Migration of odorous compounds from adhesives used in market samples of food packaging materials by chromatography olfactometry and mass spectrometry (GC-O-MS)

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Abstract.

Adhesives are commonly used in the manufacture of multilayer food packaging materials. Although they are not in direct contact with the packed food, their compounds may migrate from the adhesive through the substrates to the food. The aim of this work is to determine the migrant concentration in order to evaluate the possible human risk and also to determine if this migration could affect the organoleptic properties of packed food. For this purpose, a total of 12 market samples of multilayer materials (laminates) for packaging dry food (tomatoes, cakes, cookies, breadcrumbs, flour or salt) and fresh food (pizza and pastry) produced with 5 different adhesives were analyzed by GC-O-MS. A total of 25 different compounds from adhesives were detected in these laminates. 76% of these compounds migrated into a dry food simulant (Tenax ®). Furthermore, compounds with concentrations below the MS detection limit were detected by sniffers with a high modified frequency (MF %). Acetic acid, butyric acid and cyclohexanol with vinegar, cheese and camphor odors were the most abundant compounds.

All migration data were below specific migration limits (SML) and threshold toxicological concern (TTC) recommended values according to the Cramer classification.

Introduction.

Adhesives are commonly used in the packaging industry. They can be used to manufacture multilayer packaging materials (laminates) where different substrates are combined (metal plate, aluminium foil, sheet tinplate, metallized films, common polymers, paper, cardboard or glass), to form the geometric shape of the package (for example in the paper and cardboard industries), or to affix labels (Ashley, Cochran, & Allen, 1995). Although they are used in food contact materials, no specific legislation exists in the EU for adhesives. They must comply with the Framework Regulation (EC) Nº 1935/2004 (Regulation (EC) Nº 1935/2004) that covers all food contact materials, and the ‘‘Plastics Directive’’(Commission regulation (EU) Nº 10/2011) when adhesives are applied on plastic materials. Despite the lack of specific European Legislation about adhesives, they are covered in recent Spanish Legislation (Real Decreto 847/2011) and recommendations on their use are currently being discussed by the Council of Europe.

The general principles set down in the Framework Regulation are inertness and safety. Inertness is defined in terms of a maximum overall migration limit (OML), referring to the maximum total amount of all substances that can be transferred from contact materials to food. Safety is measured with specific migration limits (SML), the maximum amount of a single substance that can be transferred to the food. SML is based on a toxicological evaluation of the substance and can also be expressed as a tolerable daily intake (TDI). The analysis of migration from food contact materials to food can be performed in the foodstuff itself or in food simulants (Regulation (EC) Nº 1935/2004; Commission regulation (EU) Nº 10/2011).

Migration is a mass transfer phenomenon, resulting from a tendency to balance all chemical potentials within a system. The migration of a compound from a food contact material to food depends on the chemical and physical properties of the compound, the food and the polymer. These may include the migrant concentration, molecular weight, solubility, diffusivity, partition coefficient between polymer and food, time, temperature, polymer and food composition, and structural properties. (Begley, Castle, Feigenbaum, Franz, Hinrichs, Lickly, et al., 2005; Catalá & Gavara, 2002; Gnanasekharan & Floros, 1997; Tehrany & Desobry, 2004)

Although in most applications adhesives are not in direct contact with food, it has been demonstrated that once incorporated into the packaging their constituent compounds diffuse through the material and may establish surface contact with the food (Barnes, Sinclair, & Watson, 2007). This potential migration has already been extensively studied in previous works (Aznar, Canellas, & Nerin, 2009; Aznar, Vera, Canellas, Nerin, Mercea, & Stormer, 2011; Canellas, Aznar, Nerin, & Mercea, 2010; Cristina Nerin, Gaspar, Vera, Canellas, Aznar, & Mercea, 2012; Vera, Aznar, Mercea, & Nerin, 2011), and a great variety of migrant compounds are included in the framework of the European research project MIGRESIVES. However, less attention has been paid to off flavor or odorant compounds that could migrate to food, changing its organoleptic properties (Deschenes, Arbour, Brunet, Court, Doyon, Fortin, et al., 1995; Goulas, Riganakos, & Kontominas, 2004; Kontominas, Goulas, Badeka, & Nerantzaki, 2006; Linssen, Rijnen, Legger-Huiysman, & Roozen, 1998; Welle, Mauer, & Franz, 2002). This is an important issue given that adhesives are manufactured with different chemical substances which constitute a source of off-flavors that could affect packaged food, causing consumer complaints.

The main objective of this work is to study the migration of odorous compounds from adhesives used in laminates currently on the market to a food simulant (Tenax ®). The technique selected for this purpose is gas chromatography-olfactometry and mass spectrometry (GC-O-MS) (Fuller, Steltenkamp, & Tisserand, 1964). This allows odorous compounds to be simultaneously detected by two detectors, chemical detection by mass spectrometry and sensory detection by the human nose. The latter is often more sensitive than the former, and is capable of detecting migrant compounds at very low concentrations. Therefore, the study not only quantifies the possible mass transfer of odorous compounds in terms of possible human risk. It also evaluates the odor intensity of the migrant compounds detected by sniffers which could change the organoleptic properties of the packed food, producing a negative effect on the quality of the product.

Before the migration assay, a list was obtained of the possible migrant odorous compounds that can be found in adhesives contained in laminates. A previous study by Vera et al. (Vera, Uliaque, Canellas, Escudero, & Nerin, 2012) analyzed five different types of adhesives (hotmelt, vinyl acetate, starch, polyvinyl acetate and acrylic) commonly used in the manufacture of laminates.

In this work, the migration of compounds from twelve different market laminates used for food packaging was studied. The laminates contained the five above-mentioned types of adhesives glued to different types of substrates such as cardboard, paper and polypropylene coated cardboard. This study completes the previous work done on the identification of the odorous compounds in adhesives responsible for off-flavors in food packaging materials

2. Materials and methods

2.1. Reagents

The standards ethyl acetate (141-78-6), methyl methacrylate (80-62-6), toluene (108-88-3), hexanal (66-25-1), paraldehyde (123-63-7), p-xylene (106-42-3), butyl propanoate (590-01-2),1 -butanol (71-36-3), butyl acrylate (141-32-2), styrene (100-42-5), p-cymene (99-87-6), 2-octanone (111-13-7), 1-hexanol (111-27-3), 2-ethylhexyl acetate (103-09-3), nonanal (124-19-6), cyclohexanol (108-93-0), acetic acid (64-19-4), 2-ethyl-1-hexanol (104-76-7), camphor (76-22-2), propanoic acid (79-09-4), benzaldehyde (100-52-7), 1-octanol (111-87-5) butyric acid (107-92-6), methyl benzoate (93-58-3), naphthalene (91-20-3), allyl benzoate (583-04-0), and 4-tert-butylphenol were purchased from Sigma-Aldrich Química S.A (Madrid, Spain). All of them had analytical quality with purity above 98%. Dichloromethane, acetone and acetic acid were supplied by Scharlau Chemie S.A (Sentmenat, Spain). All of them were HPLC grade. Solutions of 4-tert-butylphenol at 1000 µg/g either in dichlorometane or in acetone were used as internal standard solutions A or B, respectively. Tenax TA 80/100 mesh supplied by Supelco (Bellefonde, USA) was used as solid simulant.

2.2. Market samples.

Twelve multilayer materials used as food contact materials forming a laminate structure [substrate 1–adhesive–substrate 2] have been studied in this work. The samples were market samples provided by different European companies and used for different packaging purposes. Some were for packaging dry food (tomatoes, cakes, cookies, breadcrumbs, flour or salt) and others for fresh food (pizza and pastry).

These laminates were manufactured from five different types of adhesives: one hotmelt (HM) adhesive based on ethylene vinyl acetate (EVA); one vinyl acetate ethylene (VAE) adhesive with diethylene glycol dibenzoate as plasticizer; one starch; one acrylic (ACR) and one polyvinyl acetate (PVA) adhesive containing triacetin as plasticizer. No more precise information about these adhesives was provided for confidentiality reasons.

Most of the substrates used for the laminate manufacture were cardboard (CB), but polypropylene coated cardboard (p_CB) and paper (paper) with different gramages and thickness were also used.

Table 1 shows the adhesives and substrates with their gramages and thickness used for laminate manufacture. The amount of adhesive applied per dm^2 of the laminate (gramage) was calculated from the mass difference of the packaging samples and the substrates. The volume to surface factor (dF) was calculated as the volume of food inside the packaging (dm^3) divided by the surface of the packaging that contained the adhesive (dm^2).

2.3. GC-O-MS

The gas chromatograph (GC) system was a CP-3800 Varian connected to a Saturn 2000 series with an ion trap mass detector and ODO I sniffing port supplied by SGE (Ringwood, Australia). Chromatographic separations were carried out on a BP-20 (30 m x 0.25 mm x 0.25 µm) obtained from SGE analytical science (Madrid, Spain). The oven temperature program was as follows. The initial temperature was set at 40°C (5 min), then raised from 40 to 220ºC at 10 °C/min, and the final temperature was maintained for 10 minutes. Helium was used as carrier gas at 1 mL/min flow. The ionization was performed by electronic impact, the ion trap temperature was 220 C; and the electron multiplier voltage was 1600V. Acquisition was carried out in SIM mode (characteristic ions are shown in Table 2). Injection was carried out by liquid injection where 1µL of the sample was injected in splitless mode from 30 ºC (0.15 min) to 250ºC at 200ºC/min with 25 psi as pulse pressure. The split valve was opened 2.5 min after the injection.

2.4. Determination of the initial concentration of the odorous compounds released by the adhesives in the laminates studied.

To determine the concentration of the odorous compounds previously identified in the market samples (Vera, Uliaque, Canellas, Escudero, & Nerin, 2012), a liquid extraction of the laminates (lam_01, lam_03, lam_06, lam_08 and lam_11) was carried out following the procedure optimized by Vera et al (Vera, Aznar, Mercea, & Nerin, 2011) . The rest of the laminates were not extracted since they had the same amount of adhesive per dm^2 and therefore the same concentration of these odorous compounds. The methodology was as follows. 1 gram of laminate was cut into small pieces and extracted three consecutive times with 2.5 mL of dichloromethane during 24 hours at 40 ºC. The three extracts were mixed and 10 µL of A solution were added as internal standard. The solution was concentrated under a stream of pure N_2 to 200 µL and analyzed by GC-MS. Two replicates of each sample were analyzed.

Previously, in order to know the toxicity of the compounds found, they were evaluated in accordance with the Cramer rules using Toxtree v1.51 software (Ideaconsult Ltd.) (Threshold of toxicological concern (TTC), 2005).

For building the calibration curves, solutions of the compounds at different concentration levels were prepared in dichloromethane and analyzed by GC-O-MS. Three replicates of each concentration level were analyzed.

2.5. Migration test.

Migration tests from these laminates were carried out using Tenax ® as food simulant since these kinds of laminates are commonly used for packaging dry food and Tenax is the recommended simulant for the migration test. In addition, liquid simulants cannot be used with cardboard packaging.

The migration tests were performed following the procedure optimized by Vera et al (Vera, Aznar, Mercea, & Nerin, 2011): Cutouts of each laminate, 1 x 8.5 cm in size, were placed in Petri dishes and covered with 0.34 grams of Tenax forming a uniform layer, 4 g Tenax per dm^2 laminate in accordance with UNE-EN 14338 (UNE-EN-14338, AENOR. 2004). Tenax was applied on the side of the laminate that comes into contact with food. This set was kept in the oven at 40 ºC for 10 days (UNE-EN-14338, AENOR, 2004). After that, it was extracted two consecutive times with 3.4 mL of acetone. The two extracts were put together and 10 µL of internal standard solution B were added. Finally, the total solution was concentrated under a stream of N_2 to 200 µL.

Two replicates of each laminate were prepared and analyzed by GC-O-MS. Six panelists sniffed the migrant sample eluted from the chromatographic column. They had to check the odor compounds previously identified from the adhesives (Vera, Uliaque, Canellas, Escudero, & Nerin, 2012) and also to characterize them by their intensities and their odor. They assigned 1 to the weakest odor, 2 to a clear perception of odor and 3 to an extremely strong intensity of odor. The modified frequency was then calculated (MF%) according to the equation [1]

$$MF(\%) = [F(\%) x I(\%)]^{0.5} \qquad \text{[Eq.1]}$$

where F(%) is the percentage of the sniffers who detected the odorous compounds and I(%) is the percentage of intensity calculated by the mean of the values of intensity given by all panelists (Dravnieks, 1985).

This methodology allowed us to check compounds which were not detected by mass spectrometry. They were able to be detected by the human nose because of the higher sensitivity of the sensory eruption. This fact is very important in the study of migration of compounds to food since the organoleptic properties of the packaged food could be affected.

The concentrations of the migrant odor compounds were calculated as µg of the compound that migrated to Tenax ® (food simulant) per dm^2 of laminate in contact with it. The values were expressed as mg of compound per Kg of food using 6 dm^2 of laminate. This ratio corresponded to 1 kg of food simulant established by the EU Regulation (Commission regulation (EU) Nº 10/2011), and these values were compared with the specific limit of migration SML (Commission regulation (EU) Nº 10/2011; Real Decreto 847/2011).

From these data, the estimated daily intake (EDI) established by the FDA (Food and Drug Administration of United States) (Rock, Barsan, & Weimar, 2008) was calculated using the following equation [2]:

EDI(mg/personxday)=mig (mg/Kg)x3Kg(food intake per person and day)xCF [Eq.2]

where CF is the fraction of the daily diet expected to be in contact with a specific packaging material (for adhesives, CF is 0.14).

In order to check the possible human risk, these migrant values (EDI) were compared to the maximum values for human exposure (mg per person per day) established by Cramer for each toxicity class. The values for class I, II and III are 1.8; 0.54 and 0.09 mg per person per day, respectively (Threshold of toxicological concern (TTC), 2005).

3. Results and Discussion.

The main aims of this work are to determine the migration of the odor compounds from the adhesives used in multilayer food packaging materials to a food simulant. These odor compounds were previously identified in these adhesives (Vera, Uliaque, Canellas, Escudero, & Nerin, 2012).

The samples under study were market samples manufactured with the adhesives glued to different substrates to form laminates used for packaging dry food such as tomatoes, cakes, cookies, breadcrumbs, flour and salt, or for packaging fresh food such as pizza or pastry.

After the migration test, the extract was analyzed by GC-O-MS in order to check whether six panelists would be able to detect the odorous compounds and to evaluate their intensity and odor. The concentration of each migrant was measured and the migrant values obtained were compared to the specific migration limits (SML) and to the values recommended by Cramer for each class of toxicity, according to the specific classification.

3.1. Concentration of the odorous compounds from the adhesives in the laminates studied.

To determine the initial concentration of the adhesives HM, VAE, Starch, PVA and ACR in the different market laminates, they were extracted by dichloromethane and analyzed by GC-O-MS.

The analytical parameters of the GC-O-MS method and the ions used for their quantification are shown in Table 2. Good results were obtained in terms of linearity, limits of detection (LOD) and reproducibility. LOD values were between 0.01 µg/g (toluene) and 25.7 µg/g (acetic acid). RSD values were below 9.74 %.

Due to the difficulty in finding the standards of longifolene and calamenene (whose quantization ions were 161 and 159, respectively), they were quantified using naphthalene as standard.

Most of the odorous compounds found in the laminates were classified as having class I toxicity according to the Cramer rules (Table 3 and Table 4). Three compounds (Table 3 and Table 4) were of class II toxicity (cyclohexanol, allyl benzoate and calamenene) and three compounds (paraldehyde, camphor and naphthalene) were of class III toxicity.

The concentrations of the odorous compounds for the laminates manufactured with HM, VAE and Starch adhesives are shown in Table 3 and for PVA and ACR adhesives in Table 4. They are expressed as µg of compound per dm^2 of laminate.

For the HM adhesive in lam_01 (Table 3), the most abundant compound was p-cymene whose concentration corresponded to 7.9±1.2 $\mu g/dm^2$. This compound is a constituent of essential oils coming from the resin used for the manufacture of this kind of adhesive (Vera, Aznar, Mercea, & Nerin, 2011) (Jeong-Ho, Yang, Lee, & Hong, 2008). Three compounds identified in the previous work (Vera, Uliaque, Canellas, Escudero, & Nerin, 2012) (acetic acid, butyric acid and methyl butyrate) were not quantified because their concentrations were below their LODs or LOQs, respectively.

For the VAE adhesive in lam_03 (Table 3), the highest concentration was found for acetic acid (200±18 $\mu g/dm^2$). Acetic acid is commonly used in the manufacture of vinyl acetate adhesives to produce the monomer, vinyl acetate, by the addition of acetic acid to ethylene. As occurred with the adhesive HM, butyric acid, methyl butyrate, 1-butanol and nonanal were not found.

For the Starch adhesive in lam_06 (Table 3), only three compounds were quantified (methyl benzoate, allyl benzoate and naphthalene). The rest of the compounds had concentrations below their LODs or LOQs. Methyl benzoate had a concentration of

2.5±0.2 µg/dm^2 and allyl benzoate of 1.5±0.1 µg/dm^2. The benzoate ester derivates are commonly used as plasticizers (Petrie, 2000).

In the PVA adhesive (Table 4), the most abundant compound was again acetic acid with a concentration of 8500±680 µg/dm^2. This is used for the manufacture of vinyl acetate adhesives, as explained above. Ethyl acetate, whose concentration was 470±42 µg/dm^2, is a highly volatile ester with wide applications as a solvent for coating formulas such as varnishes and adhesives based on polyvinylacetate, ethyl cellulose, cellulose acetate butyrate and propionate low-viscosity cellulose acetate, polymethylmethacrylate, polyvinyl-butyral, polystyrene and synthetic rubbers (Petrie, 2000). 1-butanol was also found in a high concentration (57±6.8 µg/dm^2), as it is used as a solvent in adhesives.

For the ACR adhesive (Table 4), the most abundant compound found in lam_11 was 2-ethyl-1 hexanol (82±7.4 µg/dm^2). Together with 2-ethylhexyl acetate (11±1.4 µg/dm^2), this compound is likely to be an impurity of the methyl methacrylate used to manufacture this type of adhesive (Canellas, Aznar, Nerin, & Mercea, 2010; Nerin, Canellas, Aznar, & Silcock, 2009).

3.2 Migration test.

The migration assay was carried out with Tenax ® as a food simulant, since most of the laminates contained paper or cardboard in their structure. Besides, the use of liquid food simulants was not possible because they would have damaged the substrates and/or the structures of these laminates.

After the migration test, the extracts of Tenax ® were analyzed by GC-O-MS for two purposes. Firstly, to sniff the samples and evaluate the migrants according to the MF (%) and secondly, to calculate the concentration of the migrants in order to check if the concentrations were below the specific migration limit SML and the values recommended by Cramer.

The migrant concentrations and their MF (%) are shown in Table 3 for the laminates manufactured with HM, VAE and Starch adhesives and in Table 4 for the laminates with PVA and ACR adhesives. Migration values are expressed as µg compound per dm^2 of laminate and the MF(%) criteria previously established was to be higher than 20%.

Sixty six percent of the number of compounds previously detected (Vera, Uliaque, Canellas, Escudero, & Nerin, 2012) migrated to Tenax ®. For the adhesive HM (Table 3), the migrant compounds with the highest migration concentrations in both laminates (lam_01 and lam_02) were p-cymene and nonanal. These compounds were also detected by the sniffers with MF of 41% and 31%, respectively. The concentrations of all the migrant compounds were higher in lam_01 than lam_02. This can be explained by the fact that migration is a phenomenon which is closely related to the partition and diffusion coefficients. The partition coefficient between adhesive (HM) and the substrates CB and ppCB is related to the solubility of the compounds in both media. This solubility is called the Hildebrand solubility parameter (δ), which is a numerical value that indicates the relative solvency behavior of a specific compound (AIC, 1984; Durkee, 2004; Tehrany & Desobry, 2004). When their intermolecular attractive forces are similar, and therefore similar δ values are required for good solubility, the migration of the compounds is expected to be similar too. It is known from a previous work (Vera, Aznar, Mercea, & Nerin, 2011) that the solubility of the adhesive EVA is $\delta \sim 17.5$ $MPa^{1/2}$ and that of polypropylene is $\delta \sim 16$ $MPa^{1/2}$. In the case of lam_01, the compounds with similar solubility to EVA have a high tendency to stay in the adhesive (high partition coefficients) and therefore a low degree of migration. In contrast, in lam_02, if the compounds have a similar solubility to the polypropylene coating in the cardboard, their partition coefficients decrease and therefore the migration increases. The solubility of the compounds found in these adhesives was closer to the EVA adhesive than to polypropylene (solubility for 1-butanol, p-cymene, nonanal and naphthalene corresponded to $\delta \sim 23.1$, 18.6, 17.6 and 20.3 $MPa^{1/2}$ respectively) (AIC, 1984) and therefore their partition coefficients are lower in lam_01 than in lam_02. This could explain why the migration to lam_01 was higher than lam_02. Besides, the presence of a PP coating in the cardboard seems to reduce migration processes because it reduces diffusion.

In the case of the adhesive VAE (lam_03, lam_04 and lam_05 from Table 3), only four compounds migrated to Tenax ® (toluene, p-xylene, cyclohexanol and benzaldehyde). P-xylene and cyclohexanol only migrated from lam_05, and the migration values of the other two compounds (toluene and benzaldehyde) were higher than those found in this laminate. This could be explained by the characteristics of this laminate. Due to the type of cardboard used for its manufacture, it had a lower gramage and thickness and therefore the diffusion through the substrates increased (Dole, Feigenbaum, De la Cruz, Pastorelli, Paseiro, Hankemeier, et al., 2006). Some compounds not found in the specific migration analysis were detected by the sniffers with a MF (%) ranging from 23% to 38 %. These include cyclohexanol, acetic acid and methyl benzoate associated with with camphor, vinegar and sweet odors. The concentrations of these compounds were above their sensory threshold (detected by the human nose) but below their LODs or LOQs (detected by mass spectrometry).

Of the compounds found in the Starch adhesive laminate (methyl benzoate, naphthalene and allyl benzoate), only the allyl benzoate compound did not migrate to the Tenax® in the lam_06 and lam_07 (Table 3). The migration values of the other compounds were very similar in both laminates. The major migrant compound was methyl benzoate with a value of 1.3±0.09 $\mu g/dm^2$ in lam_06. As already mentioned, some compounds which did not migrate to Tenax ® were detected by the sniffers. Examples are acetic, butyric and propanoic acids with pungent odors associated with vinegar, cheese and rancid, respectively, with a MF(%) ranging from 20 to 33 % , or the compounds hexanal and paraldehyde with a grassy and pungent odor, respectively.

In the laminates manufactured from PVA adhesive (lam_08, lam_09 and lam_10 from Table 4), the compounds with the highest values of migration were ethyl acetate and 1-

butanol, both compounds with a high initial concentration in the laminates. Although the acetic acid had a high concentration in the laminate, its migration value was below its LOQ (85.6 µg/dm^2). However, this compound together with cyclohexanol was detected by the sniffers with a MF(%) higher than 27%. Ethyl acetate had the highest migration value, but the sniffers were not able to detect it because it was eluted at the same time as the solvent.

For the laminates glued using ACR adhesives (lam_11 and lam_12 from Table 4), five out of eight compounds were found in the migration test. The compound with the highest migration was 2-ethyl-1-hexanol with a migrant concentration of 25±2.2 µg/dm^2 for lam_11 and 6.5±0.5 µg/dm^2 for lam_12. It was also detected by the sniffers with the highest MF(%), 73 and 55%. Although the camphor did not migrate, it was detected with a lower MF(%) by the sniffers. Comparing both laminates, the same tendency was found as with the HM adhesive where the migrant concentration was higher in lam_11 (substrates of cardboard) than in lam_12 (substrates of polypropylene coating cardboard).

The migration values were calculated as µg of compound per dm^2 of laminate as well as on weight basis (mg of compound per Kg of food) to compare them to specific migration limits (SML) (Commission regulation (EU) Nº 10/2011; Real Decreto 847/2011). Only toluene and 2-ethyl-1-hexanol reached their SML, corresponding to 1.2 mg/Kg (Real Decreto 847/2011) and 30 mg/Kg (Commission regulation (EU) Nº 10/2011), respectively. For lam_03, 04 and 05, the migration result for toluene was 0.02±0.002 µg/dm^2, which corresponded to 3.13 E-7 mg/Kg, 5.87 E-7 mg/Kg and 2.86 E-7 mg/kg, respectively (for volume to surface factor dF of 63.9, 34.1 and 70.1 dm^3/dm^2, respectively). The values for 2-ethyl-1-hexanol in the laminates lam_11 and lam_12 were 25±2.2 and 6.5±0.5 µg/dm^2, respectively, corresponding to 0.067 and 0.017 mg/Kg (for dF of 0.37 dm^3/dm^2 in both laminates). These values were below their SML.

The estimated daily intake (EDI) was calculated for the rest of the compounds. None of the migration values exceeded the recommended Cramer exposure values.

Conclusion

The migration of the odorous compounds coming from adhesives used in market multilayer samples used for food packaging has been studied. These samples have been analyzed by the GC-O-MS method. This is demonstrated to be a useful and reliable tool not only for calculating the migrant concentrations in order to evaluate possible human risk, but also for having these migrant compounds detected by sniffers and thus establishing whether they could affect the organoleptic properties of packaged food. A wide range of compounds were found in the laminates. Of these, 66% of the compounds migrated onto Tenax ®, although their migrant concentrations were below their specific migration limits (SML) or the recommended Cramer values. Some compounds not found by the mass spectrometry detector in the specific migration analysis were found by sniffers with a high MF(%) value. For example, acetic acid, butyric acid and cyclohexanol with vinegar, cheese and camphor odors were clearly detected using GC-O-MS. This emphasizes the importance of using this methodology in order to identify these compounds at very low concentrations. This is very important given that the odorous compounds could affect the properties of the packed food, giving rise to consumer complaints, higher production costs or even a possible loss of brand confidence and market share.

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Table 1: Laminates code, adhesive types and substrates with their gramage (g/m^2) and thickness (µm) used for the laminate manufacture, volume surface factor (d_F) and grams de adhesive per dm^2 of laminate

Laminate codes	Adhesive type	Substrate1/Substrate2 (Gramage g/m^2 ,thickness µm)	d_F(dm^3/dm^2)	$g_{adhesive}/dm^2_{laminate}$
Lam_01	HM	CB/CB (380 g/m^2, 350 µm)	17.1	0.313
Lam_02	HM	p_CB/ p_CB (410 g/m^2, 510 µm)	17.1	0.313
Lam_03	VAE	CB/CB (350 g/m^2, 479µm)	63.9	0.491
Lam_04	VAE	CB/CB (350 g/m^2, 439 µm)	34.1	0.491
Lam_05	VAE	CB/CB (245 g/m^2, 443 µm)	70	0.491
Lam_06	Starch	Paper/Paper (38 g/m^2, 43 µm)	97.8	0.389
Lam_07	Starch	Paper/Paper (35 g/m^2, 45 µm)	398.5	0.389
Lam_08	PVA	CB/CB (350 g/m^2, 502 µm)	52.3	1.02
Lam_09	PVA	CB/CB (290 g/m^2, 428 µm)	52.3	1.02
Lam_10	PVA	CB/CB (300 g/m^2, 390 µm)	52.3	1.02
Lam_11	ACR	CB/CB (380 g/m^2, 350 µm)	37	0.156
Lam_12	ACR	p_CB/ p_CB (410 g/m^2, 510 µm)	37	0.156

HM: hotmelt; VAE: vinyl acetate ethylene; PVA: polyvinyl acetate; ACR: acrylic; CB: cardboard; p_CB: coated cardboard; d_F: volume surface.

Table 2: Analytical parameters of the GC-MS method

Compounds	**QI**	**Equation**	**R^2**	**Linear range (µg/dm^2)**	**LOD(µg/dm^2)**	**LOQ(µg/dm^2)**	**RSD (%)**
Ethyl acetate	43	y=0.4519x-0.6893	0.996	15.1-207	4.52	15.1	5.35
Methyl methacrylate	69	y=0.7854x-2.4924	0.993	0.33-20.4	0.09	0.33	4.57
Toluene	91	y=2.9631x-6.8071	0.996	0.02-15.8	0.01	0.02	5.17
Hexanal	44	y=0.6518x-0.2329	0.994	0.27-20.3	0.08	0.27	9.31
Paraldehyde	45	y=1.1999x-0.0541	0.998	2.17-30.1	0.65	2.17	4.38
P-xylene	91	y=2.1282x-0.6657	0.983	0.11-25.3	0.03	0.11	2.03
Butyl propanoate	57	y=0.9859x+0.3714	0.994	0.22-10.3	0.07	0.22	3.19
1-butanol	56	y=0.431x+0.5377	0.997	0.23-102	0.07	0.23	9.74
Butyl acrylate	55	y=2.0651x-3.126	0.989	0.98-23.7	0.29	0.98	8.61
Styrene	104	y=1.3898x+0.6425	0.983	0.07-4.73	0.02	0.07	5.46
P-cymene	119	y=1.1056x-2.3972	0.984	1.46-31.4	0.44	1.46	5.42
2-octanone	43	y=0.4631x+0.086	0.997	0.08-12.3	0.03	0.08	8.89
1-hexanol	56	y=1.1205x-1.561	0.989	1.23-25.4	0.37	1.23	8.29
2-ethylhexyl acetate	43	y=1.3717x-2.8737	0.995	0.26-40.4	0.08	0.26	4.23
Nonanal	57	y=0.3919x-0.6328	0.999	0.54-21.3	0.16	0.54	3.61
Cyclohexanol	57	y=1.5305x-1.0218	0.997	0.86-33.5	0.26	0.86	1.51
Acetic acid	43	y=0.067x+14.695	0.992	85.6-1050	25.7	85.6	2.83
2-ethyl-1-hexanol	57	y=1.3245x-0.034	0.991	5.93-186	1.78	5.93	4.61
Camphor	95	y=0.7745x+0.5557	0.997	0.24-19.7	0.07	0.24	5.99
Propanoic acid	74	y=0.2688x-10.313	0.984	65.1-1170	19.5	65.1	3.53
Benzaldehyde	106	y=0.6982x-1.2539	0.999	0.46-22.4	0.14	0.46	3.21
1-octanol	56	y=0.2232x+0.084	0.995	0.47-34.8	0.14	0.47	7.06
Butyric acid	60	y=0.622x-1.6504	0.996	32.4-760	9.71	32.4	9.11
Methyl benzoate	105	y=1.5326x-1.7061	0.999	0.36-46.5	0.11	0.36	2.85
Naphthalene	128	y=3.7331x-2.1625	0.989	0.03-13.7	0.01	0.03	1.32

Allyl benzoate	105	y=1.3672x-3.5529	0.997	1.07-17.5	0.32	1.07	3.93

QI: quantification ions, LOD= 3 x standard deviation of black measure x slope of calibration measure and LOQ = 3.3 x LOD

Table 3: Odorous compounds identified in the market laminates came from the adhesives HM, VAE and Starch, toxicity class according to Cramer rules (TC), odor description, quantification ions (QI), initial concentration of the odorous compounds in the laminate expressed as µg of compound per dm^2 of laminate and migration values in Tenax expressed as µg of compound per dm^2 of laminate and modified frequency (MF%) calculated according to the equation [1].

Compounds (TC)	**Odor**	**HM (µg/dm^2)**	**Mig(µg/dm^2) Lam_01 (MF%)**	**Mig(µg/dm^2) Lam_02 (MF%)**	**VAE (µg/dm^2)**	**Mig(µg/dm^2) Lam_03 (MF%)**	**Mig(µg/dm^2) Lam_04 (MF%)**	**Mig(µg/dm^2) Lam_05 (MF%)**	**Starch (µg/dm^2)**	**Mig(µg/dm^2) Lam_06 (MF%)**	**Mig(µg/dm^2) Lam_07 (MF%)**
Toluene (I)	Paint				0.09±0.01	0.02±0.002	0.02±0.002	0.02±0.002	<LOQ	<LOQ	<LOQ
Hexanal (I)	Grass, fat								<LOQ	<LOQ	<LOQ
Paraldehyde (III)	Pungent								<LOD	<LOD (28%)	<LOD (23%)
P-xylene (I)	Sweet				0.1±0.02	<LOQ	<LOQ	0.1±0.009			
1-butanol (I)	Medicine	0.2±0.04	0.2±0.03	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Butyl acrylate (I)	Pungent fruit								<LOD	<LOD	<LOD
P-cymene (I)	Gasoline	7.9±1.2	7.3±1.0 (31%)	2.7±0.2							
1-hexanol (I)	Resin				2.6±0.2	<LOD	<LOD	<LOD (22%)			
Nonanal (I)	Fresh	0.8±0.1	0.8±0.1 (41%)	0.6±0.08(39%)	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Cyclohexanol (II)	Camphor				1.9±0.3	<LOD (24%)	<LOQ (31%)	0.7±0.08(51%)			
Acetic acid (I)	Vinegar	<LOD	<LOD	<LOD	200±18	<LOD (32%)	<LOD (23%)	<LOD (37%)	<LOD	<LOD (22%)	<LOD (20%)
Propanoic acid (I)	Rancid								<LOD	<LOD (33%)	<LOD (22%)
Benzaldehyde (I)	Burnt sugar				2.5±0.2	0.5±0.03(28%)	0.5±0.04(35%)	0.6±0.04(35%)			
Longifolene (I)	Woody	0.4±0.06	0.1±0.02(22%)	<LOD							
Butyric acid(I)	Cheese	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOQ	<LOD (22%)	<LOD (20%)
Methyl benzoate (I)	Aromatic				0.6±0.07	<LOD (24%)	<LOD (26%)	<LOD (38%)	2.5±0.2	1.3±0.09	1.1±0.09
Methyl butyrate (I)	Cheese	<LOQ	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Naphthalene (III)	Tar	0.4±0.05	0.2±0.03(28%)	<LOQ					0.2±0.01	0.1±0.008(21%)	0.03±0.003(20%)
Allyl benzoate (II)	Sweet, floral								1.5±0.1	<LOQ	<LOQ
Calamenene (II)	Herb spice	0.4±0.07	0.3±0.06(22%)	0.2±0.02(20%)							

Table 4: Odorous compounds identified in the market laminates came from the adhesives PVA and ACR, toxicity class according to Cramer rules (TC), odor description, quantification ions (QI), initial concentration of the odorous compounds in the laminate expressed as µg of compound per dm^2 of laminate and migration values in Tenax expressed as µg of compound per dm^2 of laminate and modified frequency (MF%) calculated according to the equation [1].

Compounds (TC)	**Odor**	**PVA (µg/dm^2)**	**Mig(µg/dm^2) Lam_08 (MF%)**	**Mig(µg/dm^2) Lam_09 (MF%)**	**Mig(µg/dm^2) Lam_10 (MF%)**	**ACR (µg/dm^2)**	**Mig(µg/dm^2) Lam_11 (MF%)**	**Mig(µg/dm^2) Lam_12 (MF%)**
Ethyl acetate (I)	Fruity, sweet	470±42	56±3.9	65±5.8	72±6.5			
Methyl methacrylate (I)	Sharp fruity					8.7±0.8	4.5±0.5	4.0±0.4
Hexanal (I)	Grass, fat	1.2±0.1	0.8±0.07	1.2±0.1	1.2±0.1			
Butyl propanoate (I)	Earthy, sweet					0.2±0.02	<LOD	<LOD
1-butanol (I)	Medicine	57±6.8	41±3.7 (22%)	56±5.1 (27%)	44±3.5 (23%)	1.2±0.1	<LOD	<LOD
Butyl acrylate (I)	Pungent fruit					1.2±0.1	1.1±0.1 (31%)	1.1±0.1
Styrene (I)	Gasoline, balsamic					0.07±0.06	0.003±0.0004(20%)	<LOD
2-octanone (I)	Herb, resin	0.3±0.03	0.1±0.01 (33%)	0.2±0.01 (34%)	0.2±0.01 (33%)			
1-hexanol (I)	Resin, green	9.7±1.2	<LOD	<LOD	<LOD			
2-ethylhexyl acetate (I)	Sharp					11±1.4	8.5±0.7 (52%)	2.5±0.3 (23%)
Cyclohexanol (II)	Camphor	4.0±0.36	<LOD (27%)	<LOD (32%)	<LOD (31%)			
Acetic acid (I)	Sour, like vinegar	8500±680	<LOQ (33%)	<LOQ (35%)	<LOQ (35%)	<LOD	<LOD	<LOD
2-ethyl-1-hexanol (I)	Green					82±7.4	25±2.2 (73%)	6.5±0.5 (51%)
Camphor (III)	camphor					<LOD	<LOD (21%)	<LOD
1-octanol (I)	moss, mushroom					1.0±0.08	<LOD	<LOD
Butyric acid(I)	Rancid, cheese	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD