

Research

A meta-analysis of the impact of water-solved pollutants on the protein content of *Pistia stratiotes* L.

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Abstract

Due to the high cost of conventional water cleaning procedures, an affordable alternative for developing countries is the use of *Pistia stratiotes* L. Although these plants adsorb toxic chemicals in their tissues, other studies report a high protein content in its biomass and propose to use it as a fodder or even for human consumption. Therefore, this study aimed to identify the impact of water-solved pollutants on the content of protein in the tissues of *P. stratiotes* through a meta-analysis of currently available literature. Scientific reports, which included the biochemical analysis of the species when exposed to pollutants in the growing media were retrieved. The statistical analysis identified that chromium, wastewater sludge from a sugar factory, fluoride and linear alkyl benzene sulphonate reduce the content of protein. On the contrary, metals such as copper and zinc showed a slight tendency to promote the accumulation of protein in the biomass. Only the use of municipal wastewater sludge consistently promoted the increase of protein. Since most pollutants reduced the protein content and others also pose a bioaccumulation risk, *P. stratiotes* is not recommended to be considered as a fodder or to be included in human diet without previously ensuring its chemical innocuity.

Abbreviations

DW Dry weight
FW Fresh weight
SD Standard deviation

1 Objective

Human activities such as agriculture, farming, industry or urban are sources of different types of contamination [4, 16, 22, 26]. As a result, water quality diminishes, being unsuitable for human consumption or even agricultural use [4]. This problem is critical and requires immediate attention [3].

Due to its low costs, bioremediation is an important alternative to retrieve harmful pollutants from water [15, 16]. Different species have been proposed to separate residues from water, such as aquatic macrophytes [31], mangroves

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Table 1 Meta-analysis results of the content of protein (dw) of *P. stratiotes* L

Study	Experimental			Control			Mean difference	MD	95 %-CI	Weight	
	Total	Mean	SD	Total	Mean	SD				I*	2**
(Sinha et al., 2009a)	72	19.76	0.71	15	24.34	0.69	+	-4.58	[-4.9; -4.1]	0.0%	8.5%
(Satyakala and Jamil, 1992)	18	7.67	0.00	6	11.45	0.00		-3.78		0.0%	0.0%
(Mondal and Nayek, 2019)	36	0.11	0.01	12	0.12	0.01		-0.01	[-0.02; 0.00]	0.0%	8.7%
(Ganesh et al., 2008)	36	3.69	0.35	6	5.95	0.32	+	-2.27	[-2.55; -1.99]	0.0%	8.6%
(Olkhovych et al., 2016)	3	0.21	0.02	3	0.15	0.01		0.06	[0.03; 0.10]	0.0%	8.7%
(Olkhovych et al., 2016)	3	0.26	0.02	3	0.15	0.01		0.11	[0.07; 0.14]	0.0%	8.7%
(Olkhovych et al., 2016)	3	0.26	0.02	3	0.15	0.01	+	0.11	[0.08; 0.15]	0.0%	8.7%
(De et al., 1985)	108	17.32	<0.1	36	17.85	<0.1		-0.53	[-0.53; -0.53]	100%	8.7%
(Lakra et al., 2019)	12	1.76	0.19	6	2.67	0.38		-0.91	[-1.24; -0.58]	0.0%	8.6%
(Ayyasamy et al., 2008)	15	14.71	1.68	3	16.58	0.85	+	-1.86	[-3.15; -0.57]	0.0%	7.5%
(Tewari et al., 2008)	24	15.13	2.48	24	12.19	4.07		2.93	[1.02; 4.84]	0.0%	6.4%
(Karmakar et al., 2016)	24	10.17	0.36	6	11.71	0.37		-1.54	[-1.87; -1.21]	0.0%	8.6%
(Chawla et al., 1989)	20	0.96	0.05	4	1.06	0.02	+	-0.10	[-0.14; -0.06]	0.0%	8.7%
Common effect model	374			127				-0.53	[-0.5; -0.5]	100%	--
Random effects model								-0.78	[-1.7; 0.1]	--	100%

Heterogeneity: $I^2 = 100\%$, $\tau^2 = 2.7019$, $p = 0$ Impact of dissolved pollutants in water on the protein of *P. stratiotes*

When exposed to chromium, copper, zinc, a combination of copper and zinc, mercury, different types of effluents and toxic compounds.

[32] and terrestrial plants [19]. Despite the presence and concentrations of pollutants, these plants grow, accumulate metals and other compounds in their tissues; they survive, and their biomass can be used to improve water quality [27].

Because of its biochemical composition, *Pistia stratiotes* L., also known as water lettuce, is a macrophyte whose biomass is used for different purposes such as the production of compost [1], bioethanol [34], biohydrogen [21], or biogas [5, 18]. Also, recent studies have shown that *P. stratiotes* pose a dry base protein content of close to 10% [17, 29]. This makes it an attractive species to be used as fodder for cattle in sustainable farming [20] and it has even replaced ingredients of balanced fodders in fish farms [14], reducing costs.

Pistia stratiotes has been recommended to mitigate the impacts of pollution [2, 3] and could simultaneously be considered to harness protein-rich biomass [14] contributing to farming sustainability. Although this might be an exciting approach, consuming this bioremediation-produced biomass could represent health risks for cattle or humans. Therefore, it is necessary to describe the influence of different pollutants on the quantity of protein of *P. stratiotes*. The present study aimed to identify the impact of water pollutant compounds on the protein content of *P. stratiotes* through the meta-analysis of current literature.

2 Data description

2.1 Literature selection

An extensive literature search was done using different platforms such as Academic Search Ultimate, BioOne, Access, Emerald, Fuente Académica, ScienceDirect, and Springer. The search was conducted without any time constraints, aiming to capture all relevant literature regardless of publication date. As a consequence, a total of 534 articles was obtained and

Fig. 1 Regression model bubble plot resultant of the meta-analysis correlation between exposure time (days) and the protein content of *P. stratiotes* (% dw)

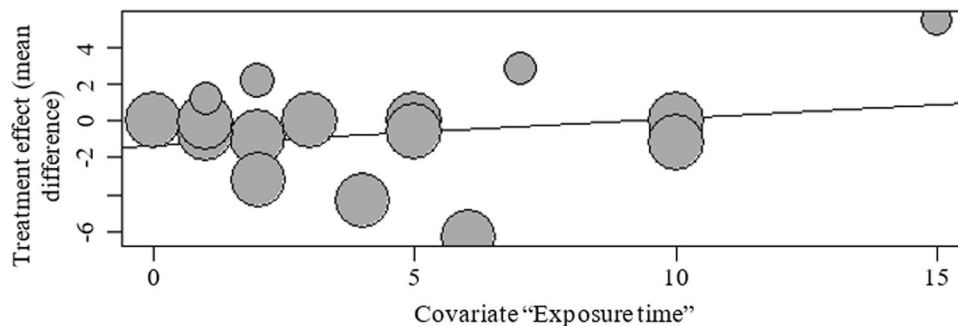


Table 2 Overview of data files

Label	Name of data file/data set	File types (file extension)	Data repository and identifier (DOI or accession number)
Data file 1	Formulae and equations [6]	Word file (.docx)	Figshare (10.6084/m9.figshare.24635961)
Data file 2	Figures [7]	Word file (.docx)	Figshare (10.6084/m9.figshare.24636078)
Data file 3	Tables [8]	Word file (.docx)	Figshare (10.6084/m9.figshare.24636090)
Data file 4	Protein content of <i>Pistia stratiotes</i> related to pollutants exposure time [9]	CSV Comma-delimited (.csv)	Figshare (10.6084/m9.figshare.24636933)
Data file 5	Complete data for meta-analysis of <i>Pistia stratiotes</i> when exposed to pollutants [10]	CSV Comma-delimited (.csv)	Figshare (10.6084/m9.figshare.24637005)
Data file 6	Metaanalysis script [11]	R script (.r)	Figshare (10.6084/m9.figshare.24637035)
Data file 7	Results description [12]	Word file (.docx)	Figshare (10.6084/m9.figshare.24841281)
Data file 8	Results discussion [13]	Word file (.docx)	Figshare (10.6084/m9.figshare.24841632)

reviewed using the terms “*Pistia stratiotes* AND protein”. From the retrieved studies, only those that satisfied the inclusion criteria were considered for the meta-analysis [33]. Research articles must: (1) Include at least one experimental group which was contrasted with a control group, (2) treatments should include a pollutant compound as a factor, (3) at least one dependent variable had to be the amount of protein measured in fresh or dry weight. Retrieved studies were found to be conducted in 7 countries, including the United States, Mexico, Ukraine, Romania, Uzbekistan, India, and China.

Altogether, 501 articles did not include quantification of protein in *P. stratiotes* and were not considered. A total of 22 articles were excluded due the lack of information on the reports (sample size, mean or standard deviation) or no comparison among treatments and control groups without water-solved pollutants. Thus, based on these inclusion and exclusion criteria, only 11 articles that included 135 treatments were considered for meta-analysis.

2.2 Dataset structure

The information was extracted from tables and text, while the ImageJ software estimated data from charts and graphs [25]. Two treatments were considered per research article, the experimental and the control. The mean and standard deviation of each study were used to avoid overestimation for artificial repetitions. As a result, the number of paired data was reduced from 101 to 13 [23]. All the information was organized in a dataset to compare the studies, treatments and to normalize data [30] (see table 1, labeled as data file 5). Thus, the mg of protein per g of dry weight (DW) was transformed to percentage of protein using the proper mathematical formular (see Table 1).

When the fresh weight (FW) of *P. stratiotes* was reported, the protein value in DW was estimated. Since *P. stratiotes* has 93.81% of average water content [28, 29], the following formula calculated the dry weight protein content from FW protein. The data was excluded when the protein content could not be estimated using the previous formulas. Another dataset was created by subdividing the results considering their exposure time to polluting compounds (see table 1, labeled as data file 4) using the proper mathematical formular (see table 1, labeled as data file 1).

2.3 Statistical analysis

The random effect model was implemented for the meta-analysis based on an estimate of the mean value of pollutant treatments compared with the mean value of the control treatment. Both groups were standardized by standard deviation (SD) and independent repetitions [30].

The statistic squared tau (T^2) was associated with the P value (P) to calculate heterogeneity among studies ($\alpha \leq 0.05$). In this analysis, the null hypothesis was rejected when a P value was lower than 0.05, meaning that pollutants affected the protein content of dry biomass of *P. stratiotes* compared with the control group. The significance among treatments was estimated depending on the distance from SD bars to mean values [30] (see table 1, labeled as data file 3). All analyses and graphs were performed with the package metafor by using the software R 4.1.2 [24]. A regression model was used to calculate the impact of the exposure time on the protein quantity in the tissues of *P. stratiotes* (Fig. 1 labeled as data file 2) (Table 2). Results are described in Table 1, labeled as data file 7.

3 Limitations

This analysis was restricted to English publications [23]. Although this might have excluded relevant research in other languages, most of the peer reviewed scientific knowledge is included in the reviewed data bases. Also, qualitative studies, such as using *P. stratiotes* as medicine or its biochemical analysis after a chemical or physical treatment for its biochemical modification were excluded. As a result, these subjects are underrepresented in this article.

Through the literature search, the lack of information about the variability of protein of *P. stratiotes* was evident. It should also be mentioned that changes in the biochemical composition are caused by multiple factors including the physiology of the plant and the environment; however, not all articles reported detailed information on these aspects making a deeper discussion impossible (see table 1, labeled as data file 8).

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Data availability The data described in this Data Note can be freely and openly accessed on Fig share. Please see Table 1 and references [6–13] for details and links to the data.

Code availability The software employed in this study, R version 4.1.2, is openly accessible online, allowing for transparency and reproducibility of the analysis. Researchers interested in replicating the statistical analysis performed in this study can refer to the provided code in Table 1, labeled as data file 6. The availability of the code enhances the verifiability of the results and facilitates a rigorous examination of the methodology employed in this research.

Declarations

Competing interests The research leading to these results received funding from Consejo Nacional de Humanidades, Ciencia y Tecnología (CONAHCYT) under Grant Agreement CVU 696757. All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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