0.64 (3);<br>DEHP: 0.51-1.24 (3);<br>DEHA: 0.53 (1) | Page and Lacroix 1995 |
| Miscellaneous, total diet | 4 | ppm | DEHP: 0.26-0.53 (3) | Page 1996 |
| Oily foods in jars | 158 | mg/kg | DEHP: 3-825 (17);<br>DEHA: 22-180 (8);<br>DiNP: 10-270 (13);<br>DiDP: 9-740 (12) | Fankhauser-Noti and others 2006 |
| Oily foods in jars | 33 | mg/kg | DEHP: 20-430 (5);<br>DEHA: 80-115 (2);<br>DiNP: 15-150 (6);<br>DiDP: 55-705 (9) | Fankhauser-Noti and Grob 2006 |
| Pickle | 17 | μg/g | DEHP: 0.03-2.2 (17) | Page and Lacroix 1995 |
| Pork pie | 2 | mg/kg | DBP: 5.5-9.5;<br>BBzP: <0.05-12.0;<br>DCHP: 6.2-12.0 | Castle and others 1988a |
| Pork, fat | 1 | mg/kg | DEHA: 63.9 | Castle and others 1987 |
| Pork, hock | 2 | mg/kg | DEHA: 1.8-2.1 | Castle and others 1987 |
| Pork, loin joint | 4 | mg/kg | DEHA: 2.5-36.3 | Castle and others 1987 |
| Poultry | 8 | μg/g | DEHA: 0.7-14 (8) | Page and Lacroix 1995 |
| Poultry, total diet | | mg/kg | DPP: 0.01;<br>DBP: 0.2;<br>DiBP: 0.06;<br>BBzP: 0.03;<br>DEHP: 0.7 | MAFF 1996a |
| Sandwich | 3 | mg/kg | DBP: 11.0-13.0;<br>BBzP: 13.0-15.0;<br>DCHP: 14.0-16.0 | Castle and others 1988a |
| Sandwich | 10 | μg/g | DEHA: 7.9-110 | Page and Lacroix 1995 |
| Sandwiches/bread | 5 | mg/kg | DEHA: 64-325 (2) | Kozyrod and Ziaziaris 1989 |
| Soft drinks | 10 | μg/g | DEHP: 0.006-0.11 | Page and Lacroix 1995 |
| Spinach pie | 2 | μg/g | DEHA: 160-280 | Page and Lacroix 1995 |
| Supper, duplicate diet | 21 | ng/g | DBP: 5.7-7.4 (2);<br>BBzP: 0.9-18.0 (11);<br>DEHP: 24-200 (19);<br>DEHA: 2.4-23.5 (9);<br>DiNA: 13-96 (6);<br>DiNP: 10 (1) | Tsumura and others 2003 |

*Continued*

**Table 2—Continued.**

| Food | *n** | Unit | Phthalate or adipate | Reference |
|---|---|---|---|---|
| Supper, duplicate diet | 21 | ng/g | DEP: 0.5-1.1 (2); DBP: 5-48 (6); BBzP: 1.3-8.2 (13); DEHP: 16-4400 (20); DEHA: 3.0-698.7 (15); DiNP: 10-211 (9) | Tsumura and others 2001a |
| Total diet | 29 | mg/kg | DBP: 0.09-0.19 (6); BBzP: 0.017-0.019 (8); DEHP: 0.11-0.18 (11); DEHA: 0.13-0.14 (13) | Petersen and Breindahl 2000 |
| Vegetables | 5 | μg/g | DEHA: 0.4-3.1 (4) | Page and Lacroix 1995 |
| Vegetables, total diet | 18 | μg/g | DBP: 0.11-0.63 (2); DEHP: 0.09-0.14 (3) | Page and Lacroix 1995 |
| Vegetables, total diet | 3 | ppm | DEHP: 0 | Page 1996 |
| Wine | 16 | μg/g | DEHP: 0.01-0.03 (9) | Page and Lacroix 1995 |
| Wine | 3 | ng/mL | DEP: 5.5; DBP: 4.7; DEHP: <2 | Carrillo and others 2007 |
| Wine, Japanese | | μg/g | DBP: 0.275; DEHP: 0.127 | Yano and others 2002 |
| Yoghurt with fruit | 3 | μg/kg | DBP: <9; BBzP: <4; DEHP: 15-37; DiNP: <5; DiDP: <5 | Sorensen 2006 |

*Number of samples.
Numbers in brackets are the number of samples detected positively for the phthalate.

at levels ranging from 0.33 to 0.98 mg/kg, while other phthalates were detected at lower levels; DPP (<0.001 to 0.03 mg/kg), DiBP (0.06 to 0.26 mg/kg), DBP (0.09 to 0.40 mg/kg), BBzP (<0.004 to 0.25 mg/kg). Levels of total phthalates (as DMP) ranged from 1.2 to 10.2 mg/kg. The following phthalates were also detected but not quantified in some composite samples: DiPP (diisopropyl phthalate), DHP, DCHP, and DHpP (diheptyl phthalate).

In a follow-up survey (MAFF 1998), 39 samples (35 powdered and 4 ready-to-feed liquid) of 14 different infant formula products were analyzed for phthalates. These samples included 19 samples of casein-dominant formulas, 14 samples of whey-dominant formulas, and 6 samples of soy-based formulas. Levels of phthalates in the formula samples from this survey were considerably lower than those found in the previous survey (MAFF 1996b). DEHP was detected in 23 of the 39 samples at levels ranging from 0.05 to 0.44 mg/kg; BBzP was detected in only 8 samples (0.004 to 0.012 mg/kg); DBP detected in 9 samples (0.007 to 0.09 mg/kg); and levels of DiPP, DPP, DiBP, and DiDP were all below the method detection limits. Levels of total phthalates (as DMP) ranged from <0.1 to 0.6 mg/kg, about 12 to 17 times lower than those found in 1996 (1.2 to 10.2 mg/kg).

The sources of phthalates detected in the infant formula samples were not identified in both surveys (MAFF 1996b, 1998). The packaging is unlikely the source since the cans for the powdered infant formula do not have polymer coating in general and the metal cans for the liquid formula are known to have epoxy coatings that contain bisphenol A but not phthalates. However, since the milk-based infant formulas (both casein-dominant and whey-dominant) are made from cow milk, the phthalates may have already been in the milk used for the production of the infant formulas due to contamination during the milking process (such as by using plasticized PVC tubing either for milking or for the bulk transfer between tankers and storage tanks). Since manufacturers have to modify cow milk to resemble human milk as closely as possible by adjusting carbohydrate, protein, and fat levels and adding vitamins and minerals, phthalates could also have been introduced into the final formula products due to the contamination in this process.

In a survey conducted by Petersen and Breindahl (2000), 11 samples of infant formulas (powdered and liquid) were analyzed for phthalates. Levels of phthalates were low: DEHP (0.04, 0.06 mg/kg), DEHA (0.02, 0.05 mg/kg), BBzP (0.004, 0.01 mg/kg), and DBP was not detected.

Levels of phthalates in the only powdered infant formula sample analyzed by Casajuana and Lacorte (2004) were also low, with the highest level for DEP (76.4 μg/kg), followed by DEHP (20.5 μg/kg), DBP (18.4 μg/kg), DMP (1.38 μg/kg), and BBzP (1.18 μg/kg).

A total of 27 samples of powdered infant formulas from different countries collected in 2001 to 2002 were analyzed by Yano and others (2005) for DBP and DEHP. DBP and DEHP were detected in all samples, with higher levels of DEHP (34 to 281 ng/g) than those of DBP (15 to 77 ng/g). DEHP was the highest in the samples from Turkey (281 ng/g), followed by Japan (218 ng/g), UK (180 ng/g), Thailand (172 ng/g), and Vietnam (123 ng/g). DBP was the highest in the samples from Japan (77 ng/g), followed by Indonesia (32 ng/g). The authors claimed that various coatings were found for the formula cans (epoxy, PE, or polyvinyl chloride), but they could not relate the phthalate levels to any of these coatings.

Similar results were also obtained by Sorensen (2006) for DEHP, with levels ranging from 37 to 138 μg/kg for 6 powdered infant formulas and 10 to 23 μg/kg for 2 liquid infant formulas. Levels of other phthalates (DBP, BBzP, DiNP, DiDP) were all below detection limits.

Although phthalate monoesters are more commonly monitored in human milk and other biological fluids, they were also determined in 10 samples of milk-based infant formulas (2 liquid, 8 powdered) in a study by Mortensen and others (2005). Only 2 phthalate monoesters were detected in the formulas, mono-n-butyl phthalate (mBP) at 0.6 to 3.9 μg/L and mono-(2-ethylhexyl) phthalate (mEHP) at 5.6 to 9.1 μg/L, while levels of the other

phthalate monoesters were below the detection limits. The reason for the presence of phthalate monoesters in infant formulas is that milk-based infant formulas are made from cow milk that contains phthalate monoesters due to the metabolism of phthalates by enzymes.

### Human milk

Compared to the limited information on phthalates in foods, information on phthalates in human milk is even more scarce. Phthalates were determined in human milk only recently for the first time in Canada and also in North America by Zhu and others (2006). In this study, levels of phthalates were determined in a total of 86 human milk samples collected manually (without using breast pumps) from 21 breast-feeding mothers over a 6-mo postpartum time. Among the 6 phthalates analyzed, only DEP, DBP, and DEHP were detected in the samples, while the other 3 phthalates (DMP, BBzP, and DOP) were not detected in any of the samples. DEHP was detected in all 86 human milk samples with the arithmetic mean value of 222 ng/g (range: 156 to 398 ng/g, 95% confidence limit), and it was detected in 1 sample at a level as high as 2920 ng/g. DBP was detected in 85 human milk samples, at much lower levels than DEHP, with the arithmetic mean value of 0.87 ng/g and the range of 0.62 to 1.2 ng/g, while DEP was detected only in 15 of the 86 human milk samples with the arithmetic mean value of 0.31 ng/g. A clear trend of either increase or decrease of phthalate levels was not observed for either DBP or DEHP in the human milk samples collected during the 6-mo postpartum period (0.5, 1, 2, 4, and 6 mo) from all 21 mothers. The authors suggested that the fluctuation of DBP and DEHP levels in human milk may be a reflection of the day-to-day short-term exposure of the individual participants rather than an indication of long-term exposure. However, the fluctuation of DBP and DEHP levels in human milk could also be due to the hydrolysis of phthalates to their respective monoesters by milk esterases prior to analysis since all human milk samples were not acidified to eliminate the esterase activity.

In a study conducted by Hogberg and others (2008), human milk samples were collected by using breast pumps from 42 mothers when the babies were 14 to 20 d of age. Phosphoric acid was added to the milk samples to avoid enzymatic hydrolysis of the phthalate ester. The human milk samples were analyzed for both phthalates and their metabolite monoesters. DiNP and DiDP were not detected in any of the 42 human milk samples. DEHP was detected in 39 of the 42 human milk samples at levels ranging from 0.45 to 305 ng/mL with the mean of 17 ng/mL and median of 9.0 ng/mL. BBzP was detected in 41 of the 42 samples at levels ranging from 0.06 to 4.4 with the mean of 0.75 ng/mL and the median of 0.49 ng/mL. DEP, DBP, and DOP were detected in no more than 12 samples, with the maximum levels of 1.45, 20, and 11 ng/mL, and the average levels of 0.30, 2.8, and 1.1 ng/mL, respectively. Levels of mono-phthalates in human milk samples were low. mEHP was detected in 16 of the 42 samples at levels ranging from 0.49 to 6.5 ng/mL with the average of 1.3 ng/mL, and mBP was detected in 11 samples at levels ranging from 0.54 to 5.7 ng/mL with the average of 1.2 ng/mL. While monobenzyl phthalate (mBzP), mEP, and miBP were detected in no more than 3 samples with the maximum levels of 4.4, 2.5, and 2.1 ng/mL, respectively.

Compared to the parent phthalates, phthalate metabolites are more frequently monitored in human milk samples. For example, Calafat and others (2004) detected mBP, mEHP, and mNP in 3 pooled human milk samples with total (and free) mean concentrations of $1.3 \pm 1.5$ ($1.1 \pm 1.4$), $7.8 \pm 6.8$ ($7.7 \pm 6.8$), and $15.9 \pm 7.7$ ($16.1 \pm 6.9$) ng/mL, respectively. Thus, the phthalate metabolites in human milk were mostly in their free (nonglucuronidated) form. However, since the samples were not treated immediately after collection to eliminate the enzymatic activity that might have falsely elevated the phthalate metabolites levels, the above results might include an unknown contribution from the metabolites formed from the enzyme-induced hydrolysis of possible contaminant phthalates introduced during the sampling process.

Higher levels of phthalate metabolites were observed in the 36 human milk samples by Mortensen and others (2005). Levels of mBP ranged from 0.6 to 10900 $\mu$g/L with the mean of 359 $\mu$g/L and median of 3.5 $\mu$g/L, mNP from 27 to 382 $\mu$g/L with the mean of 114 $\mu$g/L, mEHP from 2.7 to 72 $\mu$g/L with the mean of 13 $\mu$g/L, mEP from 0.07 to 15.4 $\mu$g/L with the mean of 1.78 $\mu$g/L, mBzP from 0.2 to 10 $\mu$g/L with the mean of 1.2 $\mu$g/L, while mMP was detected in only 4 of the 36 samples with a mean of 0.17 $\mu$g/L. Half of the samples were also analyzed after enzymatic deglucuronidation in order to measure the total (free and glucuronidated) phthalate metabolite content, and the results show that phthalate monoesters were present almost exclusively in free form (69% to 97%). Although 13 of the milk samples were collected using breast pumps, only mEP and mBP were found at significantly higher levels in samples collected with pump than those without a pump.

In another study conducted by Main and others (2006), human milk samples were collected as additive aliquots from 1 to 3 mo postnatally from 65 mothers in Denmark and 65 mothers in Finland during the period of 1997 to 2001. Six phthalate monoesters were detected in all milk samples, except for mMP that was not detected in 2 of the 65 Danish and in 4 of the 65 Finnish samples. The median levels of the 6 phthalate monoesters were 0.10, 0.93, 4.3, 0.9, 9.5, and 101 $\mu$g/L for the Danish samples and 0.09, 0.97, 12, 1.3, 13, and 89 $\mu$g/L for the Finnish samples for mMP, mEP, mBP, mBzP, mEHP, and miNP, respectively. A significant difference between the Danish and Finnish samples was observed for 4 phthalate monoesters, with higher levels of mBP, mBzP, and mEHP in the Finnish samples, and higher levels of miNP in the Danish samples.

### Milk and milk products

Since phthalates are lipophilic, they are more likely to be present in fatty foods at high concentrations, especially when these products are in contact with materials containing phthalates as plasticizers, such as the PVC tubing for milk and PVC film for milk products. Compared to other foods, phthalates have been monitored more frequently in milk and milk products. Levels of DEHP in Norwegian retail pasteurized skimmed milk in cartons were 20 and 25 $\mu$g/kg compared to 35 $\mu$g/kg for UK retail pasteurized full milk in cartons, while DEHP levels in Norwegian homogenized, pasteurized cream in cartons were as high as 1400 $\mu$g/kg (Castle and others 1990). Similar results were also obtained by Petersen (1991) for 2 Danish retail whole milk samples with DEHP levels ranging from 0.05 to 0.14 mg/L. A clear relationship between DEHP levels and fat contents in milk and cream was demonstrated by Sharman and others (1994), DEHP levels in milk with less than 1% fat ranged from 0.02 to 0.04 mg/kg, 0.05 mg/kg for milk with 1% fat, 0.10 to 0.38 mg/kg for milk with 3% fat, and 1.06 to 1.67 mg/kg for cream with 35% fat. In a study conducted by Casajuana and Lacorte (2004), whole milk samples packaged in Tetra Brik and HDPE bottles were analyzed for DMP, DEP, DBP, BBzP, and DEHP, and their levels ranged from 0.97 to 1.75 $\mu$g/kg, 36.5 to 85.3 $\mu$g/kg, 7.30 to 50.3 $\mu$g/kg, 1.11 to 2.88 $\mu$g/kg, and 15.1 to 27.2 $\mu$g/kg, respectively, and only the levels of DBP had considerable differences in milk packaged in Tetra Brik (7.30 and 9.49 $\mu$g/kg) and HDPE (50.3 and 40.6 $\mu$g/kg). Levels of DEHP in raw milk (7 to 30 $\mu$g/kg) were found to be very close to those in pasteurized and homogenized milk (13 to 27 $\mu$g/kg) by Sorensen (2006). Phthalate metabolites were also

determined in cow milk by Mortensen and others (2005), with mBP at 1.4 to 2.8 μg/L and mEHP at 7.1 to 9.9 μg/L.

Since DEHA-plasticized PVC films are commonly used for wrapping cheese, DEHA has been found in various cheeses at high concentrations due to their high fat contents. Levels of DEHA in various cheese samples ranging from 27.8 to 135 mg/kg were observed by Castle and others (1987). Higher levels of DEHA (31 to 429 mg/kg) were found in 36 cheese samples by Kozyrod and Ziaziaris (1989). In a Canadian study (Page and Lacroix 1995), both DEHA and DEHP were detected in various cheese samples at levels ranging from 2.1 to 310 μg/g and 0.3 to 5.5 μg/g, respectively. BBzP, DBP, and DEHP were also detected in butter and margarine samples wrapped with plastic films (Page and Lacroix 1992) at levels as high as 47.8, 10.6, and 11.9 μg/g, respectively.

### Fish, poultry, and meat

Phthalates in fish were determined in the early 1970s. The level of DEHP in samples of fresh water fish from Canadian lakes and rivers was 104 ppb, and DBP was detected in some of the samples (Williams 1973a), indicating contamination of the lakes and rivers by phthalates due to widespread use of consumer products containing phthalates. DEHP was also detected in canned fish products at levels ranging from 40 to 160 ppb, and DBP was detected at 37 and 78 ppb (Williams 1973a).

Since PVC film is commonly used for wrapping meat, plasticizer used in PVC film was also detected frequently in meat. In a UK survey of DEHA levels in retail foods wrapped in plasticized PVC film (Castle and others 1987), DEHA was detected in fresh meat at levels ranging from 1.0 to 8.0 mg/kg, 1.8 to 63.9 mg/kg in fresh pork, 2.9 to 10.6 mg/kg in fresh lamb, and 8.5 to 53.1 mg/kg in fresh chicken wrapped with PVC film plasticized with 18% to 25% of DEHA. Levels of DEHA in cooked chicken ranged from 9.4 to 48.6 mg/kg after being wrapped with PVC film plasticized with 23% to 26% of DEHA (Castle and others 1987). In the 44 fresh meat samples analyzed by Kozyrod and Ziaziaris (1989), DEHA was detected in 5 samples at levels ranging from 49 to 151 mg/kg. DEHA was also detected by Page and Lacroix (1995) in meat (1.0 to 9.5 μg/g), poultry (0.7 to 14 μg/g), and fish (0.3 to 220 μg/g) packaged with plastic film containing DEHA.

### Total diet samples

A total diet study consists of purchasing foods commonly consumed at retail level, processing them as for consumption, often combining the foods into food composites, homogenizing them, and analyzing them for the chemicals of interest. It is the most reliable way to estimate the dietary intake of chemicals by large population groups and is supported and recommended by the World Health Organization (WHO). Although total diet studies have been conducted in various countries for many different chemical contaminants, phthalates were determined in total diet samples only occasionally in a few countries.

The very first data on phthalates in total diet samples were from the Canadian total diet study conducted in the mid-1980s (Page and Lacroix 1995), in which a total of 99 food composites in several categories (dairy, meat, poultry and fish, cereal, vegetables, fruits, and miscellaneous) were analyzed for DEP, DBP, BBzP, DEHP, and DEHA. DEP and DEHA were not detected in any of the 11 dairy food composites, DBP was detected only in butter (packaged in paper-foil) at 1.5 μg/g, BBzP was detected only in yogurt in a plastic tub (0.6 μg/g), Cheddar cheese in plastic wrap (1.6 μg/g), and butter (0.64 μg/g), while DEHP was detected in all 11 dairy food composites at levels ranging from 0.01 μg/g in skim milk (in paperboard) to 3.4 μg/g in butter. DEP and BBzP were not detected in any of the 12 meat, poultry and fish food composites, DBP was detected in only 1 composite, fresh-water fish, at 0.5 μg/g, while DEHA was detected in 4 of the 12 composites with the highest level (7.5 μg/g) in ground beef, and DEHP was detected in 7 of the 12 composites with the highest level (2.6 μg/g) in poultry. For the 19 cereal composites, BBzP was detected only in crackers (0.48 μg/g), DEP was detected in 7 composites with highest level in apple pie (2.2 μg/g), DBP was detected in 11 composites with the highest level in wheat flour (1.9 μg/g), DEHP was detected in 13 composites with the highest level in Danish pastry and doughnuts (3.4 μg/g), while DEHA was detected in only 4 composites, with the highest level in Danish pastry and doughnuts (22 μg/g). Levels of phthalates in vegetables and fruits were low as expected, with only DBP and DEHP detected in a few of the 18 vegetable composites, and DEP, DBP, DEHP, and DEHA detected in only a few of the 16 fruit composites. Phthalates were detected in only a few of the 23 miscellaneous composites, with the highest levels of DEP, DBP, DEHP, and DEHA at 5.3 μg/g in chocolate bars, 0.64 μg/g in margarine, 1.24 μg/g in margarine, and 0.53 μg/g in muffins, respectively.

Levels of DEHP in the samples from the Canadian total diet study conducted in 1996 were in general lower than or the same as those found in the 1986 study. For example, DEHP was not detected in 13 food composites compared to DEHP levels from 0.02 μg/g to 0.14 μg/g in the same food composites in 1986, while DEHP levels in butter (3.2 μg/g in 1996 compared with 3.4 μg/g in 1986) and ice cream (0.83 μg/g in 1996 compared with 0.82 μg/g in 1986) were about the same (Page 1996).

In a total diet study conducted by the United Kingdom MAFF (1996a), total phthalates (as DMP) were determined in food composites in 8 food groups (carcass meat, meat products, offal, poultry, eggs, fish, fats and oils, milk, and milk products) at levels ranging from 0.5 mg/kg for milk and milk products to 8.8 mg/kg for poultry. Individual phthalates were also determined for selected food groups (carcass meat, poultry, eggs, milk), levels of DPP ranged from <0.001 to 0.04 mg/kg, DiBP from 0.002 to 0.06 mg/kg, DBP from 0.003 to 0.2 mg/kg, BBzP from 0.002 to 0.09 mg/kg, and DEHP from 0.3 to 0.7 mg/kg.

In a Danish study (Petersen and Breindahl 2000), 29 samples of 24-h duplicate diets were collected from randomly selected persons in the population and analyzed for phthalates and DEHA. DBP, BBzP, DEHP, and DEHA were detected in 6 to 13 of the 29 samples at levels ranging from 0.09 to 0.19, 0.017 to 0.019, 0.11 to 0.18, and 0.13 to 0.14 mg/kg, respectively.

In Japan, 2 identical studies were conducted to determine levels of phthalates and adipates in 1-wk duplicate diet samples (Tsumura and others 2001a, 2003). During the 1st study, samples of 1-wk duplicate diet were collected from hospitals in 1999, while the same samples in the 2nd study were collected from the same hospitals in 2001 following the regulation of DEHP-containing PVC gloves in Japan. The duplicate diet samples consisted of a 7-d varied sequence of breakfast, lunch, and supper that included rice or bread, noodles, fish or meat, vegetables, soup, and milk. Lower levels of phthalates were observed in the 2001 duplicate diet samples in general; the average DEHP levels in 1999 and 2001 duplicate diet samples were 46 to 478 ng/g and 77 to 103 ng/g, respectively, and the average DEHA levels were 6.5 to 78.2 ng/g and 4.7 to 12.7 ng/g for the 1999 and 2001 samples, respectively. This indicated that plasticized PVC gloves contributed considerably to the phthalate levels in the duplicate diet samples in 1999. DiNA was detected very frequently in the duplicate diet samples collected from one of the hospitals in 2001, with the highest level of 16500 ng/g in a lunch meal and the average level of 896 ng/g. This was due to the PVC cling film used in the hospital that contains DiNA.

### Foods in glass jars with metallic lids

Since the PVC gaskets in the metallic lids for bottled foods in glass jars contain various plasticizers, these plasticizers can

migrate into foods, especially oily or fatty foods. For example, Tsumura and others (2002b) analyzed 12 bottled foods and found the highest concentrations of DBP, DEHA, and DEHP at 2560, 227, and 42367 ng/g, respectively. In a Swiss market survey conducted in 2005 (Fankhauser-Noti and others 2006), levels of DEHP, DiNP, DiDP, and DEHA in bottled foods were as high as 825, 270, 740, and 180 mg/kg, respectively. Similar results were also found for phthalates in oily bottled foods; levels of DEHP, DiNP, DiDP, and DEHA were as high as 430, 150, 705, and 115 mg/kg, respectively (Fankhauser-Noti and Grob 2006).

### Bottled water

As stated earlier, plastic bottles should be as strong and rigid as possible, thus plasticizers such as phthalates are not used in the production of the plastic bottles. The dominant, if not the sole, source for phthalates in bottled water is from environmental contamination, and the levels of phthalates in bottled water are low in general. In the 3 samples of bottled water analyzed by Yano and others (2002), levels of DBP and DEHP were below 0.02 $\mu$g/g. Levels of DEHA and 6 phthalates (DMP, DEP, DBP, BBzP, DEHP, DOP) were all below 0.35 $\mu$g/L in a sample of bottled mineral water analyzed by Serodio and Nogueira (2006). In a recent study (Cao 2008), samples of bottled water products in various container types (glass, PET, polycarbonate) were analyzed for DEHA and 8 phthalates. DEP, DiBP, DBP, and DEHP were detected at levels ranging from 0.065 to 0.1, 0.161 to 0.481, 0.075 to 1.717, and 0.052 to 0.338 $\mu$g/L, respectively, and considerable differences in phthalate levels were not observed among the bottled water in different container types.

However, there are several reports claiming that migration from PET bottles could be the source for the phthalates in the bottled water contained in PET bottles. For example, Montuori and others (2008) found that levels of phthalates in bottled water in glass containers were below or close to the detection limits, while slightly higher levels of phthalates were observed for bottled water in PET containers: DMP at 0.10 $\mu$g/L, DEP at 0.35 $\mu$g/L, DiBP at 0.45 $\mu$g/L, DBP at 0.52 $\mu$g/L, and DEHP at 0.02 $\mu$g/L. In the study conducted by Casajuana and Lacorte (2003), levels of phthalates in the initial water samples in PET, PE, and glass containers were below or close to the detection limits, but slightly higher levels of phthalates were detected in these samples after storage for 10 wk, with the highest average concentrations of 0.003, 0.432, 0.046, 0.196 $\mu$g/L for DMP, DEP, DBP, DEHP, respectively. A nonmigration pattern with a sudden increase in DEHP levels in water samples contained in PET bottles during storage was also observed by Biscardi and others (2003), from a constant level of 0.40 $\mu$g/L during storage of 1 to 8 mo to another constant level of 3.2 $\mu$g/L in the same water sample after storage of 9 to 12 mo.

### Beverages

Information on phthalates in soft drinks is very limited, and the available results agree well in general. Yano and others (2002) found that the average DBP levels in Japanese and Korean beverages were 0.034 and 0.023 $\mu$g/g, respectively, and the average DEHP levels in Japanese and Korean beverages were 0.032 and 0.018 $\mu$g/g, respectively. Slightly higher levels of DBP (0.275 $\mu$g/g) and DEHP (0.127 $\mu$g/g) were found in Japanese red wine and beer (Yano and others 2002). While DEHA, DEP, and BBzP were not detected in any of the 8 beverages in plastic containers analyzed by Kato and others (2002), levels of DBP ranged from 5.8 to 105.3 ng/g with the average of 45.9 ng/g, and levels of DEHP ranged from 3.3 to 36.3 ng/g with the average of 18.5 ng/g. These levels were considerably higher than those found in the bottled water products, indicating the potential sources of phthalates other than the containers themselves, which should be investigated further.

### Others

Phthalates were also detected at very high levels in various miscellaneous foods in which no packaging materials were used, indicating contamination of the environments (air, water, soil) due to the widespread use and disposal of products containing phthalates. In the early 1970s, Stalling and others (1973) observed unknown late-eluting peaks in the chromatograms of fish and water extracts analyzed for pesticides. These unknown peaks were identified later on as phthalates. Levels of DBP in fish were as high as 500 ppb, and DEHP as high as 3200 ppb. Slightly lower levels in fish were observed by Williams (1973a), DEHP as high as 160 ppb, and DBP as high as 78 ppb. Phthalates were also detected in chicken eggs (Ishida and others 1981), with the average levels of DBP and DEHP at 0.098 and 0.182 ppm, respectively. DiBP and DEHP were detected in all Italian citrus essential oils, with the average levels of 1.38 to 4.89 and 0.59 to 3.30 mg/kg, respectively (Di Bella and others 1999). DEHP was also detected in a Chinese vegetable at levels ranging from 2.64 to 75.5 mg/kg (Du and others 2006).

## Analytical Methods for Phthalates in Foods

Like other chemical contaminants, analysis of food samples for phthalates involves sample preparation, extraction, clean-up, separation, and detection. Extraction and clean-up are the most challenging parts for phthalate analysis in foods and are often the critical steps in deciding the levels of detection limits of the overall methods.

### Extraction and clean-up

As shown in Table 3, traditional solvent or liquid–liquid extraction is the most frequently used method for extraction of phthalates from foods, especially fatty food samples. Various solvents (either singly or as a mixture) have been used in the initial extraction, such as acetone–hexane (Startin and others 1987a, 1987b; Castle and others 1988a, 1988b; Page and Lacroix 1995), heptane (Kozyrod and Ziaziaris (1989)), methanol–hexane (Castle and others 1990; Sharman and others 1994), ethanol-diethyl acetate-pentane (Petersen 1991), acetonitrile (Page and Lacroix 1995; Tsumura and others 2001a, 2003), dichloromethane (Page and Lacroix 1995), pentane (Petersen and Breindahl 2000), hexane-dichloromethane (Yano and others 2002), acetonitrile-hexane (Yano and others 2005), methanol–hexane-MTBE (Sorensen 2006), and pentane–acetone–hexane–MTBE (Hogberg and others 2008). Multiple extraction with the same or different solvents is often essential for a complete extraction, this is followed by water removal from the extract with sodium sulfate and an evaporation step to concentrate the sample extract under nitrogen flow. Various solvents were used to reconstitute the residue, such as dichloromethane-cyclohexane (Startin and others 1987a, 1987b; Castle and others 1988a, 1988b, 1990; Petersen 1991; Sharman and others 1994), hexane (Page and Lacroix 1995; Tsumura and others 2001a; Tsumura and others 2003; Sorensen 2006), ethyl acetate-cyclohexane (Petersen and Breindahl 2000), acetonitrile (Yano and others 2002), and ethyl acetate (Casajuana and Lacorte 2003).

Further clean-up of the extracts is always necessary for the fatty foods to isolate phthalates from the fat. This is often performed by size-exclusion chromatography (SEC) where extracts are injected onto a column packed with Biobeads SX3 or PL-gel and eluted with dichloromethane-cyclohexane (Startin and others 1987a, 1987b; Castle and others 1988a, 1988b, 1990; Petersen 1991; Sharman and others 1994) or with ethyl acetate-cyclohexane (Petersen and Breindahl 2000) and pentane-MTBE (Hogberg and others 2008). Clean-up was also performed with columns packed with FLorisil, silica gel (Page and Lacroix 1995;

**Table 3—Sample extraction, clean-up, and analytical methods for phthalates in foods.**

| Food samples | Extraction | Clean-up | Analysis | Analytes | Detection limit | Reference |
|---|---|---|---|---|---|---|
| Cheese, meats, fish, sandwiches, cakes, fruit, vegetables, cooked meals | Samples blended with acetone–hexane (1:1). Supernatant decanted and the residue re-extracted with acetone–hexane 2 more times. The combined extracted dried over sodium sulfate, evaporated to dryness, and the residue redissolved in dichloromethane-cyclohexane (1:1). | Extracts cleaned up with automated SEC system. Extracts (1.5 mL) loaded on a glass column packed with 80-cm bed of Biobeads S-X3, and eluted with dichloromethane-cyclohexane (1:1) at 3.0 mL/min. | GC-MS | DEHA | $<$0.1 mg/kg | Startin and others 1987b |
| Candy, chocolate, meat pasty, pork pie, chicken pie, sandwiches | Sample (30 g) extracted with150 mL of acetone/hexane (1:1) twice. The combined extracts dried with sodium sulfate, evaporated to dryness. Residue redissolved in 20 mL of dichloromethane/ cyclohexane (1:1) for clean-up. | Extract clean-up performed by automated size-exclusion system.1.5 mL of sample extract injected on a 1 m $\times$ 25 mm I.D. glass column packed with 80 cm bed of Biobeads SX3. Eluted with dichloromethane/cyclohexane (1:1) at a flow rate of 3 mL/min. Eluting fraction containing DEHP collected and evaporated to small volume under nitrogen. | GC-MS | DBP, DCHP, BBzP | 0.05 mg/kg | Castle and others 1988b |
| Cheese, meat, poultry, sandwiches | Sample (20 g) mixed with heptane (100 mL) and sodium sulfate (5 g) and centrifuged at 2000 $\times$ *g* for 15 min. Supernatant analyzed directly by GC. | n/a | GC-FID | DEHP, DiOP, DEHA | 30-70 mg/kg | Kozyrod and Ziaziaris 1989 |
| Edible oil | Sample (4 g) dissolved in heptane (20 mL) and analyzed directly by GC. | n/a | GC-FID | DEHP, DiOP, DEHA | 30 to 70 mg/kg | Kozyrod and Ziaziaris 1989 |
| Fruit juices, soft drinks, milk, fruit | Sample (20 g) extracted with heptane (4 $\times$ 25 mL). The combined heptane extracts dried over sodium sulfate and analyzed by GC. | n/a | GC-FID | DEHP, DiOP, DEHA | 30-70 mg/kg | Kozyrod and Ziaziaris 1989 |
| Milk | Sample (10 g) mixed with methanol (5 mL), hexane (3 mL), potassium hydroxide (0.3 g). Shaken for 30 min and centrifuged at 3000 rpm for 5 min. The upper phase transferred to a vial, and the solvent evaporated under nitrogen and the resultant fat redissolved in 1.5 mL of dichlormethane/ cyclohexane (!:1) for clean-up. | Extract clean-up performed by automated size-exclusion chromatography. A total of 0.25 mL of extract injected on a column packed with Biobeads SX3, eluted with dichloromethane/cyclohexane (1:1). Eluting fraction at 15 to 18 mL evaporated to 200 to 300 $\mu$L under nitrogen at 60 °C. | GC-MS | DEHP | 5 $\mu$g/kg | Castle and others 1990 |

*Continued*

**Table 3—Continued.**

| Food samples | Extraction | Clean-up | Analysis | Analytes | Detection limit | Reference |
|---|---|---|---|---|---|---|
| Milk | Sample (10 mL) extracted with 10 mL of ethanol, 5 mL of diethyl ether, and 5 mL of pentane. Organic phase collected in a separating funnel containing 1% NaCl solution. Aqueous residue re-extracted twice with 5 mL of diethylether/pentane (1:1). The 1% NaCl solution drained, discarded, and the combined extracts washed twice with 2% NaCl solution. Extract evaporated to dryness. The dried extract redissolved in 15 mL of dichloromethane/cyclohexane (1:1) for clean-up. | Extracts cleaned up by gel permeation chromatography on a column packed with Bio-Beads S-X3 soaked in dichloromethane/cyclohexane (1:1). The eluate evaporated to near dryness, redissolved in 5 mL of isooctane for analysis. | GC-ECD | DEHP | 0.05 to 0.2 mg/L | Petersen 1991 |
| Milk, cream, butter, cheese | Sample (10 g) mixed with methanol (5 mL), hexane (3 mL), potassium hydroxide (0.3 g). Shaken for 30 min and centrifuged at 3000 rpm for 5 min. The upper phase transferred to a vial and the lower phase extracted twice with hexane (3 mL). The combined hexane extracts evaporated under nitrogen and the resultant fat redissolved in dichloromethane/cyclohexane (1:1) for clean-up. | Extract cleaned up by size-exclusion chromatography employed a 40 × 1.5 cm column of Biobeads SX3 with dichloromethane/cyclohexane (1:1) as eluate at a flow rate of 0.5 mL/min. Injection volume was 0.25 mL. Eluting fraction containing DEHP collected at 34.7 to 42.2 min. and evaporated to 100 $\mu$L under nitrogen. | GC-MS | DEHP | 0.01 mg/kg | Sharman and others 1994 |
| Nonfatty foods (fruits, vegetables, fruit juices and drinks, wines, beers, maple syrup, cereal grains) | Samples blended with acetonitrile and filtered. Filtrate diluted with water and extracted with hexane and dichloromethane (10:1). Hexane extract washed with water, dried through anhydrous sodium sulfate, evaporated to dryness and made to volume with hexane for analysis. | n/a | GC-MS | DEP, DiBP, DBP, BBzP, DEHP, DOP, DEHA | 0.05 to 0.5 $\mu$g/g | Page and Lacroix 1995 |
| Fatty foods (animal tissues, fats, cheese) | Samples blended with sodium sulfate and dichloromethane. Dichloromethane was filtered and removed by rotary evaporation. Lipid transferred in a small quantity of hexane and made to 5 mL. | Phthalates isolated from lipid by sweep co-distillation, Florisil trapping and selective elution. | GC-MS | DEP, DiBP, DBP, BBzP, DEHP, DOP, DEHA | 0.05 to 0.5 $\mu$g/g | Page and Lacroix 1995 |

*Continued*

**Table 3—Continued.**

| Food samples | Extraction | Clean-up | Analysis | Analytes | Detection limit | Reference |
|---|---|---|---|---|---|---|
| Milk and cream | Samples blended with acetone and hexane and centrifuged. Hexane removed and extraction with hexane repeated. Hexane extract dried and lipid material recovered. Lipid transferred in a small quantity of hexane and made to 5 mL. | Phthalates isolated from lipid by sweep co-distillation, Florisil trapping and selective elution. | GC-MS | DEP, DiBP, DBP, BBzP, DEHP, DOP, DEHA | 0.05 to 0.5 $\mu$g/g | Page and Lacroix 1995 |
| Bottled water | 25-mL bottled water sample enriched on an LC column. Eluted by a linear gradient from 50% to 100% acetonitrile in water over 10 min, and detected at 254 nm with LC-DAD. | n/a | LC-DAD | DEP, DiBP, DBP, BBzP, DEHP, DOP, DEHA | 0.005 $\mu$g/g | Page and Lacroix 1995 |
| Citrus essential oils | Samples analyzed directly without extraction and clean-up. | n/a | GC-MS | DMP, DEP, DPP, DBP, DiBP, BBzP, DEHP, DOP | 3 to 40 ng/mL | Di Bella and others 1999 |
| Baby food, infant formulas, total diet samples | Sample (5 to 30 g) extracted with 100 mL of pentane. Supernatant reduced to dryness. Residue dissolved in 5 mL ethyl acetate/cyclohexane (1:1). | Extracts cleaned up on a semi-automatic Omnifit GPC column packed with Biobeads S-X3, eluted with ethyl acetate/cyclohexane (1:1). Elutae fraction reduced to dryness and reconstituted with 0.5 mL of isooctane. | GC-MS | DBP, BBzP, DEHP, DEHA | 0.015 to 0.35 mg/kg | Petersen and Breindahl 2000 |
| Water | Extraction performed by direct-immersion solid-phase microextraction. SPME fiber: polyacrylate. Extraction time: 90 min. Extraction temperature: 45 °C. | n/a | GC-MS | DMP, DEP, DBP, BBzP, DEHA, DEHP, DOP | 0.007 to 0.17 $\mu$g/L | Peñalver and others 2000 |
| Duplicate diet samples | Sample (5 g) extracted with 100 mL of acetonitrile twice. Acetonitrile extract treated with 7 g NaCl, aqueous layer removed. Forty milliliters hexane saturated with acetonitrile added to the organic layer, shaken. Acetonitrile evaporated. Residue dissolved with 5 mL of hexane twice. | Extracts cleaned up on Florisil and Bondesil PSA dual layer column, eluted with 10 mL of 5% (v/v) of acetone in hexane. Eluate evaporated and reconstituted in 2 mL of hexane for analysis. | GC-MS | DEP, DPP, DBP, DPeP, DHP, BBzP, DCHP, DEHP, DiOP, DOP, DiNP, DEHA | 0.2 to 25.8 ng/g | Tsumura and others 2001a; 2003 |

*Continued*

**Table 3—Continued.**

| Food samples | Extraction | Clean-up | Analysis | Analytes | Detection limit | Reference |
|---|---|---|---|---|---|---|
| Drinking water | Extraction performed by direct-immersion solid-phase microextraction. SPME fiber: Carbowax-divinylbenzene. Extraction time: 60 min. Extraction temperature: 25 °C. | n/a | GC-MS | DEP, DBP, BBzP, DEHP | 0.005 to 0.04 μg/L | Luke-Betlej and others 2001 |
| Water | Extraction performed by direct-immersion solid-phase microextraction. SPME fiber: PDMS-DVB. Extraction time: 30 min. Extraction temperature: 80 °C. | n/a | GC-MS | DMP, DEP, DBP, BBzP, DEHA, DEHP, DOP | 2 to 27 ng/L | Peñalver and others 2001 |
| Beverages | Sample (5 g) extracted with 2.5 mL of hexane-dichloromethane (10:1) twice. Extract dried over sodium sulfate, solvents removed under nitrogen. Residue reconstituted with 200 mL of acetonitrile for analysis. | n/a | HPLC-UV | DBP, DEHP | 0.004 μg/g | Yano and others 2002 |
| Beverages | Simultaneous steam distillation and extraction. | n/a | GC-MS | DEP, DBP, BBzP, DEHP, DEHA | 2 to 5 ng/mL | Kato and others 2002 |
| Bottled water | Sample (250 mL) extracted with SPE cartridge. Eluted with 5 mL of dichloromethane/hexane (4:1) and 5 mL of methanol/dichloromethane (9:1) at 1 mL/min. Eluate dried under nitrogen and reconstituted with ethyl acetate to 0.3 mL for analysis. | n/a | GC-MS | DMP, DEP, DBP, BBzP, DEHP | 0.002 to 0.004 μg/mL | Casajuana and Lacorte 2003 |
| Powdered infant formula | Sample (2 g) extracted with 4.5 mL of acetonitrile saturated with hexane. The mixture stirred for 3 min, treated with ultrasonic washer for 20 min, and centrifuged at 4000 rpm for 20 min. Extracts filtered, washed with 0.5 mL of hexane saturated with acetonitrile. | n/a | GC-MS | DBP, DEHP | | Yano and others 2005 |
| Milk | Extraction performed by headspace solid-phase microextraction. | n/a | GC-MS | DMP, DEP, DBP, BBzP, DEHP, DOP | 0.12 to 1.8 ng/g for 3.25% milk | Feng and others 2005 |

*Continued*

**Table 3—Continued.**

| Food samples | Extraction | Clean-up | Analysis | Analytes | Detection limit | Reference |
|---|---|---|---|---|---|---|
| Water | Extraction performed by direct-immersion solid-phase microextraction. SPME fiber: PDMS-DVB. Extraction time: 20 min. Extraction temperature: 100 °C. | n/a | GC-MS | DMP, DEP, DBP, BBzP, DEHP, DOP | 2 to 103 pg/mL | Polo and others 2005 |
| Milk and milk products | Sample (1.5 mL) extracted with 1.5 mL methanol, 2 mL of hexane, and 2 mL of MTBE twice. The combined extract evaporated to dryness at 70 °C under nitrogen flow. Residue redissolved in 3 mL of hexane. | For DBP, BBzP, and DEHP, extract (2 mL) mixed with acetonitrile (2 mL). Hexane phase discarded. Extraction repeated with 1 mL of hexane. The acetonitrile phase evaporated to dryness at 70 °C under nitrogen. Residue redissolved in 0.5 mL of acetonitrile. For DiNP and DiDP, extract (1 mL) diluted with hexane (3 mL) and applied to a glass column packed with 1.5 g of deactivated silica. Column eluted with 0.7% ethyl acetate in hexane. The 1st 28 mL was discarded. The next 24 mL evaporated to dryness at 70 °C under nitrogen. The residue redissolved in 0.5 mL of acetonitrile. | LC/MS/MS | DBP, BBzP, DEHP, DiNP, DiDP | 4 to 9 μg/kg | Sorensen 2006 |
| Human milk | Extraction performed by headspace solid-phase microextraction. SPME fiber: PDMS. Extraction time: 60 min. Extraction temperature: 90 °C. | n/a | GC-MS | DMP, DEP, DBP, BBzP, DEHP, DOP | 0.12 to 1.8 ng/g for 3.25% milk | Zhu and others 2006 |
| Fruits of *Benincasa hispida* | Powdered sample extracted with chloroform at 60 °C for 1 h. | Ten grams of chloroform extract injected on a silica gel column and eluted with hexane/chloroform. | GC-MS | DEHP | | Du and others 2006 |
| Drinking water | Sample extracted by stir bar sorptive extraction followed by liquid desorption. | n/a | GC-MS | DMP, DEP, DBP, BBzP, DEHA, DEHP, DOP | 3 to 40 ng/L | Serodio and Nogueira 2006 |
| Wine | Extraction performed by headspace solid-phase microextraction. SPME fiber: PDMS-DVB. Extraction temperature: 70 °C. | n/a | GC-MS | DMP, DEP, DBP, DEHP, BBzP, DOP | 0.15 to 2.2 μg/L | Carrillo and others 2007 |
| Vegetable oil | Extraction performed by headspace solid-phase microextraction. SPME fiber: PDMS. Extraction time: 60 min. Extraction temperature: 40 °C. | n/a | GC-ECD | DMP, DEP, DBP, BBzP, DEHP, DOP | 0.2 to 0.5 mg/kg | Holadova and others 2007 |

*Continued*

**Table 3—Continued.**

| Food samples | Extraction | Clean-up | Analysis | Analytes | Detection limit | Reference |
|---|---|---|---|---|---|---|
| Human milk | Sample (10 mL) extracted with pentane/acetone and hexane/MTBE after addition of sodium chloride and water. Acetone washed away with water. | Cleaned up using gel permeation chromatography. Extracts loaded on PL-gel column and eluted with pentane/MTBE (1:1) at 5 mL/min. | GC-MS | DEP, DBP, BBzP, DEHP, DOP | 0.12 to 3.0 ng/mL | Hogberg and others 2008 |
| Bottled water | Extraction performed by direct-immersion solid-phase microextraction. SPME fiber: PDMS-DVB. Extraction time: 20 min. Extraction temperature: 25 °C. | n/a | GC-MS | DMP, DEP, DiBP, DBP, DEHP | 0.02 $\mu$g/L for DEHP | Montuori and others 2008 |
| Bottled water | Extraction performed by headspace solid-phase microextraction. SPME fiber: PDMS-DVB. Extraction time: 60 min. Extraction temperature: 90°C. | n/a | GC-MS | DMP, DEP, DiBP, DBP, BBzP, DHP, DEHA, DEHP, DOP | 0.003 to 0.085 $\mu$g/L | Cao 2008 |

n/a = not applicable.

Tsumura and others 2001a, 2003; Sorensen 2006; Du and others 2006; Hogberg and others 2008).

Contamination of laboratory environment has been an issue for phthalate analysis since the 1970s; phthalates were found in many of the common laboratory materials and reagents, such as tubing, cork, glass wool, filter paper, alumina, Florisil, sodium sulfate, sodium chloride, and so on (Giam and others 1975; Ishida and others 1981). Sources of phthalates in the laboratory environment were also investigated recently by Fankhauser-Noti and Grob (2007), the situation is certainly not any better if not even worse than the 1970s; for example, DBP and DEHP were found in commercially available hexane at levels of 100 $\mu$g/L, contamination of glassware is very common due to the presence of phthalates in laboratory air. Although the liquid–liquid extraction and the clean-up procedures are very tedious and thus more chances of being contaminated by the phthalates in the materials and reagents used, these procedures are still very useful and probably the only methods for determination of phthalates in fatty foods and will not be replaced by any new simpler methods any time soon. Therefore, every possible measure should be taken to reduce phthalate contamination in the materials and reagents used in order to keep the phthalate blank levels of the methods as low as possible; solvents should be glass redistilled or purified with aluminum oxide (Fankhauser-Noti and Grob 2007), glassware, sample vials, glass wool, adsorbents, and so on, should be solvent-rinsed and/or heated at high temperature before use. In the meantime, efforts should also be made to develop methods that have the least number of steps and use the minimum amounts of solvents, adsorbents, and other laboratory supplies in order to minimize blank levels of phthalates.

Solid-phase microextraction (SPME) is a solvent-free extraction method developed by Pawliszyn in the early 1990s (Arthur and Pawliszyn 1990). In this method, target analytes could be extracted either by a direct immersion of the SPME fiber in the liquid sample (direct immersion SPME) or by a suspension of the SPME fiber in the headspace above the liquid sample that may be heated to increase partitioning of the analytes into the headspace (HS-SPME). Although water is a simple matrix which allows using the direct immersion SPME methods, the direct immersion SPME methods offer no obvious benefits compared to the headspace SPME methods. There are also limitations with the direct immersion SPME methods, for example, when the pH values of the sample solutions have to be adjusted to the extremes (either very high or very low) in order to measure specific analytes, the SPME fibers could be damaged. And also most of the time, sample solutions have to be heated to speed up the transfer of the analytes to the SPME fiber, since the SPME fiber is also being heated in a sample solution with the direct immersion, the optimum absorption or adsorption of the analytes onto SPME fiber may not be achieved. With the headspace SPME methods, however, the headspace temperature and the sample solution temperature do not have to be the same, and the methods developed with the headspace SPME in water could easily be adapted for other more complex matrices.

Starting in the late 1990s, solid-phase microextraction (SPME) has been investigated for the determination of phthalates in water (Kelly and Larroque 1999; Peñalver and others (2000); Peñalver and others 2001; Luke-Betlej and others 2001; Polo and others 2005; Kayali and others 2006; Montuori and others 2008; Cao 2008), in wine (Carrillo and others 2007), and in vegetable oil (Holadova and others 2007). Since phthalates differ in volatility and polarity (slightly polar and volatile for the lighter phthalates, and nonpolar and less volatile for the heavier ones), a single SPME fiber may not always have the same optimum sensitivity for all phthalates. The salting effect is also not always at optimum when the sample solution is saturated with the salt; although

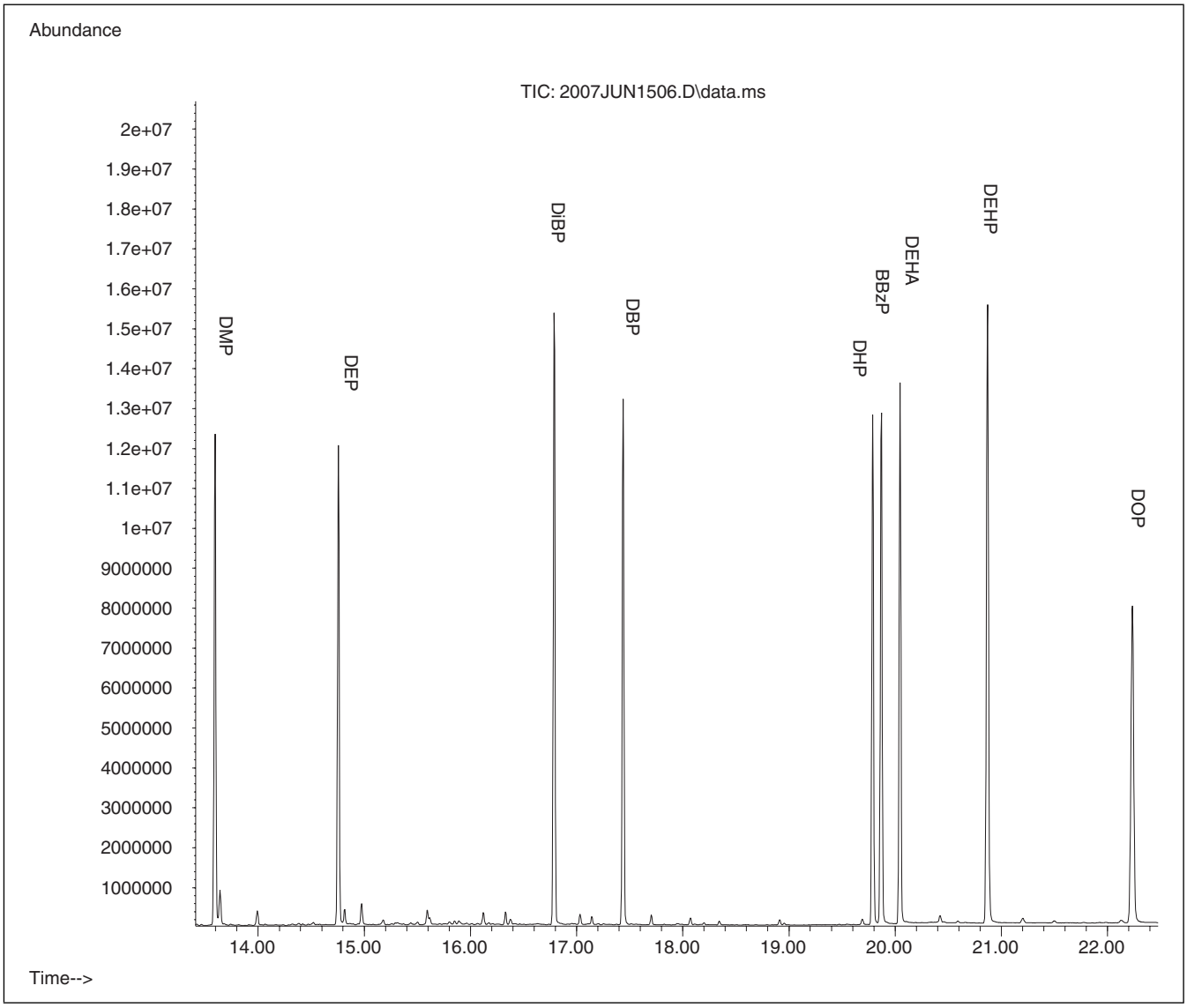


**Figure 2—GC-MS chromatogram of phthalates and DEHA. Column: DB-5MS (30 m × 0.25 mm × 0.25 μm); oven temperature: 50 °C (5 min) 280 °C (5 min) at 15 °C/min; injector temperature: 280 °C; GC-MS interface temperature: 280 °C; MS source temperature: 230 °C; electron impact (EI) ionization; scan mode; helium flow rate: 1.5 mL/min.**

this is the case for the slightly polar phthalates, salt could also suppress the partitioning of nonpolar heavier phthalates (DEHP, DOP) from water into the headspace (Cao 2008). Thus, samples may also have to be analyzed more than once with different SPME fibers and under different extraction conditions in order not to improve the method sensitivity for 1 phthalate at the cost of another.

Recently, the SPME method was also investigated for the determination of phthalates in milk (Feng and others 2005), and this method was applied in a human milk survey for phthalate measurements (Zhu and others 2006). Detection limits as low as subppb were achieved and it was demonstrated that SPME could be a promising method for determination of phthalates in foods.

Solid-phase extraction (SPE) was used once for the extraction of phthalates from bottled water samples (Casajuana and Lacorte 2003). Oil samples were also occasionally analyzed directly or after being dissolved in a solvent without any extraction and clean-up (Kozyrod and Ziaziaris 1989; Di Bella and others 1999).

## Separation and detection

Compared to the challenging extraction and clean-up procedures due to contamination from the materials and reagents used, and thus high phthalate blank levels and higher detection limits, analysis of the sample extracts is relatively simple. Phthalates are semivolatile, stable, and nonpolar (slightly polar for the lighter ones) compounds, liquid chromatography (LC) is not essential, and it is rarely used for phthalate analysis (Page and Lacroix 1995; Yano and others 2002; Sorensen 2006). Gas chromatography (GC) with capillary columns coated with (5%-phenyl)-methylpolysiloxane is the most common and frequently used separation method for phthalates. Mass spectrometry (MS) now is almost the routine detection method for phthalates after

**Table 4—List of ions of phthalates and adipate used in GC-MS analysis in SIM mode.**

| Phthalates | Quantification ion | Qualifier ions | |
|---|---|---|---|
| DMP | 163 | 77 | 194 |
| DEP | 149 | 177 | 76 |
| DiBP | 149 | 223 | 57 |
| DBP | 149 | 223 | 205 |
| BBzP | 149 | 91 | 206 |
| DHP | 149 | 43 | 251 |
| DEHA | 129 | 57 | 147 |
| DEHP | 149 | 167 | 279 |
| DOP | 149 | 279 | 150 |

separation by capillary GC, though a few other detectors (FID, ECD) were occasionally used (Kozyrod and Ziaziaris 1989; Petersen 1991; Holadova and others 2007). For a qualitative analysis of unknown samples, GC-MS is often operated in a scan mode to obtain the whole mass spectrum within the preset mass range for peak identification by comparing with the mass spectrum in the library. Figure 2 shows the typical GC-MS chromatogram of phthalates and DEHA under typical instrument conditions used for phthalate analysis. For a quantitative analysis of samples for the target compounds, however, GC-MS is often operated in selected ion monitoring (SIM) mode which has lower detection limits than the scan mode. In SIM mode, the most abundant ion (the base peak) of a compound will be used as the target ion for quantification, and another 2 less abundant ions from this compound will also be selected and used for confirmation of the peak identity by comparing ion ratios with the standard. With electron impact ionization, the most abundant ion for most phthalates is the protonated phthalic anhydride ion at m/z 149, except for DMP at m/z 163 and DEHA at m/z 129. The typical confirmation ions used for phthalates and DEHA are listed in Table 4. For GC-MS analysis in SIM mode, it is essential to calculate the ion ratios (qualifier ion/target ion) for a compound in the sample and to compare them with those of the standard, identification of a peak is considered positive only when the ion ratios and retention time are within certain limits (for example, 25%) of the standard.

Depending on the nature of food samples, extraction and clean-up procedures, and instruments used for analysis, detection limits of the overall methods for determination of phthalates in foods varied considerably. For simple sample matrices, such as water, clean-up procedure is not required and the extraction procedures used are often much more simple (SPE, SPME), and thus detection limits at low subppb levels are commonly achievable (Peñalver and others 2000, 2001; Luke-Betlej and others 2001; Polo and others 2005; Serodio and Nogueira 2006; Montuori and others 2008; Cao 2008). Detection limits for beverages were slightly higher, around low ppb levels (Yano and others 2002; Kato and others 2002; Carrillo and others 2007). However, detection limits for fatty foods were much higher, at ppm or subppm levels (Startin and others 1987a, 1987b; Castle and others 1988a, 1988b, 1990; Kozyrod and Ziaziaris 1989; Petersen 1991; Sharman and others 1994; Page and Lacroix 1995). Some improvements have been achieved recently by improving the extraction and clean-up procedure and using simple extraction method, detection limits for phthalates in milk were reduced to low ppb or subppb levels (Feng and others 2005; Zhu and others 2006; Hogberg and others 2008). Due to the high resolution of the capillary columns used in GC, methods using GC, not surprisingly, have better detection limits than those using LC (Sorensen 2006; Hogberg and others 2008).

## Summary and Conclusion

Phthalates have become ubiquitous environmental contaminants due to their wide uses in various consumer products, and contamination of the environment, especially water, is one of the sources for phthalates in foods. Since foods are the major source of exposure to phthalates, it is important to monitor levels of phthalates in various foods to provide data for human exposure assessment.

Unlike other chemical contaminants, information on levels of phthalates in foods is very limited. Most of the available results were from studies conducted many years ago, and these data may not represent the current situation and may not be useful for accurate human exposure assessment. In addition, most of the available information was for DEHP and DEHA, while information on levels of the other phthalates and adipates in foods is even more limited. Thus, up-to-date surveys should be conducted regularly to determine the current levels in foods of not only DEHP and DEHA but also phthalates with environmental contamination as the major source (such as DMP, DEP, DBP, BBzP) and phthalates, adipates, and other plasticizers that have been used as replacement for DEHP and DEHA in some food-packaging materials such as DiNP, DiDP, DiNA, DEHT. These surveys should include both the targeted surveys on foods that are in contact with materials plasticized with known phthalates and adipates and general surveys, such as the total diet, in order to determine the overall levels of phthalates in the diet. The metabolites of phthalates, mono-phthalates, are very useful biomarkers for human exposure to phthalates and could be monitored in biological fluids (human milk, blood, urine), but their levels in foods, even those originating from animals such as milk and milk products, are very low, and thus determination of mono-phthalates in foods is not necessary.

Migration from food-packaging materials plasticized with phthalates is a very important source of phthalates in foods when in contact with these packages. Although this has been investigated for various food-packaging materials, some of the information may not reflect the current situation since manufactures may have changed plasticizers in materials over the years. The regulations on the use of plasticizers in food-packaging materials vary from country to country; plasticizers banned in 1 country may be permitted for use in food-packaging materials in other countries. Thus, up-to-date studies should be conducted worldwide to investigate migration of phthalates, adipates, and other plasticizers in the current food-packaging materials.

Although methods are available for the determination of phthalates in various food types, detection limits of these methods, especially for fatty foods, are very high due to the high blank levels of phthalates caused by the contamination of laboratory reagents and various materials used. This will either underestimate or overestimate the assessment of human exposure to phthalates depending on the values used for those samples with phthalate levels less than the detection limits. Thus more stringent measures should be taken to minimize the blank levels of phthalates for existing methods to improve the detection limits. Better methods for phthalate determination should also be developed which preferably should be automated, simple, reliable, and involve a minimum amount of sample preparation; and the feasibility of using the SPME methods for determination of phthalates in foods should be investigated.

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