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Possibility of application of kenaf fibers (*Hibiscus cannabinus* L.) in water hardness reduction

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ABSTRACT

The increasing demand for high-quality water has resulted in the development of new and cost-effective techniques for water softening. The main aim of the present study was to investigate the capillary effect of kenaf (*Hibiscus cannabinus* L.) on water softening. Water samples were taken from water distribution system of Shiraz city with hardness of 352, 466, 502, and 612 mg/l as $CaCO_3$. Two different lengths of kenaf (1.2 and 1.9 m) were tested. Hardness reduction efficiency for two lengths of kenaf were tested in the timescales of one, two, three, and five hours and were analyzed with linear mixed model (Alpha = 0.05). Results showed that the average of hardness reduction was 108.43 and 163.74 mg/l as $CaCO_3$ for kenaf with lengths of 1.2 and 1.9 m, respectively. The maximum hardness reduction was achieved at the first timescales of filtration and during the 5 h of filtration, the average of efficiency for the two lengths decreased from 53.03 to 4.54%. The results also indicated that the length of kenaf has a dominant positive effect on water hardness, while time has a negative effect. This study confirms that kenaf has a considerable potential in water softening.

Keywords: Hardness reduction; Water softening; Kenaf; *Hibiscus cannabinus* L.

1. Introduction

Surface and groundwater can have some contents more than the drinking water standards, such as hardness, heavy metals, and fluorides, which are usually found in groundwater [1,2]. These parameters can be objectionable and could have health-related problems [3,4]. Hardness of water is commonly defined as the presence of polyvalent metal cations. In most cases, calcium (Ca^{2+}) and magnesium (Mg^{2+}) are the most common causes of water hardness. The combination of Ca^{2+} and Mg^{2+} ions with bicarbonates leads to temporary hardness, while permanent hardness is mainly due to the combination of these ions with sulfate, chloride, and nitrate [5,6]. The classification of water hardness depends on the degree of hardness and its value is usually expressed as mg/l of $CaCO_3$. Water which contains calcium carbonate at a concentration of less than 60 mg/l is considered as soft,

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while with concentrations in the range of 60–120 mg/l, 120–180 mg/l, and more than 180 mg/l is regarded as moderately hard, hard, and too hard, respectively [5].

Although, there is no convincing evidence on the adverse health effects of water hardness on human health, it is a nuisance for residential and industrial units [6]. Common problems associated with hard water are scale formation and deposition in residential and industrial pipes and facilities, membrane clogging, and declining the efficiency of heat exchangers and soaps [7–9]. The principal water treatment processes are chemical precipitation, ion exchange, reverse osmosis, electrodialysis, nanofiltration, distillation, and evaporation [10–16]. All the above techniques have some problems such as sludge production, conversion of temporary hardness to the permanent type, formation of monovalent cations (i.e. sodium), precipitation of $CaCO_3$, energy consumption, etc. Moreover, due to the high retention of ions and operating costs, the production of potable water by these processes is limited [9,17–21].

Kenaf (*Hibiscus cannabinus* L.) is an annual dicotyledonous herb [22] in the Malvaceae family and is related to cotton and okra [23]. This plant is easily cultivated and grows well in the tropical regions like many parts of Iran. Kenaf has several applications such as in rope, automobile and textile industries, various grades of paper and cardboard products, building materials, animals' feeds, and absorbent products for cleaning up chemicals and oil spills [24–26].

During recent years, there has been an increased interest in the use of herbaceous materials for water and wastewater treatment. Muyibi and Evison used Moringa Oleifera seeds as a coagulant for water softening [27]. In another study, the filtration characteristic of a ground kenaf core was examined by Lee and Eiteman [28]. Shukla and Pai applied purified biopolymeric material and jute fibers for the adsorption of heavy metals ions like Cu(II), Ni(II), and Zn(II) from aqueous solutions [29]. A new application of kenaf (*H. cannabinus* L.) as a microfiltration membrane for water treatment was reported by Radiman et al. [24]. The ability of short hemp fibers in biosorption of heavy metallic ions from aqueous solutions was studied by Pejic et al. [30]. Hu et al. conducted a study on the potential of rice bran hemicelluloses A (RBHA), hemicelluloses B (RBHB), and hemicelluloses C (RBHC) for binding heavy metal ions [31].

The main purpose of this study was to investigate the application of kenaf fibers (*H. cannabinus* L.) for water softening as a simple and inexpensive technique, especially in small communities in water softening.

2. Materials and methods

In this work, the softening process of water carried out in bench scale. Water samples with hardness of 352, 466, 502, and 612 mg/l as $CaCO_3$ were taken from the water distribution system of Shiraz city (Shiraz, with a population of 1,455,073 citizens, is the capital of Fars province that is located in southwest of Iran).

Dried kenaf fibers were purchased from local market. In order to remove the natural color of kenaf, 250 cc of bleaching solution consisting of 5 wt% of sodium hypochlorite and sodium hydroxide was added to 5 L of distilled water. Kenaf fibers were cut to length of 1.2 and 1.9 m and immersed in bleaching solution for about 10–15 min at room temperature. Finally, kenaf fibers were washed with distilled water and were dried in the sunlight. In all experiments, equal amounts of kenaf fibers were used and sampling from filtered water was performed in the timescales of 1–5 h. Fig. 1 shows the water softening reactor. As shown in this figure, water flows through kenaf fibers from the feed water tank to the collection tank due to capillary action. In order to pass water through kenaf fibers, they were floated in a length of 5 cm in the water. The measured parameters in both samples and filtered water are given in Table 1.

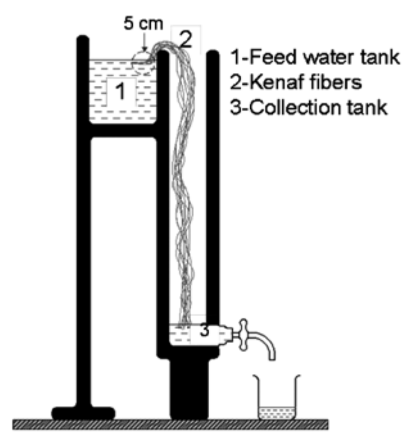

Fig. 1. Water softening reactor with kenaf fibers in laboratory bench scale.

Table 1
The measured parameters used in experiment

Row	Parameters
1	Total hardness (mg/l as $CaCO_3$)
2	Temporary hardness (mg/l as $CaCO_3$)
3	Permanent hardness (mg/l as $CaCO_3$)
4	Alkalinity (mg/l as $CaCO_3$)
5	Electrical conductivity (µs/cm)

Table 2
Mean and standard deviation of water hardness reduction and efficiency

Length (m)	Hardness reduction (mg/l as $CaCO_3$)	Efficiency (%)
1.2	108.43 (±85.28)	22.78 (± 17.45)
1.9	163.74 (± 95.40)	34.44 (± 19.39)

Hardness was measured by using EDTA Titrimetric method according to Standard Methods for the Examination of Water and Wastewater [12].

The efficiency of hardness reduction was calculated and analyzed by means of a linear mixed model and SPSS statistics software (Ver. 19.0). A linear mixed model is useful particularly in settings when repeated measurements are made on the same statistical units or when measurements are made on clusters of related statistical units [32]. Hardness of water, length of kenaf fibers, and filtration time were the predictive variables which were used in the model. The response variable included hardness reduction or efficiency of filtration, and p-value was less than 0.05.

3. Results and discussion

The results of this study revealed that the kenaf fibers decreased temporary and permanent hardness of water. The results are presented in Tables 2–4.

The efficiency of kenaf fibers with the length of 1.9 m was 1.5 times greater than the length of 1.2 m in reduction of hardness (see Table 2).

Fig. 2 shows the effect of length of kenaf fibers and filtration time on reducing the water hardness. As can be seen from this figure, the maximum hardness reduction was achieved at the first timescale of filtration. After 5 h of filtration, the average of kenaf fibers efficiency decreased from 53.03 to 4.54% and had no effect on water hardness (see Table 4). This trend was similar to other parameters listed in Table 1.

Furthermore, the effect of water hardness and filtration time on reducing the water hardness and efficiency are shown in Figs. 3 and 4, respectively.

Results also indicated that all predictors have significant effects ($p = 0.001$ or less). As shown in Tables 5 and 6, the time of filtration has a negative effect on both hardness reduction and efficiency of kenaf fibers. In addition, the length of kenaf fibers has a positive effect on the amounts of hardness reduction and efficiency.

Table 3
Total hardness reduction in different timescales

Time (h)	Length of kenaf (m)	Total hardness (mg/l as $CaCO_3$)			
		352	466	502	612
1	1.2	167.9	231.1	256.4	327.2
	1.9	142.2	194.6	216.3	281.3
2	1.2	262.4	354.3	389.8	487.3
	1.9	190.7	264.7	299.7	383.3
3	1.2	288.4	383	426.2	531.4
	1.9	212.8	303	341.9	435.8
5	1.2	338.6	448.5	487.6	596.6
	1.9	323.7	437.4	475.8	588.8

Table 4
Mean and standard deviation of measured parameters

Parameter	Time (h)			
	1	2	3	5
Hardness reduction (mg/l as $CaCO_3$)	253.96 (± 44.94)	152.71 (± 51.34)	116.68 (± 46.01)	20.98 (± 6.40)
Efficiency of hardness reduction (%)	53.03 (± 4.89)	32.14 (± 10.45)	24.74 (± 10.10)	4.54 (± 1.84)
Permanent hardness (mg/l as $CaCO_3$)	127.16 (± 43.62)	81.58 (± 32.16)	64.99 (± 37.94)	12.79 (± 6.98)
Temporary hardness (mg/l as $CaCO_3$)	128.80 (± 15.80)	72.51 (± 29.33)	52.81 (± 25.44)	8.19 (± 3.09)
Alkalinity (mg/l as $CaCO_3$)	59.49 (± 44.81)	56.97 (± 34.65)	42.51 (± 23.97)	33.55 (± 27.96)
Electro conductivity (μs/cm)	393.13 (± 97.44)	280.63 (± 183.81)	198.63 (± 105.87)	98.88 (± 91.97)

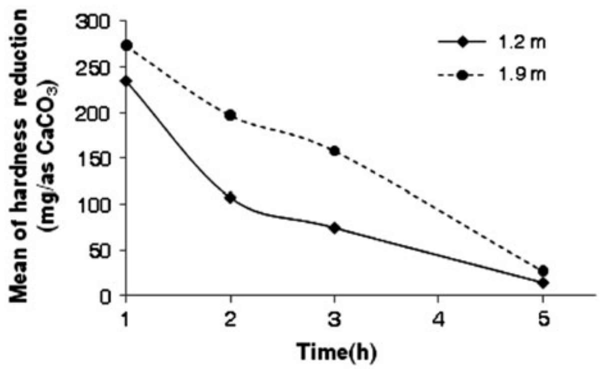

Fig. 2. Effect of length of kenaf fibers and filtration time in reducing the water hardness.

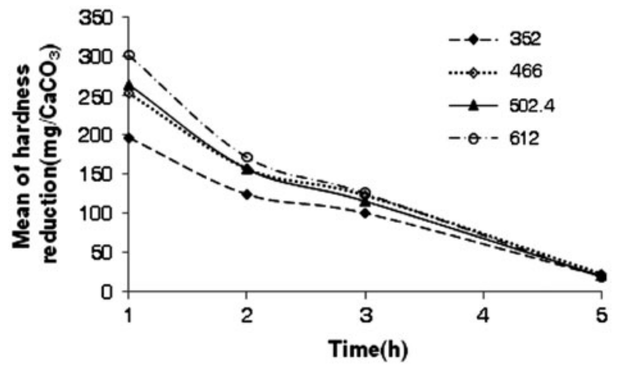

Fig. 3. Effect of water hardness and filtration time in reducing the water hardness.

The models achieved for calculating the amount of hardness reductions and the efficiency of hardness reduction are as follows:

$$HR = 4.58 + 118.31L - 42.94T + 11.54H$$

$$EF = 23.18 + 25.95L - 8.17T - 3.03H$$

where HR = hardness reduction (mg/l as $CaCo_3$); EF = efficiency of hardness reduction; L = length (m); T = time (h); H = hardness of sample (mg/l as $CaCo_3$).

It seems that the driving force which causes the water to move up through the kenaf fibers is capillary force. Due to the selective sorption of ions to the pores of kenaf fibers, the hardness of water reduced. Therefore, after a certain time (5 h), the kenaf fibers are saturated and their ability to reduce hardness of water is lost.

Since the fluoride of black tea is very high [33], it is recommended to consume fluoride free water, so water treated by kenaf will be a good choice to be used.

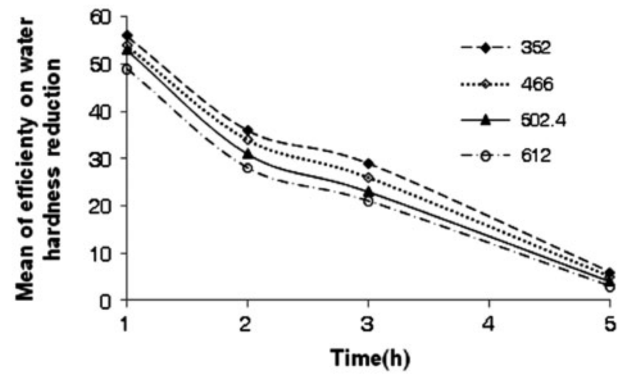

Fig. 4. Effect of water hardness and filtration time on efficiency.

4. Conclusions

The purpose of this study was to test the ability of kenaf fibers as a natural herbaceous material to reduce drinking water hardness, and a novel route for water softening has been demonstrated. According to our investigation, *H. cannabinus* L. has a considerable potential in water softening and could be used for removing ions responsible for water hardness. We found that the length of kenaf fibers has a significant

Table 5
Estimates and statistical parameters of hardness reduction

Parameter	Estimate	S.E	df	t	Sig.	95% Confidence interval	
						Lower bound	Upper bound
Intercept	4.58	18.82	13.93	0.24	0.81	−35.80	44.96
Length (m)	118.31	6.53	9.68	18.12	<0.001	103.70	132.92
Time (h)	−42.94	3.74	16.69	−11.48	<0.001	−50.84	−35.03
Hardness (100 mg/l as $CaCO_3$)	11.54	2.46	9.68	4.69	0.001	6.03	17.05

Table 6
Estimates and statistical parameters of efficiency

Parameter	Estimate	S.E	df	*t*	Sig.	95% Confidence interval	
						Lower bound	Upper bound
Intercept	23.18	2.59	10.33	8.94	<0.001	17.43	28.93
Length (m)	25.95	0.91	8.66	28.52	<0.001	23.88	28.02
Time (h)	−8.17	0.59	17.77	−13.95	<0.001	−9.41	−6.94
Hardness (100 mg/l as $CaCO_3$)	−3.03	0.34	8.66	−8.84	<0.001	−3.81	−2.25

effect on reducing hardness of drinking water. Increasing the length of kenaf fibers would increase predominantly the amount of hardness reduction. The average of total hardness reduction was 108.43 and 163.74 mg/l as $CaCO_3$ for kenaf fibers with lengths of 1.2 and 1.9 m, respectively. Better results can be acquired by consecutive implementation of kenaf fibers. After 5 h of filtration, the average of total hardness reduction dropped from 253.96 to 20.98 mg/l as $CaCO_3$. Results also indicated that the kenaf fibers could be recovered and reused for further runs after washing with distilled water. The mechanism of adsorption of ions on kenaf fibers and their interactions are not fully understood. Therefore, further studies have to be carried out to provide an insight into the influence of kenaf fibers in water softening process.

Water softening with kenaf fibers in comparison with other methods, such as reverse osmosis, ion exchange, filtration, electrodialysis, nanofiltration, and distillation, can be applied as a small-scale or household facility, especially in tropical regions and small rural areas because of the ease of application and low operating costs. Furthermore, this method can be considered as an environmentally friendly technology to prepare soft water.

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