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Bioremediation of paper and cardboard recycling industry wastewater by native yeasts

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ABSTRACT

Paper industry produces large volumes of wastewater causing environmental pollution due to containing high levels of organic matter. In the present study, native yeasts of one of the paper and cardboard recycling industries wastewater were isolated and identified, and their efficiency in the wastewater bioremediation was investigated. In this experimental study, after sampling, the yeast strains of the wastewater were isolated and identified. After preparing the yeast suspension, experiments were performed on the main sample of the wastewater and the modified samples with pH 5, 6, and 7, dilution of 25% and 50%, and incubation time of 48 and 96 h. The efficiency of these yeasts in removing chemical oxygen demand (COD) was also investigated. The results showed that this industrial wastewater contains high levels of turbidity and COD. Two types of yeast, including *Candida glabrata* and *Candida albicans*, were identified. The optimal pH for *C. albicans* was 6 and for *C. glabrata* was 5. According to the results of the experiments, COD removal efficiency by these yeasts was 71% and 81.8%, respectively, at incubation time of 96 h and dilution of 25% of the wastewater at optimal pH. It seems that according to the characteristics of these isolated yeast species and their ability to remove COD, they can be considered as an economic and eco-friendly option for the treatment of the mentioned industrial wastewater.

Keywords: Bioremediation; Chemical oxygen demand removal; Yeast; Paper and cardboard recycling industry; Wastewater treatment

1. Introduction

Industrial wastewater is one of the major causes of environmental pollution, especially in developing countries [1]. The pulp and paper industry ranks sixth in terms of environmental pollution after the oil, leather, cement, steel and textile industries [2]. In these industries, raw materials, such as wood and timber or recovered fibers are used to produce paper and cardboard. In recent decades, due to economic and environmental reasons (natural resources conservation, waste reduction, and pollutant emission reduction), using recycled paper has increased [3]. Water consumption in pulp and paper industries has been estimated to be 75–450 m^3 per ton of product, leading to the production of a large volume of wastewater (about 60–300 m^3 per ton of product) [3–5]. The two main sources of wastewater production in these industries are pulping and cardboard production processes and the main part of wastewater pollution is related to the pulping stage [6]. This wastewater contains a lot of organic compounds (depending on the nature of the raw materials,

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process and used chemicals, final products and water reuse) that can have adverse effects on the receiving environment [5,7].

Various physical, chemical, and biological methods or their combination have been used for wastewater treatment. The most commonly used physical and chemical treatment methods include absorption, microfiltration, electrical coagulation, coagulation and flocculation, ultrasonic, reverse osmosis, ion exchange, chemical precipitation, photocatalytic processes of titanium dioxide and zinc oxide under ultraviolet radiation, hydrogen peroxide, Fenton, photo-Fenton, ozone, and proxone or a combination of these methods. However, these methods are not cost-effective, and in some cases, the BOD (biochemical oxygen demand) and COD (chemical oxygen demand) of the treated effluent may be higher compared to other conditions. Moreover, these methods may cause excessive sludge production. Other limitations, such as operation and maintenance problems and secondary pollution have been also mentioned in various resources [1,4,7–10]. The conventional biological treatment methods, such as aerated lagoons and activated sludge are inefficient in the removal of some pollutants [11]. Wastewater treatment of the pulp and paper industry has not been successful due to lack of the desired microorganism, loss of genetic potentiality in undesirable environmental conditions, the production of resistant compounds and poor process optimization for full-scale wastewater treatment [12].

To overcome these limitations, bioremediation methods, including the use of fungi, bacteria, yeasts, algae, and enzymes, have been proposed as a treatment method or in combination with other physical and chemical treatment methods [7,13,14]. The conducted studies mainly focused on using various bacteria and fungi due to the presence of various enzymes to degrade pollutants, such as lignin, phenolic compounds, dyes, COD, and BOD in the pulp and paper industry wastewater. These microorganisms have been isolated from various environments, including soil contaminated with wastewater or other environments [4,8,11,15–17]. Fungi are commonly found in pulp and paper industry wastewater and they produce extracellular enzymes and can resist at higher wastewater load, compared to bacteria [3]. Furthermore, fungi are more able of degrading lignocellulose due to higher C/N ratios of lignocellulosic compounds [18]. Yeasts, as a group of single-celled fungi, are widely present in the environment and play significant roles in biotechnological usages [19]. Recent studies have shown that some yeasts can have the potential to treat paper mill wastewater and colored wastewater in the conditions of lab-scale due to their high tolerance to low pH, high salinity and high amount of COD [19]. Also, yeasts are a reliable microbial source due to their properties, such as high-temperature resistance, osmotic pressure and acidic conditions, a good enzymatic system in the body and the ability to adapt to different environments and decomposing of some persistent pollutants and toxic organic compounds, and they can play an important role in biological wastewater treatment [20]. To the best of the authors' knowledge, no studies have been reported so far on COD removal from paper and cardboard recycling wastewater by native yeasts. While some yeast species have at least one pollutant degrading enzyme and have the potential to be used in treating the paper industry wastewater due to having enzymes and mycelium [7]. Therefore, this yeast species may offer a new method with significant performance and low cost for treating paper and cardboard recycling wastewater which has a high amount of COD.

However, there was a gap in research regarding bioremediation by native yeasts for wastewater treatment of the cardboard recycling industry (due to different characteristics of wastewater in this industry). Hence, this study, it was tried to address this gap by isolating and identifying native yeasts and study their ability for wastewater treatment in a paper and cardboard recycling industry in Yazd city. This industry has used chemical methods for wastewater treatment, but due to the fact that the BOD of this wastewater is 5,600 mg/L and the ratio of BOD/COD is 0.456, it has the ability of biological treatment and this method can be used as an efficient method for treating wastewater. In addition, due to the need of this industry to reuse water in producing paper and cardboard, it can help reuse water by reducing pollution.

2. Materials and methods

2.1. Materials

Cultivation environments of Sabouraud Dextrose Agar (SDA), CHROMagar Candida, and other chemicals used in this study were purchased from Merck, Germany, and had the analytical grade.

2.2. Characteristics of wastewater and treatment plant of paper and cardboard recycling industry

The wastewater samples used in this study were collected from a paper and cardboard recycling industry in Yazd. This industry uses recycled paper and cardboard to produce cardboard. The treatment plant in this industry consists of coagulation and flocculation and sedimentation tank unit. In order to investigation the qualitative characteristics of the wastewater, composite samples of raw wastewater (outlet of the craft unit) were kept at 4°C and transferred to the laboratory to determine the qualitative parameters. Temperature, pH, and EC parameters were measured at the sampling site and turbidity, total suspended solids (TSS) and COD parameters were measured in the laboratory. Given that the effluent of the coagulation and flocculation unit was used for bioremediation experiments; the quality of the effluent was examined using the same method.

2.3. Separation and identification of native yeast strains of paper and cardboard recycling industry wastewater

In order to separate the native yeast strains of this industry wastewater, the sample was taken from the outlet of the craft unit. After diluting the effluent to 10^{-9} dilution by sterile distilled water, 0.1 mL of 10^{-5}, 10^{-6}, and 10^{-7} dilutions were cultured on the Sabouraud Dextrose Agar culture medium with streptomycin using the pour plate method. Cultivated mediums were incubated at 28°C–37°C for 24–48 h. Then, for purification, sampling was performed from growing colonies on the medium and after cultivation in separate Sabouraud Dextrose Agar mediums, the samples were incubated at 28°C–37°C for 24–48 h. After that, CHROMagar Candida differential culture medium was used to identify yeast species.

The germ tube test was used to determine the species and type of *Candida albicans* yeast (*C. albicans*). Several yeast colonies were mixed with 1 cc of fresh human blood plasma and incubated at 37°C for 2 h. Then, by adding a drop of the suspension on the microscope slide, the identification of *C. albicans* was confirmed.

2.4. Preparation of yeast suspension

From the selected yeasts (*Candida albicans* and *Candida glabrata*), pure cultures were prepared separately and incubated at 28°C–37°C for 24–48 h. Then, sterile physiological serum was used to prepare a homogenous suspension containing 1×10^7 CFU/mL of each yeast, separately. This suspension was used for wastewater bioremediation experiments.

2.5. Sample preparation

The coagulation and flocculation effluent sample was used to perform the experiments. To prevent the interference of suspended particles, the samples were centrifuged at 6,000 rpm for 15 min [17,21]. Parameters of total Kjeldahl nitrogen and phosphate were measured according to the guidelines presented in the standard methods for the examination of water and wastewater and the carbon to nitrogen ratio in the samples was adjusted using ammonium chloride in the range of 10–12 [22]. After preparing the dilution and pH adjustment using sulfuric acid 1 N, the samples were sterilized at 121°C for 15 min and at the pressure of 1 atm in an autoclave [23,24].

2.6. Bioremediation experiments

Sterilized samples were inoculated with 10 mL of the suspension containing 1×10^7 CFU/mL of each yeast and incubated in 140 rpm shaker at 28°C for 96 h. The volume of all samples in the experiments was 100 mL. The experiments were performed on the sample of raw wastewater (wastewater sample without pH adjustment and dilution), variables of pH (5, 6, 7) and dilution (25% and 50%) along with control samples. Control samples included wastewater samples without inoculation of yeast strains. At incubation times of 0, 48 h, and 96 h, reactor sampling (250 mL Erlenmeyer flask) was performed. Then, using centrifugation of the samples at 3,500 rpm for 5 min, the obtained supernatant was used to measure COD.

2.7. Analysis methods

A pH meter (L2012, LABTRON, Iran) was used to measure the pH. Turbidity was measured by a turbidity meter (A-TUR-1.16, Andishe Sazan Electricity Industry, Iran) and electrical conductivity (EC) was measured by multiparameter (HQ40d, HACH). COD was measured by the closed reflex method (Method: 5220-D) using the DR6000 spectrophotometer (HACH Co.). Turbidity and TSS were measured according to the standard methods for the examination of water and wastewater [25]. The data were analyzed by excel 2016 and Minitab software 18 using the response surface method at p-value < 0.05.

3. Results and discussion

3.1. Determining the qualitative characteristics of paper and cardboard recycling industry wastewater

To determine the qualitative characteristics of paper and cardboard recycling industry wastewater, a composite sample was taken from raw wastewater. Given that for bioremediation experiments, samples were selected from the coagulation and flocculation effluent, the quality of the effluent was also determined.

Table 1 shows that raw wastewater of the paper and cardboard recycling industry contains high amounts of turbidity, TSS and COD, and has neutral pH. Various studies on the characteristics of the pulp and paper industries wastewater have also shown that the wastewater in these industries contains high concentrations of organic compounds (high COD), near-neutral pH, and high turbidity [26–28]. The effluent from the coagulation and flocculation unit also contains high amounts of COD and alkaline pH. Given that this chemical treatment process is also unable to effectively remove COD, it seems that using a complementary treatment method, such as biological treatment for industrial wastewater can help to reduce COD.

3.2. Identifying the native yeast strains of the paper and cardboard recycling industry wastewater

After cultivating the wastewater samples in a special and differential culture medium, two types of yeast,

Table 1
Characteristics of paper and cardboard recycling industry wastewater

Parameter	Average ± SD	
	Raw wastewater	Outlet of coagulation and flocculation process
pH	6.74 ± 0.46	10.85 ± 1.90
EC (ms/cm)	9.83 ± 1.39	11.01 ± 1.41
Temperature (°C)	24.17 ± 0.12	25.13 ± 0.023
Turbidity (NTU)	1,837.93 ± 1,342.108	133.83 ± 124.46
TSS (mg/L)	1,481.67 ± 583.36	497.33 ± 206.55
COD (mg/L)	12,401.88 ± 4,657.06	7,519.77 ± 997.16

including *Candida glabrata* (*C. glabrata*) and *Candida albicans* (*C. albicans*) were identified. The yeasts had small, creamy or mucosal colonies that appeared purple and green in the CHROMagar Candida culture medium, respectively. Macroscopic images of the two yeasts are shown in Fig. 1. According to the conducted studies, some yeast species, such as candida, have high oxidizing power and can be used to treat wastewater. The yeasts can use organic and complex compounds for their metabolism and convert them to non-toxic compounds. The characteristics of yeasts include high temperature resistance, osmotic pressure and acidic conditions. In addition, they have a well enzymatic system and can adapt to different environments. Yeasts also have high potential for decomposition of some persistent pollutants and toxic organic compounds [20].

3.3. Evaluation of COD removal efficiency by C. glabrata and C. albicans in the initial pH of the wastewater

At the beginning of the experiments, the effectiveness of these two yeasts in removing COD from the raw wastewater sample (wastewater sample without pH adjustment and dilution) was investigated. The results of this part of the experiments showed that in the case of using *C. albicans*, COD removal efficiency was 19.6% after 48 h and 39.11% after 96 h. In the case of using *C. glabrata*, COD removal efficiency after 48 h was 5.81% and after 96 h it was 17.36% (Fig. 2).

The results showed that due to the high rate of COD, which is one of the characteristics of wastewater in this industry, as well as alkaline pH of wastewater, the two

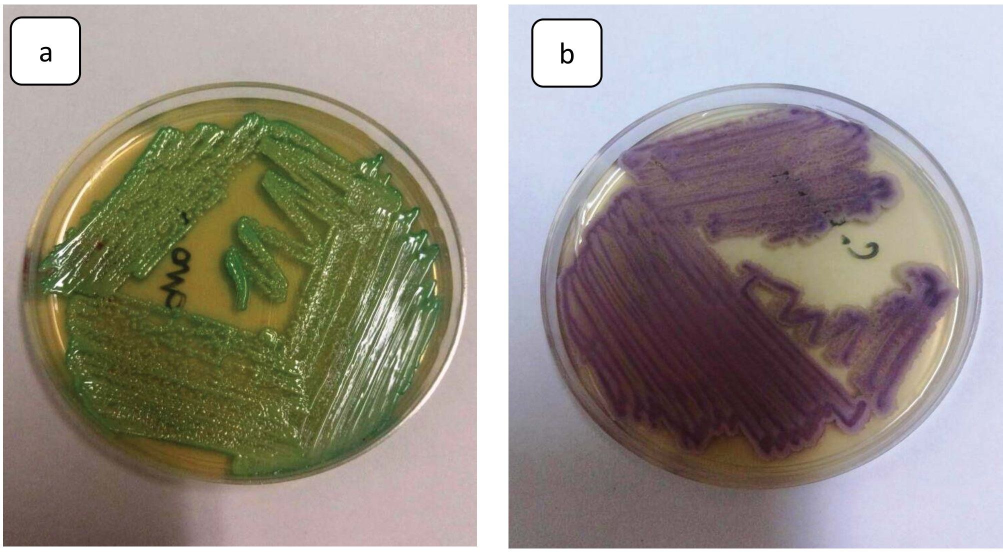

Fig. 1. Macroscopic images of (a) *C. albicans* and (b) *C. glabrata*.

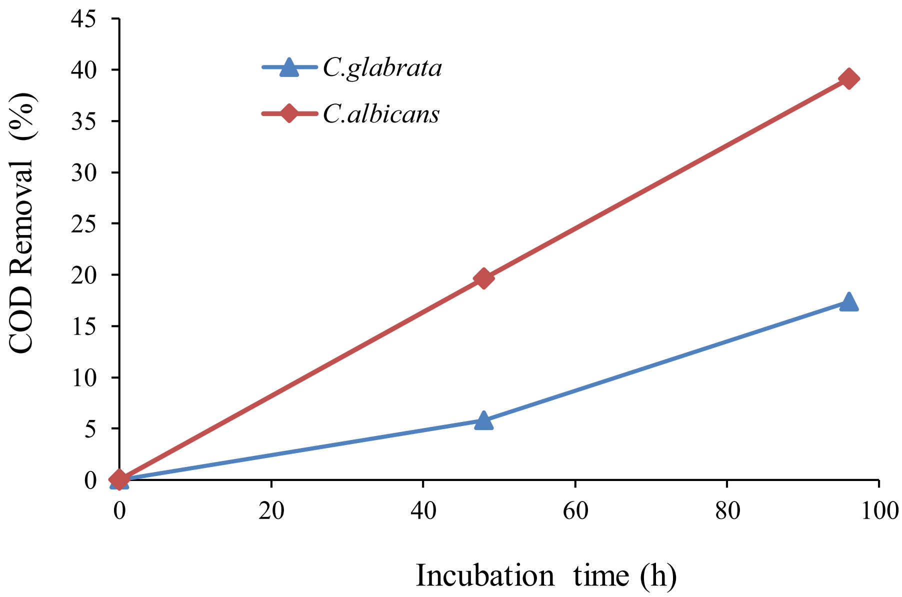

Fig. 2. COD removal efficiency by *C. glabrata* and *C. albicans* in the initial pH of the wastewater.

yeasts, especially *C. glabrata*, had low efficiency to remove COD. Therefore, in order to investigate different variables and optimize the test conditions, these experiments were performed at different pH and dilutions of wastewater to determine the optimal conditions for COD removal by these yeasts.

3.4. Evaluating the effect of pH on COD removal efficiency by C. glabrata and C. albicans

pH is one of the important and influential factors in decomposition of pollutants by microorganisms. Various microorganisms have a minimum, maximum, and optimal pH for growth and metabolism, and microbial cells are significantly affected by the environment pH [29]. Therefore, in this study, to investigate the effect of this variable on COD removal efficiency by *C. glabrata* and *C. albicans*, the experiments were performed at pH 5, 6, and 7 for 96 h in dilution 25% of the wastewater.

Fig. 3 shows that COD removal efficiency by *C. albicans* at pH 5, 6, and 7 after 96 h is 26.6%, 71%, and 27%, respectively.

Based on the results of Fig. 4, COD removal efficiency by *C. glabrata* at pH 5, 6, and 7 after 96 h is 81.8%, 75%, and 64%, respectively.

Based on the results, the highest COD removal efficiency by *C. albicans* was at pH 6 (71%) and the highest COD removal efficiency by *C. glabrata* was at pH 5 (81.8%). Moreover, the yeasts at different pH had various

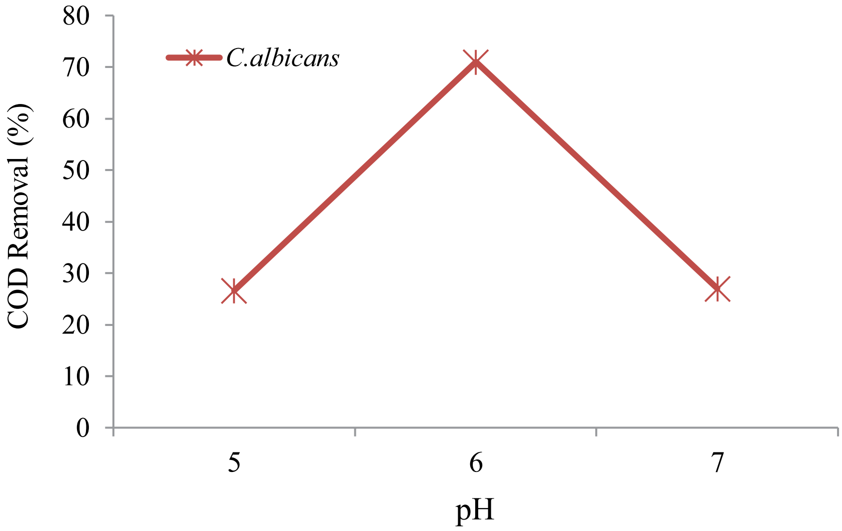

Fig. 3. Effect of pH on COD removal efficiency by *C. albicans* (incubation time of 96 h, dilution of 25%).

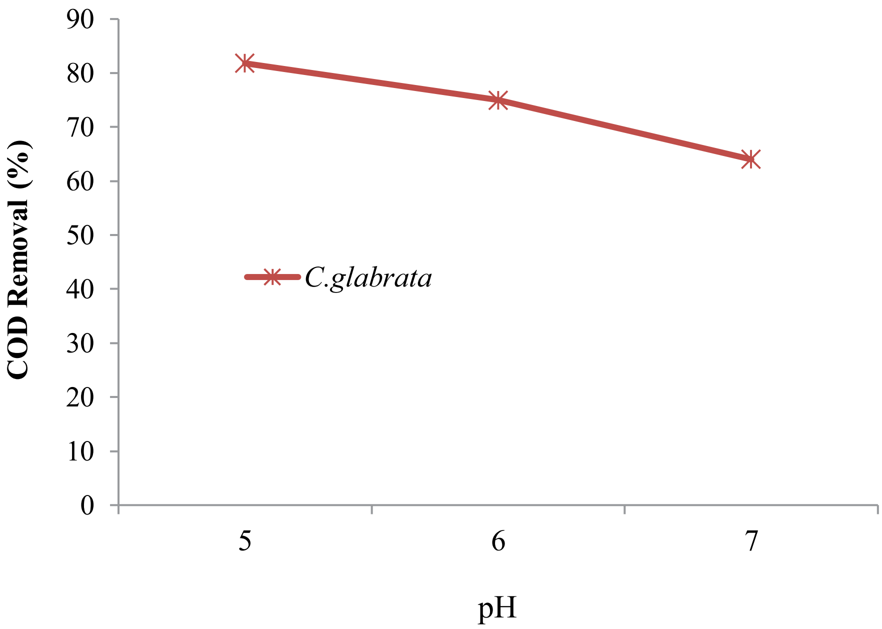

Fig. 4. Effect of pH on COD removal efficiency by *C. glabrata* (incubation time of 96 h, dilution of 25%).

COD removal efficiencies, and each had an optimal pH for growth, and generally at acidic and near-neutral pH of the wastewater compared to alkaline pH (examined in the previous stage) could grow better and therefore had better efficiency in removing COD from this industrial wastewater. Studies have also shown that yeasts grow in acidic environments at pH 5–6 [20]. In a study by Fernandes et al. (2014), *Cryptococcus podzolicus* isolated from another medium was used for wastewater treatment, and the COD removal efficiency at pH 4.5–5, after 32 h, was reported 68% [14]. In another study, *Cryptococcus* sp. was used to remove dyes and lignin from the pulp and paper industry wastewater. According to the results of this study, dye removal was 27% and lignin removal was 24% on the fifth day. pH 5–6 had also the greatest effect on dye removal from the wastewater [7]. Rajwar et al. [30] used isolated fungi from sewage sludge to treat wastewater in the pulp and paper industries. In this study, the highest dye removal efficiency (76.37%) was obtained by *Nigrospora* sp. fungus at pH 5. Therefore, pH plays an important role in the optimal growth of yeast and producing biomass and enzymes, and thus plays an significant role in removing COD of wastewater. Analysis using response surface method indicated that no statistically significant differences were observed in the amount of COD removal at different pH (5, 6 and 7) levels (p-value = 0.446). It shows that all three pH levels had a similar function in removal of COD from paper and cardboard recycling industry wastewater.

3.5. Evaluating the effect of incubation time (contact time) on COD removal efficiency by C. glabrata and C. albicans

The decomposition duration of wastewater pollutants by microorganisms is one of the effective parameters in the process of wastewater treatment and on the other hand, this period of time should be applicable to the real scale. Therefore, in this study, the contact time of *C. glabrata* and *C. albicans* and the wastewater at 48 h and 96 h, optimal pH, and dilution 25% was investigated.

Fig. 5 shows that COD removal efficiency by *C. albicans* at optimal pH 6 after 48 h is 64.3% and after 96 h is 71% and by *C. glabrata* at optimal pH 5, after 48 h is 76.6% and after 96 h is 81.8%.

Based on the results, both *C. albicans* and *C. glabrata* at optimal pH in 48 h had a good efficiency in removing COD in the paper and cardboard recycling industry wastewater, and most organic compounds decomposition occurred during this period. Moreover, the highest COD removal efficiency by these yeasts was obtained after 96 h. In previous studies using *Cryptococcus podzolicus* yeast, isolated from another medium and used for wastewater treatment, COD removal efficiency was reported 68% after 32 h [14]. In another study, in which *Cryptococcus* sp. was used to remove dye and lignin from pulp and paper industry wastewater, dye removal was 27% and lignin removal was 24% on the fifth day of incubation [7]. A study by Patel et al. showed that *Rhodosporidium kratochvilovae* yeast could remove 92.22% of COD, 84.59% of TDS, 77.36% of BOD and significantly remove dye, lignin, and phenol from pulp and paper industry wastewater in 144 h [2]. In various studies that have used fungi in paper industry wastewater treatment, high removal efficiency of pollutants was reported after 3–6 d [14] and in other studies the maximum removal of COD (58.7%) was reported after 15 d of incubation [31]. Barapatre and Jha [17] reported that *A. flavus* can remove 31%–51% of dye and 39%–61% of lignin after 10 d of incubation. The study by Kreetachat et al. [32] on using *Fibrodontia* sp. to remove pollutants from the pulp and paper industry wastewater showed that this fungus can remove 61.58% of dye and 48.32% of the total organic content during the 5-d incubation period. Considering that the long periods are not applicable in the industry [14], one of the characteristics of the studied yeasts is their high metabolic power and rapid growth [20]. According

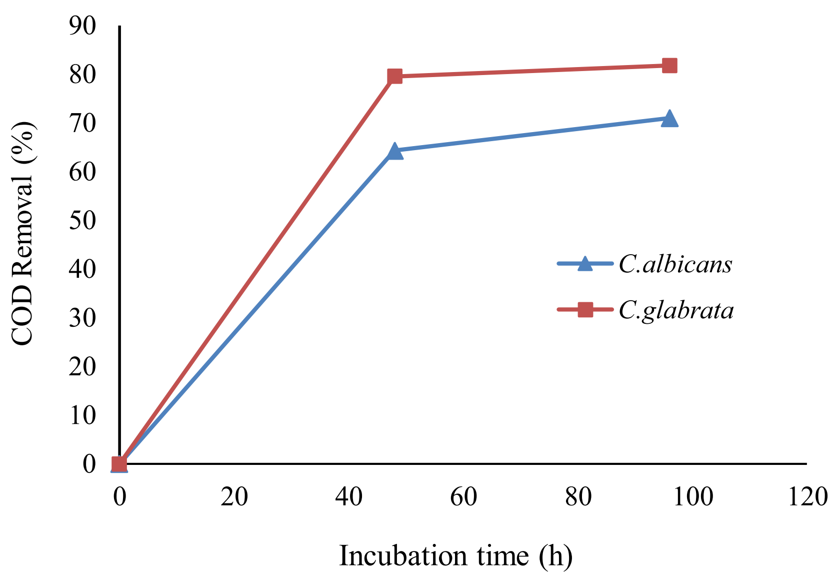

Fig. 5. Effect of incubation time on COD removal efficiency by *C. glabrata* (pH = 5) and *C. albicans* (pH = 6) in dilution 25% of the wastewater.

to the results of COD removal efficiency obtained in this study by native yeasts of the wastewater after 48 and 96 h, this period (compared to some studies) can be an appropriate time to reduce COD by the yeasts separated from the wastewater. Analysis using response surface method indicated that no statistically significant differences were observed in the amount of COD removal at different incubation times (p-value = 0.209). It shows that incubation time had a similar function in removal of COD from paper and cardboard recycling industry wastewater.

3.6. Evaluating the effect of the wastewater dilution on COD removal efficiency by C. glabrata and C. albicans

Due to the fact that the studied paper and cardboard industry wastewater has high rates of COD (about 6,626.45 mg/L), it can affect the growth of yeasts, and on the other hand, changing the pollutant concentration is one of the important parameters in wastewater treatment. At this stage, by diluting the wastewater at 25 and 50% dilutions, the efficiency of these yeasts at different dilutions at optimal pH was investigated.

Fig. 6 represents that in dilution 25%, COD removal efficiency by *C. albicans* at optimal pH 6 after 96 h is 71% and by *C. glabrata* at optimal pH 5, after 96 h, is 81.8%. Moreover, in dilution 50%, COD removal efficiency by *C. albicans* at optimal pH 6 after 96 h is 39% and by *C. glabrata* at optimal pH 5 after 96 h is 60.3%.

These results suggest that the growth of these yeasts can be affected by different concentrations of COD. The study by Hosseini et al. examined the bioremediation of the cardboard recycling industry wastewater using fungal species, including *Aspergillus flavus*, *Aspergillus niger*, and *Penicillium digitatum* during 10 d of incubation. According to the results of this study, the highest dye removal efficiency (50.58%) was for *A. flavus* at pH 7 and in dilution 25% and the highest COD removal efficiency (70.98%) was for *digitatum P.* at pH 5 and in dilution 25% [6]. Karn et al. studied decomposition of pentachlorophenol by *Pseudomonas stutzeri* bacteria in the treatment of pulp and paper industry wastewater. They reported a decrease in bacterial cell growth due to an increase in pentachlorophenol concentration from 50 to 600 mg/L [33].

The results of this stage showed that *C. glabrata* and *C. albicans* are able to grow and remove COD at different dilutions. Even in non-diluted wastewater, investigated in the first stage of the experiments, they were able to grow to some extent, indicating that by optimizing other conditions and without dilution, these yeasts can be effective in the wastewater treatment. Therefore, it is predicted that these native yeasts can be used in treatment of this type of wastewater. Analysis using response surface method indicated that there was a statistically significant difference in the amount of COD removal in the used dilutions (p-value = 0.018). It shows that the amount of COD removal in two dilutions of 25% and 50% is completely different, so that the maximum COD removal efficiency was observed at dilution of 25%.

3.7. Evaluating the yeast consortium efficiency of C. glabrata/ C. albicans

Given that the simultaneous activity of microorganisms in removing pollutants may be more effective than their separate activity, at this stage the consortium efficiency of these two types of yeast in removing COD at pH 5 and in dilution 50% of the wastewater was examined. The results of this stage showed that COD removal efficiency by these two yeasts after 48 h is 34.85% and after 96 h is 41.63% (Fig. 7).

In some studies, microbial consortium has performed well in removing contaminants. Tyagi et al. studied the removal efficiency of BOD, COD, and lignin from pulp and paper industry wastewater by a bacterial-fungal consortium isolated from soils contaminated with effluent. The removal efficiencies of BOD, COD, and lignin, after 9 d, were 87.2%, 94.7%, and 97%, respectively [16]. Chandra et al. examined the pulp and paper wastewater treatment by a bacterial consortium with ligninolytic enzyme activity isolated from soils contaminated with effluent. In this study, the removal

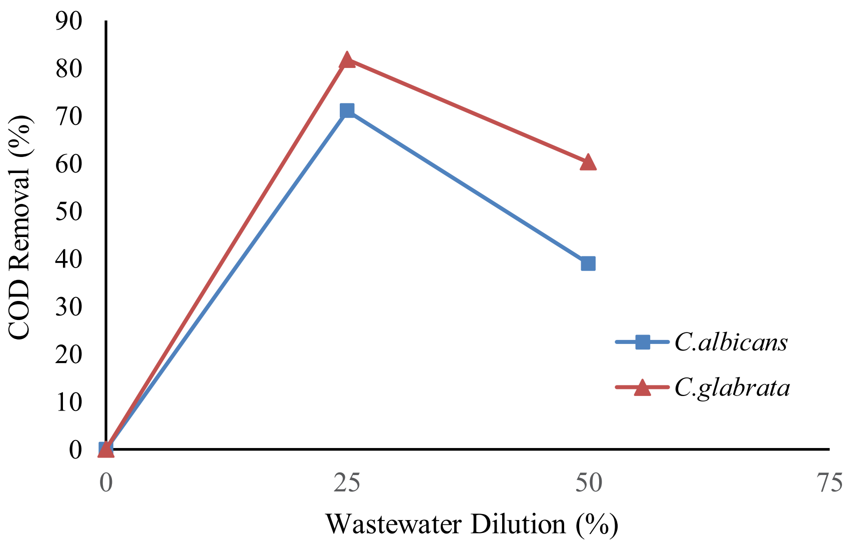

Fig. 6. Effect of the wastewater dilution on COD removal efficiency by *C. glabrata* (pH = 5) and *C. albicans* (pH = 6) in 96 h.

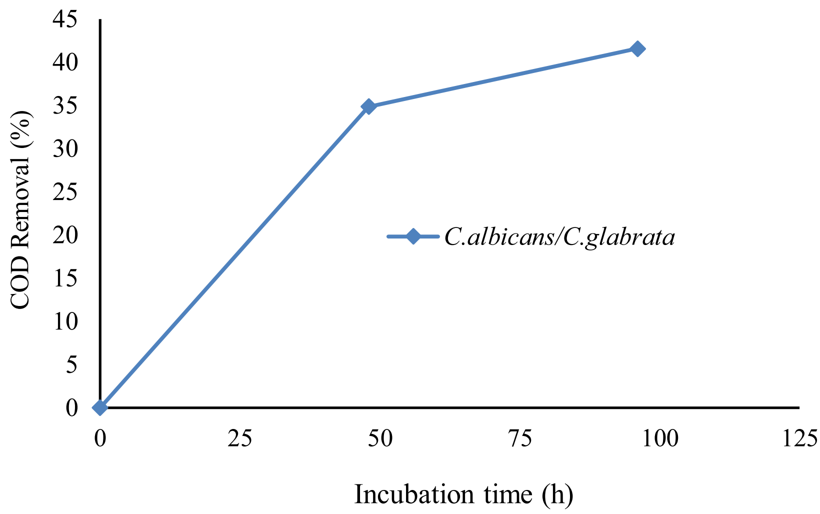

Fig. 7. The yeast consortium efficiency of *C. glabrata*/*C. albicans* in removing COD (pH = 5, dilution of 50%).

Table 2
Maximum removal efficiency of COD by native yeasts used in this study compared to other yeasts reported in references

Pollution supply	Pollutant	Yeast	Incubation time (h)	Removal efficiency (%)	References
Pulp mill	COD	*Cryptococcus podzolicus*	32	68	[14]
Olive mill wastewater	COD	*Rhodotorula mucilaginosa*	168	56.91	[34]
Pulp and paper mill	COD	*Rhodosporidium kratochvilovae*	144	92.22	[2]
Paper and cardboard recycling industry	COD	*Candida albicans*	96	71	This study
Paper and cardboard recycling industry	COD	*Candida glabrata*	96	81.8	This study

efficiency of dye was 96.02%, COD was 91%, and BOD was 92.59% (during incubation period of 216 h) [8].

In the present study, comparing the results of investigating consortium of the yeasts with the results of evaluating their separate efficacy shows that the separate application of these yeasts has a significant effect in removing COD. Especially in the case of *C. glabrata* yeast, which has COD removal efficiency of 60.3% at optimal pH 5 and dilution of 50% after 96 h, and has COD removal efficiency of 81.8% in dilution of 25% after 96 h, can be more effective in wastewater treatment of this industry.

Table 2 reveals the maximum removal efficiency of COD by *C. glabrata* and *C. albicans* used in this study compared to other yeasts reported in references. According to Table 2, the maximum removal efficiency of COD by native yeasts used in this study was promising and therefore these native yeasts can be considered for the removal of COD from paper and cardboard recycling industry wastewater.

Given that these species have the ability to oxidize and consume organic and complex compounds and can use them for their metabolism [20], under optimal conditions, such as pH and proper growth time, they are able to remove COD in this wastewater.

4. Conclusion

In this study, the quality of wastewater in one of the paper and cardboard recycling industries was examined and two types of yeast, including *C. glabrata* and *C. albicans* were identified in the wastewater of this industry. The efficiency of these yeasts in removing COD at different pH conditions, dilution, and incubation time were investigated. The results of this study showed that *C. albicans* yeast at optimal pH 6 and *C. glabrata* at optimal pH 5 had the highest COD removal efficiency. Moreover, these yeasts are able to significantly remove COD during the incubation period of 48 h. It is predicted that due to the characteristics of these yeast species separated from this wastewater as well as their ability to remove COD, they can be considered as an acceptable and eco-friendly and economic option for treating this type of wastewater.

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