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Review

Uptake of pharmaceuticals by plants grown under hydroponic conditions and natural occurring plant species: A review

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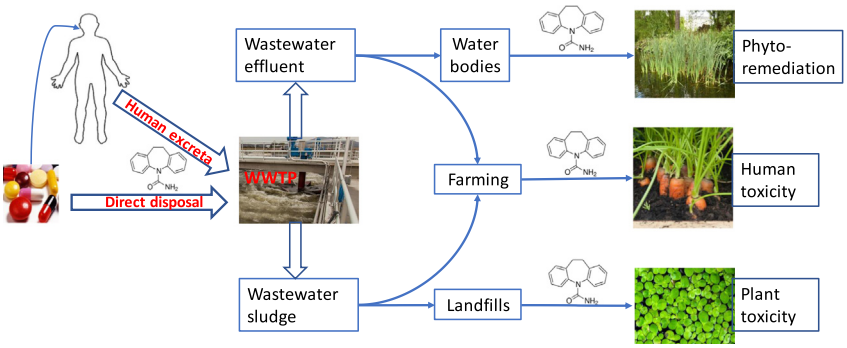
HIGHLIGHTS

- We evaluated the plant uptake of pharmaceuticals from water and soil.
- The negative effects of plant uptake of pharmaceuticals are discussed.
- Most studies use concentrations higher than those expected in the environment.
- Plant uptake studies focused more on antibiotics than other pharmaceutical classes.
- Pharmaceutical uptake is through plant roots and translocated into aerial tissues.

GRAPHICAL ABSTRACT



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ABSTRACT

Sizeable amount of research has been conducted on the possible uptake of pharmaceuticals by plants from contaminated soil and water used for irrigation of crops. In most cases, pharmaceuticals are taken by roots and translocated into various tissues by transpiration and diffusion. Due to the plant uptake, the occurrence of pharmaceuticals in food sources such as vegetables is a public concern. Few review papers focusing on the uptake of pharmaceuticals, in particular antibiotics, and their translocation in plant tissues have been published. In the current review paper, the work conducted on the uptake of pharmaceuticals belonging to different therapeutic groups such as antibiotics, non-steroidal anti-inflammatory drugs, β-blockers and antiepileptics is reviewed. Such work includes the occurrence of pharmaceuticals in plants, translocation once taken by plants, toxicity studies as well as implications and future studies. Furthermore, the advantages and drawbacks associated with the detection and uptake of these pharmaceuticals by plants are discussed. In addition, the physico-chemical properties that could influence the plant uptake of pharmaceuticals are deliberated.

Contents

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1. Introduction

In recent years, pharmaceuticals have been found in aquatic systems which include drinking water (Odendaal et al., 2015), wastewater (Yang et al., 2017), ground water (Balakrishna et al., 2017) and surface water (Balakrishna et al., 2017). The scarcity of rainfall in winter seasons of certain countries increases the demand of using wastewater for irrigation of crops. Globally, it is generally known that wastewater treatment plants (WWTPs) are unable to completely remove organics from wastewater effluents which include pharmaceuticals during the decontamination process. Therefore, studies have shown that the re-use of wastewater effluent with pharmaceutical constituents for irrigation of crops could result in the uptake of pharmaceuticals by plant roots (Christou et al., 2017). This could result in the occurrence of pharmaceuticals in food sources such as vegetables which may cause threats to the health of the consumer. On the other hand, the uptake of pharmaceuticals by plants can be an advantage because it could assist in the reduction of the pollutant load in surface water (Cui et al., 2015). Constructed wetlands have been investigated for their ability to remove pharmaceuticals from water through the usage of certain plants (Dan et al., 2013).

Although pharmaceuticals are ingested by humans and animals for the purpose of disease treatment and prevention, as well as growth promotion (Chuang et al., 2015), extreme consumption can result in sickness. The example of this was documented elsewhere where the ingestion of 24–36 g fenoprofen led to coma, hypotension, metabolic acidosis, and respiratory depression within 4 h (Kolodzik et al., 1990). Accumulation of pharmaceuticals in plants as documented in literature lead to growth suppression and reduction in photosynthetic pigments among other side effects (Carter et al., 2015; Migliore et al., 1996). The effects of extended daily consumption of pharmaceuticals through the contaminated food sources and water are not yet fully understood.

Recently, few review papers on the uptake of pharmaceuticals by plants have been documented in literature (Bártíková et al., 2016; Pan and Chu, 2017; Tasho and Cho, 2016; Wu et al., 2015; Zhang et al., 2017). The main focus of these review papers is on the plant uptake of antibiotics. For example, Pan and Chu (2017) presented a review paper on fate of antibiotics in soil and their uptake by edible crops (Pan and Chu, 2017). The review paper published by Tasho and Cho (2016) is based on veterinary antibiotics in animal waste, their distribution in soil and uptake by plants (Tasho and Cho, 2016). The review paper presented by Bártíková et al. (2016) focused on the veterinary drugs in the environment and their toxicity to plants (Bártíková et al., 2016). The overview of pharmaceuticals and personal care products in the soil–plant systems, including analytical methods for their determination in plant tissues, their fate in agricultural soils receiving treated wastewater irrigation or biosolids amendment, and their plant uptake under laboratory and field conditions has been reported (Wu et al., 2015). Most recently, uptake and translocation of organic pollutants in plants have been reviewed with more focus on antibiotics together with organics such as herbicides (Zhang et al., 2017). Therefore, the aim of the present review paper is to give an overview of the work presented on the plant uptake of pharmaceutical groups that include non-steroidal anti-inflammatory drugs (NSAIDs), antibiotics, antibacterial agent, β-blockers, calcium channel blocker, antiepileptics, steroid hormones, antidepressant, antidiabetic, antihistamine, antineoplastic agent, anti-itch, x-ray contrast agent, lipid-lowering agents, benzodiazepines and tranquilizers from soil and contaminated water. The scope of the present work includes the plant uptake of pharmaceuticals from the surrounding environment which could be sediments or water, and their translocation within the plant tissues. Further to this, the effects of the plant uptake such as toxicity to humans and plants are discussed.

2. Sources of pharmaceuticals in the environment

Pharmaceuticals enter the environment through various sources as elaborated in Fig. 1 (Kostopoulou and Nikolaou, 2008). These sources include direct disposal of pharmaceuticals into water resources, excretion into sewers that lead to the transportation of high loads of pharmaceuticals into WWTPs. Some pharmaceuticals tend to partition in sludge during wastewater treatment, which lead to their introduction into agricultural fields. Different classes of pharmaceuticals found present in sewage sludge include NSAIDs, antibiotics, antiplatelets, psychiatric drugs, antidiabetics and β-blockers (Fijalkowski et al., 2017; Subedi et al., 2014, 2013). The growth of plants or vegetables in contaminated soil or soil fertilized with sludge could result in the uptake of pharmaceuticals by plants. Recently, composted biosolids and treated wastewater have been reported as the sources of pharmaceuticals and personal care products for plant uptake (Ben Mordechay et al., 2017). In a study conducted in China, high levels of antibiotics were found in soils from vegetable greenhouses, where manure and animal feces fertilization were identified as their primary source (Li et al., 2015). The mean concentrations of antibiotic classes reported in their work decreased in the following order: tetracyclines (102 μg/kg) > quinolones (86 μg/kg) > sulfonamides (1.1 μg/kg) > macrolides (0.62 μg/kg). In a different study, Boxall et al. (2006) discovered that selected pharmaceuticals used in veterinary medicines may occur in soils for at least 5 months following the application of manure containing them (Boxall et al., 2006).

3. Physicochemical properties of pharmaceuticals

There is a wide variability in the physicochemical properties of pharmaceuticals. Such properties are summarized in Table 1. In most cases, pharmaceuticals enter the environment through excretion and end-up in water bodies. As shown in Table 1, some pharmaceuticals such as tylosin, and dilantin are relatively water insoluble and have high log K_{OW}, which could easily result in their adsorption into sediments and sludge. These become readily available for uptake by plants. Furthermore, uptake of organic compounds into plant roots partly depends on the properties of the compounds (Trapp, 2000). For example, it is documented in literature that properties such as molecular weight and hydrophobicity with the parameters K_{OW} (partition coefficient between octanol and water) and K_{OA} (partition coefficient between octanol and air) have a direct influence on plant uptake of pharmaceuticals (Calderón-Preciado