An Introduction to Recycled Packaging: Definitions, Descriptions and Challenges

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SCIENTIFIC EXECUTIVE SUMMARY

In recycled packaging the presence of non-intentionally added substances (NIAS), from the previous use or misuse of the material or the occurrence of intentionally added substances (IAS), such as plastic additives or printing inks, at higher-than-normal use concentrations, have the potential to impact on the safety and quality of the packaged product. Further, as plastics, paper & paperboards undergo gradual chemical changes during recycling, recycled packaging can have different physical properties than virgin packaging, which can affect its functionality.

The risk that NIAS or IAS pose to product safety or quality is dependent on the nature of the substances present, their concentrations, and their ability to migrate from the recycled packaging into the product. The migration of a substance is dependent on the concentration present, the packaging material type (e.g. paper, PET, PP) and its properties (thickness, porosity), the product's composition (level of fat) and physiochemical properties (pH) and the conditions (temperature, time, humidity) under which the packaged product is stored.

As recycled material are likely to contain more degradation and breakdown products, non-targeted screening should be considered when assessing contaminants in either the packaging material and substances that have migrated from the packaging material

A number of NIAS or IAS have the potential to migrate from the packaging into the food it contains. Migration is considered to be a four-step process involving diffusion-desorption-sorption-adsorption, where chemicals that diffuse through the packaging material are ultimately absorbed by the food they contain (and vice versa). This process is strongly influenced by the interactions of components of the food with the packaging material

Not all detected NIAS in recycled packeting have been identified and neither has the origin of all of the NIAS detected been established. Many identified substances (IAS or NIAS) present in packaging material (recycled or virgin) and/or which had migrated into the food are substances not included in the EU list of substances allowed to be used in materials intended to come in contact with food. Some substances have been detected in food at concentrations higher than their migration limit (SML, 10 µk/kg for NIAS). In addition, some substances identified in both recycled plastic and recycled board are substance (e.g. some phthalates) which have been classified as being substances of very high concern (SVHC). However, few toxicity studies have been carried out on substances that have the potential to migrate from packaging into foods and very few studies have calculated the daily intake of substances (NIAS or IAS) that have the potential to migrate from recycled packaging material into food.

To provide confidence that recycled packaging does not pose a threat to the safety or quality of the product it contains, its entire production process, from the collection of the material to be recycled through to the production and testing of the final recycled packaging should incorporate risk assessment-based approaches which identify risks and establish and monitor critical control points designed to control the identified risks.

1. Introduction

The use of food packaging has steady increased over the last 50 years owing to globalisation, the expansion of supermarkets and constraints on households' time (Chakori et al., 2021). Despite the vital role that food packaging plays in ensuring food safety and shelf-life, facilitating food storage, handling, transport and distribution, and by providing a way to communicate product information, food packaging waste is now contributing to one of the highest profile environmental concerns.

In response to concerns expressed by consumers, advocacy groups and governmental agencies many countries have set ambitious goals to reduce the economic and environmental cost associated with food packaging. This includes steps to reduce the volume of packaging used and the establishment of targets (voluntary or regulated) for the percentage of recycled material used in packaging (recycled packaging).

Packaging materials such as metal and glass containers are termed permanent materials as their inherent properties do not change during repeated recycling processes. In contrast, packaging materials such as thermoplastics, paper & paperboards are termed non-permanent materials as they undergo gradual chemical changes during the recycling processes, which leads to their limited recyclability and concerns around the build of substances in the recycled packaging that are not present in packaging made from virgin material. There is concern that these so called non-intentionally added substances (NIAS) have the potential to impact on human health as well as the functionality of the packaging and the quality and shelf-life of the food or beverage it contains.

This report provides a definition of a number of technologies and terms used in this field, then briefly outlines the processes involved in the recycling of plastic or paper/board, before providing an overview of non-permanent primary food packaging materials and the intentionally added substances (IAS) and NIAS detected in such food packaging. A comprehensive list of the wide range of IAS and NIAS that have been reported to be found in packaging is presented in the Tables and in an aligned systematic review on the detection, migration, toxicity and dietary exposure of consumers to IAS and NIAS in foods from packaging. The impact of recycled material on the functionality of the packaging and the quality or shelf-life of the food it contains is discussed in an aligned review. An in-depth discussion on the regulations pertaining to the use of recycled packaging is outside the scope of this report, however, where pertinent to the topic being discussed relevant references are highlighted.

2. Definitions

The European Parliament's Waste Framework Directive of 2008 defines recycling as "any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. Therefore, recycling can be classified as a function of the final product of any given recovery process.

Primary recycling: the material is mechanically reprocessed into a product that has equivalent functional properties (e.g., transparency, barrier properties, and mechanical strength) to the virgin material. An example of primary recycling is where PET recovered from post-consumer bottles is used in the fabrication of new bottles. This is also referred to as close-loop recycling.

Secondary recycling: the material is mechanically reprocessed into a product that has poorer functional properties than the virgin material. An example of secondary recycling is in the production of flooring tiles from mixed polyolefins (e.g., polypropylene (PP), polyethylene (PE)). This is also referred to as open-loop recycling or downcycling.

Tertiary recycling (also known as chemical recycling): decomposition of plastic waste into its constituents (e.g., monomers, oligomers) and other substances, such as liquid, gaseous or solid hydrocarbons. For example, getting dimethyl terephthalate and diols from PET waste (Geueke, 2014; Horodytska et al., 2020; Merrington, 2011).

Quaternary recycling, where the waste polymer is incinerated to generate energy

Recycled content is the proportion by mass (usually expressed as a percentage) of pre-consumer and post-consumer recycled material in packaging is of the quantity of packaging material

Pre- consumer (also referred to as **post-industrial**) material is material diverted from the waste stream during manufacturing (excluding rework).

Post-consumer material is material waste generated by households or by commercial, industrial and institutional facilities.

Functional barrier is as a layer or multi-layer associated with food contact materials which prevents the migration of substances from behind that barrier into the food. It is defined in EC Regulation 10/2011 as a layer or multi-layer within food contact materials or articles, which prevents the migration of substances (< a given detection limit dependent on the toxicity of the substance and the Limit of Detection for the substance) from behind that barrier into the food. In the US the FDA defines functional barrier in terms of targeted materials, e.g. a 25-micron thick PET layer intended for use at room temperature conditions and below.

3. Brief overview of the recycling of Plastics

Plastic can be obtained from either well characterised pre-consumer waste streams or from post-consumer waste streams (e.g., kerb side collection) which can be very poorly characterised in terms of polymer type and the presence of IAS or NIAS.

Effective waste collection is a vital first stage for efficient recycling. By separating waste correctly at the point of collection, the recycling process is more efficient and will increase the quality and quantities of recycled products. The second crucial stage involves the plastic being sorted based on resin and colour, using approaches that range from manual sorting to mechanized automation processes that involve shredding, sieving prior to separation density or complex spectrophotometric (UV/VIS, NIR, Laser) approaches. It is worth repeating that effective recycling relies on effective and efficient collection and sorting.

The collected sorted plastic is then turned into new packaging via either a mechanical or a chemical recycling process

3.1 Mechanical Recycling

Mechanical recycling involves intact plastic being shredded and the fragments treated with chemicals that assist in removing impurities and contaminants such as food and chemical residues to eliminate impurities like paper labels or NIAS using a range of washing steps that incorporate various degrees of friction and wash temperatures depending on the resilience of the plastic.

The cleaned material is then melted and usually extruded into the form of pellets which are used to manufacture the recycled packaging which may or may not incorporate a percentage of virgin plastic. Mechanical recycling can cause intramolecular polymer bonds to break which lowers the MW distribution of the polymers and impact on its mechanical (increased brittleness) and optical (increased opacity) properties. This breaking of the bonds limits the number of times that plastic can be mechanically recycled.

Currently within Australia and New Zealand capacity exists to mechanically recycled PET (both countries) and HDPE (Australia). With companies particularly in Australia markedly increasing their mechanical recycling capabilities and capacity.

3.2 Chemical recycling

Chemical recycling involves using energy to break down collected sorted plastics into monomers and other basic chemical elements (“depolymerization”). This process enables materials that are difficult to be recycled by mechanical means to be recycled and it removes contamination. Chemically recycled monomers can be used as virgin material alternatives in the manufacture of new polymers. There are different types of chemical recycling processes, including pyrolysis, gasification, solvent dissolution and chemical depolymerisation and other specialist processes which are evolving.

Chemical recycling where the material is returned back to monomers offers the opportunity for an infinite number of cycles to be achieved without the necessity to incorporate virgin plastic.

Several companies are offering polymers (Mainly rPET, also HDPE) with chemically recycled content and new chemical recycling plants are being built around the world, with the closest to New

Zealand being in Australia. An advantage of the use of chemically recycled content is that its content and functionality is less likely to be affected if the feedstock contains contaminants. For example, the FDA has determined that chemical recycling processes that produce post-consumer recycled polyethylene terephthalate (PET) or post-consumer recycled polyethylene naphthalate (PEN) are of suitable purity for food-contact use (i.e an individual opinion letter for each process is not required).

3.3 Chemical Vs Mechanical Recycling

Owing to the high capital cost to build a chemical recycling plant and the relatively limited output they can achieve (against demand), chemical recycling is often considered to be best suited as way to complement mechanical recycling and to enable the recycling of opaque, coloured, multi-material or other difficult to recycle applications. In addition, it offers the ability for polymer suppliers to offer pre-blended feedstock, including recycled content that can be recycled an indefinite number of times.

Chemical recycling is economically more marginal compared to mechanical recycling. Out of 17.8 million tonnes of plastic packaging collected in the EU in 2018, 42% was recycled, 39.5% incinerated, and 18.5% sent to landfills. Most of the waste was recycled mechanically, and only very limited volumes (less than 0.1 million tonnes) were treated by chemical recycling processes (ECHA/2020/571, 2021).

The recycling rate of plastics is typically related to technological limitations and the quality of the input material (Antonopoulos et al., 2021), while the application of recycled plastics in food packaging is determined by its final physicochemical properties and safety and by legislative restrictions ((EC) No 282/2008, 2008; FDA, 2020). For single-use plastic packaging materials globally only 14% of plastic packaging is collected for recycling of which only 5% is successfully recycled into new plastic.

4. Brief overview of the recycling of paper and board

The making of recycled paper / board starts with collecting and sorting recovered material into types, or grades. Paper or board may come from curb side cycling or from post-industrial sources. At this stage paper / board contaminated with food, heavy dirt, chemicals, or other substances is set aside for burning, composting, or transport to landfills. Paper / board is generally not sorted based on whether it had previously been used for a food grade or non-food grade application.

The graded paper/board is transported to a paper mill and stored until needed. The first processing steps involves the graded paper/board being added a pulper containing chemicals such as sulphur dioxide, caustic soda and sodium sulphide and water. The pulper chops the paper into very small pieces, and the chemical mixture in the vat breaks the paper down into strands of cellulose, or fibres. The paper pulp is then forced through a screen to remove contaminants such as pieces of plastic, glue, tape or staples. The screened pulp is then placed into cone-shaped cylinders that spin the paper to remove any additional debris. De-inking removes glue residue and other adhesives and strips printing ink from the paper. There are several common methods of de-inking, including a process called flotation, which involves using surfactants to separate adhesives and ink from the paper pulp. Once the pulp is free of contaminants and ink, it is beaten until the fibres swell. This makes the fibres easier to work with. Coloured paper requires chemical stripping to remove the dyes from the paper before reforming can take place. Bleaching with hydrogen peroxide or oxygen increases the brightness of the paper and removes any remaining colour. The next involves mixing the pulp with additives, whose functions include pH adjustment, water repellency, aiding binding, increasing mechanical strength and aiding processing. The resulted pulp is sprayed onto flat, wire screens. Water drains from the pulp, causing the paper fibres to bond together and form new sheets of paper/board. The sheets pass through multiple press rollers to squeeze out any remaining water, before the sheets of paper to board pass through heated metal rollers. Once dry the material is ready for use.

Paper and paperboard can be recycled up to seven times before being required to be mixed with new fibres/virgin pulp and the recycled content is mostly directed to paper and cardboard packaging applications. Paper/board containing recycled fibre content, can be but it not usually used in direct food contact applications. The current major food related application for recycled board is in the production of corrugated paperboard used in the produced of cardboard outer cartons.

5. Acceptance and Regulations on the use of recycled packaging in food contact applications

Worldwide views on the use of recycled packaging range from the mandating of strict targets and requirements for it use in all food packaging applications through to a total ban on its use in food contact applications. Within a country expectations and regulations can vary from one plastic type to another or between the use of plastic or paper/board.

Note that currently there is no widely agreed method for measuring the amount of recycled content in recycled packaging. Although tests can be conducted in a laboratory on a case by case basis to determine if recycled content is present, the process in practice usually relies on recycled packaging manufacturing maintaining good procurement records and chain of custody controls to enable the calculation, verification, and reporting of recycled content. Further, currently a label stating that the packaging contains recycled materials provides little information on the amount of recycled material it contains (British Plastic Federation, 2020; Zero Waste Europe, 2021)

Worldwide regulations and the information required to prove the safety of recycled packaging vary significantly. Approaches range from proving the effectiveness of the recycling process to remove specific contaminants, to demonstrating the safety of the recycled feedstock used, through to the requirement to incorporate a functional barrier to prevent the migration of possible contaminants from the packaging into the food. In short, in countries where the use of recycled packaging is acceptable, the expectation is that recycled packaging must meet the same safety standards required for virgin packaging and the onus if on the packaging manufacturing / supplier to demonstrate that it achieves this.

For example in the EU recycled plastic materials and articles can only be placed on the market if they contain recycled plastics exclusively obtained through an authorised recycling process, and one which focuses on safety evaluation on a case-by-case basis for individual recycling processes by the European Food Safety Authority (EFSA) followed by an individual authorisation. In 2018 it was reported that 95 % of the described plastic recycling processes were for PET while the remaining 5% was for PP and/or HDPE (Geueke et al., 2018), however, it is acknowledged that changes and developments are occurring fast in the recycled packaging space.

Aotearoa New Zealand does not have specific regulations for plastic recycling and its use in food packaging applications, rather there is a general statement that packaging materials must be safe and fit for purpose. In addition, it is well understood that companies need to ensure that the packaging materials they use, including recycled packaging, meet the market access requirements for the countries they are exporting to (e.g. China, the EU, the US). Irrespective of the need to meet the expectations of the importing country the lack of Aotearoa New Zealand specific regulations is considered by some food producers to be a gap in the regulatory framework which in some other jurisdictions is used to assure the food safety of the recycled materials. However, within Australia and New Zealand there is considerable debate among food companies and packaging suppliers on the need for further controls and what form (regulations, guidelines, standards) they should take.

Note that world regulations and expectations around the use of recycled packaging are in a very dynamic state. For, example, in Feb 2022 a total of 28 environmental organizations in the EU asked the European Commission not to approve a new regulation, currently in the draft stage (European Commission, 2022), which would have allowed the use of recycled plastics to be expanded to materials in contact with food. In an open letter (Dorota Napierska, 2022) addressed to the European Commissioner for Health and Food Safety, Stella Kyriakides, it was pointed out that "as it is now written, the draft proposal allows novel technologies for plastic recycling to operate at scale and produce recycled plastic for food contact use in the EU before any assessment of its efficiency in removing hazardous chemicals." The new standard was proposed to replace the previous EU Regulation 282/2008 on the use of recycled plastic in food contact materials ((EC) No 282/2008, 2008) with the aim of increasing the amount of recycled content in food packaging and other food contact materials with food.

6. Overview of the safety concerns around the use of recycled packaging

The primary safety concerns associated with the use for recycled packaging is the concern that IAS or NIAS present in the packaging will migrate into the food it contains and result in safety and quality concerns. Substances that may be present in recycled packaging are those that originate from the manufacturing process (IAS) and which are modified or concentration by the recycling process or NIAS that become associated with the recycled feedstock owing to its intended or unintended use.

The European Commission published a chemicals strategy for sustainability in October 2020 to increase the safety of recycled materials and products by, for example, removing endocrine-disrupting and other hazardous chemicals from everyday products, such as food contact materials. In the same year, the "farm to fork strategy" for a fair, healthy and environmentally-friendly food system was also adopted. Among its objectives, this strategy aimed to improve food safety and public health through a reduction in the use of hazardous chemicals in different food-related areas such as food packaging (EC-COM (202)-381, 2020; EC-COM (2020)-667, 2020)

Substances (NIAS/AIS) that maybe present in packaging originate from a wide variety of sources and reactions. They includes substances used for the initial polymerization step in the making of virgin plastics, such as monomers or catalysts and their impurities or additives that are included during the manufacturing process to achieve special material properties (plasticizers, antioxidants, light stabilizers, thermal stabilizers, lubricants, antistatic agents, slip additives) and their impurities; starting substances from the incomplete polymerization during the formation of polymers, and solvent residues (Arvanitoyannis & Bosnea, 2004; Hahladakis et al., 2018; Muncke, 2009). Note that residual monomers and aides to polymerization are not classified as NIAS since they are IAS. In contrast, impurities, reactions intermediates (oligomers), breakdown products, oxidation products formed by the reaction of package components with exterior oxygen, degradation products formed during the recycling of packaging material are all considered NIAS.

NIAS also include absorbed organic compounds from the food, that the recycled packaging previously contained such as flavour or odour compounds (for instance essential oils from soft drinks residues) or the residues from non-food grade materials (mouthwash, personal hygiene, household cleaners, cosmetic products, etc.) as well as compounds that are present owing to the re-use packaging to store non-food grade materials prior to its disposal. The types NIAS present include inorganic elements such as silicon, calcium, iron, aluminium, among others, and lineal & cyclic oligomers (please, see the table in supplementary data for more detailed information). Degradation or breakdown of authorized products and their impurities formed during the recycling processes (Geueke et al., 2018).

6.1 Substances of concern

Article 19 of the Regulation (EU) No 10/2011 ((EU) No 10/2011, 2011) requires that substances with a molecular weight up to 1000 Da that are not listed in Annex I (i.e. previously assessed as being safe) be assessed following internationally recognized scientific principles for risk assessments. Risk assessment generally involves four steps: hazard identification, hazard characterization, exposure assessment and risk characterization.

NIAS with a molecular weight exceeding 1000 Da are generally not considered of relevance for risk assessment, since they are not generally absorbed by the body. However, compounds with a higher molecular weight may be subjected to an in vivo hydrolysis, thus generating smaller oligomers that the body can absorb (Hoppe et al., 2016; Peters et al., 2019).

NIAS requiring a risk assessment, which are not classified as being either carcinogenic, mutagenic or toxic to reproduction (CMR), should not be detected using a migration test at a concentration > 10 µg/kg, (ILSI Europe, 2016). CMR substances should not intentionally be added to food contact packaging and they should not be non-intentionally present at an exposure threshold value above 0.017 µg/L in food, which can be also used as a practical migration limit for genotoxic NIAS for which no specific toxicological data are available (van Velzen et al., 2020).

Along with CMR substances other substances considered to be substances of very high concern (SVHC) include: substances that are persistent, bio-accumulative or toxic for the environment (PBTs); substances that are very persistent and very bio-accumulative (vPvBs) or substances giving rise to an equivalent level of concern to substances meeting the above criteria. Such substances may have endocrine-disrupting properties, or have properties, that although not meeting the criteria for being a CMR, PBT or vPvB, there is scientific evidence of probable serious effects to human health or the environment - such substances will be identified on a case-by-case basis

The use and market application of SVHC is regulated in Europe by REACH (Registration, Evaluation, Authorisation and Restrictions of Chemicals). As of October 2021, there were 219 substances on the SVHC candidate list and 52 substances on the SVHC authorization list. A substance on an authorization list cannot be placed on the EU market, unless an authorization is granted for its specific use, or the use is exempted from authorisation.

It has been reported that food contact materials are a significant source of human exposure to some SVHC such as flame retardants (hexabromocyclododecane), stabilizers (Pb), or/and softeners (bis(2-Ethylhexyl) phthalate) (Geueke et al., 2018; Muncke et al., 2020). The health relevance of these SVHC depends on the toxicity of the substance and the level of exposure. It should be considered that not all substances are monotonic (as the dose increases, so does the effect) for instance, endocrine disruptors (e.g., bisphenol A, phthalates) may have greater effect at lower than higher doses (non-monotonic dose-response) (Zoeller & Vandenberg, 2015).

6.2 The migration of chemicals from food packaging materials into food

The migration of substances from packaging into a food or beverage or from a food or beverage into packaging, is considered to be a four-step process involving diffusion-desorption-sorption-absorption. This process is strongly influenced by the interactions of components of the food with the packaging material.

Packaging factors that can impact on the potential for and the rate of migration include the concentration of the substance, and its polarity and size, with smaller molecules generally migrating faster than larger molecules. Inherent properties of the material include its crystallinity and porosity. Properties of the finished packaging material include its surface structure, thickness and the surface area of the product relative to the packaging. Environmental storage conditions such as temperature, humidity, and exposure time influence both the rate and extend of migration as can the composition of the product and interactions between the various components in the system (Hahladakis et al., 2018; Muncke et al., 2020). For instance, if some of the fat present in a food migrates into the packaging material it can increase the mobility of substances within the packaging material, thereby enhancing the migration of the chemicals into the packaged food.

A study on the migration of NIAS from commercial packaging, including virgin/recycled printed/unprinted paperboards, to dry foods and dry food simulant called Tenax found that migration rates were higher from paperboard than from plastics, which was believed to be related to different migration mechanisms of these materials (Urbelis & Cooper, 2021). Furthermore, the use of inner layers reduced the migration of many compounds, with higher-barrier materials (aluminium, PET, and PA) reducing migration compared to low-barrier materials (PE, paper, or paper laminated with PE or EVA). However, it was noted that inner liners may themselves contain substances with the potential to migrate to foods (Urbelis & Cooper, 2021).

Migration happens at a faster rate for highly volatile substances. However, substances with relatively higher molecular weights exhibit lower migration rates. Migration of volatile substances is believed to primarily occur owing to a gas-phase mechanism, in which substances in the packaging diffuse or evaporate into the packaging head space then subsequently desorb and finally are adsorbed onto the food (and vice versa). Volatile aromatic compounds can consequently transfer to the food without the need for direct contact between the food and the packaging. However, contact between the food and the packaging material may enhance the rate of migration (Alamri et al., 2021). Volatile compounds diffuse homogeneously through multiple layers of food packaging due to their ease of diffusion in the gas phase. During mechanical recycling, the composition of volatile compounds present can change as a consequence of the effect of high temperature and oxygen. High temperatures can lead to the emission of volatile and semi-volatile compounds into the surrounding environment, and when combined with oxygen, new oxidized substances can be generated or the concentration of existing compounds can increase (Song et al., 2019). In contrast, the migration of higher molecular weight non-volatile compounds has been postulated to occur predominantly via a contact diffusion mechanism, involving the transfer of substances from the packaging to the initial layer(s) of dry food, and the subsequent non-homogenous distribution of the substance (migrant) within the food. The main variable affecting migration via direct contact is food particle size, which dictates the total surface area in contact at the food-food contact material interface. Foods which are comprised of smaller particles have a higher surface area and a higher migration rate owing to the resulting increased contact at the food / packaging interface (Urbelis & Cooper, 2021).

In a study investigating the presence of chemicals in paper and cardboard packaging and their impact on human-relevant outcomes, a panel of cell-based bioassays was used to demonstrate a wide range of effects including the activation of oxidative stress, genotoxicity, xenobiotic metabolism and antagonistic effects on oestrogen as well as androgen receptors (Selin et al., 2021). Packaged food of potential concern included cake/pastry boxes/mats, boxes for infant formula/skimmed milk, pizza boxes, pizza slice trays and bags of cookies. Two particularly noticeable materials were cake/pastry boxes/mats and boxes for infant formula/skimmed milk, due to their heavy colouration from the printing inks which can contain mineral oil and photo initiators (Selin et al., 2021).

In general, the migration rates for substances from paper & paperboard were higher than those observed from plastics (Poças et al., 2011), owing to the inherent differences in their barrier properties. For example, it was observed by Vera and colleagues (Vera et al., 2020) that the toluene, nonanal, 2-ethyl hexanol, benzaldehyde and acetophenone had higher migration rates from paper and cardboard materials than from PE and PP.

For several types of recycled food contact materials, the migration of NIAS is reported to be more significant than the migration of IAS (Muncke et al., 2020) as NIAS can reach higher levels in recycled food packaging due to: contamination of the recycled material from the food it previously contained; its misuse; and/or the formation of degradation products during the recycling process (Coulier et al., 2007; Song et al., 2019; van Velzen et al., 2020).

EU and US regulations for food packaging plastics in contact with food include a list of authorized substances (monomers, other starting substances, additives as well as polymer processing aids) which have previously been assessed for their safety by an agency such as the European Food Safety Authority (EFSA) before authorisation. EU regulations set overall migration limits (OML of 60 mg of total constituents/kg food or 10 mg of total constituents/dm^2 food contact surface) and specific migration limits (SML, mg/kg) for food contact material and/or foods ((EC) No 282/2008, 2008). These regulations require the same level of safety for chemicals migration into foods for recycled and virgin materials and EU regulation (EU) No 10/2011 explicitly requires a risk assessment of NIAS: "NIAS are permitted in final plastic articles, but should be assessed by the manufacturer following international recognised scientific principles on risk assessment".

Such assessments however can be challenging as toxicity and exposure information is only available for a few of the IAS (authorized substances), and the identification of NIAS and studies on their impact in human health is demanding and, in many cases, not feasible owing to a lack of reference standards.

Where there is concern that substances in the packaging (virgin or recycled) may migrate into a food, an inner liner between the food and the packaging can be used to reduce the migration of compounds from the packaging into the food. In such cases paper has been shown not to provide an appropriate barrier against the migration of compounds. Polypropylene is also recognised as being a relatively poor barrier plastic. Multilayer plastic films such as PP/EVOH/PP, provides superior migration barriers due to the combination of ethylene polymers and the barrier properties obtained from vinyl alcohol polymers. Multilayer PET/SiOx/PE films also have good barrier properties owing to the medium gas barrier properties of PET being complemented by the high barrier prosperities of SiOx (Feigenbaum et al., 2005; Pastorelli et al., 2008). However, the use of inner liners are an additional cost and can reduce the sustainability of the packaging especially if difficult to recycle multi-layered liners are used.

6. 3 The determination of substances present in packaging

For the analysis of predicted or unpredicted NIAS, two strategies may be applied: targeted analytical methods for the detection of predicted NIAS or non-targeted or screening methods designed to detect analyse a broad range of substances which may differ significantly in their physical or chemical properties. All analysis strategies should detect and quantify the concentration of NIAS present in the food contact material. This is possible for predicted and known NIAS, but difficult for unpredicted NIAS since reference standards may not be available. As a practical standard, the migration level of 10 µg/kg food for NIAS is applied, as this is the level at which each migrated substance must be identified (Cecon et al., 2021; Peters et al., 2019). Although the range and number of NIAS detected by modern analytical methods is continually increasing many remain unidentified (Muncke et al., 2020).

To detect IAS and NIAS in packaging or the food it contains, gas and liquid chromatography based methods have been most widely used. For volatile organic compounds (VOCs), gas chromatography (GC) paired with solid phase microextraction (SPME) and stir bar sorptive extraction (SBSE) is a common approach (Vilaplana & Karlsson, 2008; Vilaplana, et al., 2010). Other VOC-extraction techniques include purge and trap, Likens-Nickerson distillations and solvent assisted flavour evaporation (SAFE). Gas chromatography approaches include GC-MS/MS (Jurek & Leitner 2017), GC-orbitrap mass spectrometry (Sapozhnikova, 2021), atmospheric solids analysis probe (ASAP) and atmospheric pressure gas chromatography (APGC) coupled to quadrupole time of flight mass spectrometry (QTOF-MS) (Jaen et al., 2021) and two-dimensional GC-time-of-flight mass spectrometry (Carrero-Carralero et al., 2019). Liquid chromatography methods include *HP(LC)-GC-FID* (Srbinovska, et al., 2021), LC-MS/MS (Jurek & Leitner, 2018), *HPLC-UV/FLD (*Alberto Lopes et al., 2021), HPLC-DAD Tsalbouris et al., 2021) and flow injection analysis-mass spectrometry (FIA-MS) (Habchi et al., 2018)

It is difficult to develop a quantitative analytical method when knowledge on which VOCs will be present is unknown. Again, it is not the presence of small molecular weight compounds in particular that is a problem it is the specific effect that their presence has on product safety or quality. Further, without knowledge on what the VOC will be present selecting the correct analytical conditions is fraught as all VOC extraction methods have a blind spot, i.e., compound(s) that will not be extracted or will be lost during sample preparation. It is therefore recommended to use a range of extraction and detection techniques when undertaking un-targeted studies.

7. NIAS in recycled non-permanent food packaging materials

A recent systematic review has compiled information regarding substances detected in non-permanent food packaging materials (plastics, paper and paperboard) from 110 research articles published between 2017 and 2021. The review summarises and discusses the IAS and NIAS detected in food packaging materials, their migration, toxicity and dietary exposure (Etxabide, et al., 2022).

7.1 NIAS in recycled plastics

High density, low density, linear low density and medium density polyethylene (HDPE, LDPE, LLDPE, & MDPE), polypropylene (PP) and polyethylene terephthalate (PET) are in the greatest demand within the plastic packaging sector. Typically HDPE is preferred for rigid packaging, such as bottle containers of water/dairy products, cleaning agents and care products; LDPE is used in flexible packaging such as films and stretching wraps; PP is used as hard containers, bottle caps, and takeaway & refrigerated food containers; PS, which will be banned from food packaging by 2025, is currently be used for thermal cups, egg cartons, and food trays, while PET is used for beverage bottles and food trays & jars. Some plastic products potentially contain more IAS and NIAS than others.

For plastics to fulfil specific functional requirements different additives are required, the most common being plasticizers, flame retardants, pigments, antioxidants, stabilizers, antistatic, and nucleating agents. In fact over 6000 substances have been reported to occur in plastics (Aurisano et al., 2021) including additives, solvents, unreacted monomers, starting substances, & processing. A database developed by searching regulatory positive lists and industry inventories for intentionally used food contact chemicals contained more than 12,000 substances (Groh et al., 2021).

7.1.1 Recycled PET

The elemental composition and volatile, medium, and non-volatile substances in rPET (0:100%, 25:75%, 50:50%, 75:25% & 100:0%) pellets and bottle fragments and the migration of substances from PET bottles into noncarbonated mineral water after 10 days at 40 °C has been assessed (van Velzen et al., 2020).

Analysis of the metal content in the pellets detected the presence of antimony catalyst (SML 0.04 mg/kg) (255 - 270 mg/kg), cobalt (SML 0.04 mg/kg) (1.5-6.5 mg/kg), and chlorine from PVC contaminant (authorized) (4-60 mg/kg), acetaldehyde (SML 6 mg/kg) (0.6-16 mg/kg), 2-methyl-1,3-dioxolane (NIAS, not listed in (EU) No 10/2011) (0.1-1.5 mg/kg), benzene (NIAS) (<0.1-1.8 mg/kg) and ethylene glycol (SML 30 mg/kg) (0.8-6.4 mg/kg).

In the assessment of volatile compounds in rPET pellets and bottles, acetaldehyde (SML 6 mg/kg) (0.6-16 mg/kg), 2-methyl-1,3-dioxolane (NIAS, not listed in (EU) No 10/2011) (0.1-1.5 mg/kg), benzene (NIAS) (<0.1-1.8 mg/kg) and ethylene glycol (SML 30 mg/kg) (0.8-6.4 mg/kg) were found. According to the authors, most of these volatiles were formed during a thermal degradation process. The concentration of benzene rose with the recycling content in rPET bottles, especially in rPET from co-collection systems. The authors suggested that impurities present in rPET were responsible for producing benzene. They also indicated that most of the acetaldehyde was produced during injection moulding when the material was exposed to the highest temperatures (270–290°C for 33 s), and less was produced during blow moulding of the bottles (maximal 110°C for 165 s).

Medium and non-volatile compounds such as cyclic dimers/trimers and higher molecular weight oligomers (well-known polymerisation side products in PET) were also found in the rPET pellets and bottles. As bottles made from virgin PET showed similarly high levels of oligomers (NIAS), the authors concluded that oligomers in the bottles were not influenced by the recycling content and the quality of the rPET.

The results from migration assessments revealed the presence of 2-methyl-1,3-dioxalane (NIAS, not listed in (EU) No 10/2011) (<0.55 µg/L) in all mineral waters, regardless of the use of virgin or rPET bottles. The concentration of benzene (NIAS) in the contained water was below the detection limit for bottles made with virgin PET. However, for rPET bottles, this concentration varied between 0.03 and 0.44 µg/L, with benzene present at higher levels as the percentage of recycled plastic increased in the bottles (25, 50, 70, and 100%). The concentration of styrene (authorized, it can originate from the thermal degradation of polystyrene) was below the detection limit for bottles with virgin PET and from bottles with rPET-A. However, the concentration of styrene in an aqueous simulant varied between 0.011 and 0.063 µg/L for bottles with Types B and C rPET (co-collection systems), with higher concentrations occurring as the recycled content of the bottle increased. Although styrene is not regulated as a carcinogen in the EU, it is considered a “Reasonably anticipated to be a human carcinogen” compound by the National Toxicology Program (NTP, U.S. Department of Health and Human Services). Two commonly used solvents, acetone (authorized) (0.1-0.7 µg/L) and butanone (NIAS) (0.01-0.02 µg/L), were found as migrants. Furan (NIAS, carcinogenic or reasonably anticipated to be a human carcinogen), produced in thermally treated food products, was also detected (0.05-0.13 µg/L).

Although in this study many identified substances were not included in the European Union list of substances allowed to be used in materials intended to come in contact with food, and some were anticipated to be a human carcinogen, toxicity studies were not carried out as the authors considered that the exposure to these substances at the concentration they were present at posed a low level of concern from a public health point of view (van Velzen et al., 2020).

7.1.2 Recycled polyolefin (PE & PP)

A large portion of food packaging is composed of polyolefins such as PE & PP. Polyolefins are known to degrade during utilization and recycling with a decrease in their molecular weight. Polyolefins have a high sorption capacity which makes the efficient removal of contaminants from them difficult, which means that some NIAS, may remain in the recycled plastic. Furthermore, due to the fast diffusion of chemicals through these types of plastics and their high migration potential, materials made of recycled PP & PE pose higher safety concerns than materials made of other plastics such as PET. A list of IAS and NIAS detected in different polyolefin food contact materials has been complied by Cecon and colleagues (Cecon et al., 2021). In general, polyolefin-based materials are considered to have the worst-case scenario migration potential (Coulier et al., 2007).

Note that while mechanically recycled rHDPE is becoming increasingly used as a food contact material, rPP obtained from mechanical recycling is currently not used for food contact materials. In part this is due to the fact that PP resins come in many grades, contain a wide range of processing additives and come from a wide variety of sources, all factors which pose challenges in the design of effective mechanical recycling processes. Nevertheless there is research under away to create a food safe pathway for rPP.

Coulier and co-workers (Coulier et al., 2007) studied the influence of recycling on the migration and formation of degradation products in virgin and recycled HDPE and PP crates. For the recycled crates, equal numbers of virgin crates of each polymer were ground, washed, cleaned and dried in line (the cleaning/recycling technology in the crate recycling market was undertaken). New crates were then made using standard injection moulding technology. The recycling and reprocessing cycle was repeated 5 times and in each cycle, relevant additives (0.016 wt% Irganox 1010 and 0.033 wt% Irgafos 168, 0.05 wt% Tinuvin 622 and 0.05 wt% Chimassorb 944) were added. These additives are standard additives used by the polymer producers for stabilizing HDPE and PP. In parallel, used PE and PP crates were analysed and part of them were recycled. Migration experiments were carried out under migration conditions, representing long term contact at room temperature with aqueous and fatty food simulants (10 days at 40 °C in 15% ethanol and 2 days at 20 °C in iso-octane).

Although some samples had an overall migration rate slightly above the limit of quantification (10 mg/dm^2), the authors concluded that generally there was no significant increase in overall migration with an increase in recycling steps. However, a slight increase in overall migration was observed for PE with an increase in recycling steps which indicated that the recycling of PE had an effect on the migration characteristics of the recycled product.

An increase in migration of Irgafos 168 was observed with an increasing number of recycling cycles, but Irgafos 168 has no SML. The increase in the migration of Irgafos 168 from HDPE samples into iso-octane was believed to be related to an increase in its content in the samples rather than to the recycling process itself. For the PP samples, the migration of Tinuvin 622 above the QL was observed, while the specific migration of Chimassorb 944 seemed to increase as the number of recycling cycles increased however, in this case, the SML of 3 mg/kg food was not exceeded. Migration of Irgafos 168 and Irganox 1010 was detected above the QL for almost all PP samples and their specific migration in iso-octane increased with increasing recycling steps.

Apart from OML and SML which are intentionally added additives, the authors identified and quantified semi-volatile degradation products of additives and polymers that migrated into an iso-octane food simulant. Almost all of the components that were detected in the recycled PP materials but not in the virgin PP material or components, increased significantly with an increase in recycling steps.

For the recycled HDPE samples, several substances were found that increased significantly with more recycling. Most of those components were assigned to degradation products of additives.

Many substances identified in both the PP and HDPE were not included in the European Union list of substances allowed to be used in materials intended to come in contact with food. Furthermore, some compounds had migration values higher than their SML or Cramer Class. Further, substances, such as diethylhexyl phthalate were present as a migrant at concentrations between 33 and 137 µg/kg, and so exceeded the threshold of 10 µg/kg set for NIAS. Diethylhexyl phthalate is considered to be toxic for reproduction, it has endocrine-disrupting properties (relevant for both the environment & human health) and is considered to be a SVHC, however, toxicity studies were not reported.

Compounds such as 2,2,6,6-tetramethyl-4-piperidinol (NIAS, Class III), {6-[1,1,3,3-tetramethylbutyl]-imino-1,3,5-triazine-2,4-diyl}{2-(2,2,6,6-tetramethylpiperinyl)-imino} (NIAS), & 2,4-di-tert-butylphenol (NIAS, Class III) were observed in both recycled PP and HDPE, although the concentration was generally higher for PP. Overall this study showed that migratable components were found in both PP and HDPE and that their concentration increased with an increase the number of times the material was recycled. All of these substances detected were identified or classified as degradation products of additives.

7.1.3 Recycled PS

Despite PS use being banned for food use by 2025 the following section is included for completeness.

To evaluate the health risks posed by virgin and recycled PS containers the migration of volatile compounds into both hydrophilic and acid food simulants (10% ethanol & 3% acetic acid) was investigated (Song et al., 2019). The research focused on specific compounds and their risk characterization based on the Threshold of Toxicological Concern (TTC) concept.

Briefly, the TTC is a screening and prioritization tool for the risk assessment of substances of which hazard data is incomplete but for which human exposure can be estimated. This approached is used for chemicals of a known structure, but for which toxicity data is unknown or scarce. The TTC tool establishes human exposure levels for chemicals below which there is no appreciable risk to human health. It should note that the TTC approach may result in uncertainty (Bschir, 2017; Van Bossuyt et al., 2017).

A total of 99 volatile and semi-volatile compounds were found in expanded PS containers, including hydrocarbons, aldehydes, ketones, alcohols and esters. Aromatic compounds such as ethylbenzene, o-xylene, benzaldehyde, acetophenone and benzoic acid ethyl ester, either did not appear in virgin expanded PS containers or were present in a higher abundance in recycled samples. Additives were only detected in recycled EPS containers (2,6-di-tert-butyl-4-methylphenol (a common antioxidant) and diisobutyl phthalate (plasticizer/catalyst). 17 different compounds were found in virgin and recycled expanded PS containers.

Styrene, ethylbenzene, o-xylene, cis-1,2-diphenylcyclobutane, and trans-1,2-diphenylcyclobutane were detected in food simulants. Only styrene is an authorized substance in (EU) No 10/2011, however, it is considered a “Reasonably anticipated to be a human carcinogen” (NTP, U.S. Department of health and Human Services). Ethylbenzene and o-xylene are classified as Class I, and cis-1,2-diphenylcyclobutane and trans-1,2-diphenylcyclobutane are classified as Class III of the Cramer toxicity. The authors concluded that analysed materials comply with current (EU) No 10/2011 for food contact materials in terms of maximum concentration of migrants present. However, no toxicity studies were undertaken.

7.1.4 Summary

In summary the level of research activity and consequently the amount of known about potential NIAS present varies dramatically between plastic type. Packaging containing rPET has been the most extensively tested for the presence of NIAS and challenge tests have been defined for this material. Packaging containing rHDPE has been less extensively tested for the presence of NIAS and challenge tests have yet been developed or at least are not widely available. Little is know about NIAS potentially present in rPP and rPS will soon no longer be relevant. What is apparent from the studies reported to date is that the inherent nature of the plastic, its prior use, and how it is obtained and subsequently recycled can have a dramatic effect on the number and concentration of the NIAS it may contain.

7.2 NIAS in recycled paper & paperboards

In the EU, paper-based food packaging materials have to comply with basic rules concerning safety, listed in (EC) No 1935/2004 and EU Directive (2008/98/EC). However, unlike plastics, there is no specific legislation governing the use of (recycled) food contact paper & paperboard materials. In 2009, the Council of Europe (CoE) completed guidance for particular food contact materials with no specific regulations (paper and board materials and articles intended to come into contact with foodstuffs) where a list of additives that may be used in the manufacture of paper & paperboard materials and articles intended to come into contact with foodstuffs is displayed. Some EU Member States have specific legislation or recommendations on food contact paper, being the German

Federal Institute for Risk Assessment (Bundesinstitut für Risikobewertung (BfR)) Recommendation 36, respected by industry throughout the EU. In the preconditions for the use of recycled fibres as raw materials for the production of paper, known substances that may be introduced by paper recycling require specific inspections and their content and migration into foodstuffs are limited (Severin et al., 2017). In the US, the FDA permits the use of pulp from recycled fibre (21 C.F.R. Section 176.260), if the pulp does not contain poisonous or deleterious substances that migrate into food. This regulation, however, does not require that additives found in the recycled pulp must comply with the regulations applicable to paper (21 C.F.R. Sections 176.170).

It is important to appreciate that regulations pertaining to the use of recycled paper & paperboard as primary food packaging are subject to change. For example, in 2020, Switzerland, removed the restriction that recycled paper could only be used in certain named foodstuffs unless made from production waste of non-printed fresh fibres that meet the requirements applicable to them, to a rule that aligned more closely with Article 3 of the EU's Framework Regulation to allow use of recycled paper, provided that any migration of components from recycled paper to foodstuffs 1) does not pose a danger to human health, (2) is technically unavoidable, and (3) does not cause unacceptable changes to the composition of food in keeping with Article 49 of Swiss Ordinance 817.02 on Foodstuffs and Commodities

When in contact with food, paper presents little resistance towards the migration of chemical compounds due to paper and board materials being heterogeneous, with open and porous structures consisting of cellulosic fibres and air pores. Importantly, unlike plastics, recycled paper & paperboard is not separated into food-grade and non-food grade streams before recycling.

Chemical substances of different origins are present in the recycled product, including additives used in the production of paper-based products (fillers, retention aids, sizing agents, coatings, biocides, synthetic binders, inks, adhesives, photo initiators, solvents, plasticizers, surfactants, and pigments). The fibre and the additives used in the recycling process are considered to be IAS, while any contaminant being adsorbed onto a fibre and reaching the final product through the recycling process are considered to be NIAS. NIAS in recycled paper and paperboards include mineral oil hydrocarbons, bisphenols, phthalates, diisopropylnaphthalenes, inorganic elements (paints and pigments), photo initiators (benzophenone, 4-methylbnzophenone) and other compounds such as 2-phenylphenol, phenanthrene, and pyrenes (Geueke et al., 2018; ILSI Europe, 2016).

Van Bossuyt and co-workers (Van Bossuyt et al., 2016), have created an inventory of substances that may be used in printed paper and board food packaging materials, which contains more than 6000 unique compounds, of which 77% are considered to be non-evaluated in terms of their potential toxicity. Based on a preliminary study of the substances physicochemical properties, they estimated that most of the non-evaluated single substances had the potential to migrate into the food and become bioavailable after oral intake. Furthermore, 19 substances were considered to be SVHC. Likewise, Pivnenko and colleagues (Pivnenko et al., 2015), compiled a list of chemical substances potentially used in paper production and paper product manufacturing, as well as chemicals identified directly in paper and identified the most critical chemicals from their list based on their harmfulness, physical-chemical properties and biodegradability.

Kejlová and colleagues (Kejlova et al., 2019) studied the toxicity of food contact paper using combined biological and chemical methods. Of the 231 tested paper & paperboard samples (samples with different pulp percentages of recycled matter, paper household and party products), only 88 undiluted sample extracts were non-cytotoxic. Of the 143 toxic samples, 76 were severely cytotoxic (32.3%), with the majority of the cytotoxic samples containing printed material. The printed parts exhibited significantly higher cytotoxicity for red, blue and yellow print and substantial cytotoxicity for black print, compared to the non-printed parts of the samples. The black print also showed an androgenic response. A total of 13 compounds were identified in the printed samples. All of the tested samples contained at least one phthalate and a photo initiator. Black print generally exhibited the highest levels of analytes, with polycyclic aromatic hydrocarbons being detected in significant concentrations. In another study, printing inks and their components were the major migrants into food, substances which at high enough doses could lead to kidney failure, endocrine disruption and lung cancer (Muncke, 2011).

Ozaki and co-authors (Ozaki et al., 2004) carried out chemical analysis and geno-toxicological safety assessment of 28 paper & paperboard (cake, pizza, sandwich and fried chicken/potato boxes, and noodle cups) products (16 virgin paper or paperboard products and 12 recycled paper or paperboard products). Substances detected in all packaging materials, included benzophenone, bisphenol A, 1,2-benzisothiazoline-3-one, 2-(thiocyanomethylthio)benzothiazole, 2,4,5,6-tetrachloro-isophthalonitrile & 2,4,6-trichlorophenol. Michler's ketone, 4-(dimethylamino)benzophenone (NIAS) & pentachlorophenol were only detected in recycled products. Some of the substances detected had previously been identified as being either carcinogenic, toxic for reproduction or endocrine disruptors: 4,4′-bis(dimethylamino)benzophenone (Michler's ketone): Carcinogenic (ECHA-candidate list); Bisphenol A: Toxic for reproduction and endocrine disrupting properties (ECHA-candidate list). The authors indicated that recycled products exhibited more DNA-damaging activity than virgin papers, and that some compounds caused DNA damage in *B. subtilis* and/or were genotoxic in the comet assay.

Gärtner and colleagues (Gärtner et al., 2009) analysed the migration of phthalates into 20 infant foods (milk powders, cereal flakes, semolina powders) packed in recycled paperboard containers. For the migration test, the authors chose the food itself as a test medium. They concluded that only the foodstuffs packed in paper bags were highly contaminated with di-isobutyl phthalate, di-n-butyl phthalate (both are toxic for reproduction), and 2,6-di-isopropyl naphthalene (Cramer class III). The authors also indicated that paper did not provide an appropriate barrier to the transfer of nonpolar and volatile substances incorporated in the paperboard into dry or non-fatty food. The application of appropriate secondary packaging (for example, aluminium-coated foil) could prevent the contamination of foodstuffs with migration active substances from recycled paperboard.

Some substances that are know to have the potential to migrate into food such as mineral oil hydrocarbons, phthalates, printing inks and photo initiators have been studied by Food Standards Australia New Zealand (FSANZ) (a survey investigating the migration of mineral oil hydrocarbons from paperboard packaging into Australian foods) and by the New Zealand Ministry for Primary Industries (a survey of packaging chemicals including phthalates, printing inks and photo initiators). Both surveys found that these chemicals at the concentrations detected were not of concern for human health. Regarding benzenes, the International Council of Beverages Associations (ICBA) developed a Guidance Document to Mitigate the Potential for Benzene Formation in Beverages which was made available to all Australian and New Zealand beverage manufacturers.

8. Concluding Remarks

Effective recycling relies on the establishment of effective and efficient collection and sorting systems

Poor separation capability during the recycling process can lead to an increase in the presence of NIAS.

Recycling processes, such as the washing / decontaminated steps during mechanical recycling, should be validated and monitored.

A larger number and a higher concentration of substances (NIAS or IAS) is generally found in recycled packaging compared to virgin packaging materials.

The number and concentration of substances (NIAS or IAS) in recycled packaging materials increases as the number of times the material is recycled increases.

The rate of migration of IAS and NIAS from packaging into food is dependent on the nature and concentration of the substance present, the packaging material use, the food type and the storage conditions.

Not all detected NIAS in recycled packaging have been identified and neither has the origin of all of the NIAS detected been established.

Many identified substances (IAS or NIAS) present in packaging material (recycled or virgin) and/or which had migrated into the food (simulant) were substances they are not included in the EU list of substances allowed to be used in materials intended to come in contact with food.

Some substances (IAS & NIA) that were detected in food were present in concentrations higher than their migration limit (SML, 10 µk/kg for NIAS).

Some substances identified in both recycled plastic and recycled board included some phthalates which have been classified as being of very high concern (SVHC)

Few toxicity studies have been carried out on substances that have the potential to migrate from packaging into foods. Of the few studies carried out the toxicity of the identified compounds was mainly determined by Cramer rules.

Heavily printed uncoated (absence of a impermeable inner liner) food contact materials are not suitable for direct contact with food, particularly foods with a very high moisture content.

Very few studies have calculated the daily intake of substances (NIAS or IAS) that have the potential to migrate from recycled packaging material into food.

To provide confidence that the recycled packaging does not pose a threat to the safety or quality of the product it contains its entire production process from the collection of the material to be recycled through to the production and testing of the final recycled packaging should incorporate risk assessment processes, CCP control- based mechanisms and robust chain of custody, documentation and reporting strategies.

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