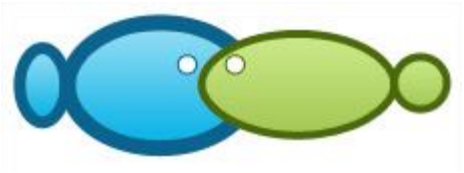

The biosorption potential of *Plocamium cartilagineum* algal biomass for the elimination of the synthetic dye Cibacron Blue

[1]Chouaib Motik, [2]Fatima Chegdani, [1,3]Mohamed Blaghen

[1] Laboratory of Microbiology, Pharmacology, Biotechnology and Environment, Faculty of Sciences, Aïn Chock, Hassan II University, Casablanca; Morocco; [2] Immunology and Biodiversity Laboratory, Faculty of Sciences, Aïn Chock, Hassan II University, Casablanca, Morocco; [3] Laboratory of Plant Biotechnology, Ecology and Ecosystem Valorization, Faculty of Sciences El Jadida, Chouaïb Doukkali University, El Jadida, Morocco.
Corresponding author: C. Motik, Chouaib.m@hotmail.com

Abstract. The presence of dyes in the textile industry waste presents a problem for the environment, as they are mostly toxic, non-biodegradable and resistant to destruction by conventional physico-chemical treatment methods. Current researches are therefore oriented towards low-cost treatment processes, in particular biological methods, using biosorbent materials such as seaweed. *Plocamium cartilagineum* (Linnaeus) (P. S. Dixon, 1967) is a red endemic alga that has demonstrated its effectiveness in various fields, with several beneficial effects of its derivatives. The antiviral, antimicrobial, cytotoxic or even acaricidal activities of *P. cartilagineum* have been the subject of several publications. In this work, the objective is to study and confirm the biosorption potential of the alga for environmental purposes. As a matter of fact, experiments were conducted to investigate the biosorption characteristics of the alga on the removal of a textile dye, the Cibacron Blue, from aqueous solution and demonstrate its potential as a low-cost biosorbent for the treatment of colored water. The effects of temperature, solution pH, biosorbent dosage, biosorbent mass and initial concentration were studied. The results obtained showed that the biosorption of this dye is a rapid phenomenon that is strongly influenced by the pH of the solution. At pH 2 of Cibacron Blue, the maximum fixation capacity of this algal biomass, deduced from the Langmuir model is equal to 25.83 mg g^{-1}. The results suggest that *P. cartilagineum* could be used as biosorbent for the effective removal of Cibacron Blue in terms of biosorption capacity, availability and low cost.

Key Words: biomass, biosorption, Cibacron Blue dyes, colorants, *Plocamium cartilagineum*, textile industry, toxicity, wastewater treatment.

Introduction. Water is central to all socio-economic processes, regardless of the level of development of society. The increase in industrial activities is putting growing pressure on the world's water resources. Indeed, these activities generate a great diversity of chemical dyes; in fact more than 10.000 commercial dyes exist with an approximate annual production of de 7 x 10^5 tons $year^{-1}$ (Rangabhashiyam et al 2018). Of this colossal production, an estimated 10 to 15% of the dyes used are effluents that enter the water cycle (Mahmoud et al 2017), an average concentration of 300 mg L^{-1} of dyes in effluents has been reported in water courses (Mokhtar et al 2017) jeopardizing the fragile natural balance that allowed life to develop on earth. Environmental protection has thus become a major economic and political issue. Every country in the world is concerned with safeguarding freshwater resources, either because they lack water or because they pollute it.

Better production and less pollution are the challenges facing industrial companies in all sectors. The legislative and normative constraints are more and more drastic. Industries as diverse as the chemical, petrochemical, agro alimentary, textile, papermaking and tanneries produce diverse effluents that require each time new investigations and the development of new specific processes. Often, the chemical substances contained in wastewater are not easily biodegradable, it is important to note

that most of these dyes are very recalcitrant and resistant to the various natural degradation phenomenons like heat, photodegradation and biodegradation (Abdallah & Taha 2012). In addition to the persistence of these molecules, there is the lack or inadequacy of conventional treatment systems: coagulation and flocculation (Kim et al 2004), chemical oxidation (Oguz & Keskinler 2008), electrochemical treatment (Fan et al 2008), or adsorption (Wang et al 2005) have all been applied for the elimination of dyes from wastewater (Isik et al 2019). Of all these approaches, biosorption remains the most interesting alternative for the treatment of dye-contaminated effluents (Daneshvar et al 2019).

Anthraquinone dyes (20 to 25% of the world market (Crepy 2004)) and reactive dyes (about 13% of the world market and 20% of the dyes used on cellulose (Pilliere et al 2001)) are the most used synthetic dyes in modern industry. Some of these dyes have been shown to be highly toxic with carcinogenic and mutagenic properties (Akar et al 2013; Wu et al 2018). Their release into the environment has a negative impact on the receiving environment (watercourse, sea, soil, ...) and represents a serious threat to humans, which requires their treatment before discharging them into this environment (Mansour et al 2011). Faced with this worrying situation, the scientific community is mobilized and works on the implementation of innovative processes to treat these pollutants. Colored wastewaters are usually treated by different conventional processes and other more innovative ones; some of these techniques have proven to be effective, although they have limitations, namely; high treatment cost, secondary pollution caused by the excessive use of chemicals and difficulties in managing the resulting sludge (Khan & Khan 2021). An interesting approach, based on the use of biological resources such as marine algae, fungal and microbial species for dyes removal, has emerged as an alternative to conventional treatment methods (Ullrich & Smith 1951; Park et al 2010).

In fact, Morocco, with its double Atlantic and Mediterranean facade, more than 3500 km long, is a country deeply influenced by the sea, which implies the existence of thousands of marine species including algae which present a very important biomass compared to other countries (Ainane 2011). The valorization of the algal biomass is considered among the most interesting international programs in the exploitation of the marine environment. The special external properties of these biosorbents, allow them to adsorb different kinds of metallic and organic pollutants from aqueous solutions (Kaparapu et al 2015; Hassi et al 2020). The use of dead cells in biosorption is more advantageous for water treatment since dead organisms are not affected by toxic losses, do not require a continuous supply of food and can be regenerated and reused for many cycles (Li et al 2018). It has been shown that dead cells accumulate as much pollutants as growing or resting cells (Tangaromsuk et al 2002; Guo et al 2012; Huang et al 2013). Hence, we proposed to study the potentialities of using a species of marine algae as a biosorbent material for the treatment of dye-contaminated water. The present work was interested in the capacity of the biomass of the endemic alga *Plocamium cartilagineum* to adsorb and eliminate the dye, using three particle sizes (0.25 mm, 0.50 mm and 1 mm). The dye selected was Cibacron Blue (CB).

For this purpose, we performed an experimental study of biosorption in batch mode, investigating the effect of some important parameters on the decolorizing power of the algal biomass used, in particular, contact time, pH, mass of the biosorbent, temperature and dye concentration.

Material and Method

Seaweed harvesting. Seaweed harvesting was carried out on September 2020 in the Dar Bouazza coastline (El Jadida road) in the grand Casablanca region of Morocco (33°31'26.522" N 7°49' 33.301" W); the average sea water temperature is 19.5°C, pH measured at harvest is 8.2. This zone is abundant in algae, in particular the chosen one: *P. cartilagineum*, object of our biosorption study.

Preparation of the algal biomass. The algae were washed with tap then distilled water in order to eliminate sand, debris and undesirable epiphytes stuck on their thallus. They

were then air-dried afterwards. The first identification of *P. cartilagineum* revealed that it belongs to the Rhodophytes phylum (red algae) (Dixon 1967). After drying, the algal biomasses were put in a thermostatic oven at 60°C for 24 h. Then crushed with an electric mill and sieved to obtain the fractions of size 1 mm, 0.50 mm and 0.25 mm.

Dosage of the studied dye**: **Cibacron Blue. The dosage of Cibacron Blue (CB) - a monochlorotriazine dye that belongs to the Anthraquinone dye groups - was performed spectrometrically using the JENWAY 6405 UV/V spectrophotometer. The wavelength λ max was 612 nm.

Biosorption studies. Biosorption assays of CB by the algal biomass *P. cartilagineum* were performed during the three months following the harvesting. Every test was carried out in duplicate and the results were reproducible. The adsorption of the dye was investigated in a batch mode, with changing some parameters such as pH, biosorbent mass, temperature and the initial concentration of the dye. We investigated at the end the adsorption kinetics of CB and estimated the maximum fixation capacity by *P. cartilagineum* biomass:

- effect of dye solution pH: the pH was adjusted to the desired value with HCl (1 M) and NaOH (1 M) solutions. We chose a pH range from 1 to 10 of CB; 3 g L^{-1} of biosorbent are put in contact with dye solutions at a concentration of 60 mg L^{-1}, under agitation of 100 rpm and at 25°C;
- effect of the mass of the biosorbent: we then attempted to investigate the influence of the mass of the biosorbent on the dye biosorption phenomenon; this parameter is studied in a solution of CB at a concentration of 60 mg L^{-1} in contact with the algal biomass *P. cartilagineum*. The chosen mass range varies between 0.50 g L^{-1} and 6 g L^{-1}. The pH of the solution is kept constant (pH 2), until chemical equilibrium is reached;
- effect of temperature on dye biosorption: effect of temperature on the phenomenon of dye biosorption is studied in a solution of CB at a concentration of 60 mg L^{-1} in contact with 3 g L^{-1} of the algal biomass *P. cartilagineum*, under agitation of 100 rpm. The chosen temperature values were 15, 25, 35, and 45°C. Finally, to evaluate the biosorption performances of CB on *P. cartilagineum* biomass depending on the initial concentration of the dye, 3 g L^{-1} of biosorbent are put in contact with dye solutions at different concentrations of 6, 12, 24, 36, 48, and 60 mg L^{-1}, at a CB pH = 2, under agitation of 100 rpm and at 25°C until chemical equilibrium is reached;
- kinetics of dye removal: the adsorption kinetics of CB was performed with an initial concentration of 60 mg L^{-1}, a volume of 100 mL, and a mass of 3 g L^{-1} of algal biomass. During the contact time, the solution was kept under constant shaking and at constant temperature and pH (shaking = 100 rpm by a water bath of brand (memmert), pH of (CB): 2 and T = 25°C). Samples of 1 mL, taken at different time intervals, allow a follow-up of the evolution of the dye concentration in the solution. The collected samples are immediately centrifuged at 8000×g for 12 min at 4°C, and the dye content is then determined spectrophotometrically.

Results and Discussion

Effect of pH. The pH is one of the external factors that influence the removal of dyes by aquatic plants, it is an important parameter in any adsorption study, since it can impact both the structure of the adsorbent by the change of charge of its surface as well as the degree of ionization of the adsorbate and the dissociation of the functional groups of the biomaterial (Kalyani et al 2008; Saratale et al 2010; Grabi et al 2021). The results represented in Figure 1 clearly show that the biosorption of CB on the biomass of *P. cartilagineum* is significantly influenced by pH. Indeed, the lower the pH, the higher the dye binding rate. The maximum fixation of CB is obtained for a pH = 1 and pH = 2, recording a fixation efficiency of about 96% for the granulometry 0.25 mm, then the fixation rate of CB decreases with the increase of the granulometry of the algal biomass,

as well as by the increase of the pH. We chose the pH 2 for the determination of the next parameters.

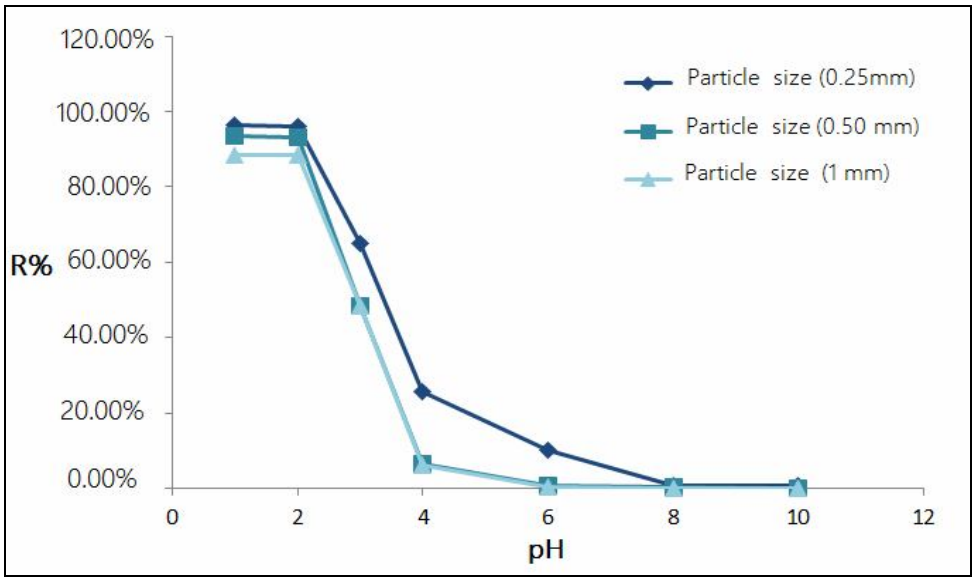

Figure 1. Influence of medium pH on the rate of fixation of CB by three granulometries (0.25 mm, 0.50 mm and 1 mm) of *Plocamium cartilagineum* biomass (R% = dye fixation efficiency, C0 = 60 mg L^{-1}, m biomass =3 g L^{-1}, T = 25°C).

The results from CB fixation are in agreement with those reported in a study that investigated reactive dyes (Remazol Black RB, Remazol Red RR and Remazol Golden Yellow RGY), where the pH:2 seemed to offer the best capabilities for reactive dye fixation by the alga *Chlorella vulgaris* (Aksu & Tezer 2005). Similar results were also recorded by a research dealing with the ability of bean peel to remove Cibacron Blue, and where biosorption increased with decreasing pH value (Grabi et al 2021). This significant binding is attributed to electrostatic attractions between the negatively charged anionic dyes and the positively charged algal cell surface. Conversely, several authors have reported results that highlight a better adsorption at higher pH, the adsorption of methylene blue on *Sargassum duplicatum* (brown alga) recorded an optimal pH of 5 and a minimal adsorption at reduced pH (Pratiwi et al 2020); while the adsorption of the same dye on *Eucheuma spinosum* showed that equilibrium was reached at pH 4 while the maximum fixation was observed between pH 8 and 11 (Mokhtar et al 2017); similar results were revealed for olive stones (Albadarin & Mangwandi 2015), as well as on the hybrid macro-alga Zinc oxide-Polyaniline (Pandimurugan & Thambidurai 2016). The explanation of these results would be that the biosorption of Methylene Blue is favorable under neutral to alkaline pH conditions or the electrostatic attractions between the cationic elements of MB+ and the negatively charged functional groups which explains the dye fixation (Kuppusamy et al 2017).

Effect of the biosorbent mass. The mass of the biosorbent is an important parameter that reflects on the feasibility and applicability of the whole process on an industrial scale (Salomón et al 2020). As shown in Figure 2, the dye binding rate increases rapidly with increasing algal mass, reaching a binding rate of 76.17% at 3 g L^{-1} for the granulometry 0.25 mm. This is followed by a pseudo plateau, for masses varying from 4 g L^{-1} to 6 g L^{-1} of algae, reflecting a slower fixation, due to the saturation of the binding sites with the dye. The maximum fixation is 97.86%, with a 0.25 mm biosorbent granulometry, reached at 6 g L^{-1} of algal biomass. Equilibrium is reached at 3 g L^{-1} of algal biomass. Above this mass, no significant difference is observed for values of 4 g L^{-1} to 6 g L^{-1} of biosorbent. This is in agreement with research results that reported that biosorption increases with increasing biosorbent mass (Waranusantigul et al 2003; Smoczyński et al 2020) which suggest that increasing the mass of the adsorbent would increase the active surface area and thus the availability of adsorption sites (Grabi et al 2021).

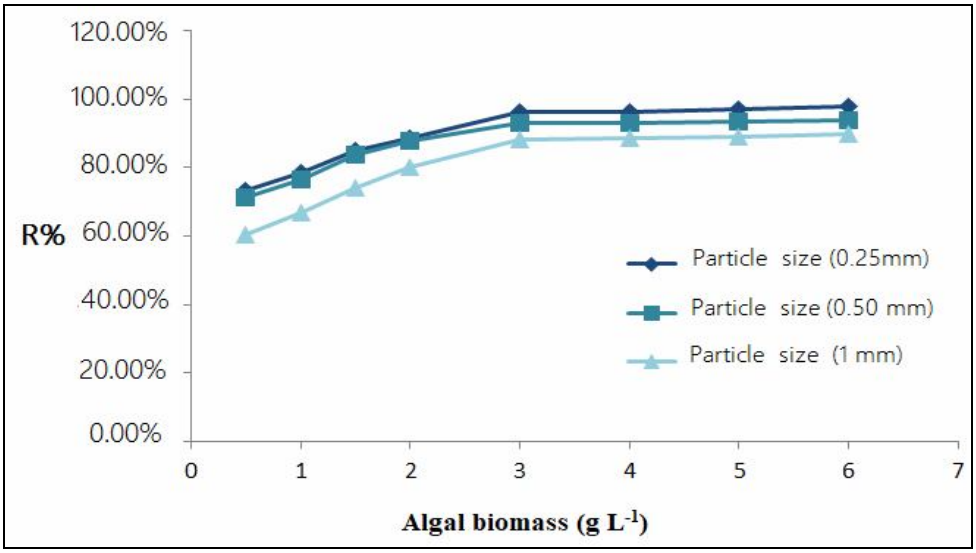

Figure 2. Influence of three particle sizes of the biosorbent (0.25 mm, 0.50 mm and 1 mm) on the fixation rate of CB (R% = dye fixation efficiency, pH : 2, C0 = 60 mg L^{-1}, T = 25°C).

Effect of temperature. Temperature is a factor that cannot be neglected in adsorption studies. The results obtained as shown in Figure 3, reveals that the amount of dye adsorbed at equilibrium is at its maximum at 25°C, recording a Q of 19.23 mg g^{-1} for the particle size (0.25 mm). Numerous publications have evaluated the effect of temperature on the biosorption of dyes. It has been shown in the study of the biosorption of Gemazol Turquoise Blue-G for example, that the biosorption of the dye increases with increasing temperature up to 25°C, beyond this value, the amount of dye adsorbed decreases (Aksu & Çağatay 2006; Argun et al 2017). The increase in biosorption at 25°C could be due to the increased activity of the biosorbent surface as well as the increased fluid's kinetic energy of the dye (Bockris & Devanathan 1963). The decrease in the biosorption capacity of the biosorbent material, above 25°C can be attributed to the deactivation of the biosorbent surface or to the destruction of some active sites on its surface (Mameri et al 1999). Consequently, the optimal temperature for dye biosorption by algal biomass was chosen as 25°C.

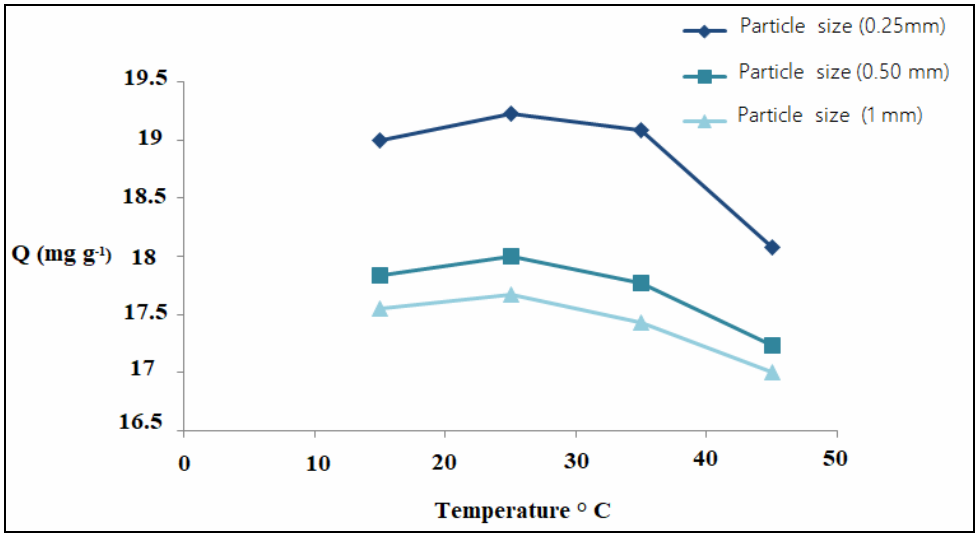

Figure 3. Influence of medium temperature on the rate of fixation of CB by three particle sizes of *Plocamium cartilagineum* biomass (0.25 mm, 0.50 mm and 1 mm) (Q = quantity of dye adsorbed by algal biomass (mg g^{-1}) at equilibrium, pH: 2, C0 = 60 mg L^{-1}, m biomass = 3 g L^{-1}).

Effect of the initial concentration of CB on the amount of dye fixed at equilibrium. Figure 4 below shows a classical representation of the fixation of a solute at equilibrium with a high affinity towards the adsorbent. We note an increase of the quantity of CB fixed with the increase of the residual concentration of this dye, then the progressive appearance of a pseudo-plateau corresponding to the saturation of the material in CB. It is also observed a decrease of the quantity of the fixed dye, with the increase of the granulometry of the algal biomass. Indeed, as the initial concentration of dye increases, the capacity of biosorption increases. Similar data are reported when analyzing the same factor in the biosorption study of methylene blue on two fungi (Bouras et al 2021). The increase of the initial concentration also acts positively on the biosorption of methylene blue and malachite green on *Carica papaya* wood (Rangabhashiyam et al 2018) and on a dead fungal biomass of *Aspergillus fumigatus* (Abdallah & Taha 2012). In fact, biosorbent dosage is highly effective on biosorption amount and it is obtained a higher rate of elimination and a lower rate of removal effect with low biosorbent dose (Aksu & Çağatay 2006; Vijayaraghavan et al 2006). As a matter of fact, the increase in biomass concentration causes the increase in biosorbent surface and binding area, the amount of the dissolved solution increases subsequently (Esposito et al 2001). This trend might be caused by the increase in the necessary driving force to overcome the resistance to the mass transfer of all molecules between the aqueous phase and the biosorbents (Kumar et al 2010). The biomass *P. cartilagineum* shows a good binding capacity for the studied dye.

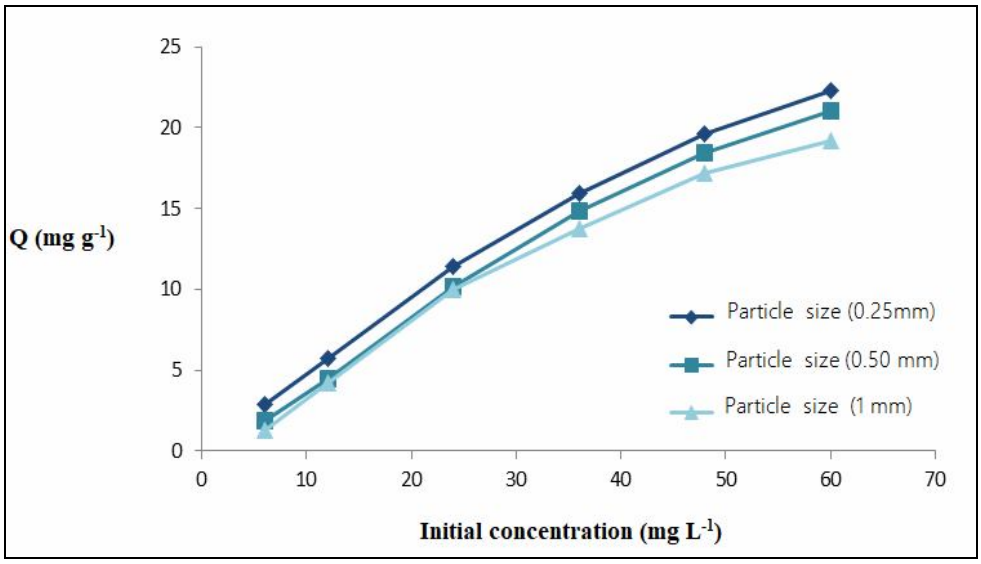

Figure 4. Influence of the initial concentration of the CB solution on the amount of dye fixed at equilibrium by three granulometries of the *P. cartilagineum* biomass (0.25 mm, 0.50 mm and 1 mm) (Q = amount of dye adsorbed by the algal biomass (mg g^{-1}) at equilibrium, pH: 2, m biomass = 3 g L^{-1}, T = 25°C).

Kinetics of CB fixation by Plocamium cartilagineum biomass. Figure 5 shows that the fixation kinetics of CB by the *P. cartilagineum* biomass can be divided into two phases: a first phase with a relatively fast fixation, followed by a pseudo-plateau translating a slower fixation of the dye until the stabilizing of its concentration, following the establishment of a chemical equilibrium. The results also show that the fixation phenomenon is very fast, and that a short fixation time is sufficient for the elimination of the dye. The equilibrium time determined for the dye when brought into contact with the three particle sizes of the algal biomass is recorded in Table 1.

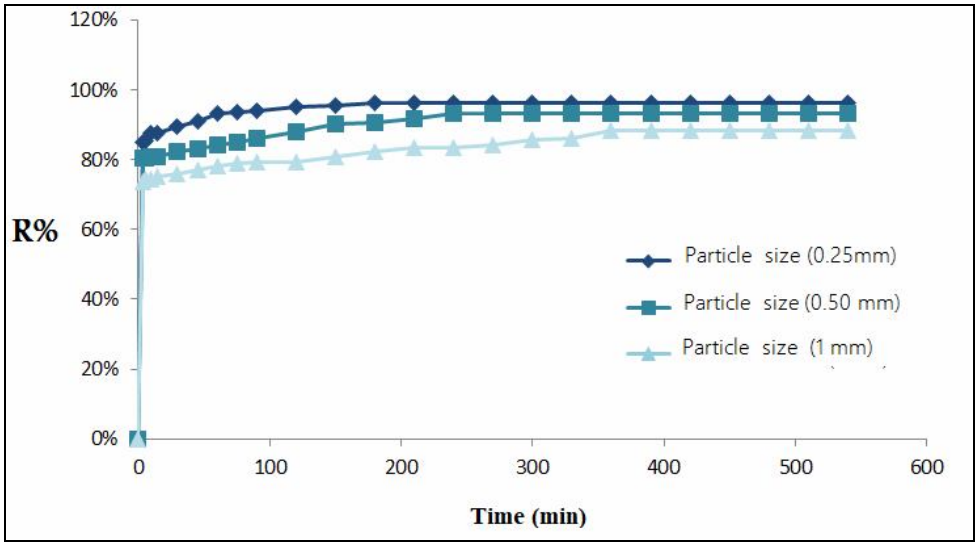

Figure 5. Kinetics of CB removal by three biomass Plocamium cartilagineum particle sizes (0.25 mm, 0.50 mm and 1 mm) (R% = dye fixation efficiency, pH: 2, C0 = 60 mg L^{-1}, m biomass = 3 g L^{-1}, T = 25°C).

Table 1

Time (min) needed for the establishment of the equilibrium of adsorption on the biosorbent material

	Equilibrium time (min)		
Adsorbate	*Granulometry (0.25 mm)*	*Granulometry (0.50 mm)*	*Granulometry (1 mm)*
Cibacron Blue	180	240	360

From the previous results we note two important observations: 1. The size of the particles plays an important role, we note that the smaller the particle size of the biosorbent material, the larger the exchange surface between the adsorbate and the biosorbent which explains a better adsorption. 2. The adsorption kinetic of CB on the biosorbent material is relatively fast. The equilibrium is rapidly reached for the smaller granulometry.

For comparison, a recent research on the biosorption of CB by been peal reported similar results (Grabi et al 2021), including two phases of adsorption, a rapid phase at the beginning explained by the availability of active sites on the surface of the biosorbent, followed by a second phase characterized by the achievement of equilibrium and thus the maximum amount of adsorption after the saturation of sites. In another study related to the biosorption of methylene blue and reactive blue 19 by the alga *Bifurcaria bifurcata* (Bouzikri et al 2020), it was concluded that the biosorption kinetics of the two mentioned dyes also occurs in two distinct stages: the first being fast and pointing out the adsorption of the dyes on the accessible sites (internal mass transfer), while the second stage being much slower, is characterized by the diffusion of the dyes to the remaining sites which are less accessible (external mass transfer) (Aarfane et al 2014). Furthermore, other studies have shown that the fixation of the tested dyes by *Chlorella vulgaris* and *Spirogyra* species follows a kinetic that can be divided into three phases. The first phase corresponds to a relatively weak fixation, which increases progressively with the contact time (phase II) to reach a peak and attain saturation at the end (phase III). These authors attributed the first phase of biosorption to the time necessary for the algae to adapt to its new environment (dye to fix) (Mohan et al 2004; Aksu & Tezer 2005).

The estimation of the maximal fixation capacity of CB by Plocamium cartilagineum biomass. By exploiting the results of the effect of the initial CB concentration on the biosorption efficiency, and in order to estimate the maximum binding capacity of CB, we used the Freundlich (Herzog 1909) and Langmuir models (Langmuir 1918). These isotherms translate the evolution of the amount of the adsorbed dyes according to its residual concentrations in the solution. The estimation of the maximum biomass binding capacity of *P. cartilagineum* was calculated by linear regression of Langmuir and Freundlich models. These models describe the interactive behavior between the dissolved bodies and the adsorbent. We chose the 0.25 mm particle size of the algal biomass for both dyes, since it represents the best results obtained from the study of the influence of physicochemical parameters.

- Langmuir model: the linear form of the Langmuir isotherm (Figure 6) is determined by the following equation: $1\ Q^{-1} = 1\ Qmax^{-1} + 1\ b^{-1}\ Qmax + 1\ Ce^{-1}$.

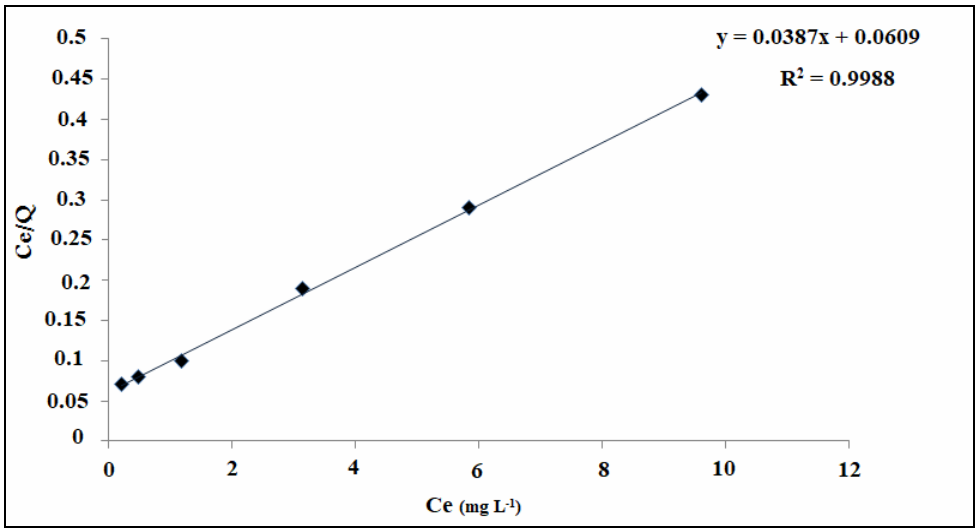

Figure 6. Langmuir isotherm related to the adsorption of CB on *Plocamium cartilagineum* biomass (pH: 2; m biomass: 3 g L^{-1}; T 25°C).

The Langmuir model can be used to estimate the maximum biosorption capacity (Q max) and affinity value (b), unattainable experimentally. This empirical model estimates the maximum biosorption potential which corresponds to complete monolayer coverage on the biomass surface with a homogeneous distribution of the adsorbate binding sites (Mokhtar et al 2017). The straight line indicates that the experimental data followed the Langmuir model. The maximum monolayer biosorption capacity (Q max) is estimated to be 25.83 mg g^{-1}, and the Langmuir constant, b, is 0.63. The results suggest that biosorption is very well represented by the Langmuir isotherm with R^2 = 0.99. The extremely high biosorption capacity also indicates the strong attraction of the electrostatic force between the dye molecules and the binding sites on the algal surface.

- Freundlich model: the linear form of the Freundlich isotherm (Figure 7) is determined by the following equation: $Ln(Q) = ln(Kf) + (1\ n^{-1})*ln(Ce)$.

In contrast to the Langmuir, the Freundlich isotherm is based on the phenomenon of biosorption occurring on the heterogeneous surface of the biosorbent active sites. In this empirical model, biosorption of sorbate molecules onto the heterogeneous biosorbent surface can occur without saturation of the sorbate binding sites (Kumar et al 2016). According to the correlation coefficients R^2 obtained, the Langmuir isotherm is more favorable. This model is based on the assumption that there is a finite or limited number of binding sites homogeneously distributed on the adsorbent surface. These sites have the same affinity for adsorption of a monolayer, and that there is no interaction between the adsorbed molecules (Langmuir 1918).

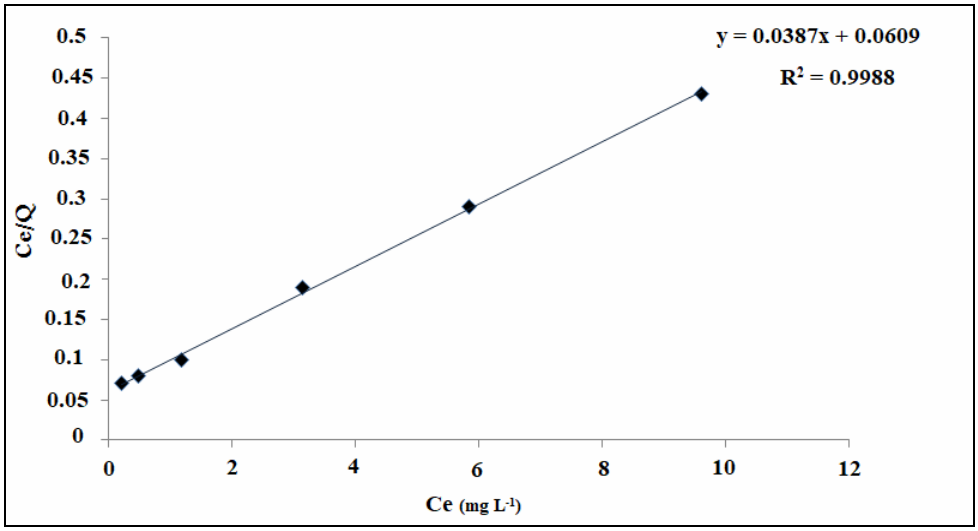

Figure 7. Freundlich isotherm related to the adsorption of CB on *Plocamium cartilagineum* biomass. (pH: 2; m biomass: 3 g L^{-1}; T 25°C).

Table 2 compares the calculated parameters for both models. From the results represented in Table 2, it can be seen that the biosorbent *P. cartilagineum* has an average affinity with CB for a Q max of 25.83 mg g^{-1}. All these data allow affirming that *P. cartilagineum* has a real potential of adsorption of CB.

Table 2

Langmuir and Freundlich parameters for the algal biomass *Plocamium cartilagineum*

Models	*Parameters*		
Langmuir	*Q max*	*b*	*R²*
	25.83	0.63	0.9988
Freundlich	*KF*	*1 n^{-1}*	*R²*
	7.87	0.5327	0.501

Table 3 is a comparison of Q max recorded in biosorption studies of different dyes on different biosorbents reported in literature. We can deduce that the biosorption of CB by the biomass *P. cartilagineum* shows respectable results. The availability and cost effectiveness of *P. cartilagineum* might provide a cheap source of biosorbents for the sequestration of toxic dyes from industrial effluents.

Table 3

Comparison of the biosorption capacity of different biosorbents and dyes

Biosorbents	*Q max (mg g^{-1})*	*Reference*
Spirodela polyrrhiza	27.62	Waranusantigul et al (2003)
Aspergillus carbonarius	21.88	Bouras et al (2021)
Penicillium glabrum	16.67	Bouras et al (2021)
Sugarcane bagasse	17.43	Meili et al (2019)
Aspergillus niger	18.54	Acemioglu et al (2010)
Orange peel	13.90	Annadurai et al (2002)
Casuarina seed-biocha	4.69	Bharti et al (2019)
Posidonia oceanica	5.56	Ncibi et al (2007)
This study	25.83	-

Conclusions. This work documented the potentiality of using the algal biomass *P. cartilagineum* as a biosorbent material for the treatment of contaminated waters by the synthetic dye Cibacron Blue. The results obtained showed that the biosorption of this dye

is a fast phenomenon and strongly influenced by the pH of the solution, the biosorbent mass, the temperature and the initial concentration of the dye. At pH 2 of Cibacron Blue, the maximum binding capacity of this algal biomass deduced from the Langmuir model is equal to 25.83 mg g^{-1}. The elaboration of a good capacity biosorbent material from the *P. cartilagineum* biomass is attractive for the removal and recovery of dyes in aqueous solutions. However, in order to confirm its decolorization capacities, it must be tested in continuous regime. The development of simple and economically profitable biological processes, such as the one described in this study, would encourage the incorporation of such low-cost processes in Moroccan companies on an industrial scale.

Nomenclature:

1 n^{-1}: Freundlich constant related to the affinity;
b: thermodynamic constant of the adsorption equilibrium (in L mg^{-1});
R^2: correlation coefficient;
R%: dye fixation efficiency;
(CB)(FNG): Cibacron Blue;
MB: Methylene Blue;
RPM: revolutions per minute;
UV/Vis: ultra-violet/visible;
X: residual concentration obtained from the calibration curve (in mg L^{-1} or mol L^{-1});
Y: absorbance;
Ce: residual concentration at equilibrium (in mg L^{-1} or mol L^{-1});
HCL: hydrochloric acid;
Kf: Freundlich constant related to adsorption;
M biomass: mass of algal biomass (in mg);
NaOH: sodium hydroxide;
Q: quantity of adsorbate fixed at equilibrium by the adsorbent (in mg g^{-1} or mol g^{-1});
Qmax: maximum saturation capacity of the adsorbent (in mg g^{-1});
C0: initial concentration of the dye in solution (in mg L^{-1}).

Conflict of interest. The authors declare that there is no conflict of interest.

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Authors:
Chouaib Motik, Laboratory of Microbiology, Pharmacology, Biotechnology and Environment, Faculty of Sciences, Aïn Chock, Hassan II University, Casablanca, Morocco, e-mail: Chouaib.m@hotmail.com
Fatima Chegdani, Immunology and Biodiversity Laboratory, Faculty of Sciences, Aïn Chock, Hassan II University, Casablanca, Morocco, e-mail: fchegdani@yahoo.fr
Mohamed Blaghen, Laboratory of Plant Biotechnology, Ecology and Ecosystem Valorization, Faculty of Sciences El Jadida, Chouaïb Doukkali University, El Jadida, Morocco, e-mail: blaghen@hotmail.com

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