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# Role of wetland plants and use of ornamental flowering plants in constructed wetlands for wastewater treatment: a review

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**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 (COD, BOD, 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 [1,2,3]. 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 for 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]. In regards to the vegetation, one of the most conspicuous features of wetlands is the role that plants play in the production of underground organisms (i.e. rot and rhizomes) in order to provide substrate for attached bacteria and oxygenation of areas adjacent to the root, and absorb and adsorb pollutants from water. Nitrogen (N), phosphorus (P) and other impurities 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 [8,9,10]. The use of the CWs technology began in Europe during the 1960's. [1], and has been replicated on other continents. The type of vegetation used are plants from natural wetlands, inlcuding *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 the 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 [12,13,14,15,16]. In recent studies (15 years ago), the goal of CWs 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 attempts to study 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 study 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. This is exudates a necessary source of carbon, which increases the removal of pollutants in anoxic conditions [20,21]. Other physical effects of root structure on CWs includes a reduction in the velocity of water flow, promotion of sedimentation, decreased resuspension, prevention of medium clogging and improved hydraulic conductivity [5,2]. 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 CWs' sediment (14 to 121 kg m$^{-2}$). Macrophytes increased the hydraulic efficiency by reducing short-circuit or preferential flow. Plant presence led to decrease saturated hydraulic conductivity in horizontal subsurface flow. This study was imperative, since monitoring macrophytes is essential for understanding and controlling clogging in CWs [23].

The removal of organic and inorganic pollutants in CWs is not only the role of microorganisms. This function is also exerted by plants, which are able to tolerate high concentrations of nutrients and heavy metals, and in some cases, plants are able to accumulate them in their tissues [24]. 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[25,26] .

Other uptakes of xenobiotic compounds (organic pollutants) are also the result of the presence of plants, involving processes such as transformation, conjugation and compartmentation [24].

## 3. Survey results of use of ornamental flowering plants in CWs

Table 1 lists examples of ornamental plants used in CWs around the world that were designed for the removal of various types of wastewater. OFP have been used in some countries, particularly in Mexico and China. In China, the most popular vegetation used is *Canna* sp., while in Mexico the ornamental plant used is more diverse, including plants with flowers in different colors, shapes and aromatic characteristics (*Canna*, *Heliconia*, *Zantedeschia*, *Strelitzia* spp).

Table 1. Examples of ornamental plants used for CWs designed for the removal of various types of wastewater around the globe.

| **Country** | **Type of wastewater** | **Vegetation** | **Removal efficiency (%)** | **Reference** |
|---|---|---|---|---|
| Brazil | Domestic | *Heliconia psittacorum* | TSS: 88, COD: 95, BOD: 95 | Paulo et al. [47] |
| | Domestic | *Alpinia purpurata*<br>*Arundina bambusifolia*<br>*Canna* sp.<br>*Heliconia psittacorum* L.F. | COD: 48-90, $PO_4$-P: 20, TKN: 31 and TSS: 34. | Paulo et al. [48] |
| | Swine | *Hedychium coronarium* | -COD: 59, TP: 44, TKN: 34 and NHx 35 | Sarmento et al. [44] |
| | | *Heliconia rostrata* | - COD: 57, TP: 38, TKN: 34 and NHx: 37 | |
| | | *Hemerocallis flava* | COD: 72, BOD: 90, TN: 52, TP: 41 and SST: 72. | Prata et al. (2013)[NRF] |
| | | *Heliconia psittacorum* L.F. | | Teodoro et al. (2014)[NRF] |
| China | Municipal | *Canna indica* | COD: 77, BOD: 86, TP: >82, TN: >45 | Shi et al. [49] |
| | 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. [50] |

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|---|---|---|---|---|
| | Domestic | *Canna indica* Linn | COD: 82.31, BOD: 88.6, TP: >80, TN: >85 | Yang et al. [51] |
| | Municipal | *Canna indica* | $NH_4$-N: 99, $PO_4$-P: 87 | Zhang et al. [52] |
| | Drain of some factories | *R. carnea*, *I. pseudacorus*, *L. salicaria* | COD: 58-92, BOD: 60-90TN: 60-92, TP: 50-97, | Zhang et al. [53] |
| | River | *Canna* sp | COD: 95, N-$NH_4$: 100, N-$NO_3$: 76, TN: 72 | Sun et al. [54] |
| | Domestic | *Canna indica* | TP: 60, $NH_4$-N: 30-70, TN: ~25 | Cui et al. [55] |
| | 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. [56] |
| | 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. [57] |
| | Domestic | *Canna indica* and *Hedychium coronarium* | TP: 40-70 | Wen et al. [58] |
| | Polluted river | *Iris pseudacorus* mixed with other natural wetland plants | TN: 68, $NH_4$-N:93, TP: 67 | Wu et al. [59] |
| | Sewage | *Iris pseudacorus*, mixed with other plants of natural wetlands | TN: 20 and TP: 44 | Xie et al. [60] |
| | Municipal | *Canna indica* | COD: 60, $NO_3$-N: 80, TN:15, TP:52 | Chang et al. [61] |
| | Simulated polluted river water | *Iris sibirica* | COD: 22, TN: 46, $NH_4$-N: 62, TP: 58 | Gao et al. [62] |
| | Synthetic | *Canna sp* | Fluoride: 51, Arsenic: 95 | Li et al. [39] |
| | Simulated polluted river water | *Iris sibirica* | Cd: 92 | Gao et al. [63] |
| | Synthetic | *Canna indica* L. | N: 56-60 | Hu et al. [64] |
| | Synthetic (hydrophonic sol.) | *Canna indica L.* | TN: 40-60, N-$NO_3$: 20-95, $NH_4$-N: 20-55 | Wang et al. [65] |
| Chile | Sewage | *Zantedeschia aethiopica*, *Canna* spp. and *Iris* spp | BOD: 82, TN: 53, TP: 60. | Morales et al. [66] |
| | Sewage | *Tulbaghia violácea, and Iris pseudacorus.* | BOD: 57-88, COD: 45-72, TSS: 70-93, $PO_4$-P: 6-20. | Burgos et al. [67] |
| | Ww rural community | *Zantedeschia aethiopica* | Organic matter: 60%, TSS: 90% | Leyva et al. [29] |
| Colombia | Domestic | *Heliconia psíttacorum* | $NH_3$: 57 | Gutiérrez-Mosq |

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| | | | COD: 70 | uera and Peña-Varón [68] |
| | Synthetic landfill leachate | *Heliconia psittacorum* | COD, TKN and $NH_4$ (all: 65-75) | Madera-Parra et al. [69] |
| | Cattle bath | *Alpinia purpurata* | SST: 58, TP: 85, COD: 63 | Marrugo-Negrete et al. [70] |
| | Municipal | *Heliconia psitacorum* | Bisphenol A:73, Nonylphenols: 63 | Toro-Vélez et al. [71] |
| 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 [72] |
| Egypt | Municipal | *Canna* sp | TSS: 92, COD: 88, BOD: 90 | Abou-Elela and Hellal [73] |
| | Municipal | *Canna* sp | TSS: 92, COD: 92, BOD: 92 | Abou-Elela et al. [74] |
| India | Paper mill effluent | *Canna indica* | 9,10,12,13-tetrachlor- ostearic acid: 92 and 9,10-dichlorostearic acid: 96 | Choudhary et al. [75] |
| | Synthetic | *Canna indica* | Dye: 70-90<br>COD: 75 | Yadav et al. [76] |
| | Synthetic greywater | *Heliconia angusta* | COD:40, BOD: 70, TSS: 62, TDS: 19 | Saumya et al. [77] |
| | Domestic | *Canna generalis* | TN: 52, T-$PO_3$: 9 | Ojoawo et al. [78] |
| | Collection pond | *Canna Lily* | BOD: 70-96, COD: 64-99 | Haritash et al. [79] |
| | Hostel greywater | *Canna indica* | COD, TKN and Pathogen all up 70 | Patil and Munavalli, [80] |
| | 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 [81] |
| Ireland | Domestic | *Iris pseudacorus* | TN: 30, TP:28 | Gill and O'Luanaigh [82] |
| 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. [83] |
| Kenya | Flower farm | *Canna* sp | BOD: 87, COD: 67, TSS: 90, TN: 61 | Kimani et al. [84] |
| Mexico | Municipal | *Zantedeschia aethiopoca* | COD: 35, TN: 45.6 | Belmont and Metcalfe [85] |
| | Domestic | *Zantedeschia Aethiopica* and | SST: 85.9, COD: 85.8, $NO_3$-N: | Belmont et al. [86] |

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| | *Canna flaccida* | 81.7, $NH_4$-N: 65.5, NT: 72.6 | |
| Coffee processing | *Heliconia psittacorum* | COD: 91, Coliformes: 93 | Orozco et al. [87] |
| Domestic | *Strelitzia reginae, Zantedeschia esthiopica, Canna hybrids, Anthurium andreanum, Hemerocallis Dumortieri* | COD: >75, P: 66, Coliforms: 99 | Zurita et al. [45] |
| Domestic | *Zantedeschia aethiopica* | BOD: 79, TN: 55, PT: 50 | Zurita et al. [88] |
| Wastewater form canals | *Zantedeschia aethiopica* | COD: 92, N-$NH_4$: 85, P-$PO_4$: 80 | Ramírez-Carrillo et al. [89] |
| Municipal | *Strelitzia reginae, Anthurium, andreanum.* | TSS: 62, COD: 80, BOD: 82, TP: >50, TN: >49 | Zurita et al. [90] |
| Groundwater | *Zantedeschia aethiopica and Anemopsis californica* | As: 75-78 | Zurita et al. [91] |
| Domestic | *Gladiolus spp* | BOD: 33, TN:53, TP:75 | Castañeda and Flores [92] |
| Mixture of gray water (from a cafeteria and research laboratories) | *Zantedeschia aethiopica* and *Canna indica* | COD: 65, NT: 22.4, PT: 5. | Zurita and White [93] |
| Domestic | *Zantedeschia aethiopica* | BOD: 70 | Hallack et al. [94] |
| Domestic | *Heliconia stricta, Heliconia psittacorum* and *Alpinia purpurata* | BOD: 48, COD: 64, TP: 39, TN: 39 | Méndez-Mendoza et al. [95] |
| Municipal | *Canna hybrids* and *Strelitzia reginae* | DQO: 86, NT: 30-33, PT: 24-44 | Merino-Solís et al. [96] |
| Municipal | *Zantedeschia aethiopica* and *Strelitzia reginae* | COD: 75, TN: 18, TP: 2, TSS: 88. | Zurita and Carreón-Álvarez [97] |
| Domiciliar | *Spathiphyllum wallisii, Zantedechia aethiopica, Iris japonica, Hedychium coronarium, Alocasia* sp, *Heliconia* sp. and *Strelitzia reginae.* | N-$NH_4$: 64-93<br>BOD: 22-96<br>COD: 25-64 | Garzón et al. [98] |
| Community | *Zantedeschia aethiopica, Lilium* sp, *Anturium* sp and *Hedychium coronarium* | NT: 47, PT: 33, COD: 67 | Hernández [46] |
| Stillage Treatment | *Canna indica* | BOD:87, COD:70 | López-Rivera et al. [99] |
| Artificial | *Iris sibirica* and *Zantedeschia aethiopica* | Carbamazepine: 50-65 | Tejeda et al. [100] |
| Community | *Alpinia purpurata* and *Zantedeschia aethiopica* | | Marín-Muñiz et al. [101] |
| 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. [102] |

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|---|---|---|---|---|
| | University | *Strelitzia reginae* | | Martínez et al. [21] |
| Nepal | Municipal | *Canna latifolia* | TSS: 97, COD: 97, BOD: 89, TP: >30 | Sigh et al. [103] |
| Portugal | Tannery | *Canna indica mixed with other plants* | COD: 41-73, BOD: 41-58 | Calheiros et al. [104] |
| | 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. [105] |
| Spain | Domestic | *Iris* sp | Bacteria: 37 | García et al. [106] |
| | Municipal | *Iris pseudacorus* | Bacteria: 43 | Ansola et al. [107] |
| Sri Lanka | Municipal | *Canna iridiflora* | BOD:66, TP: 89, $NH_4$-N:82, N-$NO_3$:50 | Weragoda et al. [108] |
| Taiwan | Domestic | *Canna indica* | N-$NH_4$: 73, BOD: 11 | Chyan et al. [109] |
| | | *Canna indica* | N-$NH_4$: 57, N-$NO_3$:57 | Chyan et al. [110]*** |
| Thailand | Domestic | *Canna* sp | COD: 92, BOD: 93, TSS: 84, $NH_4$-N: 88, TP: 90 | Sirianuntapiboon and Jitvimolnimit [111] |
| | Seafood | *Canna siamensis*, *Heliconia* spp and *Hymenocallis littoralis* | BOD: 91-99, SS: 52-90, TN: 72–92 and TP: 72–77 | Sohsalam et al. [112] |
| | Domestic | *Heliconia psittacorum* L.f. and *Canna generalis* L. Bailey | TSS: Both>88, COD: 42-83 | Konnerup et al. [113] |
| | Fermented fish production | *Canna hybrida* | BOD, COD, TKN: ~ 97 | Kantawanichkul et al. [114] |
| | Collection system for business and hotel | *Cannae lilies, Heliconia* | BOD: 92, TSS: 90, $NO_3$-N: 50, TP: 46 | Brix et al. [115] |
| | Domestic | *Crinum asiaticum*, *Spathiphyllum clevelandii* Schott | $PO_4$-P: ~20 | Torit et al. [116] |
| Turkey | Municipal | *Iris australis* | $NH_4$-N: 91, $NO_3$-N: 89, TN: 91 | Tunçsiper [117] |
| USA | Domestic | *Canna flaccida*, *Gladiolus* sp., *Iris* sp. | Baceria: ~50 | Neralla et al. [118] |
| | Nursery | *Canna· generalis*, *Eleocharis dulcis*, *Iris Peltandravirginica.* | N: ~50, P: ~60 | Palomsky et al. [119] |
| | 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] |
| | 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. [120] |
| | Stormwater runoff | *Canna x generalis* Bailey, *Iris pseudacorus* L., *Zantedeschia aethiopica* (L.) | N and P<br>*Canna* (>90), *Iris* (>30)<br>*Zantedeschia* | Chen et al. [121] |

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|---|---|---|---|---|
| | | | (>90) | |
| | Residential | *Aeonium purpureum* and *Crassula ovate*, *Equisetum hyemale*, *Nasturtium*, *Narcissus impatiens*, and *Anigozanthos* | TSS: 95<br>BOD:97 | Yu et al. [16] |
| Vietnam | Fishpond | *Canna generalis* | BOD: 50, COD: 25-55 | Konnerup et al.[122] |
| United Kingdom | Herbicide polluted water | *Iris pseudacorus* | Atrazine: 90-100 | McKinlay and Kasperek. [123] |

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) [27, 28]. 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 CWs' resistance to environmental stress and disease [14,29].

### 3.1. *Common ornamental plants used in CWs*

A limited quantity 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.

Tabla 2. Four most commonly genera plants used in CW as identified during the survey according the 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 1). 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 [30,31].

**Figure 1.***Canna* spp

### 3.1.2. *Iris* spp

Irises are perennial plants (Figure 2), whose flowers are distinguished by a great variety of colours and miscellany of patterns on the perianth leaves [32]. 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 [32,33].

**Figure 2.***Iris* spp

### 3.1.2. *Heliconia* spp

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This species is the only genus in the plant family Heliconiaceae (Figure 3), 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 [34]. 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 [35].

**Figure 3.***Heliconia* spp

### 3.1.2. *Zantedeschia* spp

Also known as Arum or Calla lilies, a relatively small genus of eight species, forms the tribe *Zantedeschieae*(Figure 4) in the subfamily Philodendroideae [36]. 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 [36,37].

**Figure 4**.*Zantedeschia* spp

### 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 [38]. 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 [39]. 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 have been applied in different countries around the globe (Table 1), commonly in tropical and subtropical areas. A comparison of performance efficiencies of CWs with different OFP showed that the removal percentages were similar across all plant genera for TSS (62–86%), COD (41–72%), BOD (51–82%), TP (49–66%), $NH_4$-N (62–82%), $NO_3$-N (63–93%) and TN (48–72%) (Figure5). Such values are within the range reported for [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 [40] and CWs in tropical and subtropical regions [41,42], 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 5). 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 [43]. When comparing the removal efficiency of pollutants in CWs with OFP and CWs without plants (Figure5), 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.

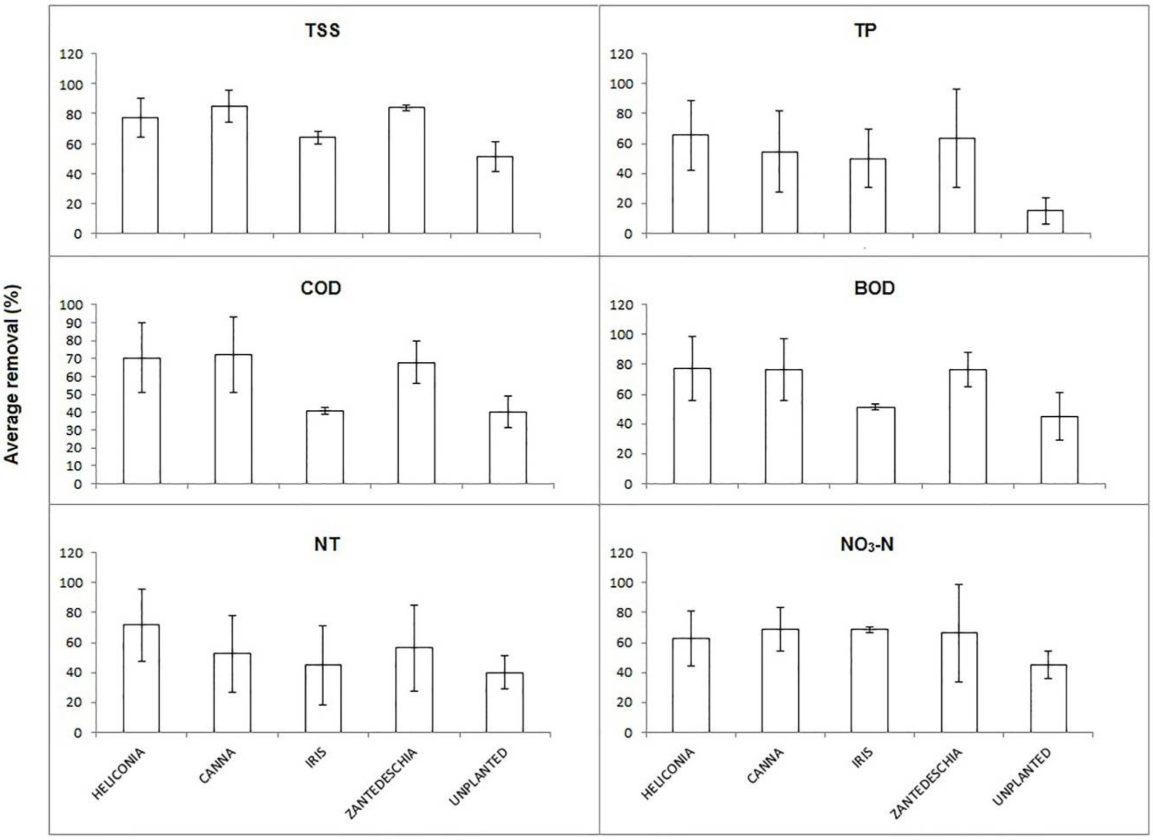

Figure5. Comparing the average removal efficiencies of contaminants using ornamental plants and systems unplanted in various CWs systems in the globe

Miller et al. [42] 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.

### 3.2. 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 [6,28,43,44].

One of the advantages of using OFP in CWs is the significant reduction of nutrient contamination (Figure. 1), representing an economical and sustainable alternative to decentralization practices; CWs are less expensive than commercial systems and are easier to build and operate [45,46]. 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).

## 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. These plants have been evaluated for the efficiency of pollutant removal in CWs, with studies concluding that they can be used for such a purpose. 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.

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