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Review

Role of Wetland Plants and Use of Ornamental Flowering Plants in Constructed Wetlands for Wastewater Treatment: A Review

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Featured Application: This study describes the importance of the use of ornamental flowering plants in constructed wetlands as wastewater treatment systems, as well as highlighting which species have been tested in terms of their ability to adapt and remove contaminants so that they can be used in new designs of domiciliary, rural and urban wetlands, generating better water cleaning, aesthetic landscape and economic potential.

Abstract: The vegetation in constructed wetlands (CWs) plays an important role in wastewater treatment. Popularly, the common emergent plants in CWs have been vegetation of natural wetlands. However, there are ornamental flowering plants that have some physiological characteristics similar to the plants of natural wetlands that can stimulate the removal of pollutants in wastewater treatments; such importance in CWs is described here. A literature survey of 87 CWs from 21 countries showed that the four most commonly used flowering ornamental vegetation genera were *Canna*, *Iris*, *Heliconia* and *Zantedeschia*. In terms of geographical location, *Canna* spp. is commonly found in Asia, *Zantedeschia* spp. is frequent in Mexico (a country in North America), *Iris* is most commonly used in Asia, Europe and North America, and species of the *Heliconia* genus are commonly used in Asia and parts of the Americas (Mexico, Central and South America). This review also compares the use of ornamental plants versus natural wetland plants and systems without plants for removing pollutants (organic matter, nitrogen, nitrogen and phosphorous compounds). The removal efficiency was similar between flowering ornamental and natural wetland plants. However, pollutant removal was better when using ornamental plants than in unplanted CWs. The use of ornamental flowering plants in CWs is an excellent option, and efforts should be made to increase the adoption of these system types and use them in domiciliary, rural and urban areas.

Keywords: ornamental flowering plants; constructed wetlands; wastewater; pollutants

1. Introduction

Nowadays, the use of constructed wetlands (CWs) for wastewater treatment is an option widely recognized. This sustainable ecotechnology is based on natural wetland processes for the removal of contaminants, including physical, chemical and biological routes, but in a more controlled environment compared with natural ecosystems [1–3]. These ecologically engineered systems involve three important components: porous-filter media, microorganism and vegetation [2]. The mechanisms for the transformation of nutrient and organic matter compounds are conducted by biofilms of microorganisms formed in the porous media and the rhizosphere zone [4,5]. The media materials (soil, sand, rocks, and gravel) provide a huge surface area for microorganisms to attach, contributing to macrophyte growth, and also act as filtration and/or adsorption medium for contaminants present in the water [6]. Regarding the vegetation, one of the most conspicuous features of wetlands is the role that plants play in the production of root and rhizomes in order to provide substrates for attached bacteria and oxygenation of areas adjacent to the root, and absorb pollutants from water. Nitrogen (N), Phosphorus (P) and other nutrients are mainly taken up by wetland plants through the epidermis and vascular bundles of the roots, and are further transported upward to the stem and leaves [7]. This provides carbon for denitrification during biomass decomposition and prevents pollutants from being released from sediments [8–10]. The use of the CW technology began in Europe during the 1960s [1], and has been replicated on other continents. The type of vegetation used are plants from natural wetlands, including *Cyperus papyrus*, *Phragmites australis*, *Typha* and *Scirpus* spp., which have been evaluated for their positive effects on treatment efficiency for nutrient and organic compounds around the globe [8,9,11]. In Americas, such species are typical in CWs, and are found mainly in the United States, where the technology has been used extensively and is implemented in different rural and urban zones [12–16]. In recent studies (15 years ago), the goal of CW studies involved an investigation into the use of herbaceous perennial ornamental plants in CWs, including the use of species with different colored flowers to make the systems more esthetic, and therefore making it more probable for adoption and replication.

This review elucidates the role of macrophytes in CWs and highlights the use of ornamental flowering plants in this type of ecotechnology around the world. This includes plants that are not typical in natural wetlands, and shows the resulting removal efficiency and their importance in rural communities. The aim of this review is to create a context regarding the advantages that the use of CWs with ornamental flowering plants provides, emphasizing that these systems could be used for more sites that require wastewater treatment. The information from 87 constructed wetlands using ornamental flowering plants (OFP) in 21 countries was reported in the literature that was analyzed. Only published or accepted (in press) papers were considered; the results of theses or abstracts of conferences were not considered.

2. Role of Macrophytes in CWs

The plants that grow in constructed wetlands have several properties related to the water treatment process that make them an essential component of the design. Macrophytes are the main source of oxygen in CWs through a process that occurs in the root zone, called radial oxygen loss (ROL) [17]. The ROL contributes to the removal of pollutants because it favors an aerobic micro-environment, and waste removal is therefore accelerated, whereas, in anaerobic conditions (the main environment in CWs), there is less pollutant removal. In a recent study [18] comparing the use of plants in high density (32 plants m^{-2}) and low density (16 plants m^{-2}) CWs, the removal of nitrogen compounds in high density CWs was twice that of CWs using a low density of plants, which is strong evidence of the importance of plants in such systems. The removal rate of total nitrogen (TN) and total phosphorous (TP) were also positively correlated with the ROL of wetland plants, according to a study involving 35 different species [19].

The roots of plants are the site of many microorganisms because they provide a source of microbial attachment [8] and release exudates, an excretion of carbon that contributes to the denitrification process, which increases the removal of pollutants in anoxic conditions [20,21]. Other physical effects in plant tissue in water include: reduction in the velocity of water flow, promotion of sedimentation, decreased resuspension, and uptake of nutrients. However, for roots and rhizomes in the sediment, the physical effects include: stabilizing the sediment surface, less erosion, nutrient absorption, prevention of medium clogging (in subsurface conditions) and improved hydraulic conductivity. Aerial plant tissue favors in the light attenuation (reduced growth of photosynthesis), reduced wind velocity, storage of nutrients and aesthetic pleasing appearance of the system [2,5]. A 5-year study evaluated the influence of vegetation on sedimentation and resuspension of soil particles in small CWs [22]. The author showed that macrophytes stimulated sediment retention by mitigating the resuspension of the CW sediment (14 to 121 kg m^{-2}). Macrophytes increased the hydraulic efficiency by reducing short-circuit or preferential flow. Plant presence led to decreasing saturated hydraulic conductivity in horizontal subsurface flow. This study was relevant, since monitoring macrophytes is essential for understanding and controlling clogging in subsurface CWs [22].

The removal of organic and inorganic pollutants in CWs is not only the role of microorganisms. This function is also exerted by plants that are able to tolerate high concentrations of nutrients and heavy metals, and, in some cases, plants are able to accumulate them in their tissues [23]. It has been estimated that between 15 and 32 mg g^{-1} of TN and 2–6 mg g^{-1} (dry mass) of TP are removed by CW plants, which was measured in the aboveground biomass [24,25].

Other uptakes of xenobiotic compounds (organic pollutants) are also the result of the presence of plants, involving processes such as transformation, conjugation and compartmentation [23].

3. Survey Results of the Use of Ornamental Flowering Plants in CWs

Many CWs around the world used OFP for the removal of various types of wastewater (Table 1). For example, in China, the most popular plants used is *Canna* sp., while in Mexico the ornamental plant used is more diverse, including plants with flowers of different colors, shapes and aromatic characteristics (*Canna*, *Heliconia*, *Zantedeschia*, *Strelitzia* spp).

Table 1. Ornamental flowering plants and removal of wastewater pollutants in CWs (constructed wetlands) around the globe.

Country	Type of Wastewater	Vegetation	Removal Efficiency of Pollutants (%)	Reference
Brazil	Domestic	*Heliconia psittacorum*	TSS: 88, COD: 95, BOD: 95	Paulo et al. [26]
	Domestic	*Alpinia purpurataArundina bambusifoliaCanna* spp. *Heliconia psittacorum* L.F.	COD: 48-90, PO_4-P: 20, TKN: 31 and TSS: 34.	Paulo et al. [27]
	Swine	*Hedychium coronarium* *Heliconia rostrata*	COD: 59, TP: 44, TKN: 34 and NHx 35 COD: 57, TP: 38, TKN: 34 and NHx: 37	Sarmento et al. [28]
		Hemerocallis flava	COD: 72, BOD: 90, TN: 52, TP: 41 and SST: 72.	Prata et al. [29]
		Heliconia psittacorum L.F.		Teodoro et al. [30]
China	Municipal	*Canna indica*	COD: 77, BOD: 86, TP: >82, TN: >45	Shi et al. [31]
	Aquaculture ponds	*Canna indica* mixed with other species	BOD: 71, TSS: 82, chlorophyll-a: 91.9, NH_4-N: 62, NO_3-N: 68 and TP: 20.	Li et al. [32]
	Domestic	*Canna indica* Linn	COD: 82.31, BOD: 88.6, TP: >80, TN: >85	Yang et al. [33]
	Municipal	*Canna indica*	NH_4-N: 99, PO_4-P: 87	Zhang et al. [34]
	Drain of some factories	*R. carnea*, *I. pseudacorus*, *L. salicaria*	COD: 58-92, BOD: 60-90 TN: 60-92, TP: 50-97,	Zhang et al. [35]
	River	*Canna* sp	COD: 95, N-NH_4: 100, N-NO_3: 76, TN: 72	Sun et al. [36]
	Domestic	*Canna indica*	TP: 60, NH_4-N: 30-70, TN: ~25	Cui et al. [37]
	Aquaculture ponds	*Canna indica* mixed with other natural wetland plants	BOD: 56, COD: 26, TSS: 58, TP: 17, TN: 48 and NH_4-N: 34.	Zhang et al. [38]

Table 1. *Cont.*

Country	Type of Wastewater	Vegetation	Removal Efficiency of Pollutants (%)	Reference
China	Wastewater from a student dormitory (University)	*Canna indica* mixed with other natural wetland plants	COD: 50–70, BOD: 60–80, N-NO_3: 65–75, TP: 50–80	Qiu et al. [39]
	Domestic	*Canna indica* and *Hedychium coronarium*	TP: 40–70	Wen et al. [40]
	Polluted river	*Iris pseudacorus* mixed with other natural wetland plants	TN: 68, NH_4-N: 93, TP: 67	Wu et al. [41]
	Sewage	*Iris pseudacorus,* mixed with other plants of natural wetlands	TN: 20 and TP: 44	Xie et al. [42]
	Municipal	*Canna indica*	COD: 60, NO_3-N: 80, TN: 15, TP: 52	Chang et al. [43]
	Simulated polluted river water	*Iris sibirica*	COD: 22, TN: 46, NH_4-N: 62, TP: 58	Gao et al. [44]
	Synthetic	*Canna sp*	Fluoride: 51, Arsenic: 95	Li et al. [45]
	Simulated polluted river water	*Iris sibirica*	Cd: 92	Gao et al. [46]
	Synthetic	*Canna indica* L.	N: 56–60	Hu et al. [47]
	Synthetic (hydrophonic sol.)	*Canna indica L.*	TN: 40–60, N-NO_3: 20–95, NH_4-N: 20–55	Wang et al. [48]
Chile	Sewage	*Zantedeschia aethiopica, Canna* spp. and *Iris* spp	BOD: 82, TN: 53, TP: 60.	Morales et al. [49]
	Sewage	*Tulbaghia violácea, and Iris pseudacorus.*	BOD: 57–88, COD: 45–72, TSS: 70–93, PO_4-P: 6–20.	Burgos et al. [50]
	Ww rural community	*Zantedeschia aethiopica*	Organic matter: 60%, TSS: 90%	Leyva et al. [51]
Colombia	Domestic	*Heliconia psíttacorum*	NH_3: 57 COD: 70	Gutiérrez-Mosquera and Peña-Varón [52]
	Synthetic landfill leachate	*Heliconia psittacorum*	COD, TKN and NH_4 (all: 65–75)	Madera-Parra et al. [53]
	Cattle bath	*Alpinia purpurata*	SST: 58, TP: 85, COD: 63	Marrugo-Negrete et al. [54]
	Municipal	*Heliconia psitacorum*	Bisphenol A: 73, Nonylphenols: 63	Toro-Vélez et al. [55]
Costa Rica	Dairy raw manure	*Ludwigia inucta, Zantedechia aetiopica, Hedychium coronarium* and *Canna generalis*	BOD: 62, NO_3-N: 93, PO_4-P: 91, TSS: 84	León and Cháves [56]
Egypt	Municipal	*Canna* sp	TSS: 92, COD: 88, BOD: 90	Abou-Elela and Hellal [57]
	Municipal	*Canna* sp	TSS: 92, COD: 92, BOD: 92	Abou-Elela et al. [58]
India	Paper mill effluent	*Canna indica*	9,10,12,13-tetrachlor- ostearic acid: 92 and 9,10-dichlorostearic acid: 96	Choudhary et al. [59]
	Synthetic	*Canna indica*	Dye: 70-90 COD: 75	Yadav et al. [60]
	Synthetic greywater	*Heliconia angusta*	COD:40, BOD: 70, TSS: 62, TDS: 19	Saumya et al. [61]
	Domestic	*Canna generalis*	TN: 52, T-PO3: 9	Ojoawo et al. [62]
	Collection pond	*Canna Lily*	BOD: 70-96, COD: 64–99	Haritash et al. [63]

Table 1. *Cont.*

Country	Type of Wastewater	Vegetation	Removal Efficiency of Pollutants (%)	Reference
India	Hostel greywater	*Canna indica*	COD, TKN and Pathogen all up 70	Patil and Munavalli, [64]
	Domestic	*Polianthus tuberosa* L.	Heavy metals (Pb and Fe: 73–87), (Cu and Zn: 31–34) and Ni and Al: 20–26	Singh and Srivastava [65]
Ireland	Domestic	*Iris pseudacorus*	TN: 30, TP:28	Gill and O'Luanaigh [66]
Italy	Synthetic	*Zantedeschia aethiopica, Canna indica*	N: 65–67, P: 63–74, Zn and Cu: 98–99, Carbamazepine: 25–51, LAS: 60–72	Macci et al. [67]
Kenya	Flower farm	*Canna* spp.	BOD: 87, COD: 67, TSS: 90, TN: 61	Kimani et al. [68]
Mexico	Municipal	*Zantedeschia aethiopoca*	COD: 35, TN: 45.6	Belmont and Metcalfe [69]
	Domestic	*Zantedeschia Aethiopica* and *Canna flaccid*	SST: 85.9, COD: 85.8, NO_3-N: 81.7, NH_4-N: 65.5, NT: 72.6	Belmont et al. [70]
	Coffee processing	*Heliconia psittacorum*	COD: 91, Coliformes: 93	Orozco et al. [71]
	Domestic	*Strelitzia reginae, Zantedeschia esthiopica, Canna hybrids, Anthurium andreanum, Hemerocallis Dumortieri*	COD: >75, P: >66, Coliforms: 99	Zurita et al. [72]
	Domestic	*Zantedeschia aethiopica*	BOD: 79, TN: 55, PT: 50	Zurita et al. [73]
	Wastewater form canals	*Zantedeschia aethiopica*	COD: 92, N-NH_4: 85, P-PO_4: 80	Ramírez-Carrillo et al. [74]
	Municipal	*Strelitzia reginae, Anthurium, andreanum.*	TSS: 62, COD: 80, BOD: 82, TP: >50, TN: >49	Zurita et al. [75]
	Groundwater	*Zantedeschia aethiopica and Anemopsis californica*	As: 75-78	Zurita et al. [76]
	Domestic	*Gladiolus* spp	BOD: 33, TN: 53, TP: 75	Castañeda and Flores [77]
	Mixture of greywater (from a cafeteria and research laboratories)	*Zantedeschia aethiopica* and *Canna indica*	COD: 65, NT: 22.4, PT: 5.	Zurita and White [78]
	Domestic	*Zantedeschia aethiopica*	BOD: 70	Hallack et al. [79]
	Domestic	*Heliconia stricta, Heliconia psittacorum* and *Alpinia purpurata*	BOD: 48, COD: 64, TP: 39, TN: 39	Méndez-Mendoza et al. [80]
	Municipal	*Canna hybrids* and *Strelitzia reginae*	DQO: 86, NT: 30-33, PT: 24–44	Merino-Solís et al. [81]
	Municipal	*Zantedeschia aethiopica* and *Strelitzia reginae*	COD: 75, TN: 18, TP: 2, TSS: 88.	Zurita and Carreón-Álvarez [82]
	Domiciliar	*Spathiphyllum wallisii, Zantedechia aethiopica, Iris japonica, Hedychium coronarium, Alocasia* sp, *Heliconia* sp. and *Strelitzia reginae.*	N-NH_4: 64–93 BOD: 22–96 COD: 25–64	Garzón et al. [83]
	Community	*Zantedeschia aethiopica, Lilium* sp, *Anturium* spp and *Hedychium coronarium*	NT: 47, PT: 33, COD: 67	Hernández [84]

Table 1. *Cont.*

Country	Type of Wastewater	Vegetation	Removal Efficiency of Pollutants (%)	Reference
Mexico	Stillage Treatment	*Canna indica*	BOD: 87, COD: 70	López-Rivera et al. [85]
	Artificial	*Iris sibirica* and *Zantedeschia aethiopica*	Carbamazepine: 50–65	Tejeda et al. [86]
	Community	*Alpinia purpurata* and *Zantedeschia aethiopica*		Marín-Muñiz et al. [87]
	Polluted river	*Zantedeschia aethiopica*	NO_3-N: 45, NH_4-N: 70, PO_4-P: 30	Hernández et al. [18]
	Municipal	*Spathiphyllum wallisii*, and *Zantedeschia aethiopica*		Sandoval-Herazo et al. [88]
	University	*Strelitzia reginae*		Martínez et al. [21]
Nepal	Municipal	*Canna latifolia*	TSS: 97, COD: 97, BOD: 89, TP: >30	Sigh et al. [89]
Portugal	Tannery	*Canna indica mixed with other plants*	COD: 41–73, BOD: 41–58	Calheiros et al. [90]
	Community	*Canna flaccida, Zantedeschia aethiopica, Canna indica, Agapanthus africanus* and *Watsonia borbonica*	BOD, COD, P-PO_4, NH_4 and total coliform bacteria (all up to 84)	Calheiros et al. [91]
Spain	Domestic	*Iris* spp	Bacteria: 37	García et al. [92]
	Municipal	*Iris pseudacorus*	Bacteria: 43	Ansola et al. [93]
Sri Lanka	Municipal	*Canna iridiflora*	BOD: 66, TP: 89, NH_4-N: 82, N-NO_3: 50	Weragoda et al. [94]
Taiwan	Domestic	*Canna indica*	N-NH_4: 73, BOD: 11	Chyan et al. [95]
		Canna indica	N-NH_4: 57, N-NO_3: 57	Chyan et al. [96]
Thailand	Domestic	*Canna* spp	COD: 92, BOD: 93, TSS: 84, NH_4-N: 88, TP: 90	Sirianuntapiboon and Jitvimolnimit [97]
	Seafood	*Canna siamensis, Heliconia* spp and *Hymenocallis littoralis*	BOD: 91–99, SS: 52–90, TN: 72–92 and TP: 72–77	Sohsalam et al. [98]
	Domestic	*Heliconia psittacorum* L.f. and *Canna generalis* L. Bailey	TSS: Both > 88, COD: 42–83	Konnerup et al. [99]
	Fermented fish production	*Canna hybrid*	BOD, COD, TKN: ~ 97	Kantawanichkul et al. [100]
	Collection system for business and hotel	*Cannae lilies, Heliconia*	BOD: 92, TSS: 90, NO_3-N: 50, TP: 46	Brix et al. [101]
	Domestic	*Crinum asiaticum, Spathiphyllum clevelandii* Schott	PO_4-P: ~20	Torit et al. [102]
Turkey	Municipal	*Iris australis*	NH_4-N: 91, NO_3-N: 89, TN: 91	Tunçsiper [103]
USA	Domestic	*Canna flaccida, Gladiolus* sp., *Iris* sp.	Baceria: ~50	Neralla et al. [104]
	Nursery	*Canna· generalis, Eleocharis dulcis, Iris Peltandravirginica.*	N: ~50, P: ~60	Palomsky et al. [105]
	Domestic	*Iris pseudacorus* L., *Canna x. generalis* L.H. Bail., *Hemerocallis fulva* L. and *Hibiscus moscheutos* L.	BOD > 75, TSS > 88, Fecal baceteria > 93	Karathanasis et al. [14]

Table 1. *Cont.*

Country	Type of Wastewater	Vegetation	Removal Efficiency of Pollutants (%)	Reference
USA	Tilapia production	*Canna* sp.	TSS: 90, NO_2-N: 91, NO_3-N: 76, COD: 12.5 and NH_3-N: 7.5	Zachritz et al. [106]
	Stormwater runoff	*Canna x generalis* Bailey, *Iris pseudacorus* L., *Zantedeschia aethiopica* (L.)	N and P *Canna* (>90), *Iris* (>30) *Zantedeschia* (>90)	Chen et al. [107]
	Residential	*Aeonium purpureum and Crassula ovate, Equisetum hyemale, Nasturtium, Narcissus impatiens,* and *Anigozanthos*	TSS: 95 BOD: 97	Yu et al. [16]
Vietnam	Fishpond	*Canna generalis*	BOD: 50, COD: 25–55	Konnerup et al. [108]
United Kingdom	Herbicide polluted water	*Iris pseudacorus*	Atrazine: 90–100	McKinlay and Kasperek. [109]

A review of the available literature showed that ornamental plants are used to remove pollutants from domestic, municipal, aquaculture ponds, industrial or farm wastewater. The removal efficiency of ornamental plants was also evaluated for the following parameters: biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), total nitrogen (TN), total phosphorous (TP), ammonium (NH_4-N), nitrates (NO_3-N), coliforms and some metals (Cu, Zn, Ni and Al). There is no clear pattern in the use of certain species of ornamental plants for certain types of wastewater. However, it is important to keep in mind that CWs using ornamental plants are usually utilized as secondary or tertiary treatments, due to the reported toxic effects that high organic/inorganic loading has on plants in systems that use them for primary treatment (in the absence of other complementary treatment options) [110,111]. The use of OFP in CWs generates an esthetic appearance in the systems. In CWs with high plant production, OFP harvesting can be an economic entity for CW operators, providing social and economic benefits, such as the improvement of system landscapes and a better habitat quality. Some authors have reported that polyculture systems enhanced the CW resistance to environmental stress and disease [14,112].

3.1. Common Ornamental Plants Used in CWs

Limited quantities of OFP have been used in CWs. These types of plants are typical of subtropical and tropical regions. Our survey showed that the four most frequently used genera are, in order of most to least frequently used: *Canna* spp, *Iris* spp, *Heliconia* spp, *Zantedeschia* spp (Table 2). Species of the *Canna* genus are used in all continents, with Asia using them the most frequently. The *Iris* genus is also used in Asia, along with Europe and North America. Species of the *Heliconia* genus are commonly used in Asia and America, including Mexico, Central and South America. While *Zantedeschia* is most frequently used in Mexico (a country in North America), they are found with less frequency in Europe, Africa, and Central and South America. The use of OFP in CWs is most popular in tropical and subtropical regions, due to the warm temperatures and the extensive sunlight hours. Such environmental features stimulate a richer biodiversity than in other regions.

Table 2. Four most commonly genera plants used in CWs around the globe, identified during the 87 survey studies in 21 countries, grouped by continents.

	Asia	Europe	America			Africa	Total
			North America		Central and South America		
			USA	Mexico			
Canna	22	4	5	4	2	2	39
Iris	5	5	4	2	2		18
Heliconia	4			4	4		12
Zantedeschia		2	1	13	3	1	20

3.1.1. Canna Spp

This perennial herb belongs to the family Cannaceae (Figure 1a). It can grow in full sun or semi-shaded areas and in loamy soils, with plant heights varying from 0.75 to 3.0 m under tropical and subtropical conditions. It reportedly originated in Central and South America and spread throughout Europe, North America and many tropical regions of the world. The *Canna* genus includes 8–10 wild species and over 1000 hybrids that are used as garden ornamentals. During the last two centuries of cultivation and improvement, *Canna* has been transformed into an attractive OFP, with variability in flower colours (yellow, orange, red and salmon, achieved using colored stains) and other positive attributes [113,114].

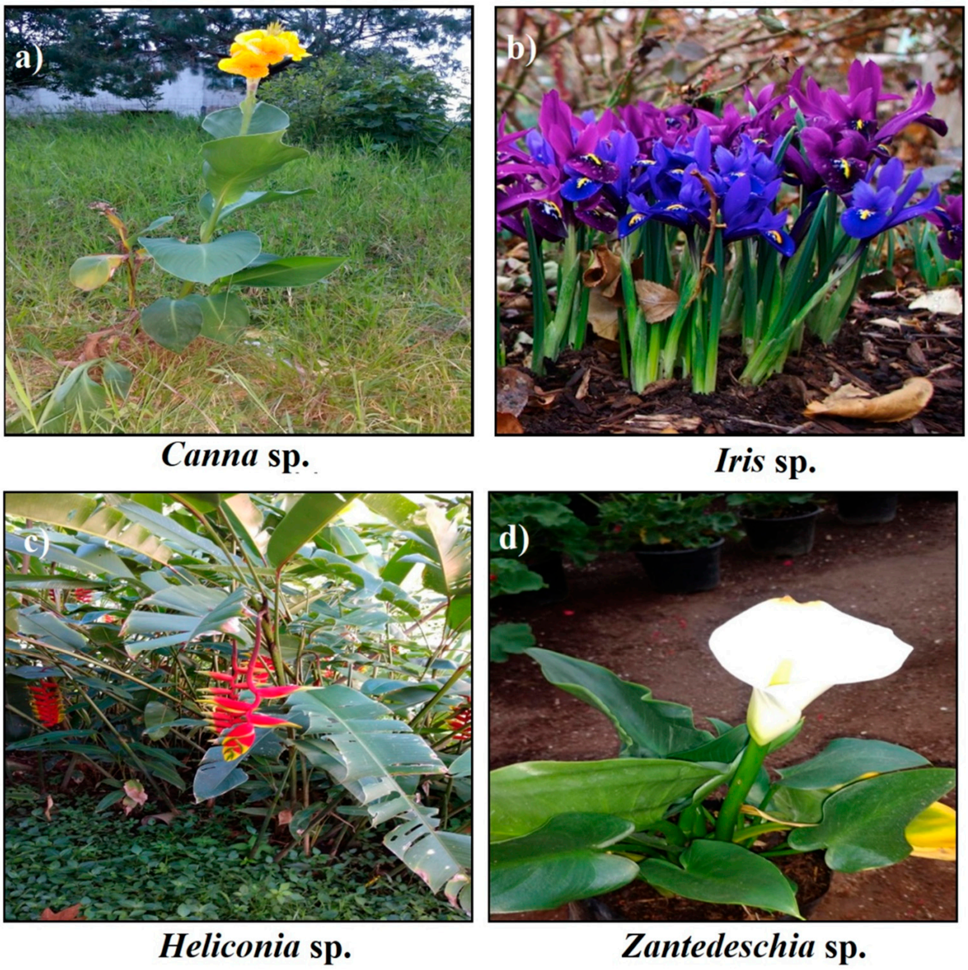

Figure 1. Popular Ornamental flowering plants used in CWs (constructed wetlands). (**a**) *Canna* sp.; (**b**) *Iris* sp., (**c**) *Heliconia* sp. and (**d**) *Zantedeschia* sp.

3.1.2. Iris Spp

Irises are perennial plants (Figure 1b) whose flowers are distinguished by a great variety of colors and miscellany of patterns on the perianth leaves [115]. Depending on the species, flower width ranges from 2.5 to 25 cm. *Iris* leaves are grass-like or sword-like and embrace the shoot with their bracts. Plant height is highly diverse, ranging from 10 to 200 cm, which allows them to be used in a variety of flower compositions. As both the leaves and the flowers are decorative, with the proper selection of species and varieties, they can add splendour to any garden from early spring until late autumn. Irises of the beardless variety (*Limniris*) are growing in popularity throughout the world, characterized by the various shapes of their perianth sepals and their untypical leafy pistils. They are low-maintenance plants and are resistant to the diseases that affect bearded irises [115,116].

3.1.3. Heliconia Spp

This species is the only genus in the plant family Heliconiaceae (Figure 1c), which is a member of the order Zingiberales. In addition to the several cellular features (short root hair cells, sieve tube plastids with starch, silica bodies, inaperturate and exineless pollen) that distinguish the Zingiberales from other monocots, there are several very conspicuous characters by which they can be recognized, including (1) large leaves with long petioles and blades possessing transverse venation, (2) large, usually colorful, bracteate inflorescences, and (3) arillate seeds. This order is most closely related to the family Bromeliaceae and their relatives in the superorder Bromeliiflorae [117]. The inverted flowers, presence of a single staminode, and drupaceous fruits are special features of *Heliconia*. Many species and varieties native from Brazil are now being grown as potted plants and as cut-flowers. The number of species of *Heliconia* ranges from 120 to over 400 [118].

3.1.4. Zantedeschia Spp

Also known as Arum or Calla lilies, a relatively small genus of eight species, forms the tribe *Zantedeschieae* (Figure 1d) in the subfamily Philodendroideae [119]. This genus is confined to Southern Africa, including Angola, Zambia, Malawi, Zimbabwe and Tanzania. Showy and decorative hybrids and varieties of *Zantedeschia* have drawn much interest among plant breeders abroad, where tubers, cut flowers and container plants form the basis of a lucrative export industry in the USA, the Netherlands and New Zealand [119,120].

3.2. Influence of Plants on Treatment Performance in Constructed Wetlands

Some studies have provided evidence of the positive effects that vegetation of natural wetlands has on pollutant removal (organic matter, nitrogen and phosphorus compounds) in constructed wetlands when compared to systems without plants [5,10]. In planted mesocosms with *Phragmites australis*, the efficiency of total nitrogen and total phosphorous removal was 97% and 91%, respectively, while, in systems without plants, the removal efficiency was 53% for total nitrogen and 61% for total phosphorous [121]. A similar situation was observed when studying fluoride ion removal in constructed wetlands, where the pollutant removal in systems without plants was 20% lower than in systems with vegetation [45]. The increase in the removal of pollutants in systems with plants is due to the increased oxygen supply to the rhizosphere through the plants' roots [2,8].

The use of ornamental plants in constructed wetlands for pollutant removal has been applied in different countries around the globe (Table 1), commonly in tropical and subtropical areas. A comparison of average performance efficiencies of CWs with different OFP showed that the removal percentages were similar across all plant genera for TSS (62–86%; $n = 26$; $p = 0.236$), COD (41–72%; $n = 49$; $p = 0.211$), BOD (51–82%; $n = 38$; $p = 0.241$), TP (49–66%; $n = 44$; $p = 0.111$), NH_4-N (62–82%; $n = 24$; $p = 0.301$), NO_3-N (63–93%; $n = 34$; $p = 0.214$) and TN (48–72%; $n = 32$; $p = 0.116$) (Figure 2). Such values are within the range reported [6] for CWs from China, India, Ireland, Spain and Thailand, as well as for the values reported in a review of wastewater treatment of CWs in developing countries [122] and CWs in tropical and subtropical regions [123,124], all using plants typically found in natural wetlands (*Cyperus*, *Typha* and *Phragmites* sp.), which were 67–92.5% for TSS, 49–81% for COD, 60–91.5% for BOD, 33–90% for NH_4-N, and 50–77% for TP. In general, the mean TN and TP removal when using ornamental plants in CWs were less than the mean removal of the other pollutants (TSS, CDO, BOD, NH_4-N or NO_3-N) (Figure 2). Such removal is influenced not only by the plants, but also by other parameters, such as filter media, or operational parameters, such as hydraulic and influent loading, which are related with the removal of pollutants in CWs and need to be considered in system designs [125]. When comparing the removal efficiency of pollutants in CWs with OFP and CWs without plants (Figure 2), pollutant removal was almost 40% higher for TSS, COD, BOD, NT and N-NO_3 in CWs with plants than in those without. For TP, the removal efficiency was almost 70% higher in CWs using ornamental plants than in those without vegetation.

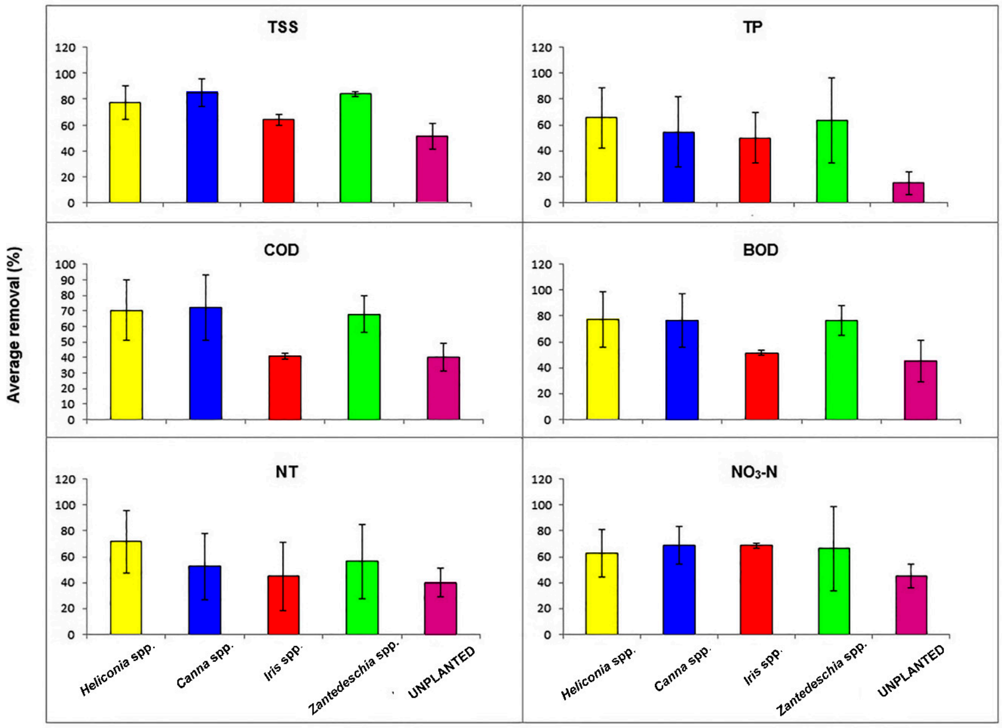

Figure 2. Comparing the average removal efficiencies of contaminants using ornamental plants and systems unplanted in various CW systems in the globe.

Machado et al. [124] evaluated the use of CWs in Brazil, including systems with ornamental plants, and concluded that warm temperatures, extensive sunlight hours and available land are important characteristics for encouraging plant growth and proliferation. Such features are typical in tropical and subtropical regions, where the option of a CW with ornamental plants can be an excellent choice for the removal of pollutants.

In cases where the wetlands are constructed to assist rural communities that involve big areas, the growth of OFP also creates a useful source of commercialization. The flowers could be sold as bouquets, as plants with attached roots for use in gardens, or for crafts made with parts of the plants, providing another strategy for convincing landowners to adopt these systems. The statistics that we report here regarding the removal efficiency of ornamental plants in CWs around the world is evidence that urban areas can also use CW systems as beautiful landscapes in supermarkets, streets, universities, hospitals, in riverine areas or as floating wetlands in rivers, lakes or lagoons. The combination of different species of ornamental plants in CWs makes the system more colorful, and, therefore, more attractive for the public.

These comparisons indicate the same general range of removal efficiency between CWs using ornamental plants and CWs with vegetation from natural wetlands. Thus, it is clear that ornamental plants should be considered in new CW designs. The use of ornamental plants could be a strategy used to increase the adoption of these systems because it makes the systems more aesthetic, and, therefore, they would not be observed as a treatment system, but instead would be seen as large outdoor planters in house gardens. We recommend the construction of domiciliary wetlands using ornamental plants to decrease water pollution and to assist with maintaining a better public health.

3.3. Advantages of Using Ornamental Plants in CWs

A range of novel and cost-effective constructed wetland systems for wastewater treatment have been engineered around the world. The influence of design parameters, such as porous media, hydraulic retention time, and flow of water, on the performance of CWs has been reported, highlighting the sustainability of this technology and the esthetic appearance using OFP [6,28,125].

One of the advantages of using OFP in CWs is the significant reduction of nutrient contamination (20–35%; Figure 2) comparing when CWs unplanted, representing an economical and sustainable alternative to decentralization practices; CWs are less expensive than commercial systems and are easier to build and operate [16,72]. Furthermore, by using plants with commercial value, the resources invested in the design, construction and maintenance of the system can be recovered in the profits of retail sales, without impeding the removal of pollutants of the system. The production of flowers in the CWs can provide economic benefits to the operators of the technology and can create beautiful landscapes using flowers such as *Canna*, *Iris*, *Heliconias* and *Zantedeschia* spp. (Tables 1 and 2). Such species have removed almost 80% of pollutants and provides color with the flowers to the systems and its use was detected in 39 countries for *Canna* genus and *Zantedeschia* genus was detected in 20 countries. In Thailand, a treatment water system with a butterfly shape was designed with the polyculture of OFP as reviewed in this study [111].

4. Conclusions

The use of ornamental flowering plants in constructed wetlands has been identified in 21 countries. The most commonly used ornamental plants are *Canna* spp., *Iris* spp, *Heliconia* spp., and *Zantedeschia* spp., which are mainly used in tropical and subtropical regions. Therefore, as CWs with OFP show good contaminants' removal efficiencies in the reviewed studies, it is suggested that further research on CWs should be developed, particularly in tropical and subtropical regions. Our survey also found that many ornamental plants are planted using a mixture of various species, or are mixed with plants from natural wetlands. There is no clear pattern in the use of a specific plant species for a certain type of wastewater, but the use of ornamental plants in wastewater treatment is a great economic and ecological option, and their flowers add to the esthetic appearance of CWs. The last characteristic could be used to increase system adoptions by the people in domiciliary, rural or urban areas. As an integral part of standard operating procedures, and the social involvement, using CWs with OFP would be a big step towards mitigating problems of small wastewater treatment systems in a timely manner.

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