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AN EVALUATION OF THE PHYTOTOXICITY OF FILTER BACKWASH WATER COAGULATION PRODUCTS FROM A POOL WATER SYSTEM

The possibility of using the process of coagulation for purifying the filter backwash water from a swimming pool water system has been presented. The assessment of the process efficiency based on the physicochemical parameters was extended by a phytotoxicity analysis of products (sludges and supernatant liquids) obtained from the coagulation processes. The phytotoxicity of sludges was examined with respect to garden cress (*Lepidium sativum*) and white mustard (*Sinapis alba*), while duckweed (*Lemna minor*) was used for studying liquids. Coagulation process was highly effective in purifying backwash water when the lowest of the studied aluminum coagulant doses (from 7 to 20 mg/dm^3) was used. Moreover, the phytotoxicity assessment of backwash water allowed the determination of the hazard toward plants, which would be posed by using the backwash water for plant irrigation. The high stimulation of the growth of plant indices, observed in samples with raw backwash water, was caused by nutritive nitrogen and phosphorus. Their removal, in the case of postcoagulation solutions, significantly contributed to the inhibition of plant growth. In turn, sludges derived from both raw washings and coagulation exhibited phytotoxicity.

1. INTRODUCTION

Filtration is a common procedure in the water purification of swimming pools. Pollutants are trapped as a result of filtration and sorption processes [1]. The one- or multistage filtration is used most often. The most common filtration materials used in swimming pool facilities are the monolayer or multilayer sand, carbon, or sand with carbon. Water is continuously filtered in the bed, until pressure losses exceeding 3 m H_2O are obtained. To meet the physicochemical and sanitary requirements in terms of water quality, it is necessary to conduct the bed rinsing process once every 2–3 days. For the correct rinsing of the filter bed, 4 to 6 m^3 of water is required (taken from the reservoir)

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for each 1 m^2 of the bed [2]. An example of a swimming pool water purification system, consisting of 4 pressure filters with diameters of 1800 mm, rinsed every 2 days on average, requires from 600 to 900 m^3 of water for a month, which is usually drained to the sewer. Since the costs of water intake and sewerage discharge continue to rise, it is imperative to seek solutions that will reduce the amount of water consumed without impairing its physicochemical and microbiological parameters.

By analyzing the possibilities for reducing water consumption and wastewater discharges in swimming pools, attention is more often drawn toward filter backwash water (FBWW). Among many possibilities for the use of water drained from swimming pool facilities, the most common are for sprinkling courts and pitches (in the case of large sports complexes), supply for toilet flushing installations, and for irrigating a variety of salt-tolerant plants. In practice, when planning the direct discharge of FBWW to the environment, particular attention should be paid to their quantity and the content of contaminants. The pool water environment, as opposed to tap water, is a specific system, in which contaminants play a specific role when introduced to the basin [3, 4]. The results of the studies performed so far show that it is impossible to use water from this method of filter rinsing, due to the high content of total suspended solids and residual chlorine [5].

Improving the quality of backwash water can be achieved, among others, by purifying them in the coagulation process, in the course of which inorganic and organic colloidal impurities would be removed along with particles that are difficult to remove. The result of effective coagulation is evident from the reduced turbidity, due to the removal of organic pollution indicators such as byproducts of disinfection and chemical oxidation, micropollutants, and microorganisms [6]. The effectiveness of the coagulation process and physicochemical properties of the treated wastewater and formed sediments, despite the passing of time, are still subject to some numerical studies [7–10]. On the other hand, after the coagulation process, the discharge of rinsing water directly into the environment requires not only the fulfillment of physicochemical standards but, above all, it requires an analysis of the potential ecotoxicological risk to plants that are in contact with the liquid and/or sediments.

Phytotoxicity is an extensive branch of ecotoxicology. Indicator organisms are used, among others, to assess the negative impact of metals [11, 12] and organic substances [13, 14] on plants, to monitor the industrial wastewater [15] and the current state of the aquatic environment [16], as well as for the quality assessment of sewage sediments [17] and sediments from industrial processes [18]. However, there are no detailed analyzes regarding the phytotoxicity of postcoagulation sediments. For this reason, the authors have analyzed this subject in the past in one of their publications [19].

The aim of the study was to evaluate the effectiveness of the coagulation process using an aluminum coagulant based on ecotoxicological tools. Effluent waters from two pool circuits for different purposes have been used in the studies. After purification, the influence of raw backwash water on the selected growth parameters and the duckweed

Lemna minor morphology was studied. In addition, sedimentation deposits were assessed for phytotoxicity using watercress (*Lepidium sativum*) and white mustard (*Sinapis alba*). The choice of dicotyledonous plants was dictated by the data regarding their response to toxicants [11–18]. An attempt was made to establish a relationship between the dose of the coagulant and the degree of the ecotoxicological response. The results obtained refer to the ecotoxicological evaluation of raw backwash water, sedimentation deposits, and purified liquids after the coagulation process.

2. MATERIALS AND METHODS

2.1. PHYSICOCHEMICAL ASSESSMENT METHODS

The quality assessment of the test FBWW before and after the purification processes was made based on selected physicochemical properties. The measurement of the conductivity and the reaction (pH) of test samples was conducted by using an inoLab® 740 multiparameter meter (WTW, Xylem). The absorbance at a wavelength of 254 nm was measured using a UV VIS Cecil 1000 (supplied by Analytik Jena AG), with a cuvette optical path length of 1 cm. The UV254 value was determined based on the measurement method provided by US EPA [20], and the final result was expressed in m^{-1}. For the determination of the turbidity of samples, a EUTECH Instruments' Turbidimeter (Model TN-100) was employed. The measurement of the color was performed using a UV VIS Spectroquant® Pharo 300 spectrophotometer (Merck) at a wavelength of 340 nm. The measurement of the chlorine concentration (total and free) was performed *in situ* by the colorimetric method using a Hach® Pocket Colorimeter™ II portable instrument. The concentrations of total nitrogen, ammonium nitrogen, total phosphorus and indices such as the phenol index, chemical oxygen demand (COD), and the total suspended solid content were determined by photometric methods (UV VIS Spectroquant® Pharo 300 spectrophotometer, Merck). The total hardness was determined by the versenate method, while the chloride concentrations by the argentometric method.

2.2. PHYSICOCHEMICAL CHARACTERISTICS OF FILTER BACKWASH WATER

The raw backwash waters analyzed in the studies were derived from the multilayer pressure filters (quartz sand, anthracite, and gravel) that include a part of the treatment system in an indoor swimming pool. FBWW was taken from two circuits of different purpose pans: hydromassage hot tubs and swimming pools. Samples for the physicochemical analyses were taken once a week for six weeks. The object of analysis, i.e. the swimming pool, was characterized by a constant, high load of 8–20 people per hour. The samples of backwash water were collected when the pool was closed after washing, from the deposits formed during the rinsing. Table 1 shows the minimum values (intake with the lowest values of physicochemical parameters), average (arithmetic mean from all samplings), and maximum (the highest recorded values) for the physicochemical parameters tested.

Table 1

Selected values of the physicochemical parameters of the analyzed backwash waters

Parameter	Hot tub circulation			Swimming pool circulation		
	Minimum	Average	Maximum	Minimum	Average	Maximum
pH	7.43	7.61	7.78	6.15	6.19	6.22
Conductivity, µS/cm	996.1	988.2	1006	829.3	840.0	852.1
Color, mg Pt/dm^3	115	224	289	45	62	78
Turbidity, NTU	13.20	45.50	55.98	3.60	6.89	9.54
Ultraviolet absorbance (UV254), m^{-1}	10.30	12.30	14.60	9.98	13.40	17.30
Chlorine (free), mg Cl_2/dm^3	0.13	0.23	0.31	0.21	0.25	0.29
Total chlorine, mg Cl_2/dm^3	0.75	1.46	1.94	0.71	0.85	0.98
Chlorine (bound), mg Cl_2/dm^3	0.98	1.23	1.32	0.51	0.60	0.68
Total nitrogen, mg N/dm^3	10.2	22.8	32.0	2.6	3.1	3.9
Ammonium, mg NH_4^+-N/dm^3	0.40	0.80	1.20	0.10	0.20	0.25
Total phosphorus, mg P/dm^3	2.60	6.30	7.60	0.97	1.60	1.97
Phenol index, mg C_6H_5OH/dm^3	1.25	1.48	1.68	0.00	0.10	0.24
Total hardness, mg $CaCO_3$/dm^3	225.9	232.5	238.8	109.6	112.0	116.6
Chlorides, mg Cl$^-$/dm^3	278.4	291.1	298.4	289.9	298.2	304.5
Total suspended solids, mg/dm^3	47	82	111	14	16	20
COD, mg O_2/dm^3	15	69	110	17	25	30
Aluminum, mg Al/dm^3	0.20	0.32	0.42	0.70	0.88	0.99

2.3. COAGULATION PROCESS

Polyaluminium chloride (PACl) was used for coagulation of filter backwash water. PACl was chosen due its widespread use in swimming pools. The coagulant was applied in doses calculated for active aluminum: 7, 13, and 20 mg Al/dm^3. To assess the coagulation efficiency and to select the coagulant dose, standard jar tests that comprised a fast agitation process (1 min at a stirrer speed of 250 rpm, during which the coagulant was introduced to the backwash water, were performed, and a flocculation process (25 min at a stirrer speed of 50 rpm was conducted in a four-stand laboratory coagulator (Velp Scientifica) and finally allowed for settling (30 min). The pH of the solution was 7.8±0.2, after the addition of 0.1 mol/dm^3 HCl or NaOH 30 sec prior to PACl. Changes in selected physicochemical parameters (turbidity, color, UV254, total phosphorus, total suspended solids, and aluminum that remained) were examined on samples that had been previously filtered on membrane filters made of polyethersulfone (a pore diameter of 0.45 µm). The removal factor (R) was calculated from the equation

$$R = 100 - \frac{100P_R}{P_C}$$

where: P_R is the pollution parameter in raw backwash water, P_C the pollution parameter in supernatant samples (liquid after coagulation).

2.4. PHYTOTOXICITY ASSESSMENT OF COAGULATION PRODUCTS

The assessment of the phytotoxicity of backwash water and supernatant samples after the coagulation process was made according to the author's method based on the US EPA recommendations [21] using *L. minor* as the indicator organism. For the conducted test series, a control sample was prepared, in which 40 cm^3 of a solution from the raised plant was used. The assessment of sample phytotoxicity was made based on the observation of either stimulation or inhibition of the growth in the number of fronds in a 7-day test (from day $t_1 = 0$ to day $t_2 = 7$) at 23 °C, with an illumination of 25 W (224 lm). The results are presented as the mean values of three performed repetitions. The coefficient of frond growth R_f (without units) and the coefficient of frond growth inhibition IR_f (%) were determined from the equations

$$R_f = \frac{\ln f_2 - \ln f_1}{\Delta t}$$

where: f_2 is the number of fronds on the last testing day, f_1 – the number of fronds on the first testing day, $\Delta t = t_2 - t_1$ – the number of testing days.

$$IR_f = \frac{R_{fc} - R_{ft}}{R_{fc}} \times 100$$

where: R_{fc} is the frond growth coefficient of the control sample, R_{ft} – the frond growth inhibition coefficient of successive samples.

The assessment of the phytotoxicity of coagulation sludges using garden cress (*Lepidium sativum*) and white mustard (*Sinapis alba*) was made based on the Phytotoxkit® test method [22]. As the raw backwash water samples contained a large quantity of hard suspended solids, the test of their gravitational compacting did not allow obtaining the amount of sludge required for performing the toxicity test. For that reason, the sludges were dehydrated by filtering the samples on medium quantitative filter papers (Chemland). In each test, 2 g of sediment sludge were used. The acute phytotoxicity test was conducted for three days in a laboratory incubator at 25 °C. The presented results are the mean values of three performed repetitions. The phytotoxicity test included a test with raw sludge in the sampled FBBW as well as control test sediments (which contained 85% sand, 10% of kaolin, and 5% of peat at pH 6.5–7.0 controlled with the addition of $CaCO_3$). The examined effects of phytotoxicity included root growth inhibition (I_R) and plant germination inhibition (I_G):

$$I_R = \frac{R_c - R_t}{R_c} \times 100$$

where I_R is the root growth inhibition, %, R_c – root length in the control sample, mm, R_t – root length in the test sample, mm.

$$I_G = \frac{G_c - G_t}{G_c} \times 100$$

where I_G is the plant germination inhibition, %, G_c the number of plants sown on the first testing day ($G_c = 10$), G_t – the number of plants germinated on the last testing day.

The plant growth inhibition (phytotoxicity) indicator and growth inhibition coefficient values were positive, while the growth stimulation was indicated by negative values.

The phytotoxicity tests of the samples were performed in parallel with the physicochemical assessment. Within the framework of this work, the authors presented the results of the phytotoxicity assessment for samples with the lowest physicochemical parameters (minimal – min) and highest (maximum – max). Because of the high concentration of free chlorine in the samples, the curve analysis of the chlorine disappearance was performed before the phytotoxicity assessment. The phytotests were performed only after the complete disappearance of residual chlorine from the samples.

3. DISCUSSION OF THE RESULTS

3.1. EFFECTIVENESS OF THE COAGULATION PROCESS

The minimum, average, and maximum values (for all six coagulation processes) are shown in Table 2. They led to the complete color removal and the reduction of total phosphorus concentration to below 0.1 mg P/dm^3 (Table 2). The absorbance value in the ultraviolet UV254 was reduced, along with the slurry content. In most cases, the turbidity of FBWW after coagulation was less than 1 NTU. Lower values of contamination removal factors were observed for rinsed water with low baseline values of physicochemical parameters. For this purpose, it would be necessary to support the process with polyelectrolytes or powdered activated carbon [23, 24]. The concentration of residual aluminum increased along with the increase of the coagulant dose. For example, FBWW with the initial concentration of 0.34 mg Al/dm^3, ended up with 0.40–0.55 mg Al/dm^3 as the dose of coagulant increased. Nevertheless, the coagulation process was considered to be suitable for reducing the most problematic indicators of the contaminants of backwash waters, even at the lowest dose of 7 mg Al/dm^3.

Table 2

Effectiveness of the coagulation processes: removal factor [%]

Parameter	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.
Dose of PACl, mg Al/dm^3	7			13			20		
Backwash water from the hot tub circulation									
Color	100	100	100	100	100	100	100	100	100
Turbidity	72.36	86.21	88.12	89.65	90.86	92.56	85.69	87.08	89.65
Ultraviolet absorbance (UV254)	80.23	84.33	87.26	70.60	75.37	79.90	32.57	41.04	47.80
Total phosphorus	97.50	98.13	98.60	96.20	98.13	99.16	93.60	94.38	96.75
Backwash water from swimming pool circulation									
Color	100	100	100	100	100	100	100	100	100
Turbidity	97.60	98.40	98.90	95.65	96.07	98.16	95.90	97.36	98.90
Ultraviolet absorbance (UV254)	48.46	56.91	62.10	26.60	28.46	42.30	23.90	24.76	26.45
Total phosphorus	98.90	99.37	100	97.40	98.73	99.10	98.20	99.05	99.85

3.2. ASSESSMENT OF PHYTOTOXICITY

A strong growth of the *Lemna minor* was observed in raw backwash waters (Table 3); the inhibition of growth was found to be negative (ranged from –113.44 to –15.67% for the water in the circulation of hot tub and from –99.40 to –20.78% for swimming pool circuit).

Table 3

Phytotoxicity values in the studied raw backwash waters and sludges

Water circuit	Study item	Indicator organism	Phytotoxicity effect[a] [%]		
			Minimum	Average	Maximum
Hot tub	Backwash water	*Lemna minor*	–113.44	–58.60	–15.67
	Sludges	*Lepidium sativum*	–102.49	–59.42	–11.40
		Sinapis alba	52.96	67.14	88.42
Swimming pool	Backwash water	*Lemna minor*	–99.40	–61.98	–20.78
	Sludges	*Lepidium sativum*	–18.40	19.56	31.16
		Sinapis alba	70.00	88.20	120.45

[a] Average result of three tests completed.

The most potential growth substances that favor the plant growth were found in the FBWW from the hot tub with the lowest values of physicochemical parameters (Minimum). The phytotoxicity assessment of crude sedimentary deposits found in the backwash water samples showed a higher susceptibility to species of *S. alba*. The inhibition of root growth was in the range of 52.96–88.42% for hot tub circuit and 70–120.45 for the circulation of the swimming pool. In the case of *L. sativum*, root growth stimulation was observed for the sludge from the hot tub circuit (I_R was between –102.49 to –11.40%). On the other hand, different results were obtained during the phytotests conducted using sediments from the swimming pool circuit (the range of growth inhibition was from –18.40 to 31.16%). The inhibition of germination did not exceed 10% in any of the tests.

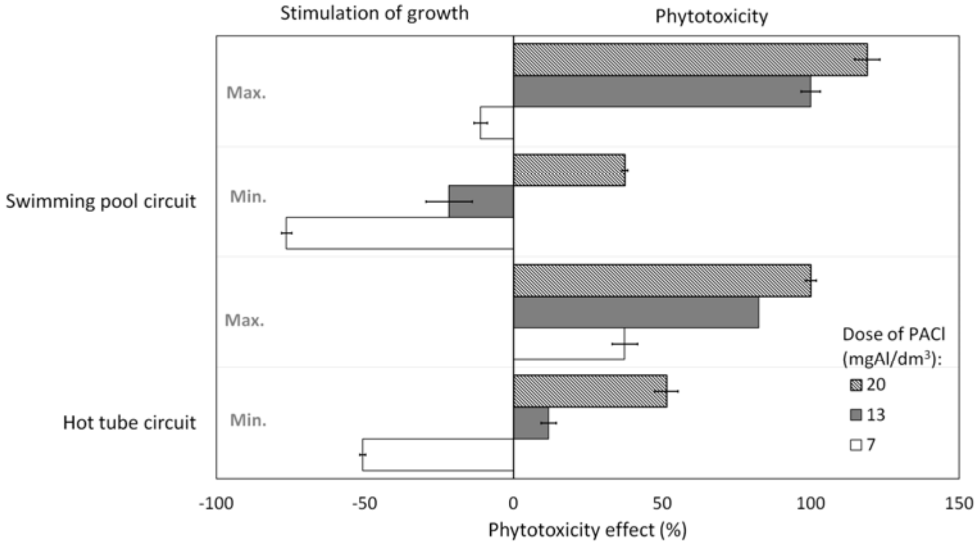

Fig. 1. Phytotoxicity of supernatant after the coagulation with minimum (Min.) and maximum (Max.) initial physicochemical parameters

Figure 1 shows a comparison of phytotoxicity between the supernatants with different output parameters (minimum and maximum physicochemical parameters of backwash waters during a six-week study). The coagulation process has reduced the ability of the backwash waters to stimulate the growth of *L. minor*. This phenomenon was observed from the supernatant after the coagulation of backwash waters from both hot tub and swimming pools. In the case of samples from the hot tub with minimal initial physicochemical parameters, the effect of the supernatant on the plants varied from the stimulation (I_R was –50.84% for the coagulant dose of 7 mg Al/dm^3) due to phytotoxicity (I_R was 51.44% for the coagulant dose of 20 mg Al/dm^3). With the maximum initial values of the physicochemical parameters of the backwash waters, this tendency becomes stronger. Phytotoxicity has been reported in the full range of investigated supernatant liquids (I_R was in range of 37.40–100%). The relationship between the coagulant dose increase and the phytotoxicity was also observed for purified backwash waters from a swimming pool. For supernatants with the best initial quality (Min.), there was a strong stimulation of frond growth at the 7 mg Al/dm^3 dose (I_R was –76.37%). The lower stimulation value was reported for inferior quality backwash waters (Max.), for the dose of 7 mg Al/dm^3. Substantiation regarding the stimulation of the growth of *Lemna minor* at low concentrations of aluminum can be found from the literature of previous studies [25].

The raw backwash water is the liquid that remains after the coagulation process in the water treatment circuit. The initial aluminum concentration was from 0.20 to 0.42 mg Al/dm^3 for the hot tub samples and from 0.7 to 0.99 mg Al/dm^3 for the swimming pool samples (Table 1). While the recoagulation of the backwash water led to the accumulation of aluminum. At a dose of 13 mg Al/dm^3, the aluminum concentration in the swimming pool sample exceeded 1.2 mg Al/dm^3. In further research, it is necessary to pay more attention to the concentrations of aluminum that may be critical for the growth of *L. minor* in backwash water samples. The observed phenomena are confirmed by the increase in oxidative stress associated with increased concentrations of aluminum in the samples tested using *L. minor* as the indicator [25]. Moreover, there was an increase in damage in the form of necrosis in the plant fronds treated by backwash waters samples after coagulation. The damage occurred mainly on the outer side of the fronds, and their number increased with the time of observations. Selected morphological changes within the fronds are shown in Fig. 2.

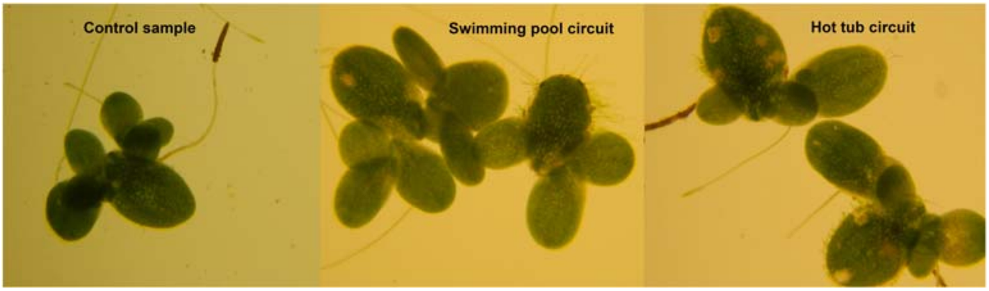

Fig. 2. Morphological changes within the fronds under the influence of the studied backwash water after coagulation (selected example); Nikon Coolpix L120, 10× optical zoom

Figure 3 presents the assessment results of the phytotoxicity of sludges from the backwashing of the hot tub circuit. The increase in the toxic effect after coagulation was observed in germination tests with *L. sativum*. For the samples with minimal initial values of physicochemical parameters and with the dose of coagulant of 7 mg Al/dm^3, the root growth was still stimulated (I_R was –31.58%); at a dose of 20 mg Al/dm^3, the inhibition value increased to about 85%. On the other hand, for samples of coagulants after the coagulation with maximal physicochemical parameters, the inhibition was observed at the full range of coagulant doses (I_R was in a range of 10.58–52.83% (Fig. 3a, Max.)).

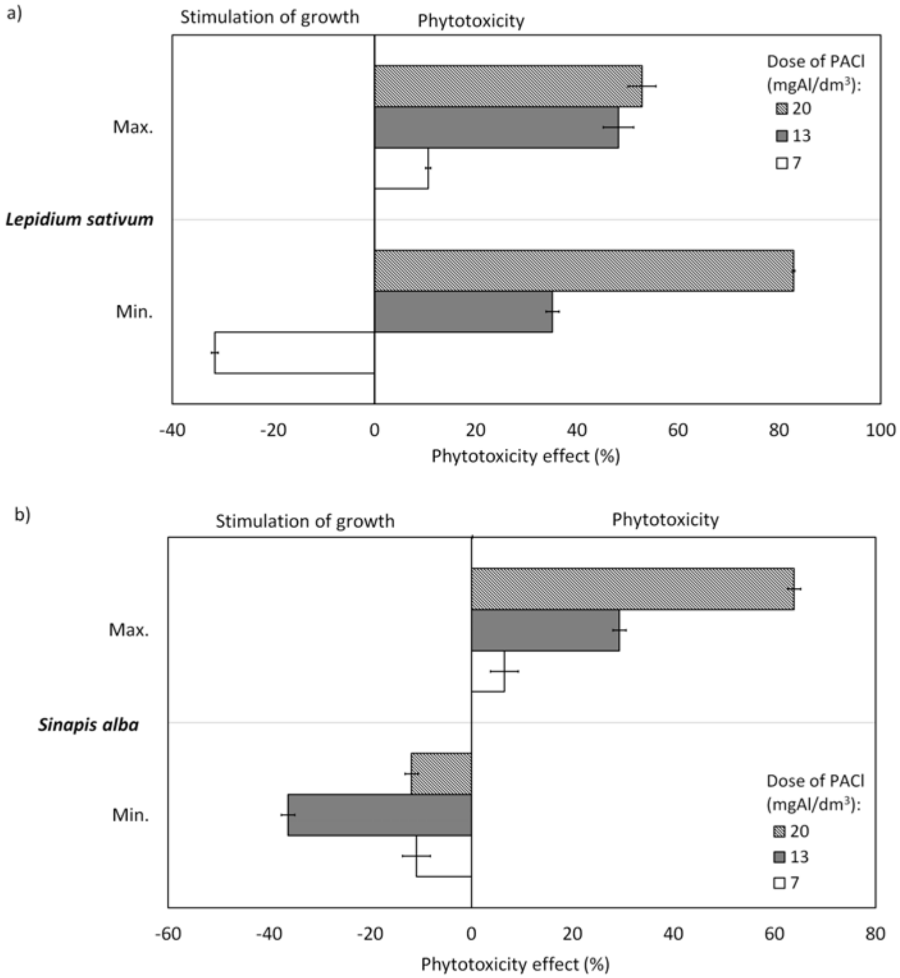

Fig. 3. Phytotoxicity of sediments after the coagulation of the filter backwash water from a hot tub circuit with minimal (Min.) and maximum (Max.) initial physicochemical parameters: a) *L. sativum*, b) *S. alba*.

This dependence was not confirmed in the growth test from *S. alba*. The inhibition of growth was observed in samples of raw sediments. The value of I_R for raw sludge samples from *S. alba* assay was 88.42%. Growth stimulation was observed in samples of post-coagulation sediments where the backwash waters was characterized by minimal initial values of physicochemical parameters (Fig. 3b, Min.)).

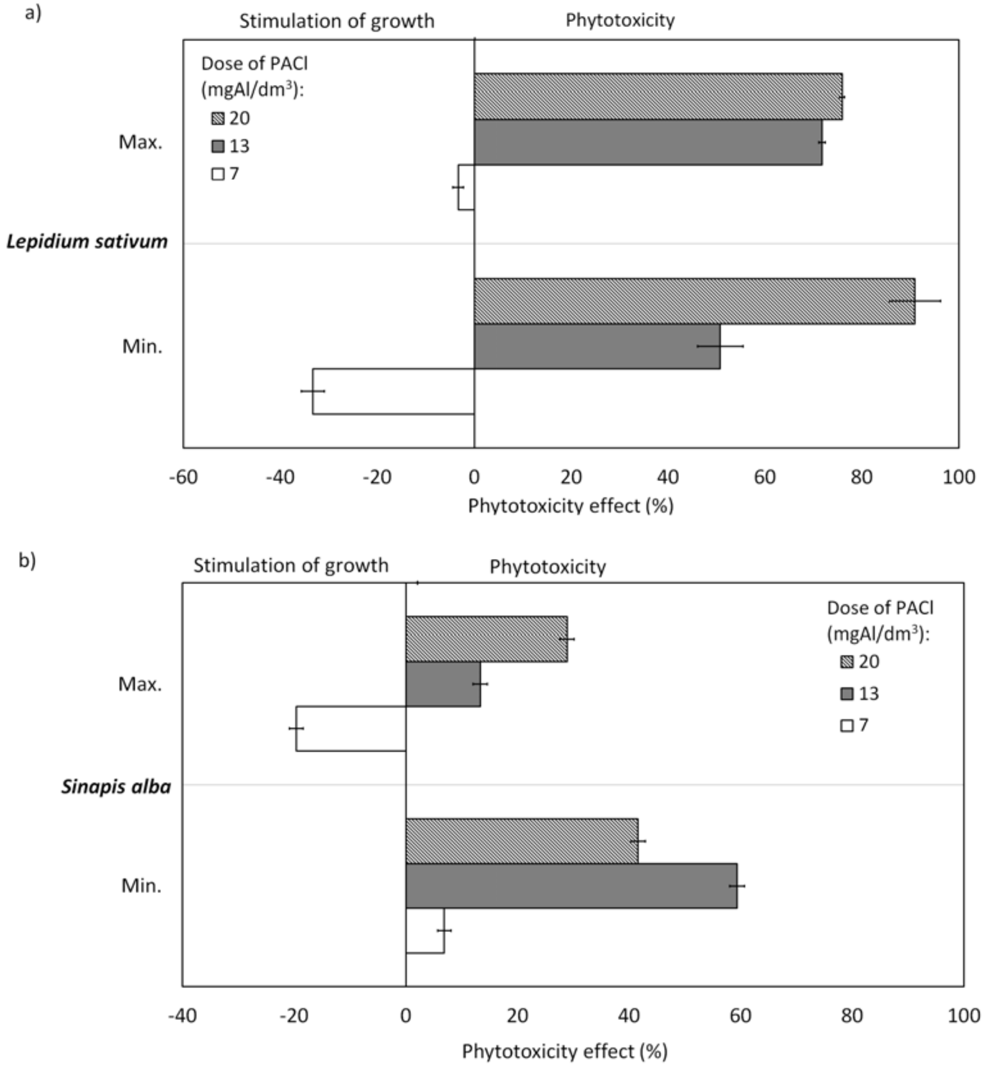

Fig. 4. Phytotoxicity of sediments after the coagulation of filter backwash waters from a swimming pool circuit with minimal (Min.) and maximal (Max.) initial physicochemical parameters: a) *L. sativum*, b) *S. alba*

However, this relationship was not linear; for a dose of 7 mg Al/dm^3, the I_R was equal to 10.85%, for 13 mg Al/dm^3, it was –36.30%, and for 20 mg Al/dm^3 it was –11.85%. The range of growth inhibition observed in the samples after the treatment process was from 6.51 to 63.85% when the backwash waters were characterized by maximum output values. The inhibition values still did not exceed the baseline in raw backwash water (Table 3). The inhibition of germination did not exceed 20% in any of the phytotests.

The dependence between the coagulant dose and the phytotoxic response of sediments after coagulation was also documented in other publications [26].

In the inhibition test using *L. sativum* for the sludge samples of backwash water from the swimming pool circulation, the stimulation of growth was observed (I_R was –18.40%). The inhibition of growth was observed for sediments derived from the backwash waters with the maximum values of physicochemical parameters (I_R was 31.16%). Figure 4a shows the test results for postcoagulation sediments using these backwash waters. At a dose of 7 mg Al/dm^3, there was an increase in *L. sativum* growth stimulation in the test with increasing quality of backwash water samples. In the sample of raw sediment I_R was –33.32%. In the bioassay with higher values of the physicochemical parameters of backwash waters, the value of growth stimulation was lower (–3.32%). For this test, plant growth inhibition was observed with an increase in the coagulant dose. On the other hand, the highest inhibition of root growth was recorded for the samples of sediment after coagulation with the highest physicochemical parameters (I_R was 90.90%). The observed high growth inhibition of *S. alba* in the assessment of phytotoxicity of raw sludges was not confirmed in samples collected after coagulation. Figure 4b shows the results for this test plant. In the sediment samples with minimum basal backwash water parameters, the lowest value of growth inhibition was reported for a 7 mg Al/dm^3 coagulant dose, which was 6.89%. In addition, the highest value of inhibition showed in test with a sludge sample with 13 mg Al/dm^3 dose (I_R was 59.36%). For sediments generated from backwash water with maximum washings parameters, the root growth was stimulated at a dose of 7 mg Al/dm^3 (I_R was –19.63%). The inhibition of growth increased with the increase of coagulant dose, and for 20 mg Al/dm^3, it was 28.89%. The inhibition of germination did not exceed 10% in any part of the phytotests.

Water-treated sludge, characterized as accumulated suspended solids and organic and inorganic matter, including precipitated phosphorus and aluminum compounds, which was produced in large quantities during the coagulation process. Among factors influencing the increase of phytotoxicity of backwash waters samples, the significant reduction in the concentration of phosphorous and nitrogen in the samples on average 85 and 60% (sources of growth especially of *L. minor* biomass), and the increase of concentration of residual aluminum (in the range from 0.5 to 1.8 mg Al/dm^3), with the increase of coagulant dose, can also be listed.

4. CONCLUSIONS

The coagulation process contributed to a considerable amount of improvement in the quality of the examined filter backwash water. The use of the lowest doses of the examined coagulant (7 mg Al/dm^3) and reducing the total suspended solid content. The high content of total suspended solids was the main obstacle for the use of irrigation for greenery. The plants used in the phytotoxicity assessment exhibited varying sensibility to both raw backwash waters and products of coagulation process. Raw backwash waters stimulated the growth of both *L. sativum*, and *L. minor*. In contrast, they also contributed to the inhibition of the growth of one of the most sensitive species, *S. alba*. For both the sludges and supernatant liquids obtained from backwash waters after coagulation processes, an intensification of the phytotoxic effect was observed.

The coagulation process can be effectively used in water recovery from filter backwash waters. On the other hand, due to the presence of nutritive substances, raw backwash waters could be used for irrigation plants. A documented adverse phenomenon is the phytotoxicity of sludges originating from both raw and backwash waters treated by coagulation. The analysis conducted is important for the possibility of using filter backwash waters for greenery, as well as preparing biopreparations. The disadvantage of the presented phytotests is the high standard deviation values for the means of all measurements, which is related to the diverse physicochemical quality of the backwash waters.

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