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WATER HYACINTH COMPOSTING AS A WASTE MANAGEMENT STRATEGY: A SYSTEMATIC REVIEW

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Abstract

*Macrophytes proliferation problem is worldwide know resulting in impacts on natural environment, human health and economic activities. These organisms have several parameters resilience, which ensures high rate of reproduction and proliferation, hindering their management. As a management difficulty consequence, however, solutions are sought to disposal this large amount of macrophytes, such as composting and fertilizer production. Thus, this study aims to conduct a systematic literature review in Scientific Platforms Science Direct and Scopus, identifying current status of macrophytes composting process, main methods, analyses and results obtained, in order to contribute in innovation studies to convert this type of weed into fertilizer. The general words source in titles, summary, or keywords specified by author were "Macrophyte" or "water hyacinth" and "compost" or "composting". Only articles dating from the last 20 years were maintained. Macrophyte composting process interest is addressed around the world because of their potential environmental, economic and social impacts, mainly for *Eichhornia crassipes*. Natural aeration predominates (56%) with composting time equal to or less than 60 days. Humidity control is essential (around 60%) like macrophytes dehydration prior to the composting process beginning. The significant quantity cellulose requires previous comminution and/or the cellulose-degrading inoculants addition. Composting process operational parameters are not standardized. Micro and macro nutrients richness can be considered for next evolutionary composting studies stage for this plant type, either by organic matter sources characteristics and/or mineral sources addition.*

Keywords: composting, macrophytes, waste management, water hyacinth, weeds.

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Introduction

The natural environment, economic activities and human health have been impacted by the proliferation of macrophytes. Biological factors of reproduction and development for these species are extremely relevant to the difficulties encountered in its management. The excessive availability of nutrients, such as Nitrogen (N), Phosphorus (P) and Potassium (K), usually associated with human activity, contribute to the formation of macrophytes floating mats (Sharma *et al.*, 2016; Bote *et al.*, 2020). These organisms withstand saline conditions (≤ 10 ppt), wide temperature range (from 1 to 40 °C) and pH (from 4 to 8) (Wilson *et al.*, 2005; Sharma *et al.*, 2016).

Macrophytes contain, on average, more than 95% water (Malik, 2007; Rezanía *et al.*, 2015a), long and hanging roots from 0.4 to 1 meters. Vegetation reproduction is asexual and its seeds remain dormant for long years (Malik, 2007; Bote *et al.*, 2020). Its proliferation can also occur from fragments of its stems (Gunnarsson and Petersen, 2007). The mass productivity of macrophytes which can vary from approximately 140 tons/ha per year (Gunnarsson and Petersen, 2007) to 400 tons, with a density of 50 to 60 kg/m² (Malik, 2007; Rezanía *et al.*, 2015a).

Macrophytes have an excellent capacity to absorb nutrients and other chemicals from the environment. Ganesh *et al.* (2012), Singh and Kalamdhad (2012), Singh and Kalamdhad (2014) and Mazumder *et al.* (2020) show the elements presence such as Chromium (Cr), Cadmium (Cd), Lead (Pb), and Mercury (Hg) in macrophyte chemical analyzes.

The proliferation of macrophytes in water bodies, however, results in impacts on the natural environment, human health and economic activities. The green mats formation on water contributes to increase of water loss due evapotranspiration (Bote *et al.*, 2020), decrease light penetration into the water (Malik, 2007), decreasing the productivity of phytoplankton (Sharma *et al.*, 2016), and can increase decomposing of submerged vegetation reducing oxygen content (Bote *et al.*, 2020), as a consequence decreasing fish habitat quality and the aquatic environment eutrophication.

Gunnarsson and Petersen (2007) and Sharma *et al.* (2016) refer to studies that correlate macrophytes excessive accumulation in water bodies with formation of real breeding grounds for vector organisms, and diseases such as malaria. Malik (2007) also presents examples of regions around the world where macrophyte infestations have become vectors disease source.

Several anthropic activities are hampered due proliferation of macrophytes in water resources. Among the main activities affected are: swimming, fishing, canoeing (Bote *et al.*, 2020), irrigation, power generation (Rezanía *et al.*, 2015a; Sharma *et al.*, 2016), and waterway traffic (Malik, 2007).

Thus, the management (proactive or reactive) of this plant type have fundamental importance, given potential impacts. Adopted management practices, regardless, for water resources where macrophytes are a reality, the final destination must be considered in the adopted action plan. Due to its fibrous tissue and its high energy and protein content, useful macrophytes applications have already been described by some authors, such as (Gunnarsson and Petersen, 2007), Malik (2007) and Rezanía *et al.* (2015a) and Rezanía *et al.* (2015b), including composting.

Thus, the study objective is realize a structured review of the literature on Scientifics platforms Science Direct and Scopus, in order to identify the macrophyte composting process status, main methods, analyzes and results obtained, in order to contribute to the continuity innovation in studies of converting this plant type into fertilizer.

Methodology

Research structure was defined for access and identification, on scientific platforms, of scientific researches on composting macrophytes, as described below.

Systematic review

Studies identification in scientific journals was performed by a systematic search on the Science Direct and Scopus platforms. The general source of words in the title, abstract or keywords specified by the author were “Macrophyte” or “water hyacinth” and “compost” or “composting”. An additional screening was realized in order to maintain only scientific researches in which composting practices were applied in/with macrophyte species. In this systematic review, only English literature reported was included in the scope of the review and only research articles were selected. Articles dated with more than 20 years old, that is, the date prior to the year 2000, were disregarded. Table 1 shows the classification criteria of the articles identified in systematic literature review.

Table 1. Classification criteria of the articles identified in systematic literature review

Criteria	Description
General	Country; Year; Observations.
Scope of the study	Composting Method; Macrophyte(s) species(s) studied; Additional organic matter(s); Additional mineral(is).
Evaluated Parameters	Composting Time; Characterization; Physical-Chemical Final Properties.

Results

Initially 125 scientific articles were identified. Figure 1 illustrates the result of the performed research on the scientific platforms. After applying the additional screening criteria specified in methodology, 88 scientific articles were maintained in the literature review. The largest fraction of these articles (63) were identified on Scopus Platform, followed by articles available in both platforms (23) and articles available only on the Science Direct Platform (2).

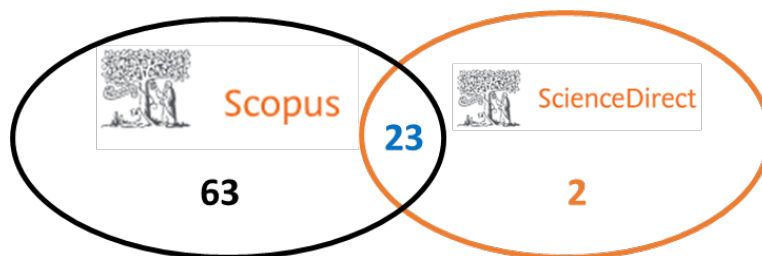


Figure 1. Quantitative data of scientific articles identified according to previously established research criteria.

The articles time distribution (Figure 2) allows identify more attention given over 2009-2016 period, corresponding to $\approx 70\%$ of the identified articles. The spatial distribution of the scientific researches identified shows a greater concentration of studies in the Asian continent ($\approx 81\%$), mainly in India which has 72% of the scientific articles. China, Thailand, Vietnam and South Korea complement the percentage corresponding to continente (Figure 3). More information about the studies can be accessed in the Complementary Archive.

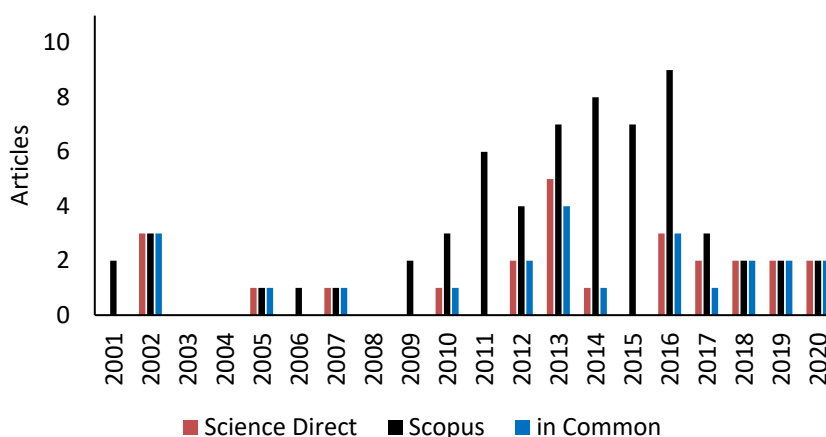


Figure 2. Year distribution of scientific articles identified in literature review.

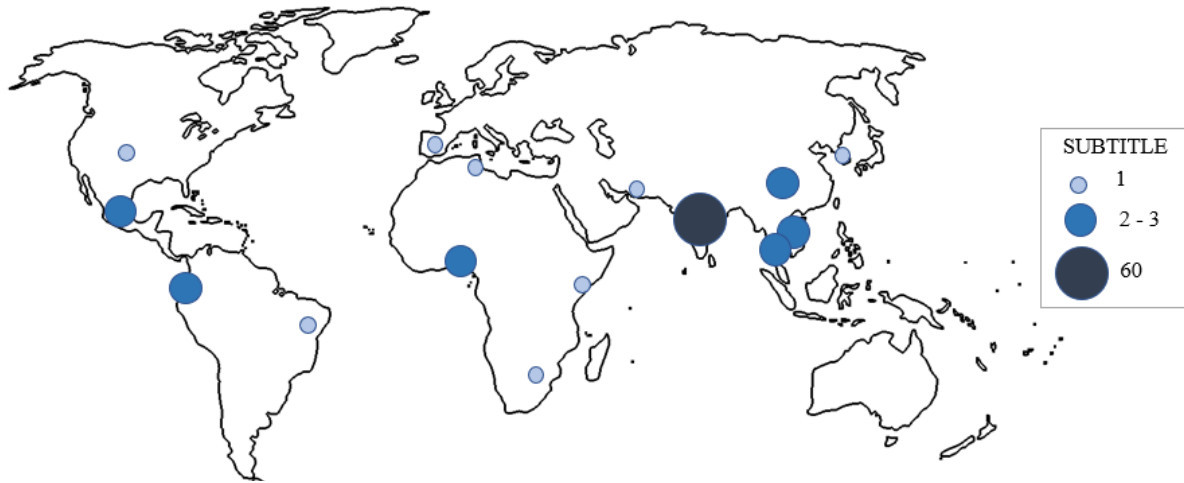


Figure 3. Spatial distribution of the studies included in the literature review.

Main macrophytes composting methods

Goyal *et al.* (2005), Martins *et al.* (2019) and Bui *et al.* (2015) used static cells for biomass composting, to produce organic fertilizer as objective. Although they realized a study in distinct locations (India and Brazil, respectively) and differed in the sources of biomass (only macrophytes; macrophytes, pruning, seeds and manure and carcass of birds and fish, respectively), both studies adopted a 90 days composting period. Bui *et al.* (2015), added pisciculture sludge to macrophytes in the Vietnam composting process, concluded the process at 45 days. These authors presented similar conclusions regarding the feasibility of using macrophytes in the composting process, attributing to this plant species an additional source of nitrogen to final compost.

Some studies adopted a consortium with conventional composting (composting with manual turning) and vermicomposting. Gupta *et al.* (2007) and Pramanik (2010) used conventional composting as a pretreatment of the compost, prior the beginning of vermicomposting process. This pre-treatment was performed over 7 days, in the developed study by Pramanik (2010), and for 21 days in the case of Gupta *et al.* (2007). The divergence in pre-treatment periods is attributed to the main objective of each study, being that of Pramanik (2010) to evaluate the microbiology involved in the process of composting macrophytes, and that of Gupta *et al.* (2007) the feasibility of using organic fertilizer from vermicomposting of cattle manure and macrophytes.

The vermicomposting periods, post pretreatment/conventional composting, differ between studies. Whereas Gajalakshmi *et al.*, (2002a), Gajalakshmi and Abbasi (2002), Pramanik (2010) and Ansari (2011) perform vermicomposting for 10 to 30 days, Balasubramanian *et al.* (2013a), Balasubramanian *et al.* (2013b), Begum (2011) and Gupta *et al.* (2007) adopt periods ranging from 60 to more than 120 days.

Gajalakshmi *et al.* (2002a), Gajalakshmi and Abbasi (2002), Begum (2011), Balasubramanian *et al.* (2013a), Balasubramanian *et al.* (2013b), Ansari (2011) adopted a consortium of conventional composting and vermicomposting, with the last one as a complementary step to maturation and compost quality improvement. As main conclusions these authors affirm that there is a greater availability of nutrient in the soil, results of the compost application, such as Nitrogen (N), Phosphorus (P) and Potassium (K), Calcium (Ca) and others, besides development improvements of evaluated crops.

The use of vermicomposting as a unitary treatment process covers a considerable portion of the studies identified (25%). Most used earthworm species in the studies are *Eisenia Fetida*, *Eudrilus. Eugeniae* and *Perionyx Excavatus*, *Lampito Mauritii* and *Drawida Willsi*, either individually, like most studies, or together, as performed by Gajalakshmi *et al.* (2001) and Karmakar *et al.* (2012). Accessed studies main results included an increase of Nitrogen, Phosphorus and Potassium levels (Yadav and Garg, 2013; Ankaram *et al.*, 2012; Karmakar *et al.*, 2012; Lourduraj and Joseph, 2010), as well such as the decrease in C/N, EC (electroconductivity) and pH parameters (Ankaram *et al.*, 2012). Nevertheless, some results identified differ in terms of compost quality. Yadav and Garg (2013) highlights the maintenance of high heavy metals values in final compound, as well as Nhi *et al.* (2010) highlights Nitrogen concentration reduction.}

Composting with natural aeration predominates in the literature reviewed studies, representing 56%. This process differs, however, from the residue disposal method, being adopted, mainly, conical cells (Karak *et al.*, 2014; Fan *et al.*, 2015; Pushpa *et al.*, 2016a; Ganesh *et al.*, 2012; Martinez-Nieto *et al.*, 2011; Alomia *et al.*, 2011, Parveen and Padmaja, 2011; Umsakul *et al.*, 2010), trapezoidals cells (Singh and Kalamdhad, 2014; Taiwo *et al.*, 2016; Kouki *et al.*, 2016) and rotating drums (Lu *et al.*, 2017; Rich *et al.*, 2018; Vishan *et al.*, 2017; Jain *et al.*, 2020). Half of the scientific researches with natural aeration identified feature composting time equal to or less than 60 days. And the other half embraces periods ranging from 90 to over 190 days.

Some of the authors who have adopted the composting, with macrophytes, by natural aeration have reinforced the importance of humidity from the composed throughout process. The partial dehydration of macrophytes, prior to the beginning of the composting process was performed by Lu *et al.* (2017), Umsakul *et al.* (2010), until reaching values between 60 and 70%. Alomia *et al.* (2011) and Martinez-Nieto *et al.* (2011) are some of the authors emphasized humidity control for composting process around 70%.

Some of the authors highlight qualities attributed to the final composting, resulting of macrophytes composition, as the increased in N, P and K concentrations (Singh and Kalamdhad (2015), Goswami *et al.* (2017). The metals presence in macrophytes composition is attributed, however, to the increase in content of potentially toxic elements throughout the composting

process, as highlighted by Singh and Kalamdhad (2013a), Singh and Kalamdhad (2013b), Singh and Kalamdhad (2013c), Karak *et al.* (2014), Singh *et al.* (2015), Singh and Kalamdhad (2016), Rich *et al.* (2018). Successful measures in mitigating toxic phases of certain elements are highlighted by the several authors: reduction of toxic phases of Copper (Cu) by use of peat (Lu *et al.*, 2017), reduction of toxic phases of Pb, Cr and others, by the use of lime (Singh; Kalamdhad, 2012a, Singh; Kalamdhad, 2014c, Singh *et al.*, 2015) and reduction of toxic phases of Pb, Cr and others, by the use of zeolite (Singh *et al.*, 2013a and Singh; Kalamdhad 2014a).

Another problem associated with macrophytes composting refers to a difficulty of degradation and maintenance a high level of cellulose, hemicellulose and lignin, as concluded by Sarika *et al.* (2014). Song (2016), Martinez-Nieto *et al.* (2011), Parveen and Padmaja (2011) and Alomia *et al.* (2011) added specific microorganisms that contributed to aid in degradation.

Varma *et al.* (2017) is the only author to describe the use of forced aeration process. Using as sources of biomass, the cattle manure and sawdust, in addition to the macrophytes, the authors compare different scenarios – by turning, composting for soil aeration, passive and forced aeration. The authors conclude that the best results of the first two types of aeration are due to the better distribution of air in the material bed.

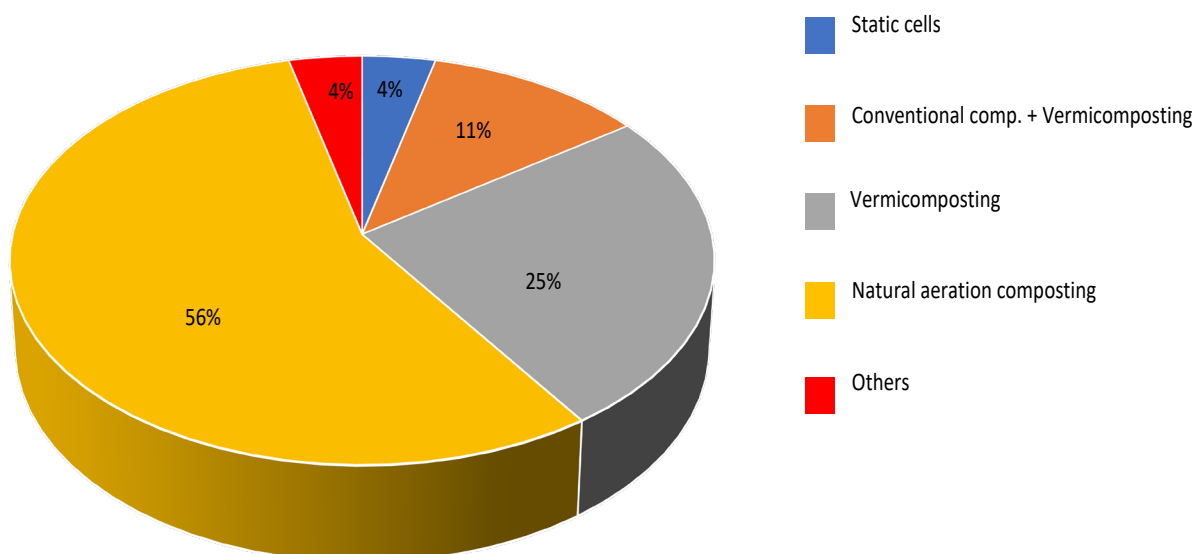


Figure 4. Illustrates the representation of composting methods identified in articles that compose the literature review.

Macrophytes Composting: species, desired product and materials additional to the process

The macrophyte species that were part of the evaluated studies were: *Azolla pinnata*, *Trapa natans*, *Ceratophyllum demersum* and *Phumdi* biomass, in India; *Arundo donax* and *Typha latifolia* in Tunisia; *Typha angustifolia* and *Phragmites australis* in South Korea; and *Eichhornia crassipes* in Brazil, China, Colombia, Spain, USA, India, Mexico, Kenya, Singapore, Thailand and Vietnam. Thus, studies related to the species *Eichhornia crassipes* corresponded to approximately 69% of the scientific researches. There were still 22 ($\approx 27\%$) studies that did not specify the macrophyte species applied in the study, however given the introductory chapter of articles it is possible to infer that part of this percentage was referring mainly to the macrophyte species *Eichhornia crassipes*.

According to information available in Sharma *et al.* (2016), *Eichhornia crassipes* have oval leaves, wide, thick, shiny and could grow above the water surface up to 1 m in height. The leaves have 10 to 20 cm in diameter. They have long stems, spongy and bulbous. Each plant consists of a rosette of six to ten sheets attached to a rhizome with a fibrous root system well developed.

Among the products that aimed to produce in the composting of 83 articles identified, dominates the production of Organic Fertilizer ($\approx 83\%$), followed by Anthropogenic soil ($\approx 9\%$), Organomineral ($\approx 5\%$), Pre-compost ($\approx 2\%$) and Slurry ($\approx 1\%$). Only 6 of the 83 researches did not used a source of organic material and/or additional mineral in composting process or after composting for production of their target product (Goyal *et al.*, 2005; Chunkao *et al.* 2012; Araiza *et al.*, 2016; Martinez-Nieto *et al.*, 2011; Packia Leksmi and Viveka, 2011; Sannigrahi and Chakraborty, 2002).

These studies, however, had their main focus on parameters evaluation of the macrophyte composting process. The other articles, mainly focused on the quality/application of the final compost, had complementation of organic and/or mineral matter. The materials used in addition to the macrophytes in composting are illustrated quantitatively, related to the number of articles where they were applied, in Figure 5.

The other additional fonts used were water lettuce and typhas (Sanigrahi, 2009), plum (Rich *et al.*, 2018), coconut shell (Umsakul *et al.*, 2010), poultry manure (Zhang *et al.*, 2014; Masaka and Ndhlovu, 2007; Martins *et al.*, 2019), buffalo manure (Nhi *et al.*, 2010), manure (Karak *et al.*, 2014; Bisen *et al.*, 2017), river sediment (Karak *et al.*, 2014), leaves (Alomia *et al.*, 2011), peat (Lu *et al.*, 2017), swine manure (Fan *et al.*, 2015; Han *et al.*, 2019), goat manure and straw bedding (Pérez *et al.*, 2015), bran (Nath and Singh, 2016), pisciculture sludge (Bui *et al.*, 2015), molasses (Naluyange *et al.*, 2014), wheat straw (Masaka and Ndhlovu, 2007), manure and fish carcasses (Martins *et al.*, 2019), poultry litter (Montoya *et al.*, 2013; Gajalakshmi and Abbasi, 2006), food scraps (Ansari, 2011; Montoya *et al.*, 2013), tailings urban solid waste (Gajalakshmi and Abbasi, 2006) and sucrose (Song, 2016).

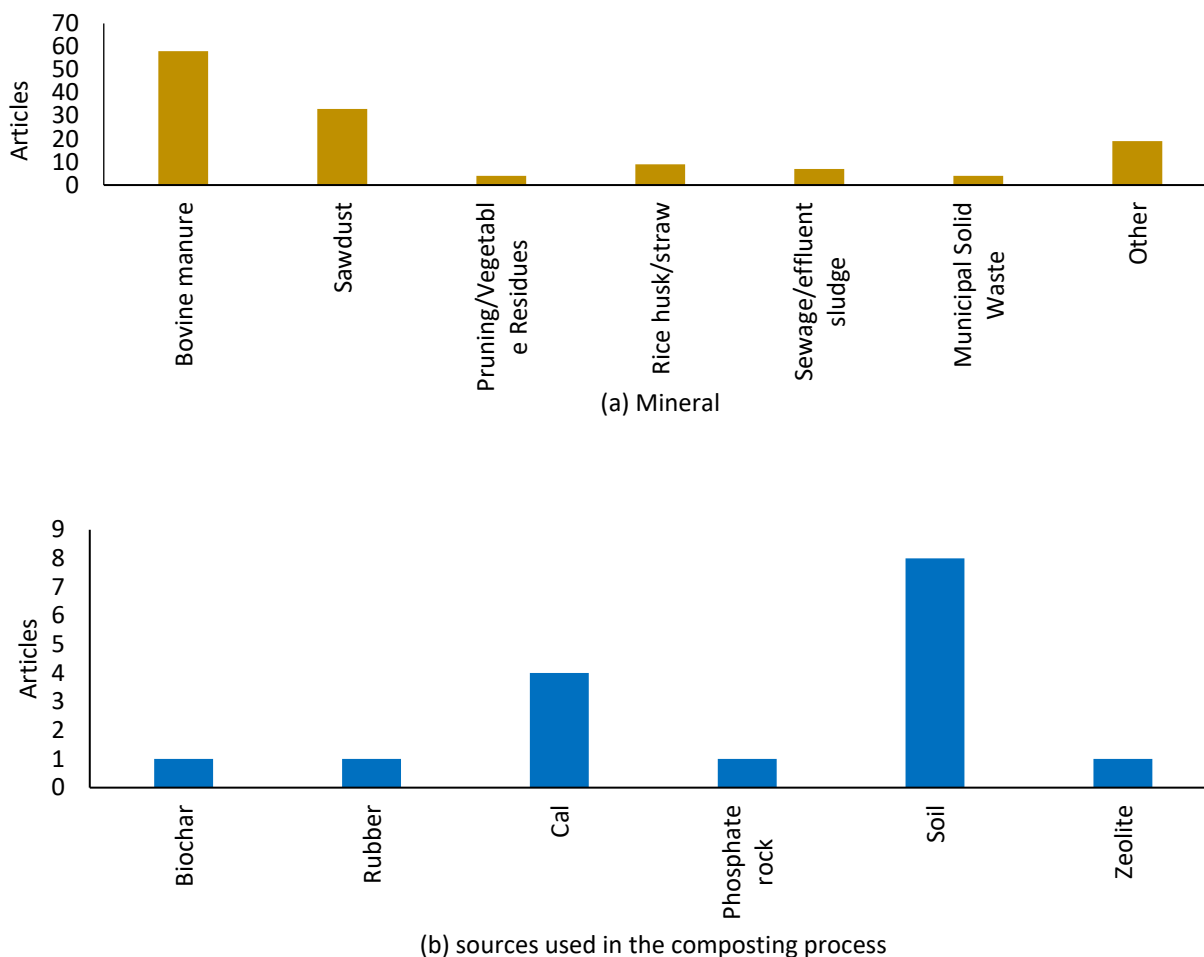


Figure 5. List of additional biomasses (a) and mineral (b) sources used in the composting process together with the macrophytes studied in each article

Compost monitoring

The composting monitoring process, performed by the authors identified in the literature review, occurred, in most cases, before proceeding with materials analysis that would be composted, along process and in the final compost.

Figure 6 illustrate analyzed parameters quantification (before, during and after composting) in literature review identified articles, divided into physico-chemical properties, macronutrients, micronutrients, toxic elements and others.

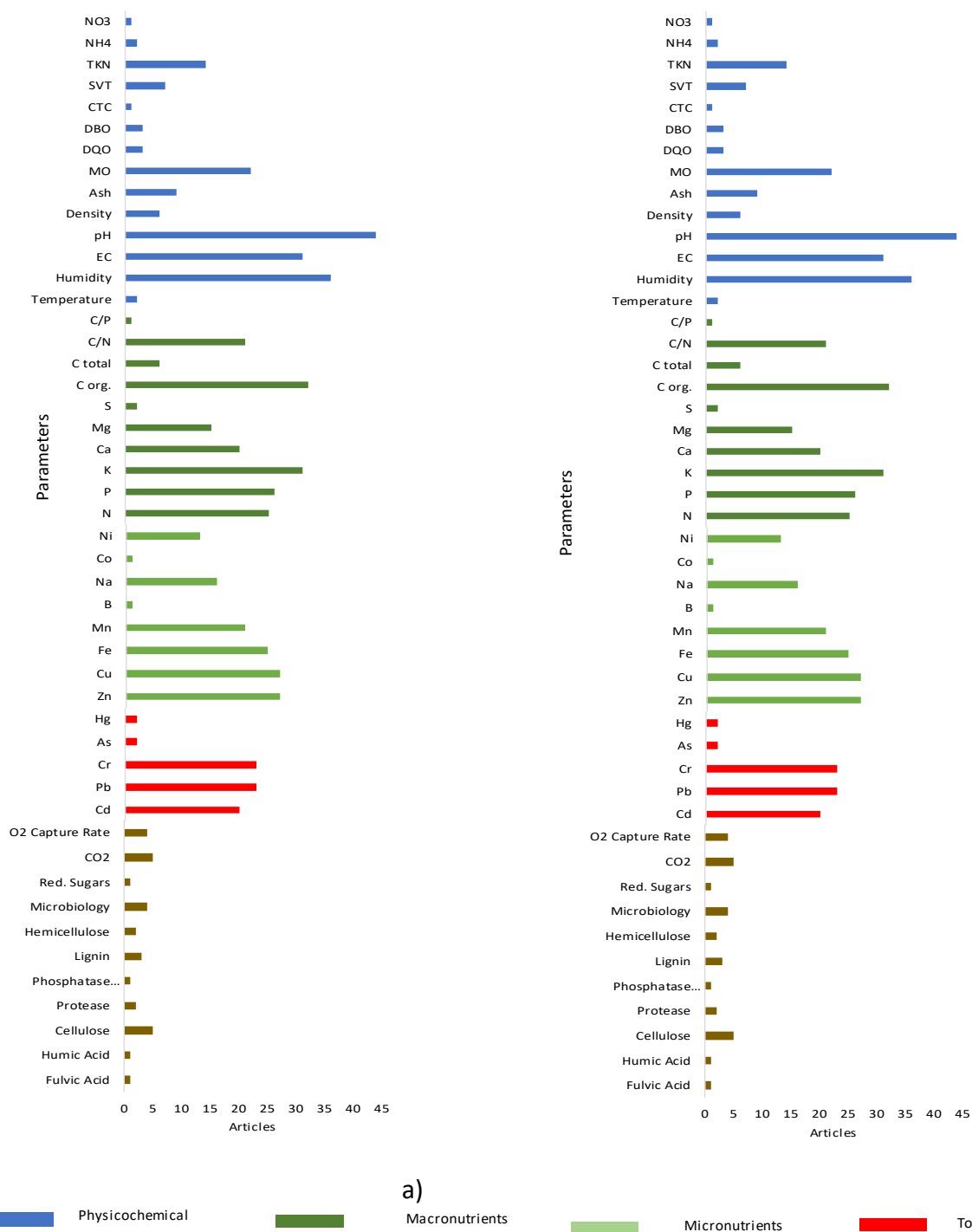


Figure 6. (a) Prior parameters evaluated to composting process macrophytes and/or biomass characterization. (b) Parameters evaluated during or after the composting process to characterize the final product.

The main parameters stages analyzed (before, during and after the composting) resemble. The physical and chemical parameters more analyzed are pH, electrical conductivity (EC) and Humidity. In a less expressive amount, however, still standing out above the others, the content of Organic Matter (OM) and Total Kjeldahl Nitrogen (TKN) are also among the most adopted by the authors.

The most adopted macronutrients in monitoring are K, N and P, the latter two being, however, surpassed in organic carbon monitoring during/after composting, also significantly adopted in monitoring prior to composting. Is also adopted C/N ratio by a large number of the authors, and its prior monitoring to composting held to be maintained at close values to ideal for process and during/after composting verifying compost maturity (Araiza *et al.*, 2016; Nath and Singh, 2016; Pushpa *et al.*, 2016a; Bisen *et al.*, 2017).

Among the micronutrients, the elements Zinc (Zn), Copper (Cu) and Iron (Fe) stand out in decreasing order, both in the previous monitoring and during/post composting. They are also monitored in some of the micronutrient articles such as Manganese (Mn), Sodium (Na), Nickel (Ni) and, in low expressive percentages, Boron (B) and Cobalt (Co).

Due to the macrophytes chemical elements assimilation characteristics (Ganesh *et al.*, 2012; Singh and Kalamdhad, 2012; Singh and Kalamdhad, 2014; Mazumder *et al.*, 2020), plant toxic elements monitoring, prior to composting, and the residual of these elements in the compound, during/after process composting, is adopted in part of the studies. Elements such as Pb, Cr and Cd are the most monitored in the articles identified in this literature review, and elements such as Hg and Arsenic (As) are also analyzed. The potentially toxic element type present in macrophytes may differ, depending on local proliferation characteristics. Thus, even that lead, chromium and cadmium are main elements potentially toxic monitored, others can be adopted.

The grouped parameters named "Others" correspond to a not framed indicators in other divisions. Some of these parameters are associated with the type of study being conducted, such as specific studies of microbiology and its influence on the composting process (Pramanik, 2010; Bisen *et al.*, 2017; Vishan *et al.*, 2017), analysis of the decomposition of the woody fraction of macrophytes (Sarika *et al.*, 2014; Devi *et al.*, 2015; Das *et al.*, 2016) or its application and potential environmental damage, to human beings and economic development (Rezania *et al.*, 2015a; Sharma *et al.*, 2016).

Final remarks

The macrophyte composting process interest is a theme continuously addressed around the world in recent years, having evolved from the focus on analyzing the feasibility of the composting process to concerns about the characteristics, mainly of toxicity, of the compost produced.

On identified studies, the spatial distribution in literature review highlights management problem for this plant type is not restricted to continental countries, such as China, India, USA or Brazil. Environmental, economic and social impacts results from macrophyte proliferation's in water resources, have being object of studies in several countries around the world.

Composting with natural aeration predominates in the literature reviewed, representing 56% (half of this one, feature composting time equal to or less than 60 days) followed by vermicomposting (25%). In general, the authors consider it necessary to maintain humidity in the composting process around 60%.

Macrophytes partial dehydration, before composting process beginning seems to be crucial to ensure near-ideal humidity values.

Eichhornia crassipes corresponded to approximately 69% of the scientific researches and the special distribution, can be considered a worldwide problem.

Macrophytes chemical composition depends on where it developed, therefore, knowing the environment where it is inserted is essential to identify possible chemical elements (nutritional or dangerous) that may be in the plant's biomass.

Cellulose significant percentage that compose the macrophytes can prolong composting process. Thus, practices such as the previous comminution of plants and / or cellulose-degrading inoculants addition throughout composting process can represent peculiar composting stages this plant type resulting from the knowledge acquired in past researches.

Composting process operational parameters are not standardized in the accessed studies, lacking adjustments, according to each scientific researches context.

The macrophyte composting studies evolution have evolved into compound production with heavy metals lesser amount in their soluble forms. Micro and macro nutrients richness can be considered for next evolutionary composting studies stage for this plant type, either by organic matter sources characteristics and/or mineral sources addition.

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