

THE STATE OF GLOBAL SCIENTIFIC LITERATURE ON CHLOROPHYLL-A

O ESTADO DA ARTE DA LITERATURA CIENTÍFICA GLOBAL SOBRE CLOROFILA-A

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ABSTRACT: Chlorophyll is a green pigment common to all photosynthetic cells of autotrophic organisms in aquatic or terrestrial environments. Techniques used to quantify this pigment include fluorescence, UV spectrophotometer, chromatography, HPLC, and remote sensing. Determination of the photosynthetic pigment chlorophyll - a (Chl-a), has been used widely in many areas of science. The present study investigated the state of the global scientific literature on Chl-a, determining the countries, approaches, and environments where Chl-a has been studied and the geographic scale used. To obtain this scientometric information, we conducted a study from the Scopus database over a 21-year period from 1990 through 2011. This period saw significant increases in the number of publications ($r=0.84$ and $P < 0.001$), different journals where publications appeared (160 journals), major papers with a multidisciplinary character, and a predominance of descriptive approaches with studies conducted in aquatic and marine habitats at a regional scale. The country with the highest number of publications was China (21.64% of total papers; location of study), and the USA had the highest number of authors (19.52% of total papers). The main determining factor for publications was socioeconomic (according to model selection criteria; AIC). This study highlight the multidisciplinary use of Chl-a, and may give some directions to new studies about this pigment.

KEYWORDS: Photosynthetic pigment. Scientometrics. Water. Phytoplankton biomass.

INTRODUCTION

The term chlorophyll (Chl-a) was proposed by Pelletier and Caventou (1818) to describe the green substance that can be extracted from leaves with the assistance of organic solvents (LLOYD; TUCKER, 1988). The Chl-a pigment captures photons (pigment-antenna), and is present in all living things that perform oxygenic photosynthesis (BJORN et al., 2009). Quantification of Chl-a has been used as a tool in various fields of knowledge, including bioenergy (SKJANES et al., 2007), biotechnology (KOZIOL et al., 2007), botany (THOMAS et al., 2001), ecotoxicology (PEREZ et al., 2008; SUBASHCHANDRABOSE et al., 2011; RIANO et al., 2012), marine ecology (HAWES et al., 2012; THOMAS et al., 2001), limnology (WETZEL, 2001; HUO et al., 2012), remote sensing (NOVOA et al., 2011; GURLIN et al., 2011) and agriculture (KRAUSE et al., 2010; ZHANG et al., 2010; FERNANDEZ-JARAMILLO et al., 2012).

Chl-a is present in both aquatic and terrestrial environments is used in various areas of science as the control variable. As this study proposed an outline of Chl-a in global research by scientometric, in order to identify research interests with this variable. Scientometric techniques can be used to quantify scientific production and the types of studies in a certain area (MACIAS-CHAPULA, 1998; VANTI, 2002). Scientometric have been used

to diagnose trends in scientific literature on, for instance, ecology (PINTO et al., 2003; BINI et al., 2005; FAZEY et al., 2005; MELO et al., 2006), global climate change (STANHILL, 2001; NABOUT et al., 2012), groups of organisms (CARNEIRO et al., 2008; PADIAL et al., 2008; NABOUT et al., 2010), genetics (QUIXABEIRA et al., 2010) bioproducts (e.g. Biodiesel; FERREIRA et al., 2014).

The present study assessed research on Chl-a over a 21-year period (1990-2011), with the intention of answering the following questions: i) What is the temporal trend in the number of studies on Chl-a? ii) Studies on Chl-a are carried out on what scales, which journals and in which environments? iv) In which countries and regions are these studies performed? v) What factors determine the scientific production of countries where publications on Chl-a appear? In the other word determine the influence of Gross Domestic Product (GPD), Human Development Index (HDI), demographic density, water availability and consumption of fertilizers, in scientific production of nations.

All the information systematized how is the use of variable Chl-a makes it feasible to analyze the results of this work as a step prior study involving the same from the perspective of having jobs that seek to supply necessary research that have not been investigated with referent study variable.

MATERIAL AND METHODS

Sampling and quantification of scientific literature

The literature utilized in this study was obtained from the Scopus database (www.scopus.com), accessed in March 2012. We used the search terms "Chlorophyll a" OR "Chl-a" OR "Chlorophyll-a" OR "Chl a" in the titles of papers that appeared from 1990 through 2011. For each article we determined i) the year of study; ii) the journal; iii) the geographic scale (local, regional, continental or global); iv) the approach used (theoretical, experimental or descriptive); v) the region or country of the study and the country of the first author (nationality); vi) the type of environment (terrestrial, marine or continental).

With respect to the approach (item IV), the term "experimental" was used for articles that used a Chl-a variable to develop laboratory techniques such as synthesis reactions, reaction kinetics, and characterization of the physicochemical properties of Chl-a, among others. Theoretical studies, in general, included revisions. Finally, descriptive studies were considered as those involving field research and/or quantification of Chl-a in the laboratory.

Data analysis

The temporal trends of number of papers were investigated using a Pearson correlation ($P < 0.05$) to relate the number of articles to the year when they were published. To investigate the determining factors for the scientific production of countries (i.e., numbers of papers by country where the study took place) several models were constructed. These models were compared using the Akaike Information Criterion (AIC) (BURNHAM; ANDERSON, 2002), in which the best model was the one that gave the lowest value of AIC. These analyses included specific countries only; papers that merely indicated the study region, such as Africa or the Atlantic Ocean, were not included in the analyses.

In the models, the number of papers for countries was regressed as a function of five explanatory variables: Gross Domestic Product (GDP, in dollars, obtained from the International Monetary Fund for the year 2011), Human Development Index (HDI, obtained on the website of the United Nations Development program - UNDP, for the year 2011), demographic density

(inhab/km²), water availability (m³) and fertilizer consumption (hundreds of mg ha⁻¹; UNDP website, accessed in September 2012). Using this set of variables, 31 different models were generated and then compared according to the selection criteria of AIC models.

The importance of these factors is summarized in the fact that scientific research is a reflection of socioeconomic and environmental factors, but tested whether these studies reflect the Chl-a in different countries through the analysis of the regression model. It is expected that countries with greater water availability, fertilizer consumption and GDP may be those who develop more work on this variable. The analysis was performed using the software SAM 4.0 (RANGEL et al., 2010).

RESULTS

Between 1990 and 2011, 2175 articles appeared that refer to studies on Chl-a. The number of articles on this subject has increased significantly along the period of the study ($r=0.84$ and $P < 0.001$) (Figure 1). We found 160 journals that published articles on Chl-a. Of these, only 20 journals published 44.01% of the total (Figure 2). We classified 2031 papers as descriptive, experimental or theoretical. Most studies were descriptive (1144 papers, or 53% of the total articles studies), followed by experimental (703 papers, 32.6%) and theoretical studies (184 papers, 8.5%). Some paper were not classified, according type of studied (descriptive, experimental and theoretical) (5.9%). Regarding geographic scale, 51.6% of publications on Chl-a were regional, 37.8% local, and 10.5% continental or global. We classified 1431 papers as the type of environment studied (terrestrial, marine or continental). The marine environment was more studied, with 37.8% of the papers (540 papers); while continental waters represented 25.7 % (369), and terrestrial environments 36.5% (522).

Regarding the nationality of the first authors, most publications were from the United States of America (USA) with 19.52% (421 papers), followed by China with 13.86% (299) and Japan with 11.21% (242). However, considering the area of study, the largest number of studies were conducted in China with 8.22% (179), followed by the USA with 3.72% (81) and Japan with 1.88% (41) (Figure 3).

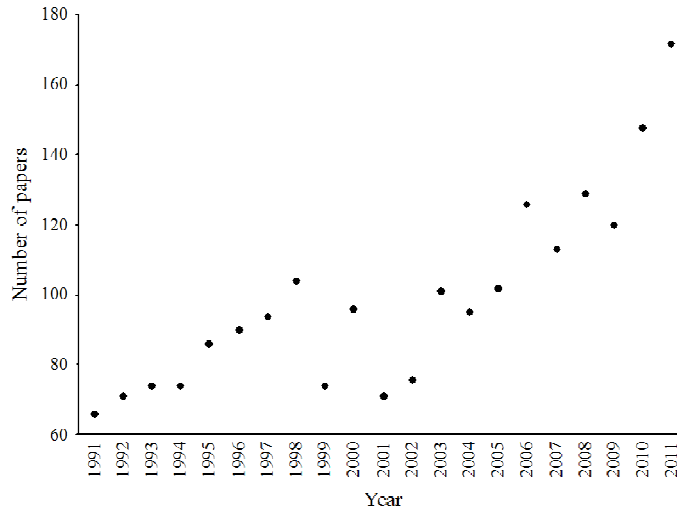


Figure 1. Temporal trend in the number of articles published per year in the period 1990 to 2011.

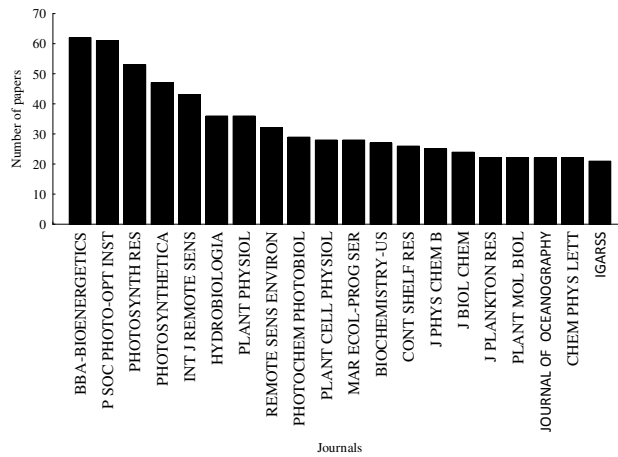


Figure 2. The principal journals where publications on chlorophyll-a have appeared.

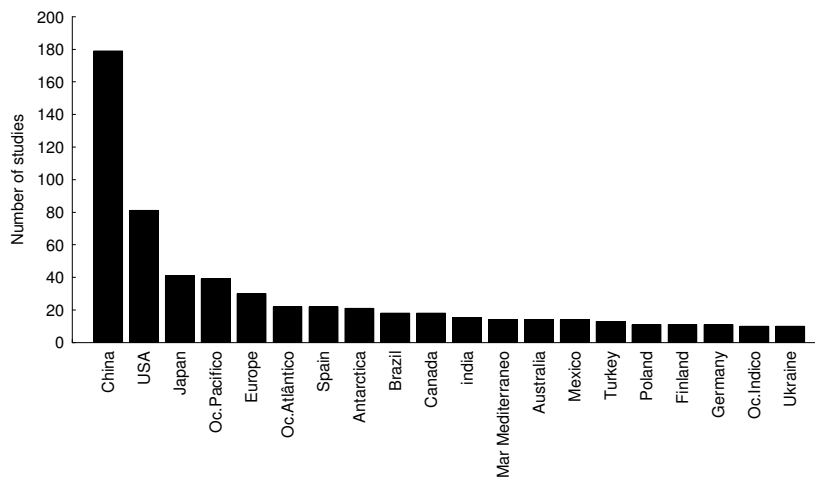


Figure 3. Countries or regions where studies were performed on chlorophyll-a.

Five of the AIC models were classified as top models ($AIC < 2$). In these models, all variables were present. The best model was composed exclusively by GDP and explained 66% of the variation in countries where publications appeared (Table 1). The GDP was present in all top models

and presented positive relation with the number of papers published by different countries (Table 2); in other words, countries with a larger number of publications on within-country study areas were those with the higher GDPs, supporting the hypotheses suggested here. Another supporting

variable was water availability, i.e., countries with more publications are those with more water availability (Table 2). In contrast, the scientific

production by country was negatively related to demographic density, fertilizer consumption and HDI.

Table 1. Results of the 31 models generated to identify the socio-economic factor that best explains the study region with chlorophyll-a. The variables are population density (inhabitants / km²) (D); GDP (millions of dollars), water availability (W); fertilizer consumption (F), HDI.

Variables	R ²	AIC	Delta AIC
GPD	0.662	10.537	0
GPD, HDI	0.669	11.813	1.275
GPD, F	0.667	12.129	1.592
D, GPD	0.666	12.206	1.668
GPD, W	0.666	12.241	1.703
D, GPD, HDI	0.677	12.933	2.396
GPD, W, HDI	0.676	12.975	2.437
GPD, W, F	0.672	13.775	3.237
D, GPD, F	0.67	13.979	3.442
GPD, F, HDI	0.67	14.083	3.546
D, GPD, W	0.668	14.411	3.873
D, GPD, W, HDI	0.68	14.945	4.407
GPD, W, F, HDI	0.677	15.387	4.849
D, GPD, F, HDI	0.677	15.453	4.916
D, GPD, W, F	0.673	16.152	5.615
D, GPD, W, F, HDI	0.68	17.562	7.024
HDI	0.104	63.213	52.676
D, HDI	0.109	65.23	54.693
W, HDI	0.106	65.42	54.882
F, HDI	0.104	65.548	55.01
F	0.035	67.213	56.675
D, W, F	0.116	67.233	56.696
D, F, HDI	0.109	67.653	57.116
W, F, HDI	0.106	67.85	57.312
W	0.018	68.166	57.629
W, F	0.048	68.832	58.294
D	<.001	69.136	58.599
D, F	0.035	69.546	59.009
D, W, F, HDI	0.117	69.751	59.213
D, W	0.024	70.162	59.624
D, W, F	0.05	71.119	60.581

Table 2. Selected models showing each variable used, the importance, the standardized regression coefficient considering all models, and the standardized regression coefficient considering only the best model. The variables are population density (inhabitants / km²) (D); GDP (millions of US dollars), water availability (W), fertilizer consumption (F) and HDI.

Variable	Importance	Coefficient
D	0.29	-0.05
GPD	1	0.47
W	0.301	0.029
F	0.28	-0.035
HDI	0.358	-0.27

DISCUSSION

Studies with Chl-a showed a growing over the years analyzed in the study, and this variable indicative of living in aquatic and terrestrial environments. The search domain knowledge in diverse habitats makes it necessary mastery of certain indicator variables immediately Chl-a is used as an indicator of biomass aquatics, vegetation.

These works were published mostly by multidisciplinary journals demonstrating that research with this variable are used in a multidisciplinary approach for the Chl-a is subject to various changes in the environment. Another important aspect of this study is that of Chl-a to be used as the main variable in research descriptive of the place are mostly regional and marine environments. Leading the way screening study concerning Chl-a as a variable of study.

This survey of the state of knowledge about Chl-a allowed us to ordinate the groups of information and results, to provide an overall view of investigations on this subject. Assessments of the state of development of a certain area may help to improve and develop new postulates, concepts and paradigms. Our results showed that over 21 years, the number of publications on Chl-a has continued to grow, a pattern also found in other scientometric studies, for instance on phytoplankton (CARNEIRO et al., 2008), macrophytes (PADIAL et al., 2008), population ecology (LIMA-RIBEIRO et al., 2007), genetic studies using flow cytometry (QUIXABEIRA et al., 2010), niche models used in invasive species (BARBOSA et al., 2012) and global climate change (NABOUT et al., 2012).

This increase in the number of publications on Chl-a can be related to the use of microorganisms in the search for field techniques in biotechnology (SHEEHAN et al., 1998; GROBBELAAR, 2010), laboratory research and the reaction kinetics (PRUZINKÁ et al., 2003; WANG et al., 2011), evaluation of the physicochemical properties of Chl-a under various treatment conditions (MAXWELL et al., 2003 ; CARBONERA et al., 2012; FERNANDEZ-JARAMILLO et al., 2012), its use in medicine (BRITTON, 1995; SCHOEFS, 2002), concern for sustainable use of the environment where this is a tracking variable (THOMAS et al., 2001; AFFONSO et al., 2011; LUGOLI et al., 2012), and also characterization of Chl-a optical properties for use in hyperspectral optical sensors of satellites, which facilitate gathering data on photosynthesis on temporal and spatial scales (NOVOA et al., 2011; GURLIN et al., 2011).

Studies on Chl-a are mostly descriptive (53%), as this variable provides an indirect measurement of phytoplankton biomass, the NDVI (Normalized Difference Vegetation Index) of a vegetated area, and water-quality parameters in limnology. All these studies are empirical in nature, where performing field research is essential (WANG et al., 2003; GARMENDIA et al., 2011). In many areas of science, a high proportion of the papers are descriptive (LIMA-RIBEIRO et al., 2007; CARNEIRO et al., 2008), especially in areas with a well-defined body of theory that has been advanced in the development of new techniques, as is the case for Chl-a.

More part of chl-a studies were developed in the marine environment. Several marine studies use Chl-a to estimate the phytoplankton biomass (e.g. GOWER; KING, 2008). Estimates of marine phytoplankton biomass have many applications, including aquaculture management (WILD-ALLEN et al., 2011), monitoring using satellite imagery (NOVOA et al., 2011; GURLIN et al., 2011) and forecasting algal blooms (SHEN et al., 2012). Chl-a is also a useful explanatory variable in continental waters, where it is used as a parameter for monitoring, quantification of photosynthetic species, quality assessment, and detection of water pollution.

Authors from the USA contributed most papers. The predominance of authors from this country has been reported in several studies (FAZEY et al., 2005; CARNEIRO et al., 2008; NABOUT et al., 2010). Part of the reason for this must be the greater investment in infrastructure and research (MUGNAINI et al., 2004; JAPPE, 2007). However, a high proportion of studies on Chl-a have been conducted in China. These results indicate a partnership between countries (for example China and the USA), where although most articles are by authors from the USA, the studies were conducted in China, or possibly American authors worked in China along with Chinese authors. Despite the importance of partnerships for increasing scientific output, this study showed that the GDP is the main variable that explained the variations in the country of the study, since this indicator expresses the sum of the wealth generated by all the various sectors. These sectors in turn are motivated by technological development and are based on scientific development. Other studies have shown a similar positive relationship between the two variables (GDP and number of papers), e.g., that of Nabout et al. (2010) on the global literature on fiddler crabs (genus *Uca*).

Finally, the present study traced the state of knowledge on Chl-a on a global scale. In spite of the

increasing number of articles, several research areas and geographical regions remain relatively unexplored, such as experimental studies and studies in continental aquatic environments. Studies in freshwater ecosystems aid in determining the quality and multi-use availability of a water body. Experimental studies are important to assess the importance of Chl-a in specific conditions, such as global climate change (BICUDO; BICUDO, 2008; KALAJI et al., 2011). Because of the importance of this environmental variable, we recommend studies on the impact of global climate change on Chl-a, because of the relative paucity of studies on climate change in aquatic environments (NABOUT et al., 2012).

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RESUMO: A clorofila é um pigmento verde, comum em todas as células fotossintéticas de organismos autotróficos, de ambientes aquáticos ou terrestres. As técnicas mais utilizadas para quantificar esse pigmento são a fluorescência, a espectrofotometria de UV, a cromatografia HPLC e o uso de sensores remotos. Assim, a determinação do pigmento fotossintético clorofila-a (Chl-a), tem sido utilizada amplamente em diversas áreas da ciência. Portanto, o objetivo deste trabalho foi investigar o estado da arte da literatura científica para o pigmento fotossintetizante clorofila-a, determinando os países de estudo, os fatores socioeconômicos- ambiental que estão ligados ao estudo de clorofila –a, abordagens utilizadas, e ainda, os ambientes estudados, a escala geográfica e as revistas. Para obter tais informações realizou-se um estudo cienciométrico, a partir da base de dados *Scopus*, numa escala temporal de 21 anos (entre 1990 e 2011). Os padrões encontrados para as pesquisas com Chl-a são o aumento temporal de publicações ($r=0.84$ and $P<0.001$), a diversidade de revistas que publicaram estudos sobre o assunto (160 revistas), maior número de publicações com caráter multidisciplinar, predomínio de estudos com abordagens descritivas realizados em ambientes aquáticos e marinhos e estudos em escala geográfica regional. A China foi o país mais estudado com 21,64% do total de artigos publicados, e os estadunidenses lideraram com o maior número de publicações sobre este assunto (19,52% do total de artigos publicados). Utilizando o critério de seleção de modelos de Akaike observou-se que as publicações são impulsionadas pelo fator socioeconômico PIB. Este estudo demonstrou o uso multidisciplinar da Chl-a e pode indicar algumas direções para novos estudos com esse pigmento.

PALAVRAS-CHAVE: Pigmento Fotossintetizante. Cienciométrica. Água. Biomassa Fitoplantônica.

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