Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2014.989270

57 (2016) 4146–4153
February

Integrated treatment technology for textile effluent and its phytotoxic evaluation

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Received 14 March 2014; Accepted 12 November 2014

ABSTRACT

Pilot-scale wastewater treatment systems were investigated for real textile effluent. The parameters of interest in this study were color (Reactive Blue-19 dye), chemical oxygen demand, and growth potential in *Triticum aestivum* (wheat) and *Lolium multiflorum* (ryegrass). The dissolved air flotation and electrochemical treatment were studied independently as well as in combination termed as "integrated" (INTG) treatment system for comparative analysis. The overall results showed that the best treatment performance was achieved through INTG treatment as reduction of 63% in COD and 72% in color was achieved without addition of any other chemical at the current density of 1 mA/cm^2 in 1 h of residence time using aluminum electrodes. The INTG-treated effluent was tested for growth potential studies and the results showed that root/shoot lengths were 20/26% and 34/35% more for wheat and ryegrass, respectively, as compared to the untreated wastewater. This pilot-scale study provides evidence that INTG treatment system is a sustainable technology and the treated effluent can be reused for irrigation purposes.

Keywords: Growth potential; Integrated treatment system; Reactive Blue dye (RB-19); Wastewater treatment

1. Introduction

Textile industries consume a huge amount of water in their processes and in result, generate significant quantity of wastewater. The textile industry's effluents are generally known to be strong in color having high chemical oxygen demand (COD) and broadly fluctuating pH values. In most of the cases, the textile effluent is highly polluted and all of the water quality parameters are found to be significantly high and above the permissible limits [1]. The conventional methods of textile effluents treatment like biological oxidation, chemical coagulation, adsorption, and activated sludge process cannot give significant removal efficiency on large scale [2]. Electrochemical techniques have been widely experimented for industrial effluent treatment for purification, reduction in color, suspended solids, COD, and for recycling purposes [3–5]. The process is reported to be very efficient in COD removal and discoloration at low energy consumption [6]. However,

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electrochemical treatment (ECT) technology claims to offer efficient removal rates for most types of wastewater impurities at low power consumption and without adding any precipitating agents but the effectiveness of the ECT is dependent on various inputs like wastewater type, current density, pH, nature of metal electrodes (aluminum, steel, iron), size and number of electrodes, etc. The variability in these parameters ultimately affect the overall treatment time and the removal efficiency [7]. Many studies [8–10] have been conducted on ECT process optimization of various industrial effluents.

Nowadays, reactive dyes are widely used in textile industry, fundamentally due to their ability to bind to textile fibers through covalent bonds [11]. Moreover, binding characteristics of these reactive dyes facilitate the interaction with the cellulosic fiber and reduce energy consumption [12]. The major environmental problem associated with the use of these reactive dyes is their excessive loss in the dyeing process resulting in limited degree of fixation and the efficiency ranges from 60 to 90% only [12]. Therefore, substantial amounts of unfixed dyes are released in the effluent displaying high organic loads as indicated by COD, low biodegradability, and high-salt contents. Traditional wastewater treatment systems have proven to be markedly inefficient for handling textile dye effluent because of the chemical stability of these dyes. There are several methods for discoloration of textile effluents like chemical precipitation, adsorption on activated carbon, and natural adsorbents, as well as several advanced oxidation processes which have received attention in recent years. The electrochemical degradation of RB-19 using titanium-based anode concerning the effect of operating conditions on treatment performance was studied by Rajkumar et al. [13] and the results showed that this method was capable of destroying the reactive groups of dyes found in textile effluents at short treatment times and low energy consumption. In another laboratory-scale study [14], the ozone-enhanced electro coagulation process was used for the decolorization of RB-19 dye and it was found that, salt concentration of 3,000 mg/L, temperature of 30˚C, current density of 10 mA/cm^2, ozone flow rate of 20 mL/min, and interspatial distance of iron electrodes of 3 cm can remove 96% of the color in 10 min. However, the industrial application of ozonation has limitations as it has high operational and production costs and the less mass transfer rate of ozone [15].

The dissolved air floatation (DAF) treatment process offers low capital investment, low operational cost, and high separation efficiency [16,17]. Moreover, DAF treatment is also beneficial in wastewater treatment as it increases dissolved oxygen and decreases color from the effluent [18,19].

There can be both beneficial and damaging effects of wastewater irrigation on crops including vegetables [20,21]. Therefore, it is mandatory to study the impact of these effluents on crop germination before they are recommended for irrigation [22]. Thus, the present investigation has been carried out to study the effect of untreated and treated effluents on seed germination.

In the present study, INTG treatment system has been used for the removal of RB-19 and COD from textile effluent. Advantages offered using proposed system are low cost, excellent efficiency, fast removal rate, and simple operational conditions for large-scale effluent treatment. In general, most of the industrial units in the developing countries have the basic aeration tanks and/or aerobic treatment facilities, thus just installing electrochemical setup in the existing facilities can enhance the treatment efficiency. However, additional test series concerning continuous operation must still be performed in order to get this concept ready for future industrial-scale applications.

2. Experimental

2.1. Collection of wastewater samples

The wastewater samples used in this study were collected from a local textile industry located at Faisalabad (The Manchester of Pakistan), in 200-L plastic drums and transferred to wastewater treatment laboratory, NIBGE, for treatment and analysis purposes. The average COD of the sample was in the range of 435 ± 20.5 mg/L. The Reactive Blue dye RB-19 was used by the industry for the color development process. This is the dye which is extensively being used in the textile industries throughout world [23]. The estimation of pH, electric conductivity (EC), and COD was carried out according to the standard methods for examination of water and wastewater [24]. A UV–vis range spectrophotometer was used to determine the wavelength of maximum absorbance (Λ_{max}) for RB-19. The anthraquinone structure of RB-19 dye is illustrated in Fig. 1,

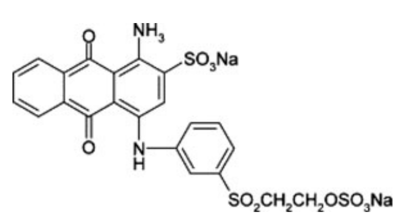

Fig. 1. Chemical structure of Reactive Blue-19 dye. Courtesy (Yang and McGarrahan [25]).

derived from [25]. The intensity of the color was determined by measuring the absorbance, at 592 nm for RB-19, and resultant data was used to calculate percent color removal efficiency using the following equation:

$$\%\ \text{Color removal efficiency} = [(A_0 - A_t)/A_0] \times 100\% \quad (1)$$

where A_0 is the absorbance before any treatment and A_t is absorbance at particular time t.

2.2. Electrochemical treatment

ECT process was carried out using a glass made rectangular pilot-scale electrochemical reactor working in a batch mode. The experimental layout and the actual setup of the INTG treatment system are shown in Figs. 2(a) and 2(b), respectively. The reactor was of 200-L capacity with a height, width, and length of 38, 30, and 90 cm, respectively. Three aluminum electrodes, rectangular in shape with the total effective surface area of 15,660 cm^2 and interspatial distance of 15 cm were used. The direct current (DC) power unit (RS 13604, Thurlby-Thandar Ltd., England) was used to control and regulate the electric current in the reactor. The treated samples were taken from the reactor at predetermined ECT times (t) 20, 40, 60, 120, and 180 min. All samples were left for 30 min as the sludge settling time. At the end of each experimental run, the sludge was collected for further analysis (unpublished data). The supernatant was used for the analysis of RB-19 and COD (in triplicates) before and after each experiment.

2.3. DAF treatment

The same textile effluent was treated using filtered atmospheric air, at a pressure of 4.0 bars (approx 4 kg/cm^2), with the help of high pressure air pump and aluminum sparger (fine pores) installed at the base of the rectangular cell. The samples were DAF treated for the predefined treatment times (t) and at the end of each treatment, the sludge produced in the sample was allowed to settle for 30 min. The supernatant was used for the analysis of RB-19 and COD (both in triplicates) before and after each treatment.

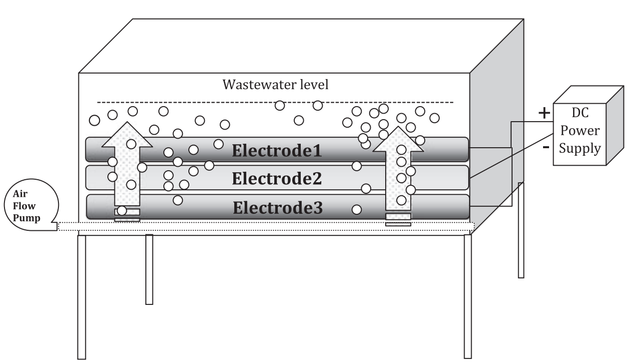

Fig. 2(a) Experimental layout of the integrated treatment system.

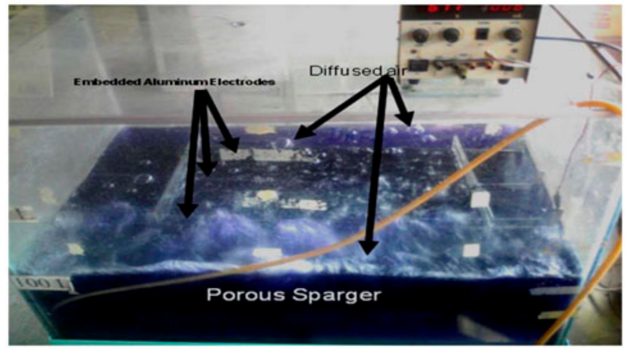

Fig. 2(b) Experimental setup of the integrated treatment system.
Note: The aluminum electrodes are embedded in the water, the DC power supply connected with anode and cathodes (electrochemical treatment); at the bottom of reactor, the porous sparger is installed which generated fine air bubbles (dissolved air floation treatment).

2.4. Integrated treatment process

The textile effluent was treated by coupling DAF and ECT process simultaneously in a single-integrated system which was a custom built unit consisting of 200-L volume fitted with three aluminum electrodes with an effective surface area of 15,660 cm^2 and interspatial distance of 15 cm each. A schematic diagram of pilot-scale INTG treatment system is depicted in Figs. 2(a) and 2(b). The system was run in batch mode with a constant current of 1 mA/cm^2. The wastewater was vigorously mixed (at a rate of 4.0 bar pressure) using the air sparger placed at the bottom of the treatment system. It was ensured that the operating parameters for DAF and ECT remained same which was necessary to study the comparative efficiencies of DAF, ECT, and INTG treatment processes. The operational parameters are same in all treatment processes and are summarized in Table 1.

2.5. Seed germination test

The healthy and uniform size seeds were selected and surface sterilized with 0.1% NaOCl and

Table 1
Operational parameters used in three different treatment processes ECT, DAF, and INTG treatment processes

Parameters/treatment	EC	DAF	INTG (EC + DAF)
Surface area of electrode (cm^2)	15,660	Not used	15,660
Air flow rate (kg/cm^2)	Not used	4	4
Volume treated (L)	200	200	200
Treatment times (min)	20, 40, 60, 120, 180	20, 40, 60, 120, 180	20, 40, 60, 120, 180
Current density (mA/cm^2)	1	Not used	1

thoroughly washed with distilled water to avoid surface contamination. Exactly 30 seeds (each of wheat and ryegrass) were placed equidistantly on soaked filter paper in sterilized glass petri dishes of uniform size. The seeds were irrigated with 5 mL each of untreated effluent, INTG-treated effluent, and distilled water (taken as control). The number of seeds germinated was recorded after 72 h. The root length and shoot length were recorded after 5 d. This experiment was run in triplicates and the results were averaged.

2.6. Germination index (GI)

Germination index was determined on ryegrass and wheat seeds as described in latest studies [26,27] using the following expression:

$$GI = \%G \cdot L_a / L_c \quad (2)$$

where $\%G$ is the number of germinated seeds expressed as % of control values, L_a the average value of root length in treatments, and L_c is the average value of root length in the control.

3. Results and discussion

Pilot-scale experiments were conducted on real textile effluent in triplicates for the determination of the effects of DAF, ECT, and INTG treatment process to explore the reduction of RB-19 and COD, at various runtimes (t).

3.1. Variation in pH and electric conductivity

The initial pH and EC of the wastewater was in the range of 7 ± 0.3 and 9.4 ± 0.1 ms^{-1}, respectively, as shown separately in (Figs. 3 and 4). Among the tested treatment processes, the pH was slightly increased (7–7.5) in DAF and ECT, but in INTG treatment process, a gradual increase up to a maximum level of 9 was observed in 3 h run (Fig. 3). It might be due to generation of aluminum ions during electrolysis on

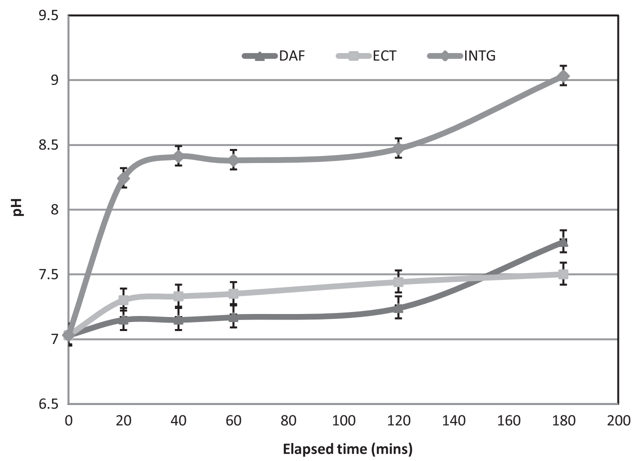

Fig. 3. pH fluctuation during DAF, ECT and integration of both treatment processes termed as integrated (INTG) treatment processes. Standard deviations were presented by error bars. Each value is means of triplicates. The significant difference between treatments is $p < 0.05$.

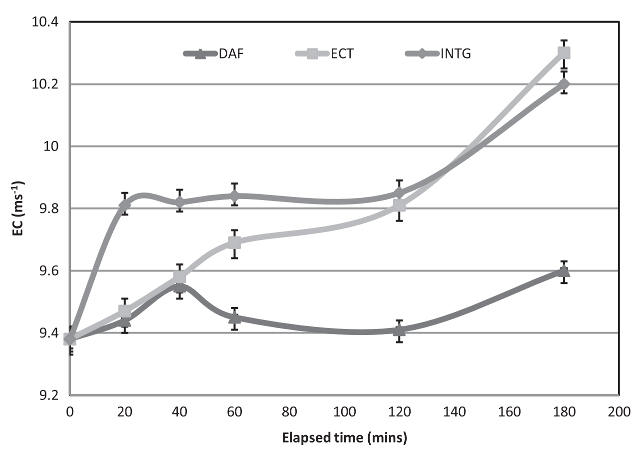

Fig. 4. Fluctuation in EC during DAF, ECT, and integration of both treatment processes termed as INTG treatment processes. Standard deviations were presented by error bars. Each value is means of triplicates. The significant difference between treatments is $p < 0.05$.

the surface of the anode and at the same time hydroxyl groups were formed at the cathode which resulted an increase in the alkalinity of the medium, a similar trend was also observed by Yang [28] using iron electrodes.

3.2. Reduction in COD using different treatment processes

The reduction in the COD of the effluent sample was investigated and the graphic representation of the data in the form of average percentage reduction is shown in Fig. 5. It was noticed that the DAF, ECT, and INTG treatment options can reduce the COD to a maximum level of 20, 43, and 70%, respectively in 180 min run. However, a non-significant reduction in COD was observed between 60 and 180 min, confirming that maximum reduction was achieved in the first hour. The INTG treatment process showed an edge on other two tested treatment processes as a reduction of 66% of COD (resulting in an effluent COD of 65 mg/L) in 1 h of treatment. It was most likely that in INTG treatment process, the agitation by DAF speeded up the mass transfer and supplied the essential oxygen required in ECT process. Moreover, the electro-precipitation process took place which contributed to the more effective removal of COD from the effluent. These findings are supportive that INTG process is a feasible and rapid treatment option for pilot-scale effluent treatment. This work support the [2] work in which the performance of pilot-scale combined process i.e. chemical coagulation, electrochemical oxidation, and biological treatment for textile wastewater treatment were studied and the results showed almost 70% reduction in COD with almost similar sets of conditions. However, Mehmoodi and Dalvand [29] found that at optimum operating condition (current density of 16 mA/cm^2, initial pH 7, polyaluminum chloride: 100 mg/L, time of 15 min), dye removal and COD removal efficiency were 99 and 88%, respectively, using polyaluminum chloride as electrolyte.

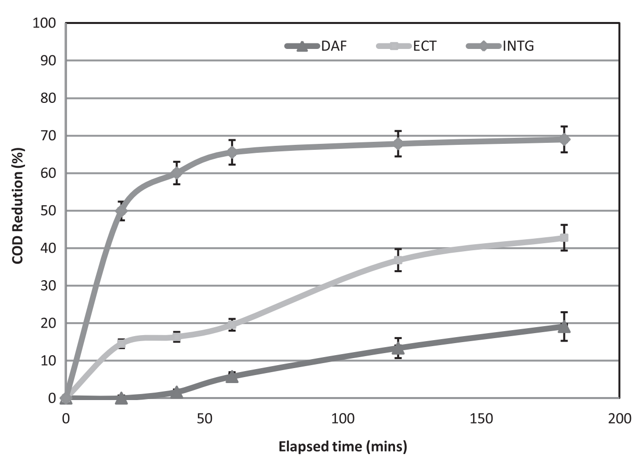

Fig. 5. COD reduction expressed in (%) during DAF, ECT, and integration of both treatment processes termed as INTG treatment processes. Standard deviations were presented by error bars. Each value is means of triplicates. The significant difference between treatments is $p < 0.05$.

3.3. Decolorization of RB-19 using different treatment processes

The decolorization of RB-19 in effluent sample was recorded before and after treatment in triplicates; the average percentage reduction is presented in Fig. 6. The results showed that DAF process was effective in color reduction up to a level of 40% in 180 min run. However, ECT and INTG treatment processes were comparatively more effective in color reduction. The results from ECT and INTG treatment process showed almost similar trends. It was observed that a maximum of 60–70% reduction in color took place just in 40–60 min of run by ECT and INTG treatment processes. A further extension in the run time till 180 min did not show any significant reduction in color. The comparative analysis of INTG and ECT process confirmed that INTG process have superior color removal efficiency than ECT process within the given time period. It has already been established that the ECT process takes advantage of the combined effect of charge neutralization/surface complexation/adsorption onto the *in situ* formed metal hydroxides, produced from the oxidation of corrodible anode materials (Al). Moreover, the combined effect of flotation/concentration/collection of the metal hydroxide flocks and the adsorbed pollutants by the hydrogen gas

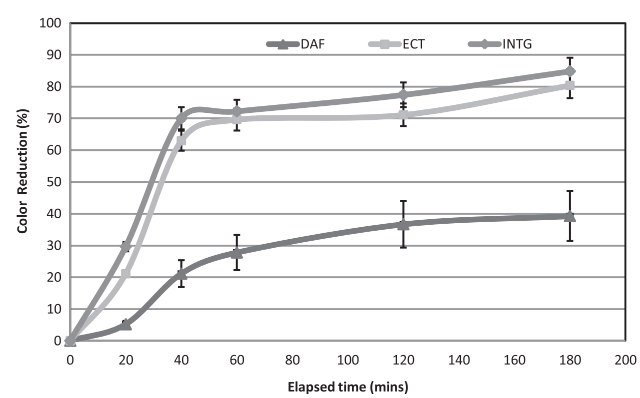

Fig. 6. RB-19 color reduction expressed in (%) during DAF, ECT, and integration of both treatment processes termed as INTG treatment processes. Standard deviations were presented by error bars. Each value is means of triplicates. The significant difference between treatments is $p < 0.05$.

bubbles formed at the cathode [30]. Therefore, in this study, the enhanced effect of DAF and ECT treatment working simultaneously in the INTG treatment process showed better removal efficiency (color and COD).

The similar trends in results were found in another study Ciardelli et al. [31] in which two different oxidation treatments, ozonation and electroflocculation processes were investigated on a pilot scale to test their efficiency in removing color and COD from wastewaters of textile industries, and ECT was found to be very efficient in removing color (80–100%) and COD (70–90%). Similarly, in another lab-scale experimental study, it has been reported that the color (induced by a red dye) and COD were effectively reduced to about 85% for synthetic textile wastewater, when the pH ranged from 6 to 9, residence time was 14 min, current density was 31.25 mA/cm^2, and water conductivity was 2.4 mS/cm for an inter-electrode distance of 1 cm [32]. These results are in contrast with our findings due to the fact that the effluent volume (8:200 L) was very low, current density (31.25 mA/cm^2:1 mA/cm^2) was very high, and the inter-electrode distance was very low (1 cm:15 cm), due to this reason the COD and color reduction might be higher i.e. 84–85%, respectively, just in 14 min run. These findings also support the opinion that color and COD removal efficiency is greatly reduced when the wastewater treatment scale changes from lab-scale studies (other studies) to pilot-scale studies (this study) (Fig. 6).

3.4. Effect of treated and untreated effluent on seed germination

The effect of INTG-treated effluent and untreated effluent on the seed germination in wheat and

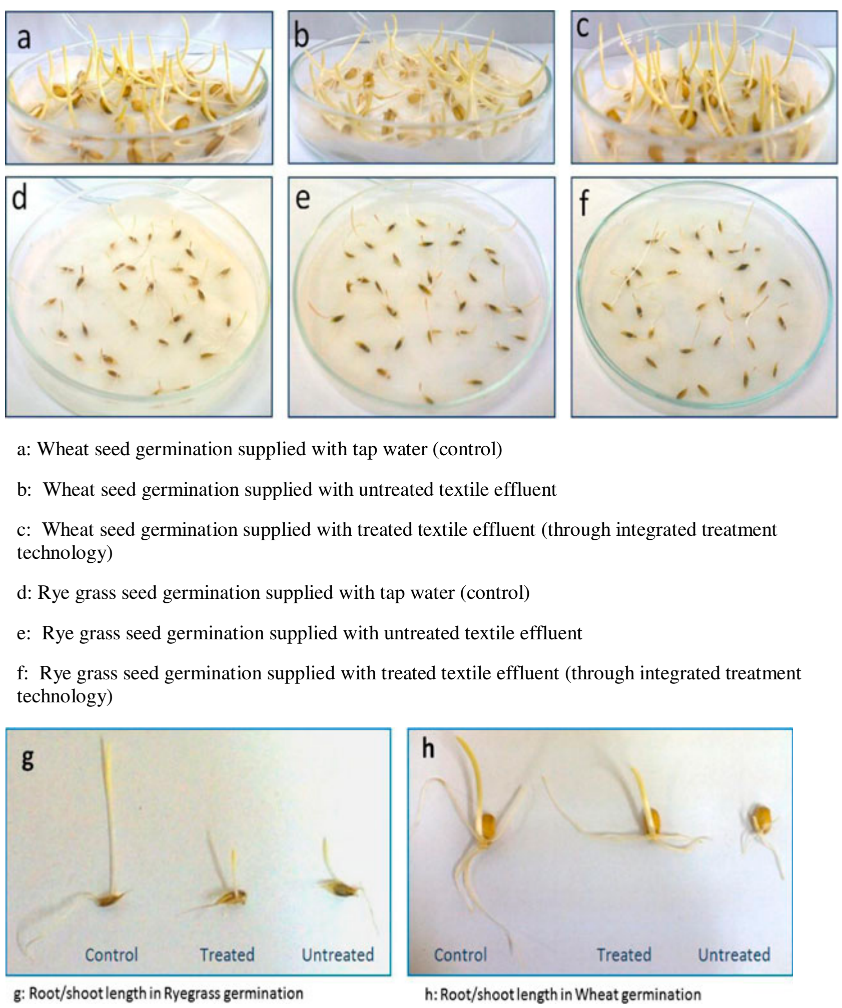

Fig. 7. The effect of treated and untreated textile effluents on seed germination of wheat and ryegrass.

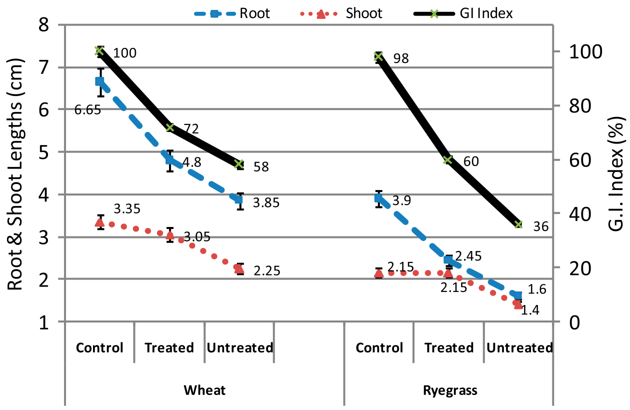

Fig. 8. The relative root, shoot length, and GI index of wheat and ryegrass in germination experiment. Seeds irrigated with tap water (control); irrigated with integrated-treated (3 h run) textile effluent (treated), and irrigated with untreated textile effluent (untreated). Standard deviations were presented by error bars. Each value is means of triplicates. The significant difference between treatments is $p < 0.05$.

ryegrass by recording root shoot lengths were studied. The seed germination in wheat was 100%, in all cases; however, in ryegrass it was 99, 89, and 95% in controlled, untreated, and treated samples, respectively. The wheat germination (W_g) and ryegrass germination (R_g) can be visualized in control, untreated, and treated effluent in Fig. 7(a)–(f), respectively. The representative close-ups of the root/shoot lengths in R_g and W_g are shown in Fig. 7(g) and (h), respectively. The average root/shoot length (cm) of wheat and ryegrass is shown in Fig. 8. The comparative analysis showed that in both cases (wheat and ryegrass) the treated effluent has more root and shoot lengths than the untreated effluent. Moreover, a significant difference in root length was recorded in both cases (wheat and ryegrass); while compared to their shoot lengths, which clearly indicate that treated and untreated effluents have more effect on roots than shoots.

The greatest effect on shoot and root lengths was observed in untreated effluent (Fig. 8). Shoot length of ryegrass in untreated effluent was only 1.4 ± 0.07 cm when compared to control 2.15 ± 0.0, which is 65% lower than control. Similarly, the root length of ryegrass in untreated effluent was only 1.6 ± 0.07 cm when compared to control 3.9 ± 0.14, which is 60% lower than control. The INTG-treated effluent has no effect on shoot length; however, the root length was reduced to 37% than control. Furthermore, the shoot length of wheat in untreated effluent was 2.25 ± 0.07 cm when compared to control 3.35 ± 0.07, which is 33% lower than control. Correspondingly, the root length of wheat in untreated effluent was 3.85 ± 0.07 cm when compared to control 6.65 ± 0.21, which is 42% lower than control. The INTG-treated effluent showed that there was minimal effect on shoot length; however, the root length was 27% lesser than control. These results clearly indicated that the overall cumulative effect of treated effluent on root–shoot length in both cases was less than the untreated effluent. Therefore, INTG-treated effluent can be used for irrigation purpose as it has low COD (65 mg/L) and color contents (72/M).

4. Conclusions

- INTG treatment process comprising of electrochemical and DAF is capable of being an effective treatment process for textile effluent treatment as compared to conventional single treatment process.
- Having observed trends over the three hours run of the processes, it has been noted that INTG treatment is capable of high removal efficiencies of RB-19 color and COD by achieving a more efficient treatment processes and is quicker (within 1 h) than traditional methods of treatment such as ECT and DAF alone.
- INTG treatment system using Al electrodes became critical in terms of color and COD reduction after 60 min treatment; however, this tested time is almost sufficient to satisfy our color removal 87% (resulting in effluent color 72/M) and COD 63% (resulting in effluent COD 65 mg/L) requirements for discharging into water bodies.
- The effluent treated with INTG treatment system meets the requirement of the national environmental quality standards for discharging color and COD in effluents. However, there is a great need to study the fate of RB-19 dye ending up in the concentrated form of the sludge.
- The INTG-treated textile effluent can be utilized for the irrigation purpose as it has comparatively less effect on plant growth parameters (root–shoot length) than the untreated effluent.

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