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Time–temperature study of the kinetics of migration of DPBD from plastics into chocolate, chocolate spread and margarine

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Abstract

Migration of low molecular weight substances into foodstuffs is a subject of increasing interest and an important aspect of food packaging because of the possible hazardous effects on human health.

The migration of a model substance (diphenylbutadiene) from low-density polyethylene (LDPE) was studied in foodstuffs with high fat contents: chocolate, chocolate spread and margarines (containing 61% and 80% fat).

A simplifying mathematical model based on Fick's diffusion equation for mass transport processes from plastics was used to derive effective diffusion coefficients which take also kinetic effects in the foods into account and to determine partition coefficients between plastic and food. With this model migration levels obtainable under other storage conditions can be predicted. The effective diffusion coefficients for both margarines stored at 5 °C ($3.0–4.2 \times 10^{-10}$ cm^2 s^{-1}) and at 25 °C ($3.7–5.1 \times 10^{-9}$ cm^2 s^{-1}) were similar to each other, lower than for chocolate spread stored at 5 °C (9.1×10^{-10} cm^2 s^{-1}) and higher than the diffusion coefficient for chocolate stored at 25 °C (2.9×10^{-10} cm^2 s^{-1}). Good agreement was found between the experimental and the estimated data, allowing validation of this model for predicting diffusion processes in foodstuffs with high fat contents.

Keywords: Migration; Plastic packaging; Fatty foodstuffs; Diffusion coefficient; Partition coefficient; Chocolate; Margarine

1. Introduction

Plastic packaging is an indispensable element in the food industry. All polymers allow mass transport processes such as permeation, migration and sorption of low molecular weight substances. However, the extent to which these phenomena occur depends on the properties of the polymers (Tehrany & Desobry, 2004).

Migration of substances into foodstuffs is a subject of increasing interest and an important aspect of food packaging. Low molecular weight substances such as plastic additives (frequently used to improve polymer properties) and residual monomers or oligomers are not chemically bound to the polymer molecules and can therefore move freely within the polymer matrix. Consumers are increasingly aware of the health risks associated with foodstuffs, and the importance of the migration of substances from packaging materials to food has attracted the interest of the scientific and legislative communities.

In accordance with the current legislation, materials intended to come into contact with foodstuffs are regulated by the Framework Regulation (EC) No. 1935/2004 (2004). Because of their unquestionable importance and widespread use, plastics are also regulated by a Specific Directive (EU Commission Directive 2002/72/EC, 2002), which establishes a list of approved monomers, other starting substances and additives authorized for the manufacture of plastic materials, as well as global and specific migration limits. Global migration refers to the total amount of all compounds that migrate into food simulants or foodstuffs.

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It is independent of migration composition. Specific migration is the amount of a certain substance that migrates from the packaging material.

Specific migration tests are often analytically complex and are very tedious and time-consuming. For these reasons the methods of determining many substances have still not been optimized. Foodstuffs are complex matrices, and therefore the legislation allows the use of food simulants (distilled water, 3% acetic acid (w/v), 10% ethanol (v/v) and olive oil) in controlled time/temperature conditions (EU Council Directive 82/711 and amendments, 1982; EU Council Directive 85/572, 1985) to simplify migration tests. Some fatty food simulants may be difficult to analyse, in which case they can be replaced by substitute or alternative fat food simulants (EU Council Directive 82/711 and amendments, 1982; EU Council Directive 85/572, 1985; Cooper, Goodson, & O'Brien, 1998). However, the best approach is to perform migration tests with real food matrices.

Modelling of potential migration is already used by the US Food and Drug Administration (FDA), as a tool to assist in regulatory decisions. The European Union has also accepted migration modelling as an alternative to laboratory testing to ensure food safety (EU Commission Directive 2002/72/EC, 2002). The model should predict the worst migration level but as close as possible to the real value.

The model may replace many migration tests and be used to assure food safety as well as the effectiveness of functional barrier materials (Helmroth, Dekker, & Hankemeier, 2002).

There have been some reports in recent years of worst case migration from packaging to food simulants (Helmroth et al., 2002; O'Brien, Cooper, & Tice, 1997; Pennarun, Dole, & Feigenbaum, 2004; Reynier, Dole, & Feigenbaum, 2002) or food (Hamdani, Feigenbaum, & Vergnaud, 1997) using mathematical modelling. Models that may be used to support regulations for food contact plastics have also been evaluated or simplified (Begley, 1997; Begley et al., 2005; Brandsch, Mercea, Tosa, & Piringer, 2002; Chung, Papadakis, & Yam, 2002; Limm & Hollofield, 1996; Petersen, Trier, & Fabech, 2005).

Migration from a plastic material into foodstuffs usually obeys Fick's laws of diffusion, and is described by two parameters.

The first is the diffusion coefficient, which measures the rate at which the diffusion process occurs. The second parameter is the partition coefficient, $K_{P/F}$, defined as the ratio of the concentration of the migrant in the polymeric material (C_P) and the concentration in the food system (C_F) at equilibrium ($K_{P/F} = C_P/C_F$). When the C_P is higher in the polymer than C_F, then $K_{P/F} > 1$. A higher $K_{P/F}$ is preferred in terms of food safety because migration is limited. The partition coefficients depend on several factors such as the physicochemical structure of food, packaging and migrant, the concentration of migrant, pH, the fat and water contents of the food, and the storage temperatures (Tehrany et al., 2004).

The EU has funded a project called FOODMIGROSURE, the aim of which is to establish a physical-chemical migration model that can describe mathematically the migration processes from plastics into actual foodstuffs (EU Project, 2002; Franz, 2005). Diphenylbutadiene (DPBD), an optical brightener, was selected as a reference substance for contact between fatty food and packaging material (EU Project SPECIFIC MIGRATION, 2000; Stoffers et al., 2004).

The aim of the present study, framed within the FOODMIGROSURE project, was the study of the migration kinetics of DPBD from a low density polyethylene (LPDE) film into chocolate, chocolate spread and margarine with different fat contents (61% and 80%) stored at different temperatures. The data obtained was used to calculate the diffusion and partitioning coefficients, which are important for predicting the specific migration under similar conditions. Diffusion and partition coefficients were determined by fitting the migration curves, i.e., the concentration of DPBD in the selected food items as a function of time, with an analytical solution of Fick's second law of diffusion.

2. Materials and methods

2.1. Plastic film

The film used was a candidate certified reference material (CRM) for specific migration testing. It is an LDPE film (thickness 444 μm) spiked with 1,4-diphenyl-1,3-butadiene (DPBD) (CAS no. 538-81-8, $M_W = 206.29$) and was produced by Fraunhofer IVV (Freising, Germany) according to a defined and recognised protocol (EU Project SPECIFIC MIGRATION, 2000; O'Brien et al., 1997; Stoffers et al., 2004). The initial concentration of the migrant in the polymer ($C_{P,0}$) was 121.4 mg kg^{-1} ± 3.1%, which corresponds to an area related maximum migration value of 491.6 μg/dm^2.

2.2. Sampling

The following fatty foodstuffs were selected for study: chocolate, chocolate spread, and two kinds of margarine with 61% and 80% fat contents (Table 1). All foodstuffs were bought in a local supermarket, except the chocolate, which was kindly supplied by FOODMIGROSURE consortium. Migration tests were carried out under real storage conditions (5 °C and 25 °C) and accelerated conditions (70 °C). The conditions of the migration tests for each of the studied food items and their fat contents, according to the nutrition labelling information, are shown in Table 1.

A total of 10 samples of each food item were prepared for each kinetic curve, for each temperature. For each kinetic time point two samples were removed and analysed as described below.

Table 1
Migration test conditions for the studied food items

Food item	Storage temperature (°C)	Test conditions
Margarine		
−61% fat // 38% water	5	2; 4; 10; 20; 30 d
−80% fat //19.8% water	25	1; 2; 4; 10; 20 d
	70	2; 4; 8; 16; 24 h
Chocolate		
−32% fat // 0.9% water	25	2; 4; 10; 30; 90 d
	70	0.5; 1; 2; 4; 8 h
Chocolate spread		
−31% fat // <2% water	5	1; 2; 4; 10; 20 d

2.3. Contact plastic/foods

Margarine and chocolate spread samples were weighed accurately (approximately 10 g) into glass washers of 0.1 dm^2 diameter and 0.8 cm depth, and were then placed in contact (one side only) with the plastic containing the DPBD (the ratio between the weight of food and the surface area of the plastic in contact was approximately 10 dm^2/kg). For chocolate, a small square was cut and the surface area was measured.

Samples were then wrapped in aluminium foil to protect them from the light, and were placed inside a transparent plastic bag.

The samples were vacuum packed to achieve close contact between the foods and the test film, and were then stored under the different conditions.

2.4. Chemicals and standard solutions

All reagents were analytical grade. Ethanol, acetonitrile (ACN) and hexane were obtained from Merck (Darmstadt, Germany). Ultrapure water was prepared using a Milli-Q filter system (Millipore, Bedford, MA, USA). Diphenylbutadiene (DPBD) (purity 98%) was supplied by Aldrich.

A primary stock solution of DPBD was prepared in ethanol (1.0 mg/ml). Intermediate standard solutions of DPBD were prepared in ACN and hexane (0.1–10.0 μg/ml). Solutions were stored in a refrigerator.

2.5. Sample preparation

The extraction method has already been validated for three representative food items (orange juice, chicken breast meat and Gouda cheese) in a previous study (Sendón-García, Sanches Silva, & Paseiro Losada, 2004). However, the method was optimized for chocolate, chocolate spread and margarine for the present study. Extraction was performed as follows: samples (10 ± 0.01 g) were homogenised with an ultra-turrax homogenizer and extracted with 20 ml of hexane and shaken for 20 min. Organic phases were separated by centrifugation (1036*g* for 20 min). Extraction with 20 ml hexane was repeated and the supernatants were then pooled and evaporated in a rotary evaporator. The fatty liquid residue obtained was extracted with 2 × 20 ml ACN. Collected phases were evaporated in the rotary evaporator and re-dissolved with 10 ml of ACN (v/v). Finally, the solution was filtered and a 50 μl aliquot injected into the HPLC. Recoveries were also calculated for 1 mg/kg food. This procedure allowed acceptable recoveries of DPBD from margarine, chocolate and chocolate spread.

2.6. Chromatography conditions

The HPLC system (Hewlett-Packard, Waldbronn, Germany) was fitted with a HP1100 quaternary pump, a degassing device, an autosampler, a column thermostatting system and a diode array UV detector.

Hewlett Packard ChemStation chromatography software was used for data acquisition. Chromatographic separation was performed with a Kromasil 100 C18 column (15 cm × 0.4 cm I.D., 5 μm particle size) (Teknokroma, Barcelona, Spain) at 30 °C.

A gradient elution method was used. Within the first 2 min the mobile phase was 65% ACN/35% water, after which the proportion of ACN was increased to 100% within 15 min. The total run time of 30 min was used for each analysis to ensure that the column was cleaned between samples. The flow-rate was 1.0 ml/min (Sendón-García et al., 2004).

3. Results and discussion

3.1. Selection of foodstuffs

Migration of compounds from plastic packages into foodstuffs is affected by many factors, but for a given migrant-polymer and under controlled/fixed time/temperature conditions, migration largely depends on the physico-chemical characteristics of the food, especially the fat content. Fats may penetrate into plastics inducing swelling or they may leach migrants (generally lipophilic) due to their ester function (Riquet, Wolff, Laoubi, Vergnaud, & Feigenbaum, 1998). Fat content is one of the parameters that most affects migration of substances into foodstuffs from food contact materials, and therefore three foods with high fat contents were selected for study: margarine, chocolate and chocolate spread.

Margarine, which is an emulsion of water and oil (W/O), has a very high fat content. Moreover, it is a semi-fluid food with low water content and that presents plastic behaviour. It allows very good contact with the packaging and therefore offers good migration potential. The chocolate selected for evaluating DPBD migration, is dark, milk free, and has a cocoa content of 40%. It comprises a dispersion of solid particles in fat, and fat crystals can be form on the surface, in a phenomenon called ‘‘blooming’’. This phenomenon may increase the potential migration of lipophilic substances because pure fat comes in direct contact with the packaging material. Chocolate spread is similar to chocolate but it has paste-like consistency (Steiner & Volansky, 2002).

3.2. Migration levels

The ratio between the amount of DPBD that had migrated at the end of each set of tests carried out at a given storage temperature and the maximum migration level of DPBD (491.6 μg/dm^2) using the selected plastic is shown in Fig. 1a. After storage at 25 °C for 90 days, 98% of the maximum level of DPBD had migrated into the chocolate. This was the highest level found. The level of migration from the chocolate spread was also high (83%) after storage at 20 days at 5 °C.

Accelerated assays (carried out at 70 °C) allowed similar levels of migration to be obtained in less time. For instance, the migration levels obtained with chocolate stored for 30 days at 25 °C were similar to those achieved after storage for 8 h at 70 °C.

The ratio between the amount of DPBD that has migrated to the studied foodstuffs after 10 days of storage and the maximum migration level of DPBD, at different storage temperatures are compared in Fig. 1b.

At a storage temperature of 25 °C, the highest migration occurred in margarine. Differences between the two margarines were negligible (after 10 days of storage, migration in the margarine with 80% fat content was 77%, and in the margarine with 61% fat content, it was 76%). In the chocolate, which has a fat content of 32%, i.e., approximately half of the fat content of the margarine, migration of DPBD was also about the half of that in the margarines stored under the same conditions. This indicates that migration increased with fat content but that after a certain fat content is reached (higher than 60%), the migration level did not change further.

At 5 °C the highest migration occurred in chocolate spread, in which 81% of the DPBD had migrated after 10 days. The migration levels in the two margarines were similar. The results indicate that other parameters also affect migration, e.g. the low water content of the chocolate spread (<2%) in comparison with margarines (20% and 40% water content). Other parameters apart from fat content, such as water content, may also be important in migration of DPBD into foodstuffs.

Legislation foresees the adjustment of the maximum migration levels found in certain foodstuffs comparing with those found in food simulants. Reduction factors are conventionally used to take account of the greater extractive capacity of the simulant for certain foodstuffs. According to the EU Council Directive 85/572/EEC margarine and

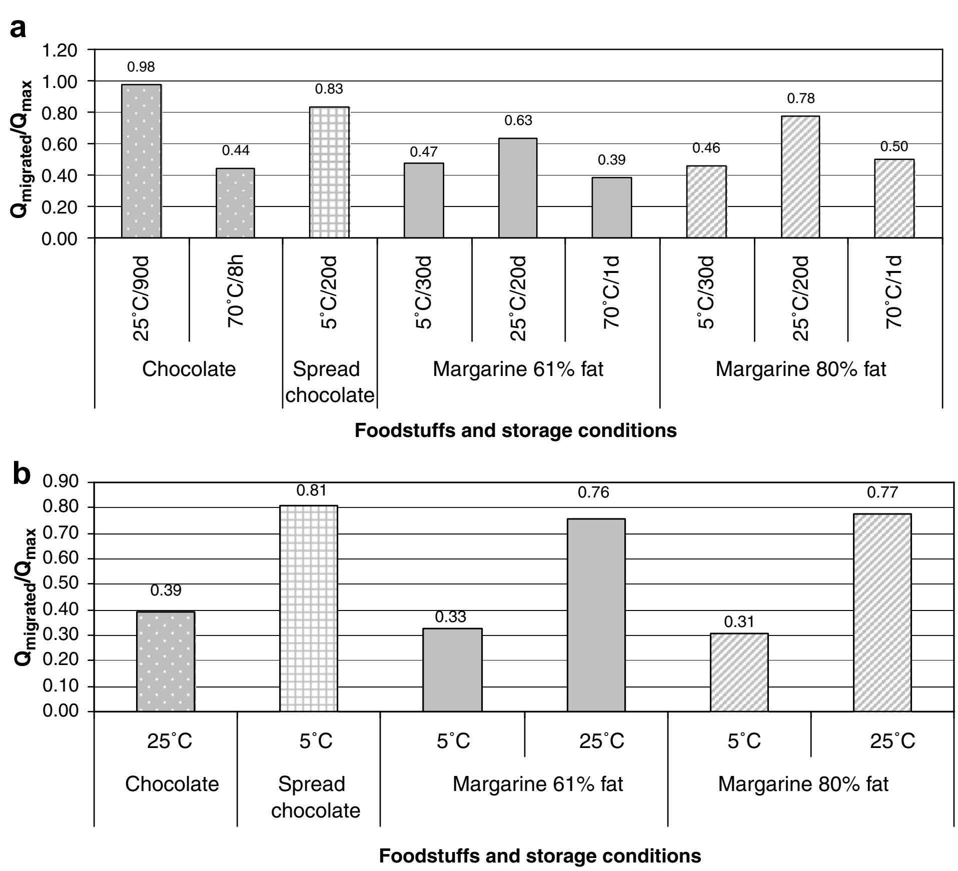

Fig. 1. Amount of DPBD migrated in relation to the maximum quantity that can migrate: (a) at the end of each migration study and (b) after 10 days storage.

chocolate have a reduction factor of 2 and 5, respectively, comparing with the migration level obtained by using olive oil as food simulant. Although we have not carried out the migration test in olive we have compared the migration results obtained with chocolate and margarine with the maximum migration levels that could be achieved if there was a complete migration of DPDB from the plastic material, which would be the worst possible scenario. Regarding our results the migration of DPDB into chocolate at 5 °C is in agreement with this reduction factor, but the results of the migration test carried out with chocolate at 25 °C and margarines did not confirm the legal reduction factors and rather indicated lower values.

3.3. Migration kinetics

3.3.1. Mathematical model

To assess migration of additives and contaminants from food-packaging films, mathematical modelling based on Fick's second Law (Eq. 1) were used. This differential equation describes migration of an additive or contaminant from an amorphous polymeric packaging film:

$$\frac{\partial C_{\mathrm{p}}}{\partial t} = D\frac{\partial^2 C_{\mathrm{p}}}{\partial x^2} \tag{1}$$

where C_{p} is the concentration of the migrant in the packaging film at time t and position x.

An analytical solution of Fick's second diffusion equation for one-dimensional diffusion and limited volumes of packaging and solvent is given by Eq. (2) (Brandsch et al., 2002; Crank, 1975; Piringer, 1994):

$$\frac{m_{F,t}}{A} = c_{\mathrm{P},0}\rho_{\mathrm{P}}d_{\mathrm{P}}\left(\frac{\alpha}{1+\alpha}\right) \times \left[1 - \sum_{n=1}^{\infty}\frac{2\alpha(1+\alpha)}{1+\alpha+\alpha^2 q_n^2}\exp\left(-D_{\mathrm{P}}t\frac{q_n^2}{d_{\mathrm{P}}^2}\right)\right] \tag{2}$$

$$\alpha = \frac{1}{K_{\mathrm{P/F}}}\frac{V_{\mathrm{F}}}{V_{\mathrm{P}}} \tag{3}$$

where $m_{F,t}$ is the mass of migrant from P into F after time t, (μg); A is the area of P in contact with F, (cm^2); $C_{\mathrm{P},0}$ is the initial concentration of migrant in P, (mg/kg); ρ_{P} is the density of P, (g/cm^3); t is the migration time, (s); d_{p} is the thickness of P, (cm); V_{P} is the volume of P, (cm^3); V_{F} is the volume of F, (cm^3); q_n is the positive roots of the equation $\tan q_n = -\alpha \cdot q_n$; D_{P} is the diffusion coefficient of migrant in polymer, (cm^2/s); $K_{\mathrm{P/F}}$ is the partition coefficient of the migrant between P and F.

To allow working with this model also in the investigated cases of polymer–fatty food contact, instead of D_{P}, an effective (for the whole polymer–fatty food system) diffusion coefficient, D, is introduced. Following D_{P} will be replaced where appropriate by this effective D value. In this way a simplified but pragmatic mathematical model can be applied.

In order to predict theoretical migration, the first step was to calculate the positive roots of equation $\tan q_n = -\alpha q_n$. The greater the number of roots, the more reliable the results are. Nevertheless, because of the considerable amount of work involved in the calculation, and in order to make the estimation feasible, 12 roots ($1 \leqslant n \leqslant 12$) were calculated for $0.01 \leqslant \alpha \leqslant 1000$.

Eq. (2) assumes that (1) the additive is initially homogeneously distributed in the polymer, (2) there is no resistance at the polymer/food interface, (3) there is no diffusion from the polymer surface that is not in contact with the solvent and (4) the polymer matrix does not change throughout the migration process (Helmroth et al., 2002).

Experimental data were fitted to the proposed model (Eq. (2)) by nonlinear regression using the Solver function (Microsoft Excel 2003). The measured values and the estimated migration curve for DPBD in margarine with fat contents of 61% and 80% fat respectively, as a function of time are shown in Figs. 2 and 3. The measured values and the estimated migration kinetics of chocolate and chocolate spread are shown in Figs. 4 and 5.

The parameters that determine the migration process are D and $K_{\mathrm{P/F}}$. The model parameters D and α were estimated by using the least-square error criteria, which minimize the sum of quadratic differences between experimental and predicted amounts of migrated DPBD. As a measure of fit, the root of the mean-square error (RMSE) was calculated as

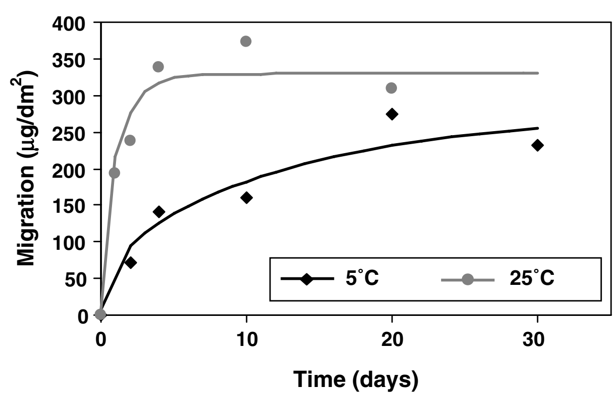

Fig. 2. Migration of DPBD into margarine with 61% of fat content at 5 and 25 °C.

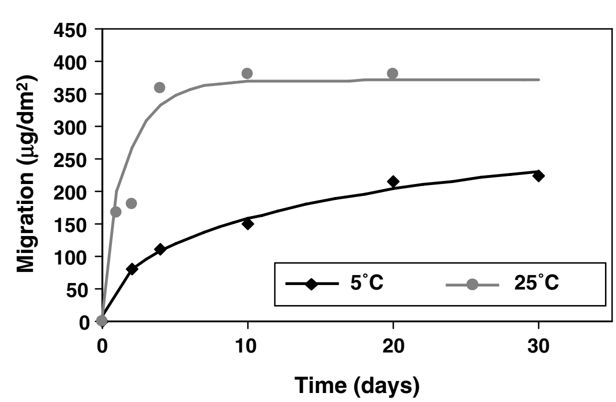

Fig. 3. Migration of DPBD into margarine with 80% of fat content at 5 and 25 °C.

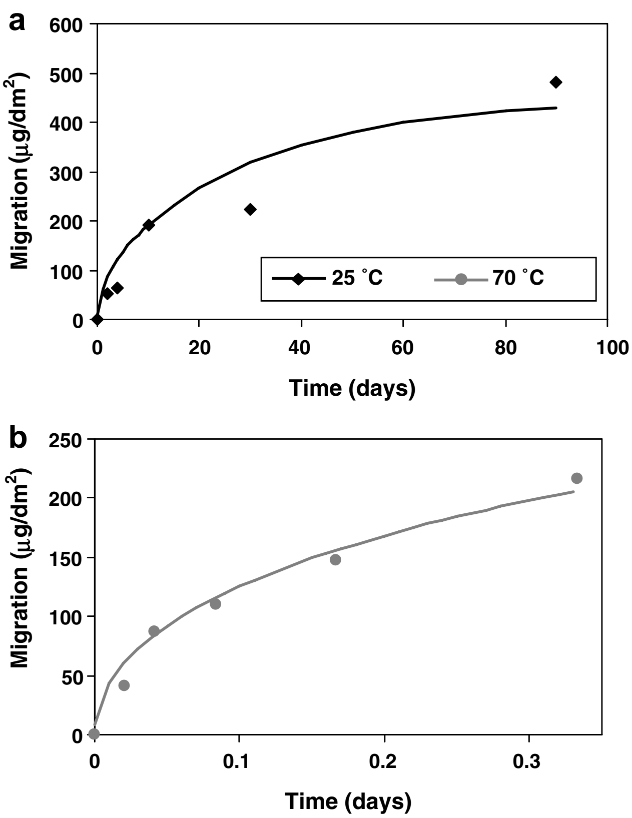

Fig. 4. Migration of DPBD into chocolate: (a) at 25 °C and (b) at 70 °C.

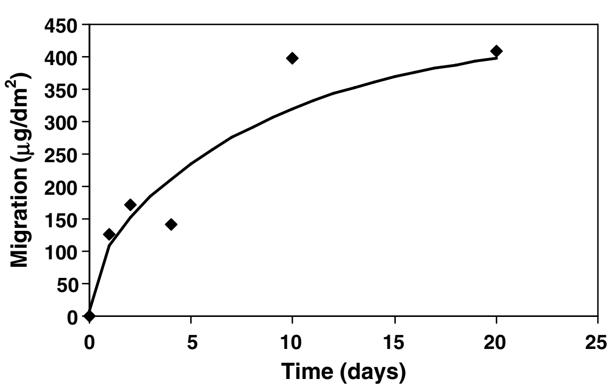

Fig. 5. Migration of DPBD into chocolate spread at 5 °C.

$$\mathrm{RMSE} = \frac{1}{c_{\mathrm{P},0}}\sqrt{\frac{1}{N}\sum_{i=1}^{N}((m_{F,t})_{\mathrm{experimental},i} - (m_{F,t})_{\mathrm{predicted},i})^2} \quad (4)$$

where N is the number of experimental points per migration curve and i is the number of observations (Helmroth et al., 2002).

From the series of experimental data for migration level (µg/dm^2) in relation to time, the model parameters α and D were calculated for each sample and storage temperature. The α and D values for chocolate, chocolate spread and margarines are shown in Table 2. A good correlation was found between experimental and estimated migration values (RMSE lower than 10%, except for chocolate at 25 °C), that is, the obtained migration values and those estimated by Eqs. (2) or (3).

3.3.2. Diffusion coefficients

3.3.2.1. The effect of storage temperature on the diffusion coefficient. Diffusion coefficients were similar for both margarines (Table 2) at 5 and at 25 °C. However, in assays carried out at 70 °C the diffusion coefficient obtained for margarine with a fat content of 80% was higher than for the other margarine. The Arrhenius equation was calculated for margarine with 80% fat content, using the following equation:

$$D = A * \exp(-E_a/R * T) \quad (5)$$

where D is the diffusion coefficient (cm^2 s^{-1}), A is a constant (so called D_o, the theoretical maximum diffusion coefficient at infinite temperature), E_a is the activation energy, R is the universal gas constant (8.314 J mol^{-1} K^{-1}), and T is the temperature (in K).

Diffusion coefficients increased with temperature and showed a good Arrhenius relationship for temperature dependence, taking into account the wide range of storage temperatures ($D = 3.8285 * \exp(-5.2 \times 10^4/R * T)$; $r^2 = 0.95$).

This equation allows prediction of the D value for margarines (with fat content higher than 60%) at any storage temperature between 5 and 70 °C.

Migration tests carried out with chocolate stored at 25 and 70 °C also showed a relationship between diffusion

Table 2
Diffusion coefficients, α, $K_{P/F}$ and RMSE values for margarine (61% and 80% fat), chocolate and chocolate spread

Food item	Storage temperature (°C)	D (cm^2/s)	α	$K_{P/F}$	RMSE (%)
Margarine (61% fat)	5	4.2×10^{-10}	1.3	13.86	5.40
	25	5.1×10^{-9}	2	9.01	6.34
Margarine (80% fat)	5	3.0×10^{-10}	1.2	15.02	1.36
	25	3.7×10^{-9}	3	6.01	8.91
	70	2.7×10^{-8}	1.1	16.38	5.89
Chocolate (32% fat)	25	2.9×10^{-10}	9	3.35	11.67
	70	1.5×10^{-8}	1.6	18.30	2.36
Chocolate spread (31% fat)	5	9.1×10^{-10}	8	2.25	9.90

coefficient and temperature. The diffusion coefficient of chocolate stored at 70 °C was approximately 100 times higher than for chocolate stored 25 °C (Table 2). However it is important to take in account that the physical states of margarine and chocolate change up to 70 °C significantly which explains the increased D values.

3.3.2.2. The effect of fat content. Diffusion coefficients for both margarines at 5 °C were similar to each other and lower than for chocolate spread (9.1×10^{-9} cm^2 s^{-1}) (Table 2). This is consistent with the high migration levels found for chocolate spread.

The diffusion coefficient for chocolate stored at 25 °C (2.9×10^{-10} cm^2 s^{-1}) was lower than those for both margarines, which may be due to the different consistency of chocolate and margarine at 25 °C. However at 70 °C, the consistency of both food items is similar, and the diffusion coefficient for chocolate (1.5×10^{-8} cm^2 s^{-1}) was similar to that calculated for the margarine with 80% fat (2.7×10^{-8} cm^2 s^{-1}). These results indicate that there is no relationship between fat content and diffusion coefficient in the food items studied.

3.3.3. Partition coefficients

The partition coefficient ($K_{P/F}$) was calculated from the α values and polymer and food volumes, using Eq. (3). The V_P for all assays with margarines and chocolate spread was 0.44 cm^3 and the V_F was 7.9 cm^3. For chocolate stored at 25 °C, the V_P for all assays was 0.27 cm^3 and the V_F was 7.8 cm^3. For storage at 70 °C, the V_P for the chocolate was 0.75 cm^3, and the V_F was 22.1 cm^3. The $K_{P/F}$ values calculated for all foodstuffs studied are shown in Table 2.

The $K_{P/F}$ values correspond to the relative solubility of the migrant at equilibrium between the plastic and the foodstuff (Begley et al., 2005). In order to calculate $K_{P/F}$ it is important that kinetic curves have reached equilibrium. Analysis of Figs. 2–5 revealed that margarines stored at 25 °C have reached equilibrium. The $K_{P/F}$ values calculated for margarines stored at 5 °C, chocolate and chocolate spread should be interpreted carefully because equilibrium was not reached at the end of the assay.

There was relationship between $K_{P/F}$ values and the amount of DPBD that had migrated at the end of each migration study as a function of the maximum quantity that can migrate from the plastic material ($Q_{\text{migrated}}/Q_{\max}$). The $K_{P/F}$ values increased as the $Q_{\text{migrated}}/Q_{\max}$ values decreased (Table 2 and Fig. 1b), and the correlation coefficient was high ($r^2 = 0.97$).

4. Conclusions

The results obtained in the present paper provide reliable information regarding the migration of model migrants in foodstuffs with a high fat content, such as chocolate, chocolate spread and margarine.

According to the results, the migration levels in margarines with 61% and 80% fat content were similar, which suggests that for higher fat contents (>60%) the level of migration is not affected by this parameter.

A simplifying mathematical model based on Fick's second Law was used to simulate the measured migration kinetics. There was very good correlation between the experimental and the modelled values. This is of great interest, for both the food industry and quality control laboratories, because it should allow migration prediction and as a consequence a reduction in the number of analyses required to test if plastic materials comply with regulations.

The results indicate that storage temperature has greater effect on the values of the coefficient diffusion, whereas the fat content has a greater effect on the values of $K_{P/F}$. However, in addition other physico-chemical properties of fatty foodstuffs, such as water or protein content, may further affect the key parameters in migration phenomena.

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