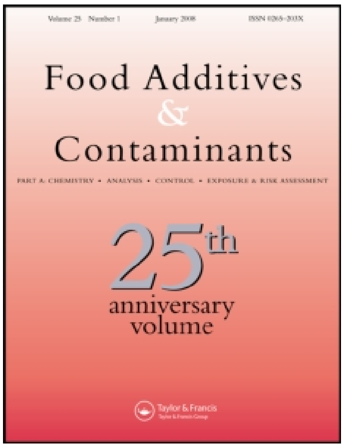

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Characterization of patterns of food packaging usage in Portuguese homes

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Characterization of patterns of food packaging usage in Portuguese homes

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This study aimed to further refine the exposure assessment of migrants from food-contact materials by characterizing, at the household level, food packaging usage (amount and type) in Portuguese urban families. Packages from domestic use were collected from a sample of 105 consumers from 34 households over a 30-day period. Collected packages (more than 6000 items) were characterized in the laboratory and data were used to estimate: (i) global packaging usage and food intake; (ii) the consumption factors (CF) that describe the fraction of the daily diet expected to be in contact with specific packaging materials and (iii) the food-type factors (FTF) that reflect the fraction of all food contacting each material which differ in nature according to six major types: aqueous, acidic, alcoholic, milky, fatty and dry. The daily intake of packaged food and beverages consumed at home ranged from 5–50 g kg^{-1} bw. Considering all materials, total package usage ranged from 0.1 to 0.6 dm^2 day^{-1} kg^{-1} bw. The ratio between package surface area in contact and the quantity of food was determined for all packaging items collected and an average value of 25 dm^2 kg^{-1} food was recorded. Data were gathered and presented in a manner compatible with current probabilistic approaches to exposure assessment. In this way, relevant consumption patterns from this type of population can be best represented in exposure assessments and subsequent risk assessments.

Keywords: exposure; probabilistic modelling; exposure assessment; food contact materials; migration

Abbreviations and symbols: A, B, C, E, D, None, food simulants; BIB, bag-in-box; bw, body weight, kg^{-1} bw; C, concentration of migrant in food or food simulant, mg kg^{-1} food; CF, consumption factors; DSC, differential scanning calorimetry; E, exposure mg person^{-1} day^{-1} or mg kg^{-1} bw day^{-1}, FTF, food type factors; FW, food weight, kg food person^{-1} day^{-1} or kg food kg^{-1} bw day^{-1}; LDPE, low density polyethylene; HDPE, high density polyethylene; Max, maximum; Min, minimum; N, number of household members; PET, polyethylene terephthalate; PP, polypropylene; PS, polystyrene; PW, packaging weigh, kg; S, packaging surface area of contact, dm^2; SML, specific migration limit, mg kg^{-1} food; μ, average; σ, standard deviation

Indices: i, household; j, packaged food item; m, packaging material; n, member of household; t, type of food: aqueous, acidic, ethanolic, dairy, dry; bw, body weight

Introduction

Exposure, in a dietary context, is defined as the amount of a certain substance that is consumed and is usually expressed as the amount of substance per mass of consumer body weight per day (Holmes et al. 2005). When applied to food contact packaging, exposure can be expressed in terms of the concentration of the substance that migrated from the material in contact and the amount of food contained in the package consumed per day (Equation (1)). To assess exposure to packaging chemicals, it is necessary to know what type of food (chemical and physical nature) is packaged in what type of material, as this determines the presence and concentration of the chemical and influences the potential for migration into the type of food (Poças and Hogg 2007).

$$\text{Exposure (mg person}^{-1}\text{ day}^{-1}) = \text{C(mg kg}^{-1}\text{ food)} \times \text{FW(kg food person}^{-1}\text{ day}^{-1}) \quad (1)$$

The concentration data (C) may be obtained by analysing real food/*packaging systems* collected from the market (monitoring real food systems) or through

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migration experiments carried out under controlled conditions of time and temperature of contact between the materials and a food simulant instead of the food itself. Mathematical models may also be used to estimate migration data (Poças et al. 2008).

The food consumption term (FW) represents the amount of food eaten that was in contact with a packaging material from which migration occurred. Therefore, this term is linked to the *packaging usage* – the amount of packaging used to pack the food that the consumer eats. Packaging usage data are very scarce and most consumption surveys have been designed to gather information on the food, regardless of their *packaging systems*. Thus, adequate information of packaging usage, usable to assess exposure to migrants from packaging, is not readily available.

Data on almost all aspects of food packaging in Portugal are virtually nonexistent. A report with market data collected through statistics of national and trade associations and through interviews to major food companies and packaging suppliers was published in 1995 (Poças and Xará 1995). However, this report lacks obvious updating, as well as the detail required for this specific purpose. The Euromonitor Report provides data (volume and value) on packaged food in Portugal but it does not give details on the *packaging systems* used (Euromonitor 2008).

The methods for estimating consumer exposure can and should follow a hierarchical, stepwise approach, proceeding from the level of more conservative assumptions and lower accuracy, often corresponding to point estimates, to the more refined probabilistic approaches. When the less exact, first level, results do not rule out the possibility of non-compliance with the relevant food safety objective, then more refined approaches are required. Different levels of refinement may be achieved depending on the type and quality of data available for each term of Equation (1) and the various scenarios. An approach between the simplified point estimates based on worst-case assumptions for both the concentration and food intake terms of the exposure equation and the elaborated probabilistic approaches considering variability and uncertainty of the inputs in the exposure equation, may involve the adoption of a similar approach to that followed by the official agencies of the US (Poças and Hogg 2007). The FDA defines a consumption factor (CF), which describes the fraction of the daily diet expected to contact specific packaging materials, and a food-type factor (FTF), which accounts for the variable nature of food contacting each type of packaging material (USFDA 2007). This corresponds to a more refined first-step approach when compared to that applied in the EU. The application of this approach here would require the development of a framework, bringing together CF and FTF, derived and adapted to the European consumption patterns of packaged food. An application of this FDA concept to the exposure of Irish children to packaging migrants was reported by Duffy et al. (2007).

The focus of this paper is on the use of consumption and food-type factors derived from data collected at consumer level. The data collected allow for a probabilistic approach as an example provided, and was collected in the scope of a national funded research project MIGRAMODEL. One of the objectives of the project was the development of a framework for exposure assessment of packaging migrants. The project focused on the collection of updated and more complete data on packaging usage enabling the refinement and possible correction of current EU assumptions to exposure estimations and to assist on prioritization of market surveillances. The data include packaging usage data collected at consumer level complemented by data collected at industry level (packaging and food associations were contacted to gather national statistical data).

Materials and methods

The collection of data within the project scope was performed in three trials that took place during 2007 and 2008: the first during a 1-week period from a sample of consumers connected to the project; the second during a 1-week period from a sample of consumer participants in a scheme of door-to-door collection of packaging waste in Porto city; and the third during a 1-month period from a second sample of consumers connected to the project. The data from this latter trial were used in the work presented here. Packages used domestically by the consumer sample were collected over 30 consecutive days and analyzed in the laboratory. This collection period was selected because in previous work a 1-week period proved to be insufficient.

The elements of the consumer sample were members of MIGRAMODEL project team, relatives and faculty members. The sample was composed of 34 households, accounting for a total of 105 persons. Separate collection of those packages used by children under 12 years only was requested. The household was characterized through a short questionnaire, considering: number of persons, weight, age and gender of each household member and level of household annual income. The household member responsible for package collection was instructed by the project team as to which packages and food contact materials should be considered. Consumers tend to disregard items such as wrapping film, bread or fruit bags as packaging. Persons were encouraged to include any item in the case of doubt. A leaflet with pictures of examples was distributed and a phone contact with the project team was available during the collection period.

The packaging materials and systems used (consumed) by each household were brought into the laboratory and analyzed for the characteristics bellow described. A total of 6297 packaging items were handled.

Type of package: each package or material was classified as bottle, jar, can, cup/lid, tray/lid, tray/wrap, flexible, liquid carton, box and folding carton.

Packaging material: the packaging materials were segmented as: glass, tinplate, aluminium, all-plastic multilayer, multilayer (multi-material), paper, coated paper (wax or PE coating), carton board and plastics. The latter were further segmented into different major types of plastics: PET, PP, HDPE, LDPE, PS. Material identification was, in most cases, based on previous knowledge and experience and confirmation, when required, was performed by DSC.

Closures for glass packages were not accounted for. Nevertheless, their amount can be estimated from data on the type of package. The data on polymeric coatings of tinplate and aluminium packages are associated with the data on these metal packages, not to the plastic class. All-plastic multilayer included laminates used mainly in flexible packaging and lids of rigid packages made exclusively from several plastic layers. Multilayer group of materials, included liquid cartons (board, plastic and aluminium; board and plastic) and flexible packaging composed of plastic, paper and metal or metalised film. The differentiation between the major plastics was performed taking into consideration the major plastic component of the package. Polyethylene was divided into two major groups only, corresponding to high and low densities. No other differentiation between different grades of a plastic was performed.

Packages characteristics

Geometry: the packages were classified according to their general geometry as rectangular, cylindrical, truncated pyramid, truncated cone, sphere or flexible for non rigid packages;

Capacity: the nominal amount of food product according to the labelling information was recorded; when it was not possible to know the amount of food contained/in contact with the material, the surface area was determined and the EU conventional ratio between the surface area of the package and amount of food – $6\,\mathrm{dm}^2\,\mathrm{kg}^{-1}$ – was assumed;

Weight/surface area: the weight and surface area of package in contact with food were measured and the ratio package surface area/mass of food was calculated for all packaging items handled in the laboratory;

All materials considered were in direct contact with the food products, except carton board, which was, in all samples, a non-direct contact material. However, because migration can also occur from non-direct contact materials, carton board was also considered in the consumption factors estimation.

Food items were grouped according to the list presented in Table 1. The list was based on the list prepared under the scope of the European FACET project (Oldring et al. 2009). This list is still in draft form and a simplified version of it was used here. The authors of the present article employed a compatible coding of food types to allow for future integration if so desired.

Each food item was assigned into a food type, corresponding to food simulants, according to European food contact legislation (Council Directive 85/572/EEC and Commission Directive 2007/19/CE): (A) water, (B) 3% acid solution, (C) 10% ethanolic solution, (D) olive oil, (E) 50% ethanolic solution, to mimic milk and some other dairy foods. In the case of food items requiring more than one testing simulant, the fattier simulant one was considered. A "None" was assigned for the cases in contact with dry, solid, non-fatty foods, like bread or flour.

The data were used to estimate:

- The global amount of used packaging material: this was calculated as the sum, for all food items, of the package surface area and weight. The total amount (all materials together in kg) were averaged by the 30-day period and by the total number of persons (Equation (2)):

$$\text{Global Packaging Usage} = \frac{\sum_i \sum_m \sum_j S_{imj}}{30 \sum_i N_i}\ \mathrm{dm}^2\,\mathrm{person}^{-1}\,\mathrm{day}^{-1} \qquad (2)$$

- The global amount of food (in kg) consumed by the population sample was calculated as above but using the item food weight FW_{imj} in Equation (2);
- The packaging usage of each household i, per body weight of the household, for all materials together, was calculated as (3):

$$\text{Packaging Usage per BW} = \frac{\left[\sum_m \sum_j S_{mj}\right]_i}{30\left[\sum_n BW_n\right]_i}\ \mathrm{dm}^2\,\mathrm{kg}^{-1}\,\mathrm{bw}\,\mathrm{day}^{-1}. \qquad (3)$$

- The weight of food consumed of each household, per body weight of the household, was calculated as above but using the FW_{mj} in Equation (3);
- The ratio of package surface area/mass of food for each type (Equation (4)) of packaging material (distribution of values):

$$[S/FW]_m = \frac{\lfloor S_{ij} \rfloor_m}{\left[FW_{ij}\right]_m}\ \mathrm{dm}^2\ \mathrm{kg}^{-1}. \qquad (4)$$

Table 1. Food groups.

Beverages	Beer
	Wine
	Spirits/liquors
	Water
	Juice & juice drinks
	Soft drinks
Dry beverages	Coffee
	Tea
	Others (chocolate powder)
Biscuits and crackers	
Cakes	
Bread	
Breakfast cereals	
Confectionary	Chewing gum
	Sugar confectionary
	Chocolate confectionary
Snacks	
Culinary ingredients	Sugar and substitutes
	Flour, cake mixes, baking powder
	Rice
	Dry pastas
	Sauce and condiments
	Jam, marmalade, honey, compote
	Chocolate spreads
	Eggs
	Dietary supplements
Oil	
Olive oil	
Fats	
Cheese	Hard
	Soft
	Fresh
	Spreadable/processed
Butter	
Milk	Liquid
	Powder
Yogurt	Liquid
	Solid
Cream	
Dairy desserts	
Meat	Fresh
	Processed/cured
Fish	Fresh
	Processed/cured
Fruit	Whole
Vegetables	Fresh
Frozen	Ready meals
	Vegetables
	Meat
	Fish
	Ice cream
	Desserts
Chilled	Ready meals
	Fish
	Meat
Preserves	Vegetables
	Fruits
	Ready meals
Dehydrated	Soups
Dried	Fruits
	Vegetables
Take-away and vending	
Baby food	Dry
	Moist

– The estimates of consumption factors (CF) that represent the fraction of the daily diet expected to contact specific packaging materials (USFDA 2007) was calculated as indicated in Equation (5):

$$CF_m = \frac{\left[\sum_i \sum_j FW_{ij}\right]_m}{\sum_m \sum_i \sum_j FW_{mij}}. \qquad (5)$$

– The estimates of food type factors (FTF) that reflect the fraction of all food contacting each material m which nature is according to the types t of foods: aqueous, acidic, alcoholic, fatty, dairy or dry (Equation (6)). This corresponds to an adaptation of the USFDA approach to the simulants foreseen in the European legislation:

$$FDF_{tm} = \frac{\left[\sum_i \sum_j FW_{ij}\right]_{tm}}{\left[\sum_t \sum_i \sum_j FW_{tij}\right]_m}. \qquad (6)$$

Food eaten out of the home was not accounted for in this analysis, which obviously contributes to underestimation of the absolute values for consumption.

Example of an exposure calculation

The exposure of the Portuguese consumer to 2-aminobenzamide (2-ABA; CAS 88-68-6) was estimated using the data gathered in this study. 2-ABA may be used as a scavenger for acetaldehyde in PET bottles. In European legislation, it is authorised for PET for water and beverages with a SML = 0.05 mg kg^{-1} food (Commission Directive 2002/72/CE). USFDA limit the use of 2-ABA subject to the restriction of levels in the finished container not to exceed 500 mg kg^{-1} in bottles intended for water and levels not to exceed 250 mg kg^{-1} in bottles intended for non-water, aqueous, acidic and low-alcohol food applications. Information from the safety evaluation (SCF 2003) indicates that the migration of 2-ABA from PET bottles containing 500 mg kg^{-1} of the substance to water, 3% acetic acid and 10% ethanol was found to have a maximum of 0.04 mg kg^{-1} food in 10% ethanol after 30 days at 40°C. For the exposure calculation examples, a single estimate of the concentration of 2-ABA was set at the SML value. The exposure is estimated under the conditions foreseen by different scenarios: (i) USFDA, (ii) European conventional assumptions, (iii) using the CF and FTF derived in the present work and (iv) using a partially probabilistic approach by combining the single-point estimate for the concentration as above described but considering the whole distribution of values found for the food intake per kg bw in the sample of consumers. The software Crystal Ball 7.2.2. (Decisioneering, Inc.) was used to fit the probability distributions to the values of the food intake FW (in kg^{-1} food kg^{-1} bw day^{-1}) and to perform the probabilistic simulation. Monte Carlo was used as sampling method with 10,000 trials for each run.

Results and discussion

Characterization of the consumer sample

The data collected through the questionnaire were used to characterize the consumer sample. Average results for bodyweight and age are presented in Table 2. Results for the children are presented separately. Figures 1 and 2 represent the distributions of weights and ages, respectively, of the whole sample population, adults and children together, which is evident from the bimodal shape of the distributions. The national statistics for population indicators was used to assess how representative the consumer sample is of the whole Portuguese population. The consumer sample used in this work was taken from the Metropolitan Porto area which represents 12% of the total population, 45% of which is classified as urban. The national average household size is 2.8 members which can be compared to the 3.1 of the present sample. The Portuguese population as a whole presents an age distribution with 15% individuals younger than 14 years and 56% in the range 24–64 years old. The sample in this study had a relatively higher percent of consumers in these two age ranges at 24 and 66%, respectively, and a lower percentage of elderly people at 4%, whereas the national average is 17%. The differences in terms of distribution by gender are not relevant with values around 50% of each gender in both cases.

Global amount of food consumed and packaging material used

The average amount of food consumed at home and the packaging materials used by adults and children together and by children alone are presented in Table 3. The average value for daily intake of packaged food of all consumers is close to the value assumed for the EU ($1\,kg\,day^{-1}\,person^{-1}$) for the assessment of safety of substances intended to be used in the production of plastic packages. The value found for the average daily intake when expressed per kg body weight is the same as the value typically assumed: $17\,g\,kg^{-1}$ bw (EFSA 2005). However, these values are most probably underestimated because the packaged food consumed out of the home was not accounted for, as explained above. Figure 3 presents the distribution of values ranging from 5 to more than $35\,g\,kg^{-1}$ bw. The types of food, according to the simulants foreseen in the EU, accounted as the percentage of food taken at home are: 18% aqueous, 10% acidic, 5% ethanolic, 25% milky and 14% fatty.

The values found for children's sample only are considerably lower than the results found for Irish children between 5 and 12 years old. Duffy et al. (2006)

Table 2. Characteristics of consumer sample: adults and children.*

	Parameter	Value
Adults and children	No. of persons in sample	105
	No. of homes	34
	Average weight, kg (±SD)	56.6 ± 23.1
	Average age, years (±SD)	30.2 ± 17.8
Children only	No. of children	20
	Average child weight, kg (±SD)	23.6 ± 10.1
	Average child age, years (± SD)	6.7 ± 3.4

Note: *≤12 years old.

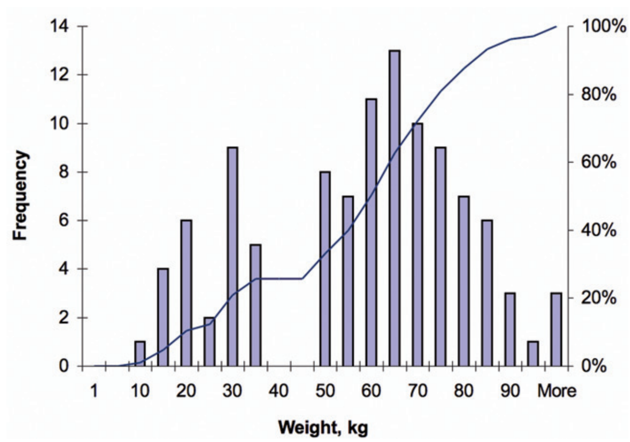

Figure 1. Consumers body weight distribution.

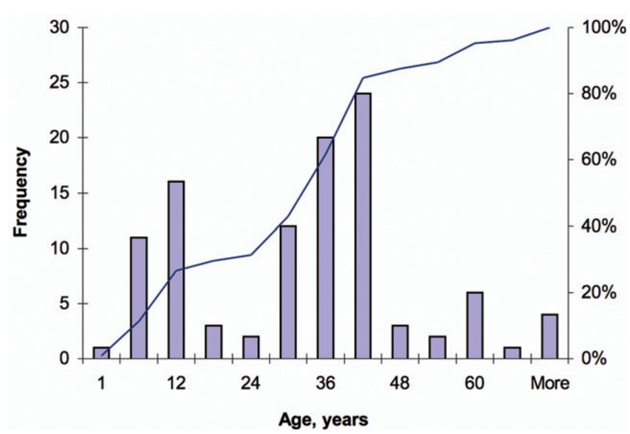

Figure 2. Consumers age distribution.

Table 3. Global results averaged by day, person and by average person body weight.

		Food weight (kg)	Package surface area (dm^2)	Package weight (kg)
Children plus adults	Total	2982	34,341	303
	Total day^{-1} $person^{-1}$	0.947	10.9	0.096
	Total day^{-1} kg^{-1} bw	0.017	0.192	0.002
Children only	Total day^{-1} $child^{-1}$	0.483	5.9	0.027
	Total day^{-1} kg^{-1} bw	0.021	0.249	0.001

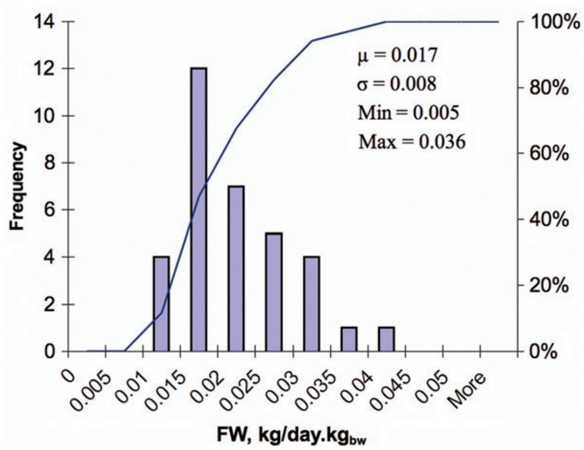

Figure 3. Distribution of values for packaged food consumed at home per day and per kg of body weight. Adults and children together.

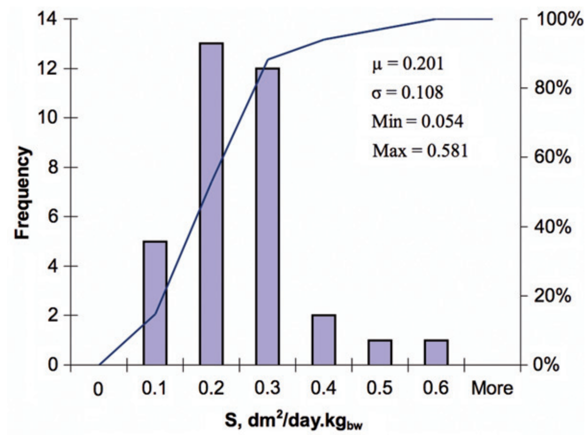

Figure 4. Packaging (all materials) surface area used, per day and per kg of body weight. Adults and children together.

estimated a mean daily consumption of packaged food, by these children, of 1.2 kg day^{-1}, corresponding to 39 g kg^{-1} bw, compared to the 21 g kg^{-1} bw found in this study for Portuguese children. The value found in this study for food intake per child – 0.483 kg^{-1} food day^{-1} $child^{-1}$ – is also low when compared to the value found for British children – 0.823 kg^{-1} food day^{-1} $child^{-1}$ (FSA 2006). The method of data-gathering followed in this study does not account for the fact that, in each household, some of the packages items collected are in fact shared by both adults and children although ending up in the adult bin, thus contributing to lowering the values found for children. The value found in this study for the whole sample data (0.947 kg^{-1} food day^{-1} $person^{-1}$) is higher than for the children, as was to be expected.

Figure 4 presents the distribution of values found for packaging usage in terms of surface area of all packaging materials that a consumer uses per day and per kg of body weight. The results obtained in this study confirm the values previously found in a 1-week study, and show values ranging from lower than 0.1 dm^2 day^{-1} kg^{-1} bw, which corresponds to the value assumed in European legislation, to values around 0.6 dm^2 day^{-1} kg^{-1} bw, a much higher value. The average value is 0.2 dm^2 day^{-1} kg^{-1} bw (standard deviation = 0.11 dm^2 day^{-1} kg^{-1} bw). This value is lower than the European average value estimated by ILSI of 20.1 dm^2 $person^{-1}$ day^{-1} that corresponds to 0.34 dm^2 day^{-1} kg^{-1} bw (Brown et al. 1997). ILSI estimates indicated a value of 12.4 dm^2 $person^{-1}$ day^{-1} for plastics that compare to the value found in this study – 8 dm^2 $person^{-1}$ day^{-1}.

Packaging surface area/amount of food in contact ratio

The ratio of packaging surface area to the amount of food in contact (S/FW) was calculated for each material (Table 4). Packages made from glass and tin plate present average ratios around 10 dm^2 kg^{-1} food and relatively low standard deviation. This could be expected because the range of formats and shapes in these packages do not vary as much as in other materials. The aluminium group includes rigid cans for foods and beverages, semi-rigid shallow trays and wrapping foil. This variation in the formats, shapes and sizes results in higher average and spreader ratios. A large proportion of PET is used in beverage packaging and in capacities as large as 5 l. Trays for confectionery and cakes, products with low density, contribute to the higher range of the distribution of values for S/FW ratio found for PET. These light products, including bread, are major applications for

Table 4. Statistics for the distribution of surface area/food amount ratios ($dm^2 kg^{-1}$ food) for each packaging material.

	μ	σ	Min.	Max.
All materials combined	24.89	48.62	0.13	700.00
Glass	9.81	4.55	4.72	70.40
Tin plate	10.64	4.16	1.67	21.90
Aluminium	49.98	23.60	3.81	72.00
PET	9.97	9.35	3.20	80.00
PP	34.32	47.66	1.00	700.00
HDPE	15.35	12.06	3.43	105.26
LDPE	16.56	15.58	2.33	92.11
PS	12.60	7.26	4.17	80.00
Plastic multilayer	35.48	42.54	2.84	646.15
Multilayer	13.13	42.91	2.22	646.15
Paper	104.01	163.34	0.13	686.67
Coated paper	45.02	41.15	2.22	142.86

flexible PP, thus yielding high values of S/FW ratio. PP secondary packaging and paper for tea bags present values around $600\,dm^2\,kg^{-1}$ food. PS entries in the database include cups for solid yogurts and other dairy products, cakes and baked products, and trays for meat, fresh cheese and some fruits. Average ratio values of $S/FW = 12.6\,dm^2\,kg^{-1}$ food ($\sigma = 7.3$) were found. Liquid cartons (aseptic and non-aseptic) are included in the group of materials referred to as multilayer. The S/FW of milk and juice liquid cartons ranges from $5.75\,dm^2\,kg^{-1}$ food for packages of 1.5 l to $\sim 13\,dm^2\,kg^{-1}$ food for smaller packages of 0.2 l. Although many other types of flexible packages, made from metalised materials and combinations of paper, aluminium foil and plastic, are included in this group, liquid cartons account for 94% of total package surface area and 97% of the food weight of this group. Paper is the material presenting the highest values of S/FW due to its use for dry, powder and lightweight products. Figure 5a presents the distribution of values of S/FW when all materials are considered together and Figure 5b presents the distribution of values for the PS, as an example.

These results emphasize that the assumptions made previously by other authors, i.e. that package geometry may be described, for safety assessments, as a cube of surface area $6\,dm^2$, containing 1 kg of food, is inappropriate today because, globally, packages sizes tend to decrease leading to an increase in contacting surface area per kg of food (Dionisi and Oldring 2002; Grob et al. 2007; Poças and Hogg 2007). In a similar study performed in The Netherlands, values for the S/FW ratio varying from 6 to 95 $dm^2\,kg^{-1}$ food were found (Bouma et al. 2003).

Estimates of consumption factors (CF)

CF represents the ratio of the weight of all food contacting a specific packaging material to the weight of all food packaged consumed. CF was calculated from Equation (5), according to the procedure followed by the FDA (Cassidy and Elyashiv-Barad 2007).

Figures 6 and 7 represent the consumption factors for adults and children combined and for children alone, respectively. A comparison between the two figures show that multilayer materials (mostly liquid cartons) have a lower use when compared to the value found in children only. For the whole sample, glass accounts for ~6% of food intake but is absent in the case of children's consumption. Plastics together account for more than 50% of the daily diet; PET accounts for 26% of the food (mostly drinks) and the remaining plastics are split at ~33% of the food. PS plastic has a higher relative importance (10%) in children's diet compared to its importance when adults are also considered (4%). This may be explained by the expected higher consumption of dairy products by children and the fact that these products are typically packaged in PS in Portugal.

The percentages of the food consumed contacting specific materials are compared to the USFDA CF in Table 5. To allow a comparison between the results of this study and the USFDA CF, some grouping of the material classes was made: consumption factors of aluminium and tinplate in this study were added and compared to the sum of the factors for metal, coated and uncoated, in FDA; plastics and all-plastics multilayer were added and compared to plastics from FDA; coated paper and multilayer multimaterial combined were compared to coated paper values from FDA; uncoated paper and carton board were compared directly. USFDA segments of adhesives, retort pouch and microwave susceptors were not considered. The comparison shows a lower usage of glass and metal in Portugal compared to USA and a higher percentage of plastics and multimaterial. The CF of some specific plastics is also presented in Table 5. After appropriate manipulation for conversion to the same base, the values found for HDPE, LDPE and LLDPE combined, and PS are very similar to the FDA values for these plastics. The value for PET, however, is very different. Results in this study show that ~26% of the food consumed at home was packaged in PET, while the correspondent CF for USA is only 7%. Since a large proportion of the PET entries in the study database is for drinks, this difference agrees with the lower values found for Portuguese usage of other materials commonly used for drinks (glass and metal), as compensation between materials used for drinks may occur.

The results for CF obtained in this 1-month study are presented for adults and children combined and for children only. The latter are compared with the results presented by Duffy et al. (2007). Unfortunately, due to the use of a different fragmentation between packaging

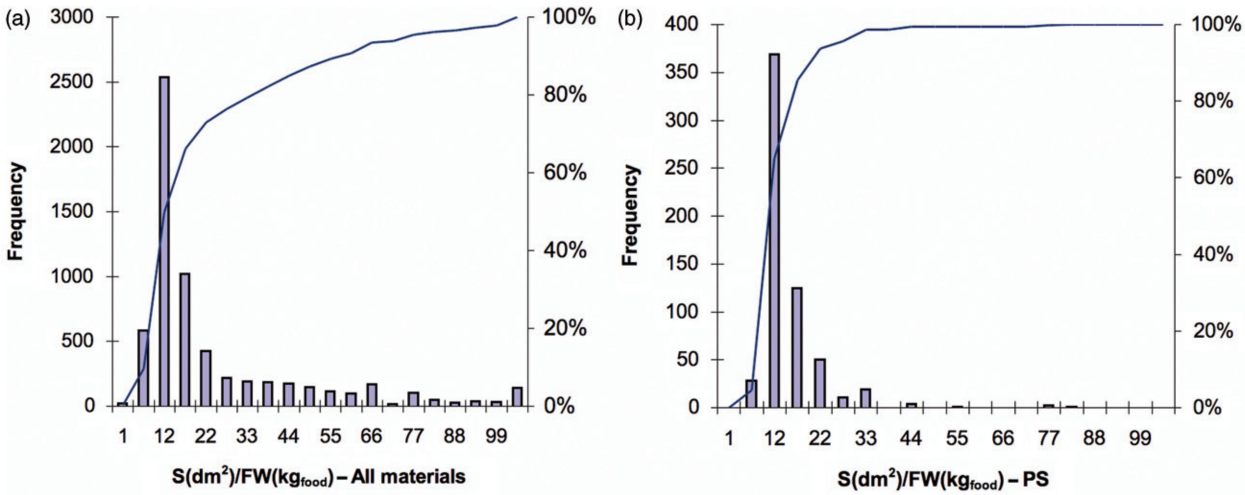

Figure 5. Distribution of values of ratio surface area/amount of food for all packaging materials together (a) and PS packaging only (b).

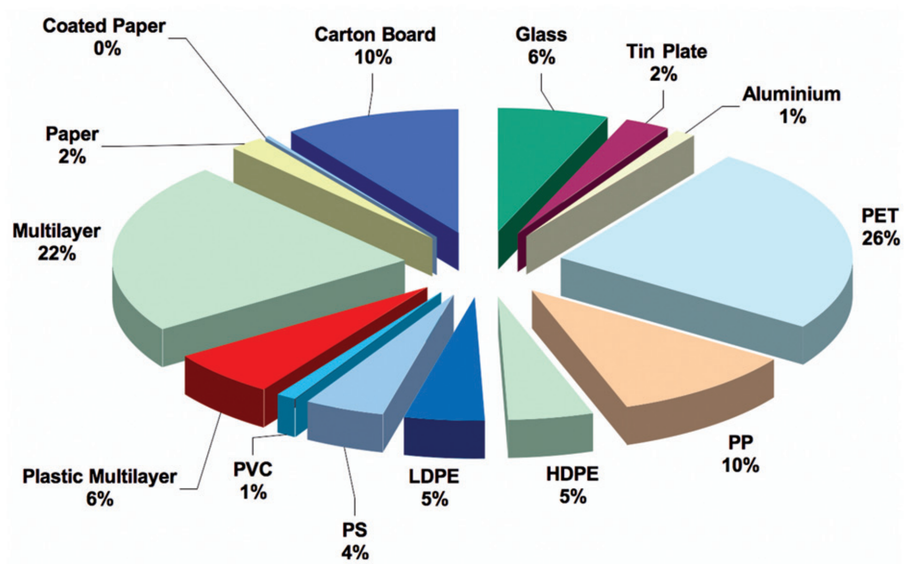

Figure 6. Percent of food consumed contacting specific packaging materials. Adults and children.

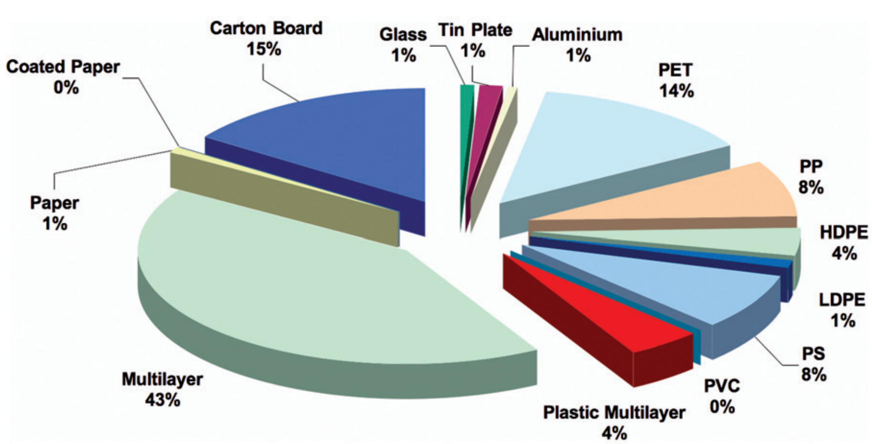

Figure 7. Percent of food consumed contacting specific packaging materials. Only children.

Table 5. Comparison between estimates of consumption factors and USFDA values.

	FDA Adults & Children	PT Adults & Children	PT Children 1–12 years	IE Children 5–12 years
Glass	10	6	1	2
Metal (coated + uncoated)	20	4	2	6
Plastics	40	56	41	80
PS	4^{+}	4	4	–
PET	7^{+}	26	14	–
HDPE	5^{+}	5	4	–
L(L)DPE*	7^{+}	5	1	–
Multimaterial	20	23	43	–
Paper and board	10	12	16	13

Notes: *LDPE and LLDPE were not distinguished.
$^{+}$PET is 16% of plastics; PS is 10% of plastics; HDPE is 13% of plastics; plastics are 40% of diet.

Table 6. Food type distribution factors for each packaging material.

	A	B	C	E	D	None
Glass	13	14	64	0	8	1
Tin plate	8	53	4	3	22	10
Aluminium	1	7	9	0	80	3
PET	73	18	0	1	5	3
PP	4	2	0	0	19	75
HDPE	0	5	0	47	11	37
LDPE	1	1	0	0	25	73
PS	1	1	0	34	50	14
Plastics multilayer	3	0	14	1	54	28
Multilayer	0	12	0	85	2	1
Paper	1	0	0	0	12	88
Coated paper	0	0	0	0	92	8
Carton board	0	0	1	3	9	87

materials, it is only possible to compare glass, paper and board classes.

Estimates of food type distribution factors (FTF)

The FTF for the different packaging material are presented in Table 6. The results presented indicate that:

- Glass usage for alcoholic products is 64% and the remainder, distributed between different types of products, fatty products, accounting for 8%;
- Tin plate is mainly used in three type of product/simulant: aqueous, acidic and fatty;
- PET, as expected, has a major application in aqueous and acidic products related to soft drinks;
- PP is used in significant proportions in dry products and in fatty foods;
- HDPE is primarily used in dairy products for which simulant E is defined;
- PS finds major application in products for which simulant E (dairy foods) and D (fatty) are assigned;
- Multilayer (multi-material) packages contain a significant proportion of liquid cartons, used for milk and juice, as reflected in the food type factors;
- Carton board is mainly used for non-contact applications, thus no simulant is specified.

The results are not directly compared with the FTF from FDA since the classification of foods is different, according to the food simulants foreseen in Europe.

The use of the CF and FTF require a complete understanding of the classification behind the factors derived. For example, if the factors are to be used to estimate exposure to an additive migrating from the LDPE family of films, the following must be taken in consideration:

- the percentage of daily food intake packaged in LDPE single-layer material is 5% (Table 5), of which ~75% is for dry food and 25% is for fatty food (Table 6);
- PE-based films are likely to be the contact layer in the multilayer and plastics–multilayer classes; the percentage of daily food intake in contact with multilayer is 22% (Figure 6), of

Table 7. Exposure estimation of 2-ABA originating from PET bottles packaging materials.

Assumptions/scenario	USFDA	EU conventional	PT deterministic	PT probabilistic
FW	3 kg food person^{-1} day^{-1}	1 kg food person^{-1} day^{-1}	0.95 kg food person^{-1} day^{-1}	LN distribution $\mu = 0.017$ kg food kg^{-1} bw day^{-1} $\sigma = 0.008$ Min = 0.005 Max = 0.036
$C_{2\text{-ABA}}$	0.05 mg kg^{-1} food	0.05 mg kg^{-1} food	0.05 mg kg^{-1} food	0.05 mg kg^{-1} food
BW	–	60 kg bw	57 kg bw	
FTF_{PET}	0.01 Aqueous 0.97 Acidic	–	0.73 A 0.18 B	0.73 A 0.18 B
CF_{PET}	0.082 PET/Polymers 0.40 Polymers/All	–	0.26 PET/All	0.26 PET/All
Exposure	4.8 µg person^{-1} day^{-1}	50 µg person^{-1} day^{-1} 0.8 µg kg^{-1} bw day^{-1}	11 µg person^{-1} day^{-1} 0.2 µg kg^{-1}bw day^{-1}	Weibull distribution $\mu = 0.20$ µg kg^{-1} bw day^{-1} $\sigma = 0.081$ Min = 0.059 Max = 0.426

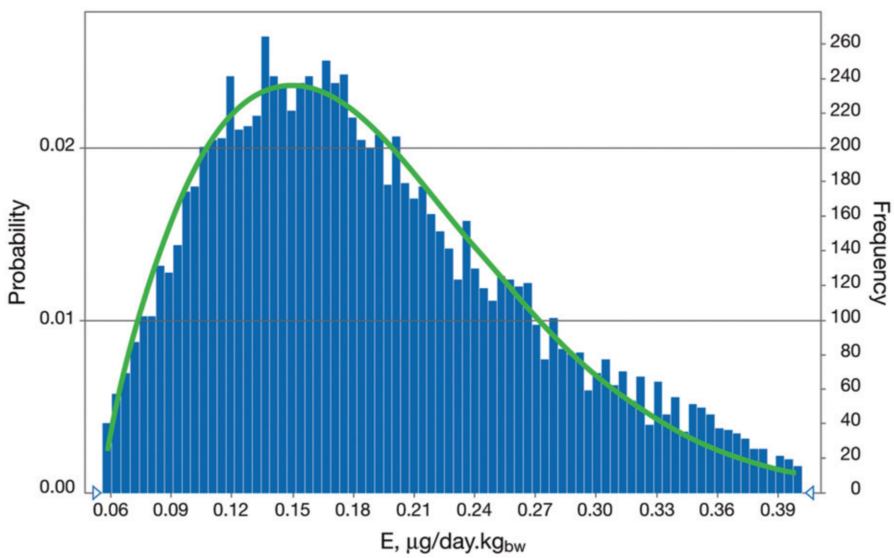

Figure 8. Distribution of values for the exposure estimate of 2-ABA from PET bottles.

which 12% is acidic foods and 85% is milky food (Table 6). The percentage of daily food intake in contact with plastics–multilayer is 6% (Figure 6), of which 54% are fatty foods, 28% are dry foods and 14% are ethanolic (BIBs for wine). These contributions should all be accounted for.

Example of exposure calculation

The results from the exposure calculations with the different assumptions and scenarios are presented in Table 7. In all cases, the concentration of migrant is the same single value set at the maximum migration limit. The USFDA scenario yields an exposure of 4.8 µg person^{-1} day^{-1} that is 10 times lower than the EU scenario, i.e. without considering the CF and FTF – 50 µg person^{-1} day^{-1}. When the CF and FTF obtained in the study are considered and combined with the food intake data for the studied sample, the value is closer to the USFDA value at 11 µg person^{-1} day^{-1}.

For the probabilistic approach, all values of consumer's food intake FW in kg food kg^{-1} bw were considered, instead of the average value only. The distribution of probability values was found to be better described by a lognormal distribution. The distribution function was truncated at the minimum and maximum values found in the study database. The estimates for exposure are presented in Figure 8. The distribution of estimated values is better fitted to the Weibull probability distribution function. The values range from 0.059 to 0.426 µg

2-ABA kg^{-1} bw day^{-1}. From the figure, the different percentiles can be read off, if required.

Conclusions

The results achieved contribute to a refinement and possible correction of current EU assumptions for exposure assessment when applied to a particular population, in this case largely Portuguese urban families of working age, concerning migration of substances from packaging into food. For any particular section of the population, Portuguese consumption patterns may reasonably be expected to be similar to those in other southern European countries with globally similar dietary habits and lifestyles. Therefore, results of this pilot study may have significance beyond the strict national scope. The data collected on consumption and food-type factors, in spite of the limitations inherent to the resources required to conduct such a study, allow for the adoption of a more realistic and more refined approach than the worst-case estimates, combining a probabilistic approach to model variables for which the distribution of values are known. The amount of packaging (in terms surface area) that the consumer uses and the food intake can be combined with migration data for a certain and specific substance that is present in the packaging material in question, and used in Equation (1) to estimate the exposure. The major limitation may be the size of the sample. Nevertheless, the number of packaging items was similar to other studies. For example, a study conducted in British children handled 6500 items (FSA 2006). The sampling method followed proved to be sufficient to gather data for the adults and children combined, but not to consider children only. This consumer segment should be further investigated. In any case, the data framework will be complemented with analyses of data obtained from industry sources.

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