PACKAGING–FOOD INTERACTION AND CHEMICAL MIGRATION

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Food packaging is intended to protect food and extend its shelf life, but it may affect food quality and safety because of chemical migration. Food quality and safety regarding packaging is a significant global concern. Legislations have an essential role in providing regulatory guidance on quality assurance systems and verifying their implementation as a means of regulatory compliance. The large number of various materials used in the manufacture of packages complicates the evaluation of food–packaging interactions. This review is an overview of literature data on the effects of printed food packaging on the migration of chemicals into foods, as well as on various migration sources of chemical compounds. Various aspects, such as the interaction between packaging and food starting with the production process of food packaging to food–packaging contact during storage, the effects of primary and secondary packaging on chemical migration, permeability of packaging materials, ink-induced migration in printed packaging, and types of transition from packaging to food, were examined in detail. Besides, studies on subjects such as the food contact materials analysis used to test the phenomenon of migration in foods and migration limits have been discussed. Moreover, studies on the use of recycled paper in packaging and its effect on migration, ink chemicals resulting from recycling and studies on this subject are included. Information is given on measures to reduce the effect of migration, low migration of printing inks, coatings and adhesives, and materials used in barrier applications. In line with this research study, suggestions were made for measures to reduce the harmful effects of chemical migration on human health and to prevent the risk of migration from packaging to food.

Keywords: food packaging, food and migration, ink migration, contamination, chemical migration

INTRODUCTION

Today, more than 95% of foodstuffs are packaged. The primary purpose of the packaging, which has become an integral part of the products in the preservation, logistics, display, and even cooking of the foods, is to protect the product from production to consumption. The concept of protection mentioned here refers to the isolation of the packaged product from external environmental effects and the existence of a physical barrier to protect the product from the external environment.[1]

Packaging protects food against spoilage caused by external factors, such as harmful odours, micro-organisms, light and oxygen.[2] Chemical migration is the transfer of some chemical compounds present in the packaging material to the food under certain conditions.[3] Transition of chemicals from packaging to food may adversely affect food quality and safety.[2] Potential migrant sources for packaging production include: low molecular mass (<1000 dalton) components of inks, overprint lacquers and adhesives, raw materials of the substrate, coating monomers, washing and cleaning chemicals, fountain solvents and non-intentionally added substances (NIAS).[4]

Food contamination refers to the formation of toxic chemicals and microbial pathogens that can produce adverse health effects. Packaging materials are an underestimated source of chemical food contamination. When packaging components migrate into food, odour, taste and aroma (organoleptic), changes may occur in the food.[5-8] Therefore, food contact materials should not contain components that may cause an unacceptable change in food and endanger human health.

Chemical migration is the mass transfer from the external source into food by sub-microscopic processes. Migration affects food in two ways: 1) it may affect food safety by migration of harmful components into food; and 2) it may affect food quality by migration of substances that impart taint or odour. Migration may occur from food packaging materials and articles through the processes of food manufacture, transport and storage, food preparation and consumption.

Different food contact materials may be used for packaging, such as plastic, glass, metal and alloys, printing inks, varnishes and coatings, ion-exchange resins, waxes, textiles and ceramics. Materials like glass and metal/alloys can be classified as inert materials. In contrast, others, such as plastics, printing inks, varnishes, and coatings, are defined as permeable materials, which allow the migration process. In the packaging process, together with ink and overprint coatings, packaging substrate components also significantly impact chemical migration. The packaging material can be a complex, coextruded or laminated structure, manufactured using different adhesives and polymers as substrates, which can be coated by varnishes and printing inks.[9] Recently, there has been an increased interest in developing new, more environmentally friendly packaging substrates. Among these substrates, the products made from vegetable fibers attract most attention.[10]

Biodegradable, highly recyclable and environmentally friendly paper and cardboard products, which are also encouraged by the energy and ecology authorities, are increasingly preferred to polymer films.[11] Increasing consumer demands for safer products require extensive research on migration in packaging production.[12] This review examines food packaging in terms of the effects of the printing process, packaging permeability, and recycling, together with paper and ink, on migration of chemicals, and then some suggestions are made to diminish the risks of migration.

Packages can be divided into two general categories according to their functional properties. Primary packaging is the packaging that is in direct contact with the product for the protection of the product. Secondary or distribution packages are packages containing one or more primary packages.[1]

The primary packaging is assumed to provide adequate protection against substance transfers. However, not all inner packaging offers this protection. In cases where the secondary packaging is used directly, without the primary packaging, the unprinted inner side of the packaging material comes into direct contact with the food. Migration into food can occur from either package.

When multi-layer materials are used in food packaging, migration from layers may occur due to diffusion and partitioning processes.[5] Castle *et al.* have shown in their study that any component of an ink system can cause migration, even if it does not come into direct contact with food.[13]

The packaging is expected to not affect the foodstuff. However, primary and secondary packaging may have different impact risks on foodstuffs.[14] The effect of primary packaging in direct contact with food or secondary packaging wrapping the primary packaging on foodstuffs is open to debate. In primary and secondary packaging, the point to be considered is that the transition from the whole packaging to the food should be within the limits of the regulation.[4]

PACKAGING AND FOOD INTERACTION

Food and beverages can interact strongly with the materials they come into contact with. The nature of the product to be packaged has a direct impact on migration. Fatty foods are more prone to migration than dry foods. Chemicals in food contact material can be harmful when ingested in significant quantities by the food, or they may give a stain or odour to the food, negatively affecting its quality.[2]

Interactions between packaging and food pose a significant risk to food. The interactions between the packaging and the foodstuff are related to the physicochemical properties of the packaging material, ink and food, changing environmental conditions, the foodstuff volume and the packaging size.[15] Other factors affecting migration include: packaging substrate type and content (carton, plastic, silicone *etc.*); the permeation of the packaging material; characteristics of foodstuffs (fatty, acidic, dry); chemical structure of migrants (vapour pressure, polarity, molecule size, *etc.*); direct or indirect contact of packaging material with food; contact surface area (1 dm^2, 1 lt, 1 gallon); contact time, as well as temperature and humidity parameters.[2,16]

Fengler reported that the migration value will increase with contact time and temperature.[17] If the packaging that comes into contact with food is not controlled, product contamination values reach legal levels very quickly. Even if contamination is not toxic or dangerous in any sense, it often causes financial damage.

Permeability is the process by which gases, vapours or liquids are transported through the walls of the package, both inward and outward. Therefore, the permeability of the packaging substrate has an impact on the possibility of migration.

The permeability of the packages differs according to the materials from which they are produced. For example, the permeability of paper and cardboard materials is related to their porous structure.

CHEMICAL MIGRATION

Chemical migration is a phenomenon known as passing of chemical compounds present in the packaging to the food. In other words, it transfers low molecular weight compounds from packaging materials to food. Migration is usually caused by packaging materials, printing inks, overprinting varnishes, cellophane, adhesives and printing chemicals (Table 1).

Migration mechanisms

Food labels and packaging may transfer ink components to food products under normal conditions of use – this is called ink migration. The passage of harmful components from ink into food adversely affects the composition, smell, taste and appearance of the packaged food, causing the food to deteriorate and ultimately endangers human health. When migration occurs, it compromises product safety and threatens consumer well-being. The migration of printing ink components from printed packaging material to food can occur by direct migration, diffusion (penetration) migration, set-off migration, and gas phase transfer (evaporation) mechanisms (Table 2).[20]

Direct migration through the substrate

In cases where the food is in direct contact with the package, a direct transition from the package to the food may occur. Low-molecular weight substances from the substrate, ink and overprint varnish films can pass from the packaging to the food inside in two or three phases (Fig. 1).

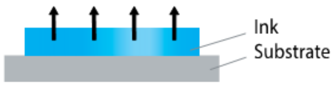
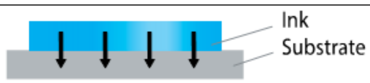
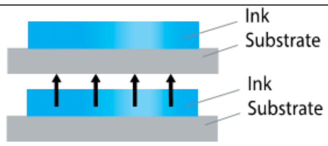
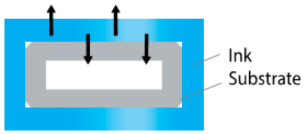
The most commonly used low-molecular weight solvents that can pass into foods through direct contact (or the space inside the packaging) are organic substances consisting of hydrocarbons, alcohols, glycol ethers, ketones, and esters.[12] Also, when polymer-based packaging materials come into contact with certain foods, they can release, for example, monomers, additives, colourants and impurities (Fig. 2).[2,24]

In fibrous and coated materials, such as paper and cardboard, harmful chemical compounds, synthetic fillers, adhesives, and other additives can pass directly from the packaging to the food. The migration processes for paper-based materials are complex. Paper and board are heterogeneous porous materials, which differ from polymers in terms of their sorption and diffusion behaviour, as well as partition coefficients.[25]

Table 1
Influencing factors in migration of chemicals[18]

Materials	• Substrate • Printing inks • Varnishes • Adhesives
Printing press	• Cleanness/hygiene • Conditions of printing press • Production speed with UV inks
Others	• Design • Traceability process of materials • Logistics • Storage

Table 2
Possible mechanisms of chemical migration[4]

1	*Direct migration –* transfer from print to food, in situations when the food is in direct contact with the print	
2	*Diffusion migration –* penetration through the substrate to the reverse side of the print	
3	*Set-off migration –* set-off from the print to the reverse side during storage of packaging in a pile (“invisible set-off”)	
4	*Gas phase migration –* volatilisation of compounds during cooking	

Diffusion migration

Diffusion refers to the spontaneous transfer of substances from a denser medium to a less dense one. In this process, molecules move randomly depending on their kinetic energy. This migration is valid for small-sized compounds (below 1000 Da). Substances known as migrant ink components can penetrate from the printed side to the unprinted side of the printing substrate, and from there to the food due to their low molecular size (molecular weight <1000 daltons). This is called diffusion migration. This type of migration is related to the porosity or permeability of the substrate and the characteristics of the ink.[26]

The kinetic dimension of migration indicates how fast the migration process occurs. The thermodynamic dimension determines how intense the transfer to the material will be (Fig. 3).

Testing conformity with certain migration limits in packages can be evaluated by applying generally accepted diffusion models based on scientific evidence.[20] Diffusion migration can be described by diffusion mathematics derived from Fick’s Law. The diffusion rate is expressed by the following Equation (1), known as Fick’s second law:

$$\partial C_p / \partial_t = D\,(\partial^2 C_p / \partial x^2) \quad (1)$$

where C_p (mg/g) – the concentration of the migrant in the polymeric material, D (cm^2/s) – the coefficient of diffusion, t (s) – the time the diffusion takes place, x (cm) – the distance between the package and the food.[27]

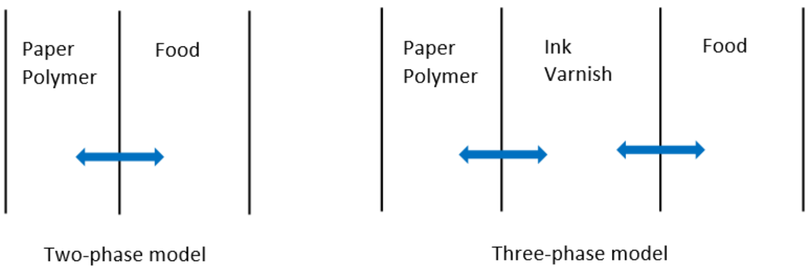


Figure 1: Direct and indirect types of migration

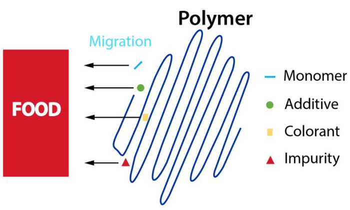


Figure 2: Migration from the packaging material

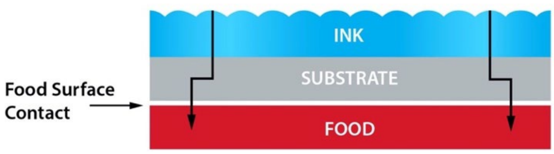


Figure 3: Diffusion migration

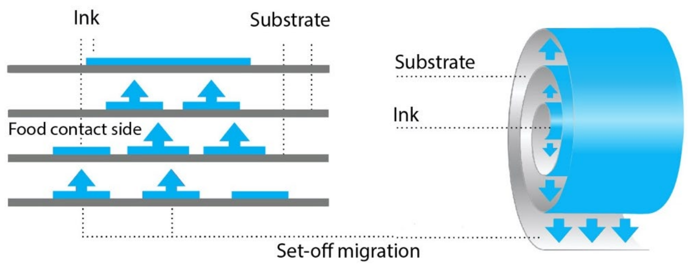


Figure 4: Migration from printed to unprinted side of packaging

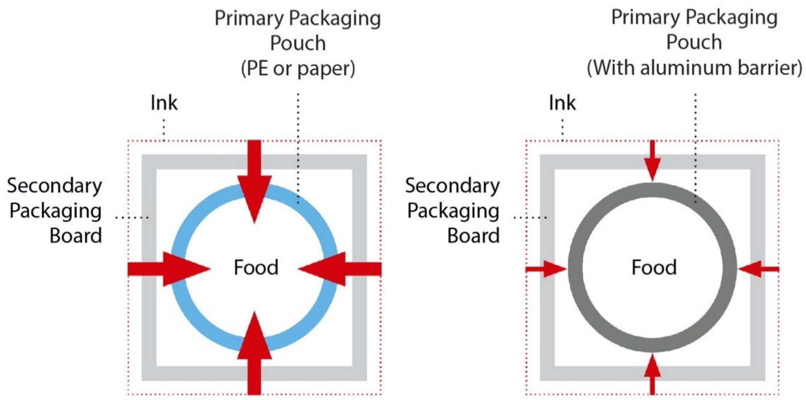


Figure 5: Gas phase migration

Set-off migration

Set-off migration means that, due to contact between printed and unprinted substrates, ink components from the printed substrate surface are transferred to the unprinted substrate surface (crossover of substances from the printed side to the opposite side). Wet or uncured ink film components on the printed surface of the packaging substrate or label migrate by contact to the unprinted bottom surface of the next substrate (the surface that will contact food). Usually, this unprinted side is the food contact side (Fig. 4).[28]

Set-off migration in substrates increases with pressure in the printed stack or reel.[5] Ink compounds on the printed substrate surface, which will then come into contact with the food, can be transferred to the packaged food. This contact also occurs in vending machines for hot drinks (coffee, milk coffee *etc*.). In this type of machines, cups made of plastic-coated cardboard and printed on the outside are stacked. Set-off migration can occur when cups are stacked within each other. When these printed cups are separated from each other, the ink or coating components move from one cup to the other cup because of the set-off effect. In this case, the chemical compounds migrate to the hot beverage.[29]

Gas phase migration

Solvents may be defined as complex chemical mixtures containing several different types of hydrocarbons, such as small aerosolisable aromatic molecules and vaporising as VOCs and as alkanes, alcohols, ketones, aldehydes, esters, ethers.[30]

Mineral oils (MOSH and MOAH) in oil-based inks and slow solvents in solvent-based and water-based inks have the potential to be retained in packaging and subsequently transferred to food.[4] This transition does not need direct contact between food and packaging.[31] Volatile compounds from mineral oil and solvents in printing inks can pass from permeable packaging materials to food through the gas phase (Fig. 5).[28,32]

Changing environmental conditions can drive migration.[4] At room temperature, almost only molecules with less than 25 carbon atoms (MOSH and MOAH) evaporate, and some pass into food.[31] Gas phase migration mainly occurs in packages where food can be heated, boiled or baked.

Ink migration

Printing inks are an essential source of migration for food packaging. Like all other materials that make up packaging, printing inks are made up of many different components. Additives, colourants (pigments, dyestuffs), binders (polymeric resins, *etc*.), solvents (oils, *etc*.), oligomers, monomers and photoinitiators are different groups of raw materials used in packaging inks.[19] These compounds may include intentionally added substances (IAS) or non-intentionally added substances (NIAS).[20]

Even if the surface (inside) of the package that comes into contact with food is unprinted, in cases where the substrate permeability is high, the contaminants in the ink printed on the outside of the package may come into contact with the food, and migration may occur. Aznar *et al*. observed the migration of ink components printed on the outside of food packaging to the inside.[5]

Even when only permitted raw materials are used in inks, non-intentionally added substances can pass into food. NIAS can result from impurities of raw materials, degradation processes, chemical reactions between components (*e.g.* crosslinking of the inks), contamination processes or previous manufacturing steps.[9]

Information must be obtained on potentially transportable substances, potential interactions and contamination risks, and possible ink restrictions. Possible impurities and cross-contamination (IAS or NIAS) in raw materials should also be considered.

UV inks based on acrylic acid chemistry derivatives are cured by chemical polymerisation.[21] During the curing process, non-crosslinked, small photoinitiator molecules and acrylate monomers are potential migration sources for packaging. Therefore, special care should be taken when printing primary food packaging with UV inks.[22] Aparicio *et al*. concluded that using polymeric photoinitiators is the best option over conventional photoinitiators for ultraviolet curing inks and varnishes used to print food packaging.[23]

Migration from recycled paper packaging materials

Fiber-based packaging greatly contributes to the circular economy, it has a higher recycling rate than other materials by volume. The latest consumer preference trends show that paper and cardboard packaging is in the top due to its environmental friendliness, easy recyclability and sustainability features. Paper and cardboard produced from partially or completely recycled fibers are already used for packaging certain food products.[33] However, recycled cartons used in packaging production can transfer undesirable compounds to the food that they come in direct contact with. For this reason, when evaluating the suitability of recycled cardboard for use as a raw material, the possibility of transferring components to the food during use (food type, contact time and temperature), the quality of the recycled paper, its source and the processes applied in recycling should be considered.[34]

The recycling process of paper can transfer harmful compounds into newly produced packaging, which could cause chemical migration to food. Although processes (such as deinking, cleaning and bleaching) are carried out to remove certain contaminants (ink, lacquer, solvent, *etc*.) in paper recycling processes, how effective these cleaning processes are in terms of preventing chemical contamination and migration is open to discussion.[35] Ink contents, which cannot be separated entirely from the printed paper fibers in the recycling process, can be transferred to the pulp to be newly produced. Cartons made from this recycled pulp carry a greater risk of migration.

Recycling paper for reuse is environmentally beneficial, but it is not just the paper's fibrous structure that enters the production cycle. Chemicals used for paper recycling and remanufacturing (bleach, paper reinforcing agents, sulfate, sulfur, *etc*.) and chemical-containing materials (ink, varnish, solvent, *etc*.) previously used in the printing process are also included in this recycling. Chemicals that have penetrated the fiber structure of used waste paper are a potential cause of migration in the transfer of unwanted chemicals to paper recycling and remanufactured cardboard products.

Waste papers contain several materials, including fillers, starch, wet/dry strength chemicals, sizing agents, coating chemicals, some adhesives, colouring additives, and various inks.[36] In the paper recycling process, harmful chemicals in waste paper and their transfer to newly produced cardboard packaging are potential reasons for migration.[35] Because of the presence of ink solvents in previously printed paper fibers that cannot be removed by recycling, re-manufactured cardboard packages continue the risk of migration, even if they are unprinted.

In particular, papers (newspaper papers, *etc.*) printed with inks that dry by penetration and oxidation (*e.g.* cold-set ink) can transfer the mineral oils they contain to packaging and food after recycling. In the research carried out by Boccacci *et al.*, it was determined that DIPN (diisopropyl naphthalene) transferred into the packaging from the cardboard produced by recycling carbonless photocopy paper.[37] According to the research conducted by Vinnagard *et al.*, it was concluded that kitchen rolls made of recycled paper contain higher levels of toxic metals than paper rolls made from virgin fibres.[38] Other studies in the literature have shown that many types of organic pollutants can potentially migrate to packaged foods. However, there have been few reports on the sources of these compounds in paper-based packaging materials.[11] Chemicals detected in paper and cardboard intended to come into contact with food are classified as indicated in Table 3.[34]

Table 3
Chemicals detected in printed paper and cardboard

Category	Chemical
Chemicals subjected to tests if known to come into contact with moist and oily food	Heavy metals (cadmium (Cd), lead (Pb), mercury (Hg)), azo dyes, pigments, inks, optical brighteners (FWAs)
Chemicals tested only on recycled paper	Polycyclic aromatic hydrocarbons (PAH) (0.01 mg/kg), di-n-butyl phthalate (DBP) (0.3 mg/kg), diethylhexyl phthalate (DEHP) (1.5 mg/kg), diisobutylphthalate (DiBP), SUM DBP + DiBP (0.3 mg/kg), benzylbutylphthalate (BBP), (30 mg/kg), diisononyl phthalate (DINP) (9 mg/kg), diisodecyl phthalate (DIDP) (9 mg/kg), benzophenone (0.6 mg/ kg), diisopropylnaphthalene (DIPN)
Chemicals tested if known to come into contact with both recycled papers and moist and oily food	4,4'-bis (dimethylamino) - benzophenone (Michler's ketone) (0.01 mg/kg), 4,4'-bis (diethylamino) benzophenone (DEAB) (0.01 mg/kg), Bisphenol A (0.6 mg/kg)

Ink components in recycled paper

Recycling paper and cardboard is encouraged in terms of sustainable use of materials. However, in the paper recycling process, the ink components that have entered the paper structure cannot be removed entirely from the paper fibers. Many cardboard manufacturers often use secondary and primary fibers in their cardboard production.

According to the results of the research conducted by Pivnenko *et al.*, mineral oils, phthalates, parabens, phenols and inorganic contaminants were found in higher concentrations in packaging produced from recycled paper, compared to virgin fiber-based products. It has been stated that these pollutants have a higher potential to cause migration into foodstuffs.[39] In the study of Maurus Biedermann *et al.*, butyl phthalates found in recycled cardboard have been detected to pass into food by direct contact.[26] Thus, the point to be considered is whether paper and cardboard printed with inks containing migrant chemicals will be included in the recycling process. In cases where the ink and pigment are not sufficiently cleaned during the recycling process, it may cause chemicals (residual solvents and mineral oils) to be transported from the recycled, unprinted papers into the final packaging via the gas phase.[12] The main migrating chemicals occurring in recycled paper are discussed below.

Mineral oils (MOAH and MOSH), which form the solvent part of offset printing ink, are various hydrocarbon groups mainly produced from crude oil. Petroleum-based oils are known to emit volatile compounds harmful to the environment, all creatures, and humans and cause problems in recycling print substrates.[40] Most of the mineral oil in recycling packaging comes from recycled newspapers, other commercial prints and packaging. During printing, these oils in the ink penetrate the paper or cardboard. Mineral oils, which are not completely separated from the paper fibers during recycling, are transported to the recycled paper and cardboard. The fact that these cartons contain mineral oil and are reincorporated into the packaging increases the migration to food.

Mineral oils contain two ingredients: saturated hydrocarbons (MOSH) and aromatic hydrocarbons (MOAH). MOSH and MOAH can have a harmful effect on health, if they get to contaminate foodstuffs during the manufacturing process or through packaging.[26] In a large-scale study conducted in 2012 by the German Federal Ministry of Food, Agriculture and Consumer Protection, raw recycled cardboard packages have been found to contain 78 to 524 mg migrant MOSH/kg and 19 to 97 mg migrant MOAH/kg, depending on quality.[31]

Inorganic chemicals, especially toxic metals, are mostly used in inks and coatings.[39] The most common ink-borne toxic metals found in recycled paper are Cadmium (Cd), Cobalt (Co), Chromium (Cr), Copper (Cu), Nickel (Ni) and Lead (Pb).[35]

Phenols and parabens – polycyclic aromatic hydrocarbons (PAH) and Bisphenol A (BPA) belong to the phenol class. Phenolic resins are used in printing inks and as polyester binders for coating paper. Phenolic resins react with drying oils to produce offset varnishes. This results in strong, glossy films with good adhesion and alkali resistance. Aromatic hydrocarbons, such as toluene and xylene, are strong resin solvents. According to the results of the study by Vinnagard *et al*., substances such as PAH and BPA cause pollution in materials containing recycled cellulose. Therefore, there is a need to identify harmful chemicals in recycled paper for direct food contact in terms of their potential toxicological effects.[38]

Phthalates are used as plasticisers in many applications in the food packaging industry, such as printing inks, varnishes, and adhesives. Plasticisers are substances that make the ink softer and more flexible, and allow it to adhere better to the substrate. Examples of plasticisers are citrates, resins, chlorinated substances, adipates and phthalates. These materials are widely used in flexo and screen printing inks. Although these inks are not in direct contact with food, it has been determined that the phthalates they contain can transfer to packaging material and food.[41] In the research conducted by Binderup *et al*., DIPN and DEHP were found in the papers produced from recycled newspapers and magazines. Both phthalates caused migration to food, but did not exceed the specific migration limit. Another finding is that the raw material used for food contact paper greatly influences the amount of chemicals in the final product, and the deinking process has a small effect on the chemical level.[33]

MEASURES TO REDUCE MIGRATION RISKS

Low migration printing

Chemical residues can be transported during the production of packages and may contaminate foods. For that reason, potential sources of contamination should be avoided in all packaging processes throughout the packaging chain. This applies to techniques, such as printing, varnishing, coating, lamination, bonding and packaging, and means that the migration problem must be considered in all food packaging production processes. Packaging printing is very complex due to its chemistry. Ink additives, dampening solutions, cleaning agents and other printing consumables used in printing processes have migration risks in adverse conditions.[42]

Some printing supplies to consider

In the printing industry, for degreasing, cleaning, *etc*. purposes, different solvents are used. In addition to these solvents, adhesives used in packaging-film lamination and moistening solvents used in offset printing may pose a risk in terms of migration, depending on the characteristics of the chemical substances they contain. These chemicals are thus harmful to both the environment and human health, considering their manufacturing processes and their migration to foodstuff.[43]

Low migration printing inks, coatings and adhesives

To be considered reliable in terms of transition, printing inks, coatings, and adhesives must not exceed the migration limit values determined by laws and regulations, and these values must be proven with appropriate analysis techniques. The label and packaging manufacturer must conduct a risk assessment to prevent any transition to packaged foodstuffs from exceeding legal limits. Migration relates to the ink, coating content, and amount of other substances that may cause migration.[21] The ink and coatings of labels, packaging, napkins, service mats and other printed materials that may come into direct or indirect contact with food should have low migration potential. They should not adversely affect the odour or taste of foodstuffs. For these materials, including printing inks, coatings and adhesives, to be considered as low migration packaging, they must not contain any migrant chemicals that will affect the appearance, aroma, smell, taste or safety of the product in the package.[14] Ink, coatings and other materials must be formulated to meet specific migration limits (SMLs) by the nature of the food.

Migration limits

Migration limits are usually expressed in mg/dm^2 of the package or mg/kg of the food content, sometimes also in ppm (parts per million) or ppb (parts per billion), depending on the concentration. This value means µg per kg of food. It is necessary to refer to the toxicological profile of the migratory material, availability of toxicological data, and expert judgment for maximum acceptable migration limits.[4] Some substances evaluated toxicologically are considered safe, if they do not exceed specified migration limits.[44] On the other hand, it is assumed that these substances, which are not biologically evaluated and can pass into food, are a potential concern for human health.[10] Migration limits have been determined for many chemicals in the toxicological risk assessment of food contact materials. The Overall Migration Limit (OML) is expressed as 60 mg/kg food or 10 mg/dm^2 surface area applied to all materials that can pass from food contact materials to foods. The Specific Limit of Migration (SML) is determined based on the toxicological assessment of those substances applied to certain permitted substances. SML is usually determined by the acceptable daily intake (ADI) or the tolerable daily intake (TDI). These limits are determined by regulating substances and materials in contact with food.[16]

Migration testing

Migration measurement requires the identification and quantification of migrating chemicals transferred from the packaging material sample to the food versus a control sample according to CEN 1186 1-15.[4,16] Methods for determining the transition of compounds from packaging materials to foods largely depend on the extraction ability of the compound under investigation. The compounds that will pass into the food occur when the packaging material is left in contact with the food for a certain time and temperature, and can be measured in this way.[12] However, it is very difficult to detect migration in real conditions; in most cases, simulants are used for migration. For example, for food with a long shelf life, migration studies are carried out at a higher temperature and in a shorter time. Instead of real foods, simulants that imitate the nature of foods and facilitate migration studies are used.[12] The choice of a simulator for migration testing of food should be determined by the expiry time of the printed packaging. Along with the shelf life of the product, the type of food is the main determining factor. Practical migration tests on the packaging material (*e.g.* organoleptic tests) help to create a comprehensive analysis of inks that will best meet food packaging needs.[4] Organoleptic tests used to analyse the odour transmission from food packaging to food are performed with an Olfactometer according to DIN 10955, EN 1230:1, EN 1230:2 standards.[14] Measuring migration from printed packaging can be more complex than assessing taste and odour. Traces of migration may not always be detected in taste and odour tests or when food is consumed, but they can be detected by very sensitive chemical analysis. The migration potential of a printed package can be measured and analysed using highly sensitive analytical techniques, such as liquid chromatography or mass spectroscopy.[4]

Barrier applications for migration

Potential chemicals in food packaging materials pass into food, resulting in undesirable results in terms of food safety and quality. In packaging that comes into contact with food, packaging materials must be produced so as to constitute a barrier structure to prevent the reaction that may occur with food.

Migration is greatly influenced by the functional barrier of the substrate. The better this barrier, the lower any potential migration is. Paper cannot be used in situations where food needs to be stored for a long time, because it has poor barrier properties, and is generally not subject to heat sealing. If it is desired to be used as primary packaging in direct contact with food by improving its functional and protective properties, it can be used with coated, laminated materials, or processed using wax, resin or lacquer.[45] Migration from cardboard or plastic laminating materials to food usually occurs through printing materials, adhesives or ink-derived compounds used for packaging production.[46] In particular, low molecular weight components (solvents, *etc.*) in ink can easily pass into foodstuffs through packages made of paper or cardboard.[47] Plastic structured films and layers used in packaging are functionally specific barriers, obstructing the access of different substances to the packaged content. Polyethylene (PE), polyethylene terephthalate (PET), polypropylene (PP), and aluminium can act as barriers that reduce or even inhibit MOH migration (Fig. 6).[48,49] Although OPP films have good barrier properties to water, they cannot block most of the compounds in the printing ink, such as mineral oils or some photo-initiators.

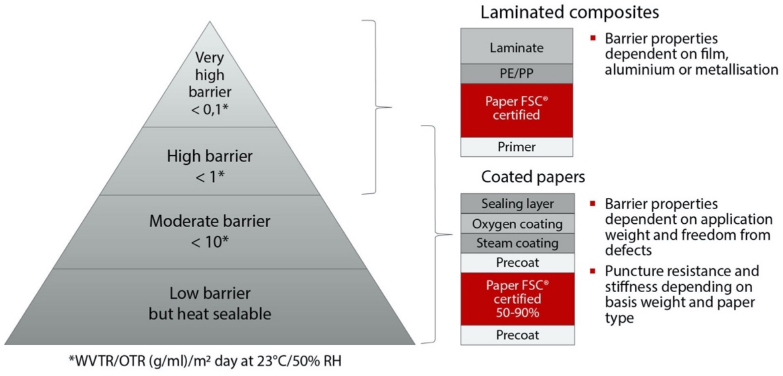


Figure 6: Barrier applications for migration

When it comes to using plastic films to serve as a barrier, the degree of migration that occurs depends on the transportable materials, the nature of the plastic layer and the temperature.[50] Packaging and food manufacturers aim to replace plastic packaging with new materials for food packaging, considering their high migration level, difficulty in recycling after lamination and harmful environmental effects. Ecological and biodegradable biomaterials are the new preferred choice for packaging in terms of barrier formation and safety. These are mostly disposable biomaterials produced from 100% natural raw materials, such as wood, wheat pulp, bamboo or palm leaves, and by chemical-free processes. It has been reported that hemicellulose-based packaging solutions serve as efficient barriers, being resistant to oil, grease, aroma and oxygen penetration. In addition, hydrophobic biopolymer-based packaging provide promising barrier properties, while also being easily recyclable.[51] It is necessary to assess the safety of these new materials before their use in food packaging, to verify that no hazardous substances migrate to the foods in quantities harmful to the health of consumers. There is no specific regulation for such materials, but regulation 1935/2004/CE applies to any FCM. It is essential to carefully examine the composition of such materials and their preparation process to ensure that they respect food safety regulations.[52]

CONCLUSION

The present review offers an overview of various aspects regarding the interaction between food and packaging, with a focus on the effects of printed food packaging on the migration of chemicals into foods, as well as on various other migration sources pertaining to the composition of the packaging itself (recycled paper), its manufacturing process and its relevant characteristics (*e.g.* permeability). The following main ideas should be highlighted:

– Printed surfaces of food packages should not come into direct contact with food, and random contact should be avoided.

– It should be considered that any component of an ink system can cause migration, even if it does not come into direct contact with food, so the primary packaging must have adequate barrier properties to protect the product.

– The manufacturing process of packaging materials intended to come in contact with foodstuffs should meet specific chemical migration limits, with respect to the composition of the material, as well as the printing inks, lacquers and adhesives used. Migration limits of these chemicals should be considered based on the toxicological risk assessment of the EFSA and FDA evaluations.

– In food packaging, low-migration products (low-migration inks, water-based lacquers, natural adhesives, *etc*.), formulated to give the lowest risk of migration, should be preferred.

– Low-migration additives (rheological regulators, driers, *etc*.) should be preferred when printing with inks, varnishes, or lacquers suitable for food packaging. These should be traceable to Good Manufacturing Practice (GMP).

– The origin of all raw materials used in the production of food packaging, which may cause migration throughout the food supply chain, should be fully documented.

– Fiber-based materials coming from recycled paper and cardboard should be evaluated to assess their suitability for contact with food according to Regulations (EC) No 1935/2004 and (EU) No 10/2011 regarding Food Contact Materials.
– When it comes to the use of recycled paper and cardboard as primary food packaging, all components that may cause chemical migration in the material (mineral oils, toxic metals, phenols, parabens, phthalates, *etc.*) should be analysed by overall and specific migration tests.
– To prevent ink migration from recycled paper material, vegetable oil-based inks should be preferred to mineral oil-based ones for printing on paper obtained with primary fiber.
– In packaging designs, the density of the ink to be applied in the print and its ratio to the print surface should be considered for the risk of migration assessment, and ink-intensive areas should be reduced as much as possible.
– Due to migration risks from printing and finishing processes, process analyses should be performed for dampening solutions, cleaning agents, bonding agents and other chemicals.
– To avoid contamination from food contact materials with a high migration tendency to food during food packaging printing, the press should be thoroughly cleaned or organised for use only in food packaging printing.
– During the transportation and storage of packaged foods, the products should be stored at the correct temperature, humidity, pressure and ventilation to prevent ink transfer from the packaging to the food. Storage conditions are very important: water or foods packed in printed packaging should not be exposed to direct sunlight, heat *etc*. because of possible chemical migration into the product from both packaging and packaging inks.
– Due to the risk of migration to food of standard printing inks, barrier layers should be used to produce food packaging.
– In contrast to inert materials, such as glass and metal, plastics like polyethylene (PE) and polypropylene (PP) may not offer an efficient enough barrier to the migration of ink into food. For this reason, inks that will not endanger consumer health should be preferred in food and personal care packaging.
– Overprint lacquer applications can significantly reduce migration from inks. However, because of the reaction between the ink and the lacquer, some new migration sources may emerge. This should be taken into account when considering the application of the materials.

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