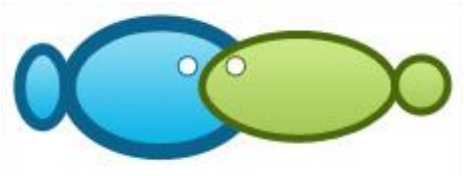

The biosorption potential of the algal biomass from *Plocamium cartilagineum* for the removal of the reactive red dye

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Abstract. Dyes are used in many industries, including textile, cosmetic, pharmaceutical, leather, but also food industries. Colored industrial effluents are an important source of water pollution that jeopardizes the existence of living beings. Physical and chemical processes are often used for the protection of the environment. However, these technologies are many times ineffective in removing dyes, expensive and not adaptable to a wide range of colored water. However, biological treatments have been shown to have real advantages compared to those previously mentioned. Biosorption is commonly known to be the preferred process for dye removal. In this study, the biosorption potential of *Plocamium cartilagineum* was evaluated for the elimination of the reactive red dye. The experiments were conducted in a batch mode, were the effect of pH, temperature, biosorbent dosage, biosorbent mass and initial concentration of the dye were analyzed. The experiment showed positive results at pH 1 and 25°C, where the maximum fixation capacity of the algal biomass, deduced from the Langmuir model, was equal to 34.72 mg g^{-1}. We concluded that the biomass of *P. cartilagineum* could actually present interesting capacities regarding the biosorption of reactive dyes, in this case the reactive red.
Key Words: algae, colorants, textile industries, wastewater treatment, water pollution.

Introduction. Nowadays, we live in a world where everything is colored: clothes, food, cosmetics, pharmaceutical products, etc. These dyes are mostly synthetic, because of their ease of synthesis, their speed of production and their wide variety of colors compared to natural dyes. In fact, synthetic dyes represent a relatively large group of organic compounds that are found in almost every sphere of our daily life (Langhals 2004). The textile industry is generating around 1 trillion dollars yearly, contributes with 7% of the total world exports and employs 35 million workers around the globe (Desore & Narula 2018). It is without a doubt, the largest generator of colored wastewater of all the industries (Senthivelan et al 2016; Khattab et al 2020).

The world production of synthetic dyes is valued at more than 700000 tons commercially available worldwide annually, of which 140000 are released in effluents during the various application and manufacturing stages (Cooper 1995). It was reported that reactive dyes are the second largest produced dyes, with 16% of the global production. They are at the quality end of the market because of their fast and easy bonding with the substrate during the application process, but also the wide range of shades of good light fastness and excellent wash fastness on cotton that they offer (Benkhaya et al 2017). In reality, 0.08-0.15 m^3 of water are needed to create 1 kg of texture, while 1000-3000 m^3 of water are wasted in the process of making 12-20 tons of colored materials (Al-Kdasi et al 2004). This wastewater, once discharged, will be abundant not only in dyes and synthetic substances, but also in other highly toxic compounds that increase environmental problems (Khattab et al 2020). Dyes are a major cause of serious hazards and environmental problems (Manzoor & Sharma 2020). They

present a potential risk once discharged into the final outlets, which are the water courses and the sea. It has been estimated that, worldwide, 80% of wastewater discharged into the environment has not been subject to any prior treatment, leading to ecosystem degradation and disastrous impacts on human health (WWAP 2017). The presence of dyes in textile industries effluents jeopardize the life conditions of aquatic fauna and flora even in low concentrations (Lellis et al 2019). This is mainly caused by the lack of light penetration hindering photosynthesis and inhibiting plant growth (Pearce 2003; Berradi et al 2019) and the increase in both the biochemical (BOD) and chemical (COD) oxygen demand (Islam & Mostafa 2019). Besides significantly compromising the aesthetic quality of water bodies, synthetic dyes also enter the food chain, show recalcitrance, bioaccumulation, and act as toxic, mutagenic and carcinogenic agents towards human health in very small doses (Lellis et al 2019). Untreated, these effluents will remain in the marine environment for a considerable time. For instance, the hydrolyzed reactive blue 19 has a half-life of 46 years at pH 7 and 25°C (Weber & Stickney 1993).

With all of this in mind, a number of treatment processes for the removal of dyes have been created and are constantly being improved by the scientific community and the concerned industries. The optimization of the treatment processes in order to have the best rate of dye removal with the lowest possible cost has become the main concern of the industry. To summarize, treatments are chemical, physical and biological (Holkar et al 2016; Hussain et al 2020; Ardila-Leal et al 2021). Among those mentioned, some have proven efficient, while others proved to be less effective. The most frequent are the physical processes. They include adsorption, membrane filtration, sedimentation, flotation, irradiation and reverse osmosis (Katheresan et al 2018). The majority of these methods are difficult to handle, are expensive and require large treatment areas where sludge is generated (Lellis et al 2019). Nevertheless, eliminating dyes that may present higher toxicity could be an interesting option (Hussain et al 2020). Chemical methods may be the more suited option for the elimination of many dyes. Still, they have the disadvantage of being the most expensive techniques, while also having a higher energy demand (Khattab et al 2020). The biological alternatives are the most viable ones, as they are environmentally friendly and cost-effective (Torres 2020). The main biological processes are: biosorption, biodegradation and bioaccumulation. Biosorption is the most attractive and preferred solution (Ho & McKay 2003; Jain et al 2003; Kaushik & Malik 2009). It represents a variant of the sorption techniques in which the sorbent is a material of biological origin. The biosorption using dead cells instead of living organisms have the advantages of eliminating the toxicity of the pollutants, not really needing any nutrients, while also allowing the possibility to store and use the biomaterial for long periods (Brady et al 1994).

In this study, we chose to use the biomass of *Plocamium cartilagineum* marine algae, which already demonstrated its value as a biosorbent in our previous experiments, conducted for the evaluation of the potential of the algae to eliminate the Cibacron blue dye (Motik et al 2022). The results obtained showed that the biosorption of the dye is a rapid phenomenon, strongly influenced by the pH of the solution. The performances of the later model were encouraging, since the maximum fixation capacity deduced from the Langmuir model was equal to 25.83 mg g^{-1}. The Reactive Red HE7B (RR) dye was chosen for the current study. This complex di-azo dye has the chemical formula $C_{52}H_{26}Cl_2N_{14}Na_8O_{26}S_8$, with a molecular weight of 1774.19 g mol^{-1} (Bankole et al 2017). The aim of this research was to determine not only the fixation ability of *P. cartilagineum* biomass for the dye, but also to examine several key parameters inevitably influencing every biosorption experiment. For this purpose, we employed three particle sizes (0.25 mm, 0.5 mm, and 1 mm) and conducted a batch biosorption experiment to investigate the effect of contact time, pH, biosorbent mass, temperature, and dye concentration.

Material and Method

Harvesting seaweed. Seaweed harvesting took place in September 2020, in the Dar Bouazza coastline (El Jadida road) located in Morocco's vast Casablanca region (33°31'26.522"N; 7°49'33.301"W). The average sea water temperature was 19.5°C, and

the pH measured at harvest was 8.2. The zone is rich in algae, particularly the one we chose for our biosorption study: *P. cartilagineum*.

The biomass preparation. The first identification of *P. cartilagineum* revealed that it belongs to the Rhodophyta phylum (red algae) (Dixon 1967). To remove sand, dirt, and unwanted epiphytes caught to the thallus, the sampled seaweeds were rinsed with tap, then distilled water. They were air-dried afterwards. The algal biomasses were dried and placed in a thermostatic oven at 60°C for 24 hours. The fractions sizes 1, 0.5, and 0.25 mm were crushed with an electric mill and sieved.

Dosage of the studied dye. Using the JENWAY 6405 ultra-violet/visible (UV/Vis) spectrophotometer, the dosage of Reactive Red (RR) was spectrophotometrically determined. The maximum wavelength was 540 nm.

Biosorption studies. During the three months following harvesting, biosorption experiments of RR by the algal biomass were conducted. Every test was repeated twice, and the results were consistent. The dye's adsorption was studied in a batch mode, with various parameters such as pH, biosorbent mass, temperature, and the dye's initial concentration being adjusted. At the end, we investigated the adsorption kinetics of RR and estimated the maximum fixation capacity by PC biomass:

1. Effect of dye solution pH: the pH was adjusted to the desired value with HCl (1 M) and NaOH (1 M) solutions. A pH range of 1 to 13 was chosen for RR; 3 g L^{-1} of biosorbent was placed in contact with dye solutions containing 60 mg L^{-1}, agitated at 100 rpm, and kept at 25°C.

2. Effect of biosorbent mass: we looked into the effect of biosorbent mass on the dye biosorption phenomena. This parameter was investigated in a solution of RR at a concentration of 60 mg L^{-1} in contact with *P. cartilagineum* algal biomass. The specified mass range is between 0.5 and 6 g L^{-1}. Until chemical equilibrium was established, the pH of the solution was held constant (pH 1).

3. Effect of temperature: in a solution of RR at a concentration of 60 mg L^{-1} in contact with 3 g L^{-1} of *P. cartilagineum* algal biomass, under agitation at 100 rpm, the effect of temperature on the phenomena of dye biosorption was investigated. The chosen temperature values were 15, 25, 35, and 45°C.

4. Effect of the initial concentration: to evaluate the biosorption performances of RR on *P. cartilagineum* biomass depending on the initial concentration of the dye, 3 g L^{-1} of biosorbent were put in contact with dye solutions at different concentrations of 6, 12, 24, 36, 48, and 60 mg L^{-1}, at pH 1 of RR, under agitation of 100 rpm and at 25°C until chemical equilibrium was reached.

5. Dye removal kinetics: 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, the adsorption kinetics of RR were evaluated. The solution was kept at a consistent temperature and pH during the contact period (shaking = 100 rpm in a water bath of brand Memmert, pH 1 and T=25°C). The evolution of the dye concentration in the solution could be tracked by using 1 mL of obtained sample at different time intervals. The dye absorption was then evaluated spectrophotometrically after the samples were centrifuged at 8000g for 12 minutes at 4°C.

For the estimation of the maximal fixation capacity of RR by *P. cartilagineum* biomass, we applied the adsorption isotherms. Langmuir and Freundlich are the most commonly used isotherms in the literature. The first is based on the following assumptions: the adsorbing solid has a limited adsorption capacity (qm), the active sites are identical and can comprise only one molecule of the solute in the monolayer, no interaction between the adsorbed molecules takes place (Langmuir 1918). The second is the most widely used in the case of a possible formation of more than one layer on the surface with heterogeneous sites of different binding energies. It is a simple and empirical model (Freundlich 1906). The Langmuir and Freundlich models are most frequently employed to explain the relationship between the amount of adsorbed dye and its equilibrium concentration. Our main purpose here is to determine the maximal

reactive red binding capacity on the basis of how the initial dye concentration affects the biosorption efficiency.

Results and Discussion

The pH influence. The pH seems to be the most important parameter in the biosorption process, since it can affect both the structure of the adsorbent and the degree of ionization of the adsorbate, as well as the dissociation of the biomaterial's functional groups (Esposito et al 2002). Several studies demonstrated the significance of the effect of this parameter on the adsorption phenomena (Blázquez et al 2009; Furuhashi et al 2019; Cruz-Lopes et al 2021).

The results in Figure 1 clearly illustrate that pH has a considerable impact on the biosorption of RR by the *P. cartilagineum* biomass. In fact, this biosorption reaches its peak at 97.35% for a granulometry of 0.25 mm. However, as the granulometry of the biosorbent increases, this percentage decreases, except that from pH 10, the fixation rate of the dye by the algal biomass for the granulometry of 1 mm exceeds that for the granulometries of 0.25 and 0.5 mm. The rate of fixation of RR falls with rising pH, until pH 12, at which point it starts increasing again. This trend has generally been observed in other biosorption studies (Won et al 2009), where similar evolution of the biosorption of Reactive Orange 16 by *Corynebacterium glutamicum* was observed and where extreme pH values were most effective. These results indicate that the increase in the binding rate of RR in acidic medium (pH 1) followed by a decreasing percentage of binding up to pH 10, and then an increase in the binding rate for pH 12 and pH 13 is due to the presence of two dye binding sites on the surface of the biosorbent material.

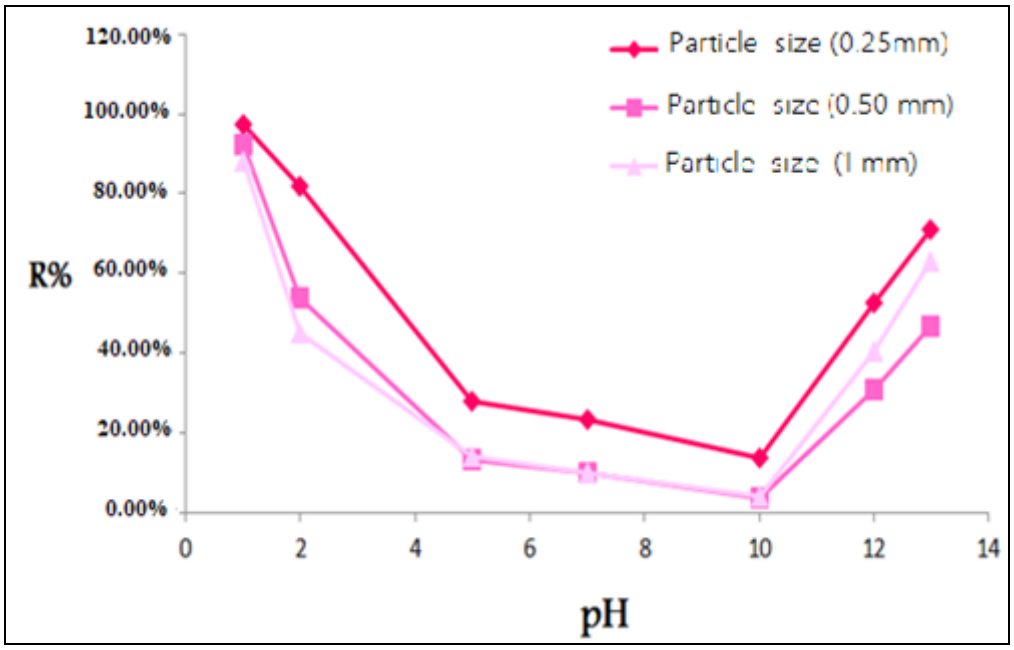

Figure 1. Influence of medium pH on the rate of fixation of RR by three granulometries (0.25, 0.5 and 1 mm) of *Plocamium cartilagineum* biomass (R% = dye fixation efficiency, pH 1, C0=60 mg L^{-1}, m biomass = 3 g L^{-1}, T=25°C).

Other investigations revealed that it is more suited to determine the ideal biosorption conditions at a low pH value. For example, the maximum reactive red 2 uptake by *Metapenaeus monoceros* occurred at pH 2 (Thiyagarajan et al 2017). This result was explained by the fact that negatively charged dye anion and positively charged biosorbent are attracted to each other electrostatically (Renganathan et al 2008). The biosorption studies of the Reactive red 23 by chitosan showed the best results at pH 1.18 and decreased with increasing pH until repulsion (El Fargani et al 2016). The authors also

explained that this behavior is related to the chitosan surface's positive charge gained in the acidic media, which draws the dye anions until saturation and repulsion. We have opted for a pH 1 for the determination of the next parameters.

Effect of the biosorbent mass. The mass of the biosorbent is a crucial factor that determines the effectiveness and industrial application of the entire process (Salomón et al 2020; Grabi et al 2021). The effect of the mass of adsorbent on adsorption of the RR was studied by changing the size of the algal biomass from 0.5 to 6 mg. The dye binding rate rises with an increase in algal mass, attaining its highest recorded binding rate of 97.35% for the granulometry of 0.25 mm. This percentage decreases as the granulometry of the biosorbent increases. Equilibrium is reached at 4 g L^{-1} for a particle size of 0.25 mm, and at 6 g L^{-1} for particle sizes of 0.5 and 1 mm (Figure 2). These results are in accordance with the biosorption of the Cibacron blue dye on the same algae (Motik et al 2022), but also with other biosorption studies (Kousha et al 2012; Olawale et al 2017), where adsorption rates increased as adsorbent dosage was increased.

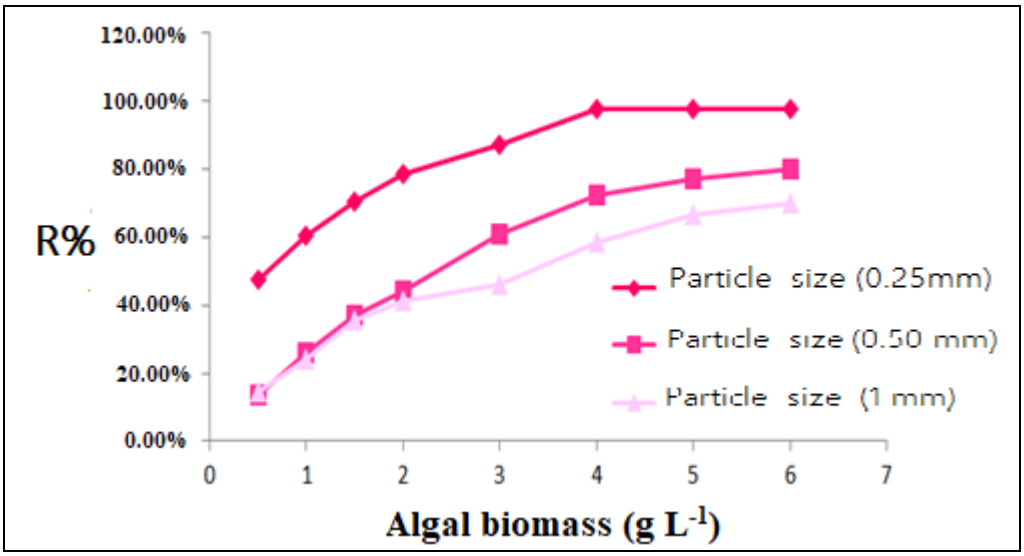

Figure 2. Influence of three particle sizes of the biosorbent (0.25, 0.5 and 1 mm) on the fixation rate of RR (R%=dye fixation efficiency, pH 1, C0=60 mg L^{-1}, T=25°C).

The biosorption of the reactive Remazol Black B by *Phormidium animale* showed similar results, as the maximum percentage of dye biosorption rate occurred at 4 g L^{-1} of algal biomass (Bayazit et al 2019). The study of the removal of malachite green dye from aqueous solution by *Ulva lactuca*, *Sargassum crassifolium*, and *Gracilaria corticata* showed that the removal efficiency of the dye generally improved with increasing algal biomass reaching the peak at 2 g L^{-1} (Omar et al 2018). Similarly, a sharp increase in the adsorbed dye was observed by increasing the dose of *Caulerpa racemosa* and also *Cystoseira barbatula* (Caparkaya & Cavas 2008; Cengiz & Cavas 2008). It has been noted that lower biomass dosages resulted in a reduction of removal effectiveness, and, as the adsorbent dose increased, the removal percentage increased rapidly (Indhumthi 2014). This behavior was explained by the increase of available sorption sites on the biosorbent surface (Saeed et al 2010). In fact, lower biomass dosage will result in a decrease of removal effectiveness because the dye's ions quickly saturate adsorption sites where the increase in the biosorbent mass will provide greater availability of surface area and, consequently, a higher uptake (Pavan & Worth 2008; Saeed et al 2010; Indhumthi 2014; Bayazit et al 2019).

Effect of temperature. The influence of temperature on various metabolic processes and transport phenomena in biological systems is independent and significant. The transport of ions across media in aqueous systems is influenced by this factor (Al-

Homaidan et al 2018). In our case, the data presented in Figure 3 demonstrate that the amount of dye adsorbed at equilibrium reaches its maximum at 25°C, recording a quantity of adsorbate fixed of 21.47 mg g^{-1} for the granulometry of 0.25 mm.

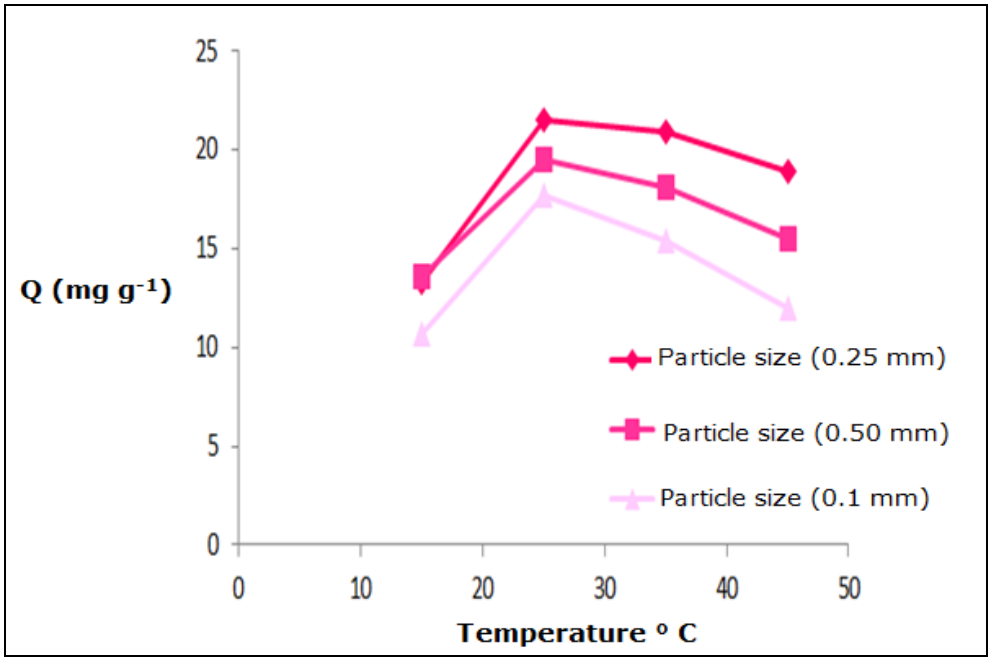

Figure 3. Influence of medium temperature on the rate of fixation of reactive red by 3 particle sizes of *Plocamium cartilagineum* biomass (0.25, 0.5 and 1 mm); Q - quantity of dye adsorbed by algal biomass (mg g^{-1}) at equilibrium (pH 1, C0=60 mg L^{-1}, biomass = 3 g L^{-1}).

This phenomenon has been observed in many biosorption studies. Many recorded a positive effect on the sorption process. According to Aksu & Çağatay (2006), dye biosorption increases with increasing temperature up to 25°C. Above this value, the amount of the adsorbed dye decreases. The increase in biosorption at 25°C could be due to the increased activity of the biosorbent surface, as well as the increased kinetic energy of the dye molecules. Another study investigating the biosorption potential of cadmium on 3 green algae showed a positive effect of temperature *for Cladophora glomerata* and *Microspora amoena*, while *Enteromorpha intestinalis* was not influenced by the same factor (Al-Homaidan et al 2018). Rajasimman & Murugaiyan (2021) suggested that adsorbed molecules spread more quickly on the outer layer and inside the absorbent pores as a result of the temperature rise. Additionally, it has been proposed that a high temperature may contribute to a low viscosity of the solution, increasing the pores of the adsorbents and, as a result, the surface area for adsorption. In the end, the increased surface area available facilitates in the diffusion and penetration of the pollutant ions into the pores of the algae, increasing the biosorption. In our study, a decrease in the biosorption process was observed above 25°C. This can be attributed to the deactivation of the biosorbent surface or the destruction of some active sites on its surface (Aksu & Çağatay 2006). Similar findings to those of our investigation were found in another work on the biosorption of cadmium by *Ulva lactuta* green alga. The sorption recorded the highest result at 30°C, and started decreasing afterwards, as the temperature did the same. According to the authors, depending on whether the process is exothermic or endothermic, the temperature may have an impact on the adsorbate's ability for equilibrium (Ghoneim et al 2014). Another biosorption research hinted that the possible weak linkage between active sites of the biomass and dye molecules at high temperatures may be the principal cause of the sorption decrease (Deokar 2016).

Effect of the initial concentration of RR on the amount of dye fixed at equilibrium. The initial concentration is a factor that must be considered in every biosorption study. The data in Figure 4 displays a typical illustration of a solute being fixed at equilibrium and having a strong affinity for the adsorbent. As the residual concentration of this dye increases, we observe an upsurge of RR fixed, followed by the gradual emergence of a pseudo-plateau corresponding to the saturation of the material.

By increasing the granulometry of the algal biomass, the same outcomes are seen, but with less dye fixed. The potential of the biosorption grows as the initial dye concentration does. This happens as a result of the dye concentration being higher, which accelerates the diffusion of the dye molecules from the solution to the surface of the biosorbent (Olawale et al 2017; Thiyagarajan et al 2017; Nasra et al 2021). Initial concentration provides an important driving force to overcome all mass transfer resistance of dye between the aqueous and solid phases (Deokar 2016). On the other hand, the pseudo plateau phase is mainly attributed to the saturation of adsorption site as suggested in the majority of published researches (Puranik & Paknikar 1999; Ghoneim et al 2014).

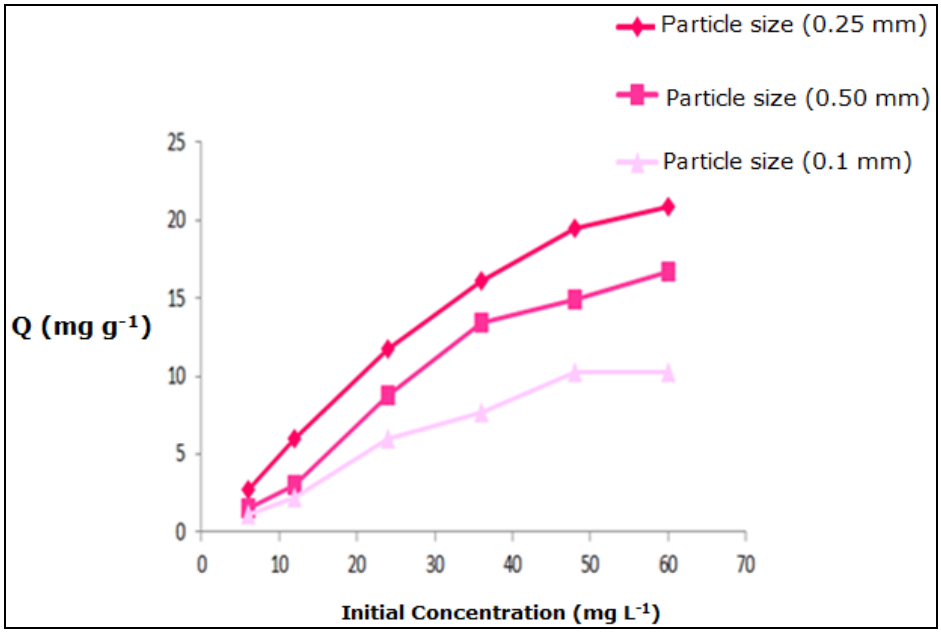

Figure 4. Influence of the initial concentration of the reactive red solution on the amount of dye fixed at equilibrium by 3 granulometries of the *Plocamium cartilagineum* biomass (0.25, 0.5 and 1 mm); Q - amount of dye adsorbed by the algal biomass (mg g^{-1}) at equilibrium (pH 1, m biomass = 3 g L^{-1}, T=25°C).

Kinetics of RR fixation by Plocamium cartilagineum biomass. According to Figure 5, there are two phases in the fixation kinetics of RR by the biomass of *P. cartilagineum*. A relatively quick fixation phase is followed by a pseudo-plateau, which means that the dye binds slower until its concentration stabilizes and a chemical equilibrium is reached. The results also demonstrate how quickly fixation occurs and how a brief period of fixation is sufficient to eliminate the dye. Table 1 lists the dye's equilibrium time when it comes into contact with the three sizes of algal biomass particles.

Positive and optimistic inferences can be drawn from our previous experiments, allowing us to judge the true potential and major impact that the algal biomass of *P. cartilagineum* can have on the removal of reactive red. The algal biomass shows a good binding capacity for the dye studied. As we have observed from using the same algae as a biosorbent material in the past research (Motik et al 2022), the size of the particles plays an important role, with smaller particle size producing a larger exchange surface between the adsorbate and the biosorbent material. This enhances the biosorption effectiveness. Additionally, the rate at which reactive red binds to the biosorbent material

is relatively fast. For smaller granulometry, equilibrium is reached quickly, as was the case for the removal of Cibacron blue dye using the same biomass as presented in Table 1.

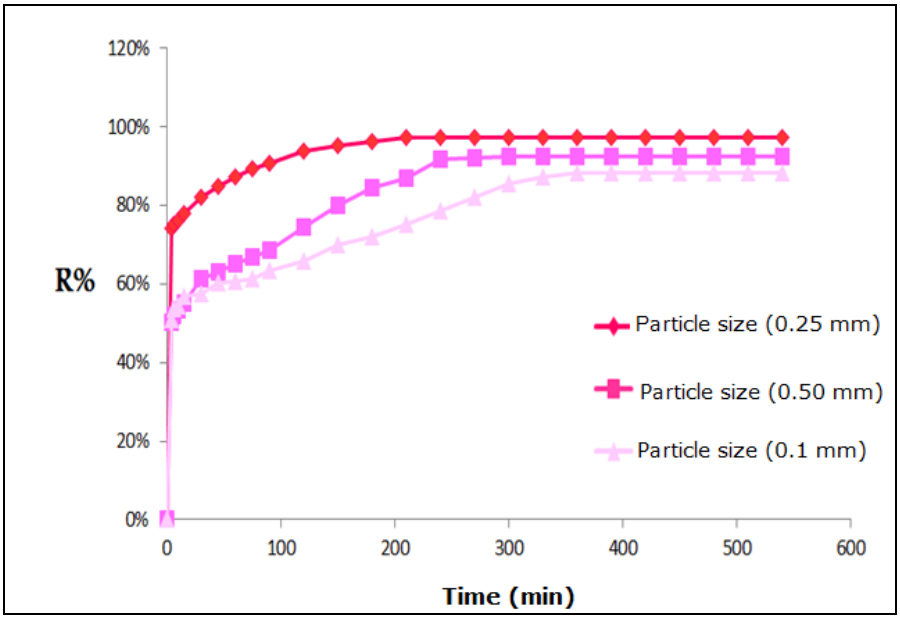

Figure 5. Kinetics of reactive red removal by 3 *Plocamium cartilagineum* biomass particle sizes (0.25, 0.5 and 1 mm); R% - dye fixation efficiency (pH 1, C0=60 mg L^{-1}, m biomass = 3 g L^{-1}, T=25°C).

Table 1

Time in minutes required to reach equilibrium for adsorption on the biosorbent material

Adsorbate	*Equilibrium time (min)*		
	Granulometry (0.25 mm)	*Granulometry (0.5 mm)*	*Granulometry (1 mm)*
Reactive red	210	300	360
Cibacron blue(Motik et al 2022)	180	240	360

The estimation of the maximal fixation capacity of RR by Plocamium cartilagineum biomass. Adsorption isotherms give qualitative details about the type of interaction between the solute and the surface at constant temperature. They provide an explanation for the distribution of adsorption molecules between the liquid phase and solid phase during an equilibrium state of the adsorption process (Yang & Qiu 2010; Mejbar et al 2019; Nandiyanto 2020).

By using linear regression of the aforementioned models, it was possible to determine the maximum binding capacity *P. cartilagineum*. We selected the 0.25 mm particle size of the algal biomass, since it represents the best results obtained from the study of the influence of physicochemical parameters. The Langmuir isotherm is based on three fundamental theoretical presumptions: (1) adsorption occurs in a monolayer; (2) all active sites are equal, and the adsorption process is uniform; (3) the adsorption of a molecule by a free site is independent of the occupancies of its nearby neighboring sites (Al-Ghouti & Da'ana 2020). The linear form of the Langmuir isotherm (Figure 6) equation is the following:

$1/Q = 1/Qmax + 1/bQmax * 1/Ce$

Where: Qmax is the maximum adsorption capacity, Ce is the equilibrium concentration of dye at the equilibrium time, b is the Langmuir constant.

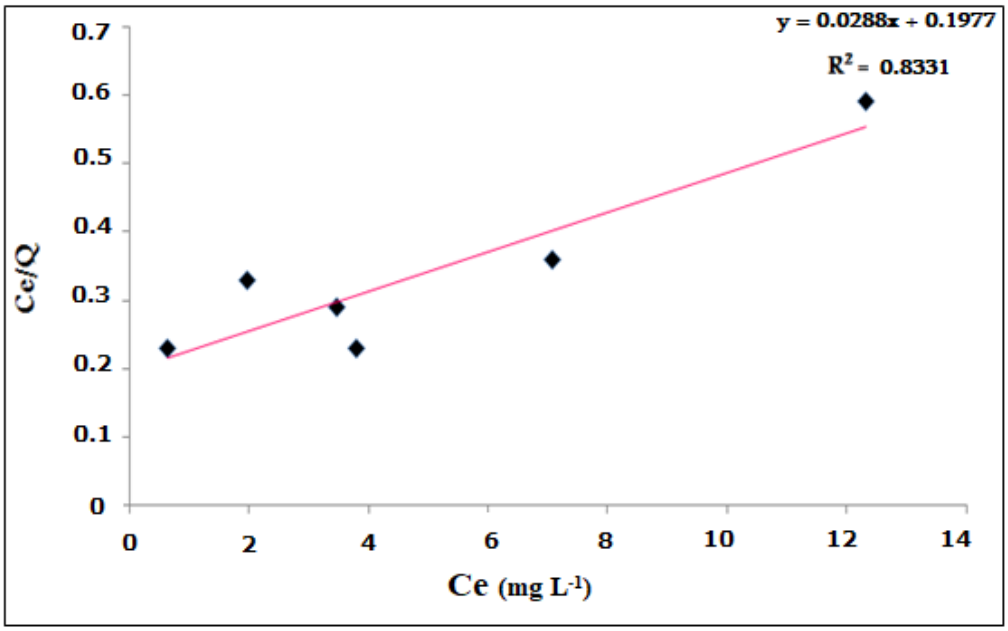

Figure 6. Langmuir isotherm related to the adsorption of reactive red by *Plocamium cartilagineum* biomass (pH 1; m biomass: 3 g L^{-1}; T=25°C); x - residual concentration obtained from the calibration curve (in mg L^{-1} or mol L^{-1}); y - absorbance.

This empirical model estimates the maximum biosorption potential, which corresponds to the complete monolayer coverage on the biomass surface with a homogeneous distribution of the adsorbate binding sites (Mokhtar et al 2017). Langmuir isotherm data gave a good linearity (Figure 6). The maximum monolayer biosorption capacity (Q max) is estimated to be 34.72 mg g^{-1}, the adsorption constant related to binding energy or affinity b is 0.63. For the favorable adsorption, R^2 value must have a value between $0<R^2<1$. In our investigation, R^2 values confirmed that the Langmuir isotherm was favorable for the biosorption of reactive red by the biomass of *P. cartilagineum*.

The linear form of the Freundlich isotherm (Figure 7) is determined by the following equation:

$$Ln(Q) = ln(Kf) + (n^{-1}) * ln(Ce)$$

Where: Q the amount of reactive red adsorbed (mg g^{-1}); Kf and n are the Freundlich constants related to the adsorption capacity and intensity of the sorbent; Ce is the concentration of the adsorbate in the solution at equilibrium (mg L^{-1}).

The Freundlich adsorption isotherm is used to model the adsorption on heterogeneous surfaces, it assesses that adsorption occurs on a multilayer adsorption mechanism, and, hence, the amount adsorbed increases with concentration. The linear regression correlation coefficient R^2 identified from the Freundlich model is equal to 0.8182. The higher R^2 values of the Langmuir isotherm suggest that this model is the fittest for the adsorption of reactive red by *P. cartilagineum* biomass. Furthermore, this biosorption occurs in a monolayer structure with a small number of uniformly distributed binding sites that have the same affinity. The results of our experiment are presented in Table 2.

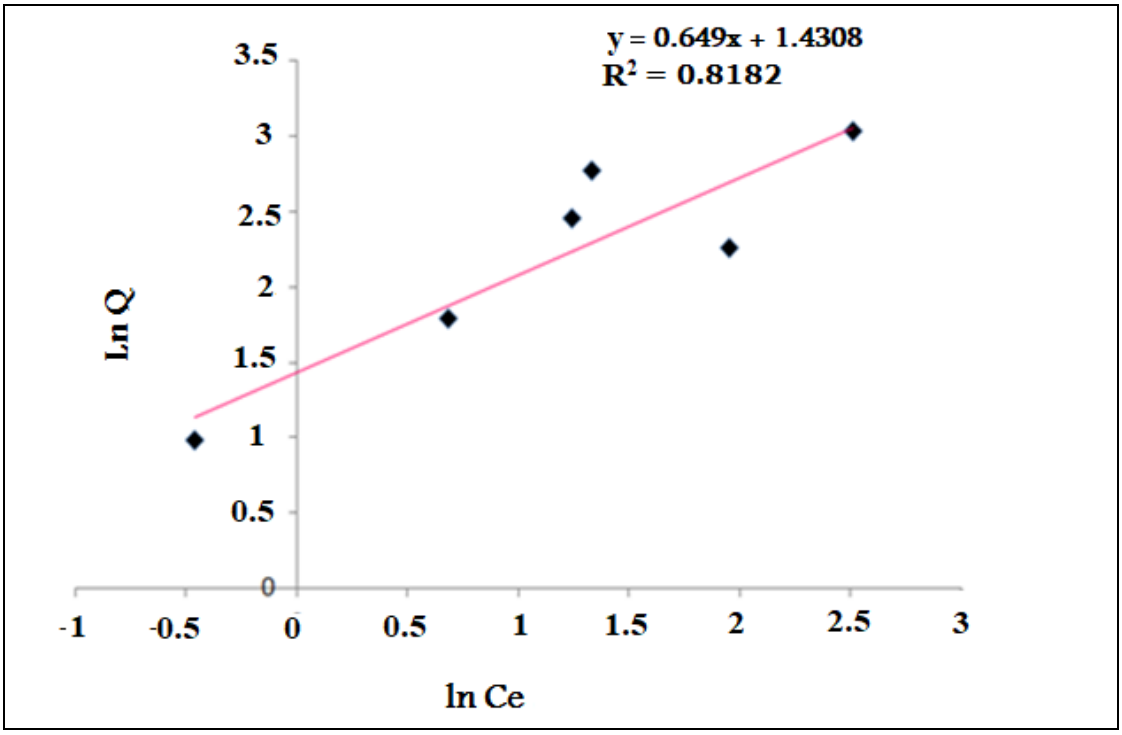

Figure 7. Freundlich isotherm related to the adsorption of reactive red by *Plocamium cartilagineum* biomass (pH 1; m biomass 3 g L^{-1}; T=25°C); x - residual concentration obtained from the calibration curve (in mg L^{-1} or mol L^{-1}); y - absorbance.

Table 2

Langmuir and Freundlich parameters for the biosorption of reactive red by *Plocamium cartilagineum* biomass

Models	*Parameters*		
Langmuir	Q max	b	R^2
	34.72	0.14	0.8182
Freundlich	KF	n^{-1}	R^2
	4.18	0.649	0.9501

Note: Q max - maximum saturation capacity of the adsorbent (in mg g-1); B - thermodynamic constant of the adsorption equilibrium (in L mg^{-1}); R^2 - correlation coefficient; Kf - Freundlich constant related to adsorption; n-1 - Freundlich constant related to the affinity.

The comparison of the values of Q in the present work and the previous one, testing the potential of the same biomass for the biosorption of a different dye, cibacron blue, allow judging the affinity of the biosorbent used for both dyes. The biosorbent *P. cartilagineum* has a higher affinity with reactive red than with Cibacron blue, with a Qmax of 34.72 mg g^{-1}, and 25.83 mg g^{-1}, respectively, according to the results displayed by Motik et al (2022). The recorded biosorption shows good results. According to sources in the literature, the comparison of the maximum adsorption capacity of different pollutants allow us to conclude that the biomass of *P. cartilagineum* can be used as an alternative adsorbent due to its high adsorption capacity (Table 3).

Table 3

Comparison of the sorption capacity of different biosorbents and dyes

Biosorbents	*Biosorbent*	*Q max (mg g^{-1})*	*Reference*
Yellow passion fruit waste	Methylene blue dye	44.7	(Pavan & Worth 2008)
Watermelon shell (*Citrullus vulgaria*)	Orange G dye	21.88	(Chigbundu & Adebowale 2017)
Rice husk	Methylene blue	40.6	(Alver et al 2020)
Moringa oleifera seeds	Indigo carmin dye	31.25	(Agbahoungbata et al 2016)
Banana peels	Reactive red	21.46	(Temesgen et al 2018)
Chitin	Cu (II) Cd (II)	20.50 13.27	(Bensaha & Sofia 2015)
Saccharomyces cerevisiae	Reactive red 120	23.48	(Navaei et al 2019)
Plocamium cartilagineum	Cibacron blue	25.83	(Motik et al 2022)
Plocamium cartilagineum	Reactive red	34.72	This study

Conclusions. In this study, *P. cartilagineum* was used to study the biosorption of the reactive red dye, and evaluate its potential for the elimination of this pollutant from aqueous solutions in a batch experiment. The biosorption of reactive red exhibits a direct relationship with the parameters studied. The biosorption was found to be pH, temperature, initial dye concentration, and particle size-dependent. At pH 1, the highest adsorption rates have been recorded and maximum biosorption intake was equal to 34.72 mg g^{-1}. The data on equilibrium biosorption were better explained by the Langmuir model. Finally, the results of this study confirmed that *P. cartilagineum* could be used as a low-cost adsorbent for the biosorption of reactive red from contaminated environment. We can conclude that this biomass has the ability to remove dye with high efficiency and low cost.

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

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Received: 18 November 2022. Accepted: 27 November 2022. Published online: 17 April 2023.
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How to cite this article:
Motik C., Chegdani F., Blaghen M., 2023 The biosorption potential of the algal biomass from *Plocamium cartilagineum* for the removal of the reactive red dye. AACL Bioflux 16(2):1077-1091.