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Incorporating Health Impacts from Exposure to Chemicals in Food Packaging in LCA

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ABSTRACT

Life cycle assessments (LCA) on the environmental and public health impacts of food and beverage packaging materials have found some advantages to plastic over glass. Entirely missing from these evaluations are the health impacts of possible chemical, e.g. endocrine disruptor, exposure through migration of chemicals from the packaging into the food product. We build a framework based on a life cycle perspective to predict which chemicals may be in a package that are not intentionally added ingredients, and we apply this approach to the US EPA's CPCAT database. In total we find 1,154 chemicals within the CPCAT database related to food-contact materials; out of these 107 are potential endocrine disruptors according to the TEDX list of endocrine disruptors. We also build a framework in an effort to begin harmonizing LCA to include health impacts of chemical exposure related to food packaging in conjunction with other traditional LCA environmental impact categories.

Keywords: Endocrine disruptor, exposure, food packaging, LCA

1. Introduction

Life cycle assessment (LCA) has long guided industry in selection of food and beverage packaging materials to minimize environmental and human health impacts (Curran 1993; Humbert et al. 2009; Marsh et al. 2007; Roy et al. 2009). Often, results suggest that plastic packaging has marginally better performance than glass, for instance for baby food containers (Humbert et al. 2009) or for alcoholic beverages (Smith, 2009). Packaging efficacy and chemical emissions during transport and disposal have been the focal issues in these LCAs. Although human health may be a relevant impact category in such LCAs, for instance due to inhalation of particulate matter or organic chemicals, lacking from these impact assessments is addressing the possibility of chemicals leaching from packaging into the ingestible products. Contamination of food products from packaging has been documented, and of particular concern are plastics and paper treated with fluorinated chemicals (Loyo-Rosales et al. 2004; Muncke et al. 2011; Tittlemier et al. 2007; Trier et al. 2011; Wagner et al. 2009). Some fluorinated and plastic-associated chemicals have demonstrated endocrine disrupting properties, meaning they may interfere with various natural hormone systems within the human body (Muncke et al. 2014; Zoeller et al. 2012). Endocrine disruptors are a chemical category of high exposure concern and are particularly complex to assess because of their atypical toxicology, often with non-linear dose-response curves and substantial low-dose effects, as well as various effects in exposed populations due to interference with hormone-dependent human development and functioning (Colborn et al. 1993; Vandenberg et al. 2012). To our knowledge, exposure to endocrine disruptors through ingestion of packaged foods has not been addressed in LCAs. In general, LCAs evaluating health impacts of consumer products, even food products, focus on health impacts due to exposure to and intake of environmental pollutants and health impacts due to chemicals embodied within the product are neglected.

Empirical evidence suggests that food contact materials, such as packaging, lead to human exposure to chemicals of concern (Loyo-Rosales et al. 2004; Tittlemier et al. 2007; Wagner et al. 2009). For example, significantly lower levels of potentially endocrine disrupting chemicals bisphenol A and bis(2-ethyhexyl) phthalate were observed in the urine of participants while undergoing a "fresh food diet intervention," where packaged foods were limited (Rudel et al. 2011). In all, substantial evidence suggests humans are exposed to chemicals within food packaging, and thus this exposure avenue must be considered in LCAs of food packaging materials in order to provide a holistic assessment of product impacts.

Risk assessment is a parallel field of study to LCA which also offers insight regarding the exposure to and human health risks of chemicals contained in e.g. consumer products. For instance, risk assessments of chemicals within consumer products tend to focus on risks associated with the product's ingredients (Wormuth et al. 2007). Although considering ingredients is an essential first step, this strategy neglects chemicals which may be in the food packaging product that are not added intentionally as a final ingredient (Muncke et al. 2014). Thus, whether product-associated health risks are considered from a risk or LCA perspective, considering the general life cycle perspective of a food package offers a more holistic consideration of what chemicals may end up in the food due to packaging that were not intentionally added package ingredients.

The present study aims to *provide a framework to incorporate toxicological health impacts due to exposure to chemicals in food packaging* that is harmonized with established LCIA frameworks used to calculate human toxicological health impacts due to life cycle environmental emissions. We consider the life cycle perspective in two distinct ways: 1) the life cycle perspective is applied in an effort to determine all possible avenues of chemical incorporation into a food package and thus into a food product and 2) the life cycle perspective is applied as an overall framework to calculate human health impacts which may result from different stages of the food product's existence.

2. Framework development

2.1. Life cycle consideration to identify chemical constituents

Literature review suggests human ingestion of chemicals due to food packaging may be influenced from various life cycle stages and through various avenues (Figure 1.). These influences were split into two distinct sequences representing before packaging and after and during packaging. For example, before a product was distributed to consumers, chemicals may be incorporated into food packaging because they: were the result of a chemical reaction or incomplete chemical reaction occurring during material acquisition or manufacturing (Muncke et al. 2014), they were ingredients of the raw materials or ingredients required for manufacturing (Lau et al. 2000; Tittlemier et al. 2007; Trier et al. 2011), or they were incorporated incidentally during manufacturing through contamination from equipment or the environment, as for instance is observed in other consumer products such as tampons (FDA, 2013). Likewise, during and after the packaging process, that is while and after the food was enclosed by the package, although contamination of the packaging material may now be negligible, migration or diffusion of chemicals from packaging into the food may occur. Migration may occur passively through the passage of time depending on temperature, pressure, and the physicochemical interactions of the food-package combination. Additionally, there are various processes which require further consideration. For example, food pasteurization through thermal sterilization often occurs within the packaging (Ranken et al. 1997), or a consumer may microwave the food within the package (Begley et al. 2005); these processes may increase migration of chemicals into the food item or cause a heat-dependent chemical reaction.

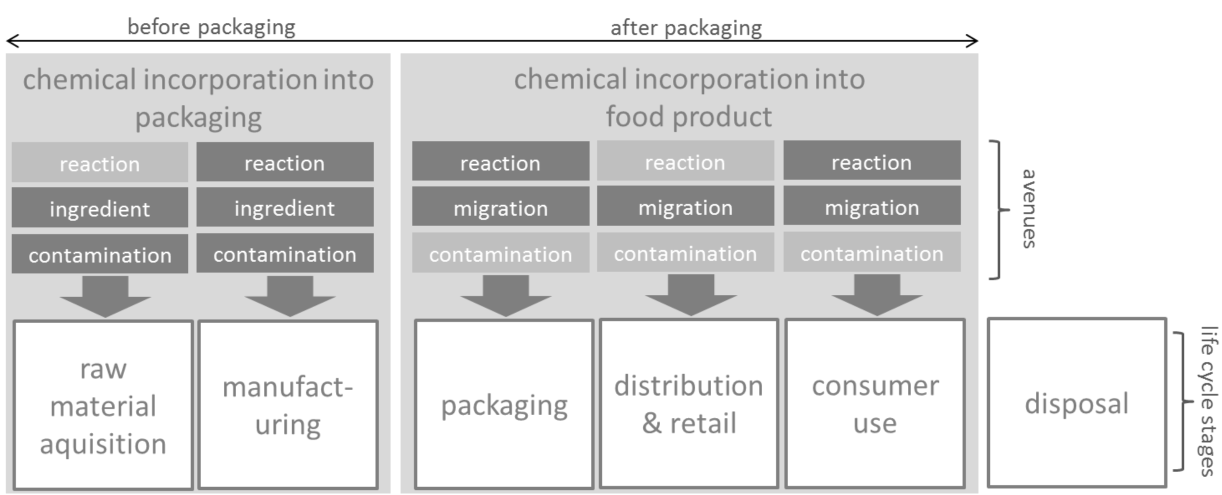

Figure 1. Relevant stages of a packaged food product life cycle, where (1) chemicals may be incorporated into the package, and (2) where these chemicals may be subsequently incorporated into the food product by various avenues (light shaded avenues are considered less relevant).

To obtain preliminary information from a life cycle perspective on which chemicals may be within food via food packaging, we mined the newly developed consumer product category (CPCAT) database publically available through the US EPA (Dionisio et al. 2014, in preparation) to look at chemicals known to be in food contact materials, as well as those known to be used in manufacturing, and as raw materials.

2.2. Development of a framework to incorporate chemical exposure to food packaging in LCA

In our framework development we considered that LCAs which include human health impacts of food packaging products may be performed using an ISO framework, generally with the following phases: 1) defining the goal and scope of the study and relevant life cycle stages; 2) collection and analysis of inventory, that is inputs and outputs of the product system; 3) assessment of impacts associated with outputs of the product system; and 4) interpretation of impacts. Typical relevant stages of a product's life cycle include, but are not limited to: the acquisition of raw materials, manufacturing, distribution, use of product, and disposal of the product. Throughout and between these life cycle stages there may be various processes also contributing to emissions such as due to transportation and waste streams.

In this study, we defined the goal and the scope around the need to include human exposure to chemicals within food packaging into an overall LCA framework in order to holistically quantify associated human health impacts. We therefore defined the relevant life cycle stages required to model this process slightly differently from traditional LCA life cycle stages. To summarize from Section 2.1, chemicals may end up in a food product via the packaging through acquired raw materials, while manufactured, while the actual packaging occurred, while the food was distributed and retailed, and while the consumer used the food product (Figure 2, top row of boxes and solid lines).

Likewise, each of these steps may lead to environmental emissions due to for example waste streams or energy use; further the disposal of the food packaging must also be considered to evaluate environmental emissions (Figure 2, top row of boxes and dotted lines). Disposal may also be important to evaluating the population-scale intake of chemicals within foods due to packaging, if food waste is significant. Inventory analysis needs to account for environmental emissions throughout the life cycle of the product, for instance from raw material acquisition to the disposal and any transportation processes occurring between and within different stages. Using the CPCAT database, a parallel inventorying process was performed analysing the various chemical inputs resulting from distinct life cycle stages in order to predict which chemicals and to what extent they may end up in a packaged food product.

In order to assess the impacts of these parallel inventories, exposure and intake of chemicals must be assessed. The intake fraction, iF, concept (Bennett et al. 2002) is often employed in LCIA models assessing human-toxicological impacts from chemical. Likewise, the product intake fraction, PiF, (Jolliet et al. 2014 in preparation; Ernstoff et al. 2014 in preparation) is a concept proposed for use in LCIA to estimate population-scale and product-user intake of substances contained in the product. The end goal was to assess the overall human health impact from exposure to chemicals in food packaging materials. This required consistent consideration of the health impacts due to environmental emissions (i.e. using the iF) versus health impacts due to use stage exposure and intake of chemicals in the food package migrating into the food product (i.e. using the PiF).

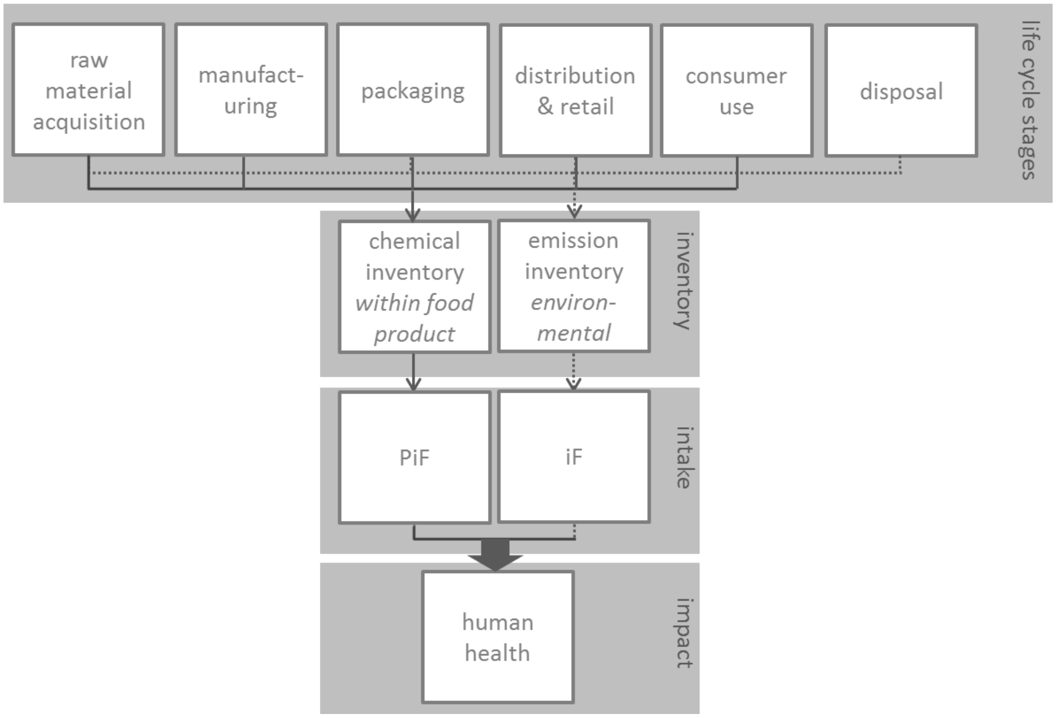

Figure 2. Contribution of relevant stages of the package's life cycle to human health impacts. Solid lines correspond to avenues in which chemicals may be incorporated into a food product, leading to human exposure and intake calculated as a product intake fraction (PiF) and dotted lines correspond to avenues in which chemicals may be emitted to the environment, leading to subsequent human exposure and intake calculated as an intake fraction (iF).

2.3.Issue of endocrine disruption

Many chemicals used within food packaging are known or suspected endocrine disruptors (Muncke et al. 2014). Perhaps due to their complicated and atypical toxicology (e.g. non-linear and non-monotonic dose response curves) (Vandenberg et al. 2012), to our knowledge, there are no methods to incorporate endocrine disruption toxicity into an LCIA framework for human-toxicological impacts, which currently relies on the assumption of a linear dose response (Rosenbaum et al. 2011). In an effort to begin including endocrine disruptors into LCIA we first employed a flagging method where chemicals were flagged if they are on lists of suspected endocrine disruptors (e.g. TEDX 2014). From here we investigated EPA approaches to approximate low-dose nonlinear chemical exposures, where at the population scale, due to tremendous individual variation, a near linear dose-response may be observed, Figure 3. (US EPA 2009).

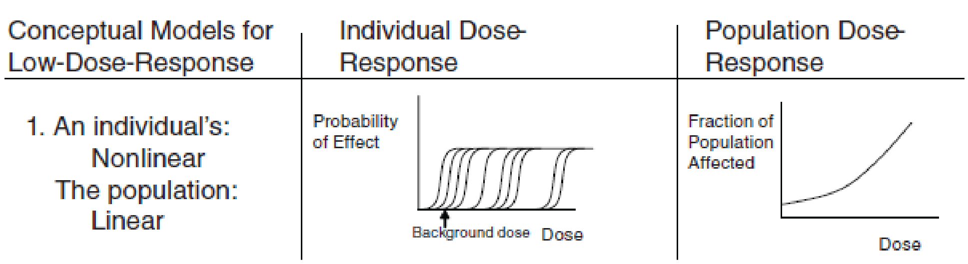

Figure 3. Demonstration of possible population scale linear dose response even when an individual's dose response may be nonlinear, taken from US EPA (2009).

3. Results

The main purpose of this paper was to develop a framework to consider exposure to chemicals within food packaging, as well as to better assess which chemicals may be incorporated into a food package and subsequently into a food product along the supply chain, therefore the main results were demonstrated in the framework development section above. Additionally, we mined the newly released US EPA consumer product category (CPCAT) database to begin understanding which chemicals may be in food products due to food packaging. In total we find 1,154 chemicals within the CPCAT database related to food-contact materials; out of these 107 are potential endocrine disruptors according to the TEDX list of endocrine disruptors. When distinguishing by life cycle stage, we find 235 chemicals associated with use as *raw materials* for food-contact products, such as packaging; 52 of these are potential endocrine disruptors. For the *manufacturing* life cycle stage we find 12 chemicals, 4 of which are potential endocrine disruptors. Table 1 shows all the manufacturing related chemicals and a sub-sample of the raw-materials related chemicals. When looking to understand the chemicals in a food package which may not be listed ingredients, raw material and manufacturing labels within CPCAT are the two distinguishable life cycle stages. All the other chemicals associated to food contact materials within the CPCAT database are listed in the database associated with the given product and thus are likely intentionally added ingredients.

Table 1. Example of chemicals likely used in food packaging manufacturing as they are listed in the CPCAT database as chemicals approved for manufacturing of food-contact materials.

Life cycle stage	CAS RN	Chemical Name	Potential endocrine disruptors
Raw material	106-89-8	1-chloro-2,3-epoxypropane	X
Raw material	126-99-8	2-chlorobuta-1,3-diene	X
Raw material	149-57-5	2-ethyl-1-hexanoic acid	X
Manufacturing	63148-62-9	baysilon	
Manufacturing	71-43-2	benzene	X
Raw material	117-81-7	bis(2-ethylhexyl) phthalate	X
Raw material	80-05-7	bisphenol A	X
Manufacturing	10043-35-3	boric acid	X
Raw material	84-74-2	dibutyl phthalate	X
Raw material	75-21-8	ethylene oxide	X
Raw material	96-45-7	imidazolidine-2-thione	X
Manufacturing	7664-38-2	orthophosphoric acid	
Raw material	131-57-7	oxybenzone	X
Manufacturing	25322-68-3	polyox WSR-N 60	
Raw material	25013-16-5	tert-butyl-4-methoxyphenol	X
Manufacturing	13463-67-7	titanium dioxide	
Manufacturing	108-88-3	toluene	X
Manufacturing	1330-20-7	xylene	X
Raw material	137-30-4	ziram	X

4. Discussion

The development of this framework is an iterative process and further insight will be gained for example, when case studies are implemented. In this discussion we focus on issues related to understanding chemical exposures due to food packaging, and do not address uncertainties related to the traditional LCIA approaches regarding environmental emission inventory of toxic chemicals.

It is difficult to identify the vast number of chemicals which may end up in a food product due to packaging because of the various contributions of the life cycle stages, and the CPCAT database is certainly not exhaustive. Further, once the chemical inventory is created and the majority of chemicals within food packaging are identified, large uncertainties are expected when estimating the subsequent concentration or migration potential of each chemical from the packaging into the food. A large amount of data is required on the variables and processes which may influence migration, for example on packaging strategies (e.g. if foods are pasteurized within the packaging), time and average storage temperature during the distribution and retail, and consumer use (e.g. if foods are microwaved within the packaging).

Further, even in the cases when the concentration of a chemical contaminant in the end food product is known perhaps due to analytical detection, data will be needed on population scale ingestion of the food product, and of course toxicity or dose response in the case of estimating resulting health impacts. Specifically for endocrine disruptors, where new information is being generated at a fast rate, we expect many years of research required to provide methods to consistently include such impacts within an LCA framework.

Aside from uncertainties in our analysis and within the defined system boundaries, there are also various considerations outside the scope of this study which may also influence the overall health impact related to a food package. For example, the food package's efficacy in controlling the growth of pathogenic bacteria on food items is an important contribution to human health.

5. Conclusion

In all, we suspect it is essential to include chemical exposures via food packaging in order to estimate the overall health impact of a food product. Many chemicals associated with food contact materials are potential endocrine disruptors and are therefore of particular concern. Insight gained through the life cycle perspective may help identify chemicals of concern which are not intentionally added ingredients, and also help consistently evaluate the extent of a food package's effect on public health both mitigated through environmental emissions and exposure occurring through consuming the packaged food. In this paper we provide the ground-work to advance future work addressing these necessary research gaps and a framework which must be iteratively developed with advances in knowledge.

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