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Freshwater ecotoxicity impacts from pesticide use in animal and vegetable foods produced in Sweden

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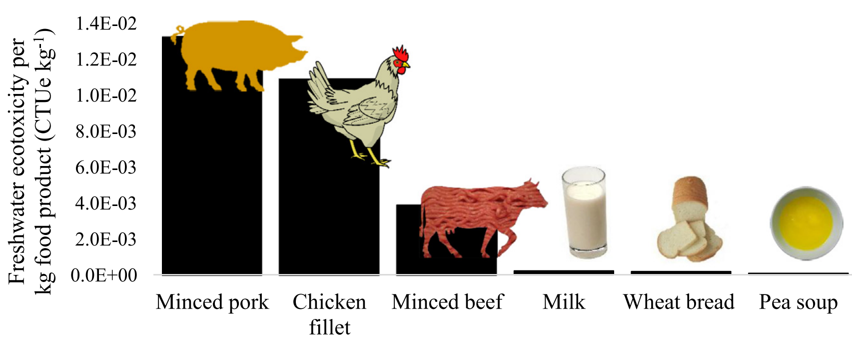
HIGHLIGHTS

- Animal-based food products have much larger impacts than plant-based food products.
- Impact potentials per kg pork > chicken > beef > milk > bread > pea soup.
- Chicken fillet and minced pork have larger impacts than minced beef and milk.
- Soybeans dominate the impact potentials of chicken fillet and minced pork.
- Replacing soybeans with local feed crops can reduce the impacts considerably.

GRAPHICAL ABSTRACT



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ABSTRACT

Chemical pesticides are widely used in modern agriculture but their potential negative impacts are seldom considered in environmental assessments of food products. This study aims to assess and compare the potential freshwater ecotoxicity impacts due to pesticide use in the primary production of six food products: chicken fillet, minced pork, minced beef, milk, pea soup, and wheat bread. The assessment is based on a detailed and site-specific inventory of pesticide use in the primary production of the food products, all of which are produced in Sweden. Soybeans, used to produce the animal-based food products, are grown in Brazil. Pesticide emissions to air and surface water were calculated using PestLCI v. 2.0.5. Ecotoxicity impacts were assessed using USEtox v. 2.01, and expressed in relation to five functional units. The results show that the animal-based food products have considerably larger impact potentials than the plant-based food products. In relation to kg pea soup, impact potentials of bread, milk, minced beef, chicken fillet and minced pork are ca. 2, 3, 50, 140 and 170 times larger, respectively. All mass-based functional units yield the same ranking. Notably, chicken fillet and minced pork have larger impacts than minced beef and milk, regardless of functional unit, due to extensive use of pesticides, some with high toxicity, in soybean production. This result stands in sharp contrast to typical carbon footprint and land use results which attribute larger impacts to beef than to chicken and pork. Measures for reducing impacts are discussed. In particular, we show that by substituting soybeans with locally sourced feed crops, the impact potentials of minced pork and chicken fillet are reduced by ca. 70 and 90%, respectively. Brazilian soybean production is heavily reliant on pesticides. We propose that weak legislation, in combination with tropical climate and agronomic practices, explains this situation.

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1. Introduction

Globally, the planetary boundaries that define the safe operating space for humanity have been transgressed for biodiversity loss (Rockström et al., 2009). According to the review by Diamond et al. (2015), there is sufficient evidence to say that also the safe operating space for chemical pollution has been transgressed. Agricultural chemicals, such as pesticides, contribute to these boundary transgressions, although it is not known to which extent. Pesticides provide many benefits but also have negative effects. Studies have, e.g., linked agricultural chemicals to surface water pollution (Stehle and Schulz, 2015) and to negative impacts on bird populations in agricultural landscapes (Hallmann et al., 2014), survival and growth of bee colonies (Whitehorn et al., 2012, Henry et al., 2012), biodiversity (Geiger et al., 2010, Beketov et al., 2013), and ecosystem functions (Schäfer et al., 2007).

Life cycle assessment (LCA) is one of the most commonly used methods for assessing the potential environmental impacts associated with a product or a service throughout its life cycle. Despite the fact that chemical pesticides are integral parts of modern food production systems, their ecotoxicity impacts are often not considered in LCA-studies of food products (Henriksson et al., 2012, de Vries and de Boer, 2010, Nemecek et al., 2016). One important reason is the lack of high-quality inventory data of pesticide use and emissions (Yang and Suh, 2015). When pesticides are included, emission inventories often rely on oversimplified assumptions, are not site-specific, and suffer from methodological inconsistencies (Rosenbaum et al., 2015, van Zelm et al., 2014).

In LCA, all impacts are expressed in relation to a functional unit that intends to capture the primary function of the assessed product (JRC, 2010). Despite this, although nutrition can be considered the primary function of food, LCA studies of food products usually only assess impacts in relation to the mass of food (de Vries and de Boer, 2010, Schau and Fet, 2008, Henriksson et al., 2012, Roy et al., 2009, Nijdam et al., 2012). Sonesson et al. (2017) developed a range of new functional units based on the quality and/or quantity of protein, as well as the dietary context. Functional units that take protein quality and/or quantity into account are interesting since proteins are essential nutrients and associated with widely different environmental impacts depending on origin and production method.

A relatively large number of studies have assessed the carbon footprints and land use of different protein sources. Generally, proteins of animal origin (especially ruminant meat) require more resources, including land, and have larger carbon footprints, than proteins of vegetable origin (Nijdam et al., 2012, Aiking, 2014, Nemecek et al., 2016, Wirsenius et al., 2010). For meat products, carbon footprints and land use generally decrease in the order beef > pork > poultry (Westhoek et al., 2011, Nijdam et al., 2012).

The aim of this study is to assess and compare the potential freshwater ecotoxicity impacts due to pesticide use in the primary production of six food products of animal and vegetable origin (chicken fillet, minced pork, minced beef, milk, pea soup and wheat bread). Since the choice of functional unit can have a large influence on results and conclusions, impacts are assessed in relation to five different functional units: kg food, food energy content, and three functional units that take protein quantity and/or quality into account. Ultimately, this study aims to contribute to more comprehensive and relevant environmental assessments of food products.

2. Method

This study uses LCA methodology to assess the potential freshwater ecotoxicity impacts from pesticide use in the primary production of a selection of food products. Primary production refers to the cultivation of the crops on which the assessed food products are based (whether directly or as animal feed). The food products are presented in Section 2.1.

The method applied here consists of four steps. First, we conducted a detailed and site-specific inventory of the pesticide use and emissions in the studied crops and regions (Section 2.2). Second, we calculated the potential freshwater ecotoxicity impacts per kg harvested crop (Section 2.3). Third, we calculated the potential freshwater ecotoxicity impacts per kg food product using a model of Swedish food production systems (Section 2.4). Finally, impact scores were expressed in relation to a selection of five different functional units (Section 2.5).

2.1. Food products, crops and study regions

Six food products, based on eight crops, are included here (Table 1). Four food products are of animal origin, and two are of vegetable origin. The food products are produced in the county of Västra Götaland, in the southwest part of Sweden. Seven of the crops are produced in Västra Götaland and one (soybean) is produced in Mato Grosso, Brazil (Table 2). In Västra Götaland, we differentiate between a plain region, characterized by relatively intensive crop production in a flat landscape, and a mixed landscape region, characterized by a mix of forests, permanent pastures, and arable lands with a mix of crop and grass production (for more information, see Chapter S1 in the Supporting Information). Mato Grosso, Brazil, represents a region with large-scale and intensive soybean production. Soil, climate, and field conditions differentiate the regions (for more information, see Chapters S3–S5 in the Supporting Information).

2.2. Life cycle inventory

The life cycle inventory consists of two parts, both of which are site-specific: pesticide application inventory (Section 2.2.1) and pesticide emission inventory (Section 2.2.2).

2.2.1. Pesticide application inventory

The crops are part of specific crop rotations (Table 2), which partly determine the need for pesticide input. For all crops except peas and soybean, pesticide application data were obtained from Sonesson et al. (2014), which compiled information about current agronomic practices in the studied crops and regions, see also SLU (2015). Glyphosate, one of the most commonly used active substances in Sweden (KemI, 2014), was added to the pesticide application data obtained from Sonesson et al. (2014), in order to increase the representativeness of the application scenarios. Pesticide application data for peas were determined based on information from the Swedish Board of Agriculture (SJV, 2015a, SJV, 2015b).

Pesticide application data for soybeans were obtained from the conventional soybean case (soybeans not genetically engineered to tolerate glyphosate) in Nordborg et al. (2014). We considered conventional soybeans, although a majority of soybeans produced in Brazil are genetically engineered to tolerate glyphosate and hence subject to larger amounts of pesticides (in particular glyphosate) than conventional soybeans, see Nordborg et al. (2014). However, there is no significant difference in the potential freshwater ecotoxicity impacts between conventional and genetically engineered glyphosate tolerant soybeans, since insecticides and fungicides, which are used regardless of seed technology, dominate the impact scores (Nordborg et al., 2014).

The pesticide application data represent current, typical, and realistic use of pesticides in the studied crops and regions and specify, for

Table 1
The food products considered here, and the underlying crops.

Food products	The crop(s) required to produce the food product
Wheat bread	Bread wheat
Pea soup	Field peas
Minced pork	Feed wheat, rapeseed, soybeans, oats, barley
Milk	Grass/clover[a], oats, barley, soybeans
Minced beef	Grass/clover[a], oats, barley, soybeans
Chicken fillet	Feed wheat, rapeseed, soybeans

[a] A mix of grass and clover is fed to dairy cows and beef cattle in the form of silage.

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