Novel Chitosan-Cellulose Backbone for Grafting Polymerization of Acrylic Acid and Application in Controlled Release

Hisham A. Essawy¹, Mohamed B. M. Ghazy², Farag Abd El-Hai²
and Magdy F. Mohamed²

¹Department of Polymers and Pigments,
National Research Centre, Dokki 12622, Cairo, EGYPT.
²Chemistry Department, Faculty of Science,
El-Azhar University, Nasr city, Cairo, EGYPT.
email: hishamessawy@yahoo.com.

(Received on: December 11, 2015)

ABSTRACT

Novel superabsorbents derived from grafting polymerization of acrylic acid onto chitosan-cellelose hybrid ((CTS/Cell)-g-PAA) exhibited good mechanical strength and elevated water absorption in a wide range of pH response. Prolonged water retention was also observed even at elevated temperatures. This could be attributed to the high grafting yield of acrylic acid and the nature of chitosan-cellulose hybrid. The superabsorbents showed good potential as devices for controlled release of soil nutrients so can be strongly recommended for use in agriculture and horticultural applications.

Keywords: Chitosan-cellulose hybrid, grafting, superabsorbents, soil, fertilizers, controlled release.

1. INTRODUCTION

Hydrogels are three dimensional network structures of hydrophilic polymers. Superabsorbent are special class of hydrophilic polymers with exceptional water absorption. They can absorb great amount of water, ranging from hundreds to thousands times of their original weight. The superabsorbents are broadly employed in several fields like cosmetics, hygienic, food industry, drug-delivery, horticulture and agriculture. Graft copolymerization of vinyl monomers onto polysaccharides such as starch, chitosan, sodium alginate, carrageenan, and cellulose stays among the dedicated routes for hydrogel formation. Chitosan, which is a natural linear polysaccharide comprising 1,4-linked 2-amino-deoxy-β-D-glycan, is a partially deacetylated form of chitin. It has free amino and hydroxyl groups which
facilitates chelation and crosslinking potential. It is so expected that the crosslinked chitosan derivatives will most likely combine the benefits of chitin and chitosan. Many reports investigated the preparation and utilization of superabsorbents as a result of their biocompatibility, bio-degradability, low toxicity, antibacterial, and potential of chelation\textsuperscript{16-21}. Chitosan was found to be a suitable backbone for the grafting of poly(acrylic acid) which yielded an excellent superabsorbent material\textsuperscript{22}. In addition, Cellulose, which is another natural linear carbohydrate polymer consisting of D-glucopyranose units joined together by β-1,4-glycosidic linkages, is the most abundant biopolymer and can be found mostly in wood and cotton, among many other sources\textsuperscript{23}. However, the superabsorbent materials based on chitosan suffer from poor mechanical properties. The addition of cellulose as reinforcing fillers into the hydrogel matrix was suggested to improve the mechanical properties along with their handling\textsuperscript{24}. Likewise, Xie and Wang\textsuperscript{25} prepared a composite from chitosan and muscovite. Unfortunately, the improvement of mechanical strength following this route was mostly accompanied by a drop in the water absorption. Other strategies were thus attempted to enhance the mechanical properties of chitosan-based superabsorbents along with their water absorption. Among these attempts, Zheng \textit{et al.}\textsuperscript{26} prepared a composite from chitosan and attapulgite via in situ grafting polymerization of acrylic acid in aqueous solution. Mucha and Pawia\textsuperscript{27} suggested that blends from chitosan and hydroxypropyl cellulose resulted in good miscibility and better optical transparency and mechanical properties. However, Yin and his team\textsuperscript{28} examined the miscibility of chitosan with hydroxypropylmethylcellulose and methylcellulose and concluded that full cannot be achieved if the hydrogen bonding between the polymers is weak.

Recently, superabsorbent materials were reported to expand the fertilizer release in soil which reduced the death rate of plants and increased their growth\textsuperscript{29}. The need to control the fertilizers liberation is anticipated to ensure the nutrients gradually released according to the requirements of a plant. This study aims to overcome the poor mechanical properties of chitosan based superabsorbents, which was verified by chemical linkage of chitosan with cellulose fibrils by chemical reaction with thiourea-formaldehyde in the presence of sulfuric acid to combine both into one entity. The chemical reaction between chitosan and cellulose by crosslinking increases the flexibility of the formed hybrid. The new crosslinked entity of chitosan and cellulose will be used as backbone for grafting poly(acrylic acid) to produce a multifunctional superabsorbent hydrogel composite considering that the combination of both in one integrated structure gives rise to a higher grafting efficiency. In this way, we get combination of advantages, which are excellent water absorbency and retention, along with the enhanced chemical activity created by the presence of chitosan. Such environment-friendly system is expected to offer more ability to bond fertilizers and help in extending their release to the soil, which is especially useful in agricultural and horticultural applications.

2. EXPERIMENTAL

2.1 Materials

Acrylic acid (AA) and ammonium persulfate (APS) were purchased from Sigma-Aldrich,
USA. Chitosan (CTS, with deacetylation above 85%) was purchased from Euromedex, France. Cellulose pure powder (Cell) and potassium hydroxide were supplied from Sd. fine Chem., India. N,N’-methylenebisacrylamide (MBA) was ordered from Merck, Germany. Potassium dihydrogen orthophosphate and ammonium nitrate (denoted together as NPK) were bought from Fluka. Other chemicals were all of analytical grade.

2.2 Preparation of crosslinked chitosan-cellulose (CTS/Cell)

A crosslinked structure comprising both chitosan and cellulose was prepared after the method introduced by Chanachai et al.\textsuperscript{30}. Briefly, chitosan (1.2 wt. %, w/v) was dissolved in 2 wt. % aqueous solution of acetic acid. A dilute aqueous cellulose suspension (1.2 wt. %, w/w) was prepared by dispersing its powder in distilled water under vigorous magnetic stirring at 60 °C for 24 h. The cellulose became like a clear homogenous solution. Thus, the chitosan solution was filtered and both solutions were mixed together, and the stirring was performed at room temperature for 24 h. The resulting solution was poured into a glass plate and dried at room temperature for 4 days then the blend was removed from the plate in the form of a film. The film was crosslinked in a homogeneous mixture including 2.5 wt. % thiourea, 2.2 g formaldehyde solution, and 2.5 wt. % sulfuric acid solution dissolved in 100 ml ethanol-water (1:1) at room temperature for 2 h. The film was washed several times with deionized water and eventually dried at room temperature for 2 days. After drying, the film was exposed to grinding and sieved to particles of less than 74 µm.

2.3 Preparation of crosslinked (CTS/Cell)-g-PAA superabsorbent composite

The superabsorbent composites were synthesized as follows; 1 g of crosslinked (CTS/Cell) particles was suspended in 30 ml distilled water under stirring in a three-neck flask equipped with a reflux condenser, a funnel, and a nitrogen line. The system was flushed with nitrogen for 30 min. Afterward, 0.1 g APS was inserted to induce the crosslinked (CTS/Cell) particles to produce radicals. After 15 min., a solution including 3.60 g acrylic acid and 0.1 g N,N’-methylenebisacrylamide (crosslinking agent) were added to the solution. The temperature was kept at 70 °C and the solution was agitated for additional 3 h to warrant completion of the polymerization. The resultant product was cooled down to room temperature and neutralized to pH 7 using 1 molL\textsuperscript{-1} KOH solution. The material was washed with large volume of distilled water to remove the residual reactants and then oven dried at 70 °C. The product was milled and the particle size of all samples was in the range of 400-840 µm. The grafting efficiency (GE) and grafted yield (GY) were determined according to equation 1 and 2\textsuperscript{31-34}.

\[
GE\% = \frac{(w_1 - w)}{(w_2 - w)} \times 100
\]

\[
GY\% = \frac{(w_2 - w)/w}{w_2} \times 100
\]

where w, w\textsubscript{1} and w\textsubscript{2} are weights of chitosan-cellulose, purified graft polymer and total weight of crude polymer, respectively. For comparison, blank samples were prepared while applying chitosan alone in the same weight ratio after dissolving in dilute acetic acid solution (1%, v/v),
the corresponding sample was denoted as CTS-g-PAA. Another sample was prepared using half the weight of chitosan and the same weight of cellulose was added as a part of the monomers solution just as filler, the sample was coded as (CTS-g-PAA/Cell). Thus, CTS-g-PAA/Cell comprises the same weights of chitosan and cellulose but employed individually rather than in one entity of crosslinked hybrid as for (CTS/Cell)-g-PAA.

2.4 Water absorbency measurements

A specific weight of the superabsorbent was immersed in distilled water at room temperature for 24 h. The swollen samples were removed from the medium by filtration. The water absorbency, \( Q (g/g) \), of the superabsorbent composites was determined by taking the water difference of the samples before and after immersion in the water and applying the following equation:

\[
Q = \frac{(M_2 - M_1)}{M_1}
\]  

(3)

where, \( M_1 \) and \( M_2 \) are the weights of the dry and swollen samples (g), respectively. \( Q_d \) and \( Q_n \) the symbols designed in case of distilled water and saline (0.9% NaCl soln.), respectively.

2.5 Loading of NPK as fertilizer to the superabsorbents

The loading of potassium dihydrogen orthophosphate and ammonium nitrate was achieved by immersing a pre-weighed amount of the dry superabsorbent into 500 ml of aqueous containing potassium dihydrogen orthophosphate (0.03 molL\(^{-1}\)), and ammonium nitrate (0.03 molL\(^{-1}\)) for 24h. Subsequently, the swollen gel was dried at 40 °C for 3 days\(^{35}\). The loading percentage was calculated using Eq. (4):

\[
\text{Loading\%} = \frac{[m_1 - m_0]}{m_1} \times 100
\]  

(4)

where \( m_0 \) and \( m_1 \) are the weights of unloaded and loaded dry gels, respectively.

2.6 Characterization of synthesized superabsorbent polymers

FTIR spectra of the samples were recorded using FTIR spectrophotometer (Jasco, Model 6100, Japan) in the range 500 - 4000 cm\(^{-1}\) at a resolution of 4 cm\(^{-1}\). The dried samples were blended with KBr and pressed into discs before acquisition. The morphological features of samples were examined using SEM (JSM-5500LV, JEOL, Ltd.), operated at a vacuum mode, after being gold coated with a sputter Coater (SPI-Module).

2.7 Controlled release of NPK fertilizer

The release of NPK as a fertilizer from the prepared superabsorbent composites was studied as follows, 1.0 g of the crosslinked (CTS/Cell)-g-PAA/NPK samples in the form of granules with 400-840 \( \mu \)m diameter was soaked individually into 1 L of distilled water. After certain time intervals, 10 ml solution of each sample was withdrawn and an additional 10 ml
of distilled water was added into the original solution to keep the amount of solution unchanged. The total fertilizer concentration was determined using digital conductivity meter\textsuperscript{36}. In addition, the contents of the fertilizer components in the solution were also estimated using an element analyzer instrument (Elementar Vario El III, Germany) in case of N, colorimetric method based on molybdovanadate reagent using a spectrophotometer (HACH, model DR/2010)) in case of P while employing atomic absorption (AA 200 series, Agilent, USA) in case of K\textsuperscript{11}. Comparison samples containing the same amount of NPK granules (400-840 μm diameter) free of any superabsorbent polymer were prepared as control and the components N, P, and K were determined as above.

2.8 Water retention of crosslinked (CTS/Cell)-g-PAA/NPK in soil

2 g of the crosslinked superabsorbent composite (CTS/Cell)-g-PAA/NPK was mixed with 100 g of dry sandy soil granules (below 840 μm diameter) and added to a 250 ml beaker along with 200 ml of distilled water. The beaker was placed in a conditioned room in which the temperature and relative humidity were 25 °C and 31%, respectively. The overall weight was followed every 4 days for a period of 4 weeks. At the same time, a controlled sample was prepared, namely, without any superabsorbent polymer. The water evaporation was quantified using the following equation:

\[
\text{Water retention (\%)} = 100 - \left(\frac{W_2 - W_1}{200}\right) \times 100
\]

Where \(W_2\) is the initial overall weight of the beaker components and \(W_1\) is the weight after the predetermined time intervals.

3. RESULTS AND DISCUSSION

3.1 Characterization of CTS/Cell hybrid

Hydrogels with chitosan units are considered as promising materials as a result of their great adsorption capacity and ability to provide a potential for regeneration and reuse after metal adsorption\textsuperscript{37}. The broadening of their applications is limited by the lack of mechanical strength poor resistance to acidic solutions\textsuperscript{38}. In order to overcome such disadvantages, intensive efforts aimed to modify the chemical nature of chitosan by combining with cellulosic structures. The concern beyond this comes from the abundance of this natural biopolymer, which exhibits high mechanical strength. The similar chemical structure presents higher possibility for obtaining a homogeneous hybrid comprising unique properties from both\textsuperscript{39}. This is expected to improve the water absorption and provide higher chemical activity. This was done in several studies by chemical crosslinking of the surface with crosslinking agents, such as glutaraldehyde (GA), ethylene glycol diglycidyl ether (EGDE), and epichlorohydrine\textsuperscript{40}, while in the current work we utilized thiourea formaldehyde resin as a crosslinking agent\textsuperscript{16}. We will explore the possibility of obtaining a novel superabsorbent based on this hybrid after grafting of acrylic acid onto its backbone.
Scheme 1: A depiction for the combination of cellulose and chitosan into crosslinked (CTS/Cell) hybrid and its subsequent use as backbone for the graft polymerization of acrylic acid, crosslinked (CTS/Cell)-g-PAA.

Scheme 1 demonstrates the linking of chitosan and cellulose into a hybrid comprising both structures with the aid of thiourea formaldehyde as crosslinking agent. In a subsequent step, the acrylic acid was grafted onto this backbone in the presence of ammonium persulfate, that provoked radical formation on the surface. Such radicals initiated the graft polymerization of the monomer on the surface of the hybrid.

Fig. 1: FTIR spectra of (A) cellulose, (B) chitosan

December, 2015 | Journal of Chemistry and Chemical Sciences | www.chemistry-journal.org
The IR spectra of cellulose and chitosan are displayed in Fig. 1. The relevant spectrum of cellulose shows bands at 3414, 1638, 1336 and 1111 cm$^{-1}$ which can be ascribed to OH stretching. The CH stretching is represented by band at 2901, 1371 and 896 cm$^{-1}$. The peak at 1430 is attributed to CH$_2$ while those at 1162 and 1057 cm$^{-1}$ reveal C-O-C stretching (Fig. 1a). The corresponding IR profile of chitosan is presented in Fig. 1b, where a stretching vibration at 3432 cm$^{-1}$ can be related to OH and NH. Additionally, peaks at 2879 and 2920 cm$^{-1}$ are attributed to the CH stretching while 1421 cm$^{-1}$ belongs to CH$_2$ stretching.

The IR spectra of both CTS/Cell bead before and after crosslinking are revealed in Fig. 2. A physical blend of these components shows simply a combination of the characteristic peaks of chitosan and cellulose (Fig. 2a). The 2088 cm$^{-1}$ band confirms salt formation on the amino sites of the chitosan with the acetate anions during the solvation in acetic acid. After achieving the crosslinking process using the thiourea formaldehyde resin a tiny difference was noticed (Fig. 2b). This difference can be demonstrated as several perturbations of many bands. The similar chemical structure of cellulose and chitosan in addition to the rich spectra of the binding resin was a hindrance for going deeply insight. The spectral change can be explained according to the undergone chemical reactions between the hydroxyl groups and methylolureas and are sufficiently proving the crosslinking process and formation of a new chitosan-cellulose hybrid.

3.2 Characterization of superabsorbent composite

Fig. 3: FTIR of (A) crosslinked (CTS/Cell), (B) crosslinked (CTS/Cell)-g-PAA.
Fig. 3 demonstrates the IR profiles of the crosslinked (CTS/Cell) hybrid before (Fig. 3a) and after grafting of acrylic acid (Fig. 3b), respectively. The hybrid before grafting exhibits signals in the range 3000-3856 cm\(^{-1}\). These signals are attributed to OH and NH stretching vibrations. However, additional bands at 1637, 1307 and 1116 cm\(^{-1}\) were also indicative of the OH stretching. The CH stretching was confirmed by the peak at 2924 cm\(^{-1}\) while the band at 1428 cm\(^{-1}\) refers to CH\(_2\). The signals at 1116 and 1186 cm\(^{-1}\) present the C-O-C stretching. The at 2140 cm\(^{-1}\) indicate that –NH\(_2\) groups of chitosan are likely be involved in salt formation with acetate ions.

Examining the IR spectra of the resulting superabsorbent (Fig. 3b) shows it is similar to the corresponding IR spectra of the hybrid. The intensity of the CH\(_2\) peaks increased and a new shoulder appeared at 1715 cm\(^{-1}\) which belongs to the carbonyl groups of the grafted polyacrylic acid. The complete disappearance of the peak at 2140 cm\(^{-1}\) constitute a proof of formation of (CTS/Cell)-g-poly(acrylic acid) in a crosslinked form. Furthermore, it is expected that irrespective of the main grafting process, the propagated acrylic acid chains participated with the –COOH groups to couple the cellulose and chitosan in one hybrid via esterification reactions on the OH groups as well as via radical-radical termination.

3.3 Morphology of superabsorbent composites

![SEM micrographs](image)

Fig. 4: SEM micrographs of (a) CTS-g-PAA, (b) CTS-g-PAA/Cell, (c) crosslinked (CTS/Cell)-g-PAA, and (d) crosslinked (CTS/Cell)-g-PAA-NPK superabsorbent composite.

The morphological features of acrylic acid grafted chitosan are consistent with a highly porous structure lacking mechanical strength (Fig. 4a). The addition of cellulose as filler during the grafting polymerization of acrylic acid led to a reinforcing action and
obstructed the porosity. This is in conformity with poor miscibility between the chitosan and cellulose under the applied reaction conditions. This can be further evidenced by the detection of some cellulose particles exist free on the chitosan surface (Fig. 4b). Permanent chemical linking of chitosan and cellulose in one hybrid using thiourea formaldehyde resin, and consequent grafting on this hybrid led to a mechanically robust material exhibiting homogeneous surface (Fig. 4c). In addition, it can be noticed the absence of free cellulose particles existing liberally on the surface of the hybrid which ensures the combination of chitosan and cellulose in one hybrid material. This hybridization thought to enhance the grafting process and water absorption as well. After grafting, NPK as fertilizer was loaded to the resulting superabsorbent. The NPK are hardly detected on the surface which ensures that the fertilizer became mostly entrapped within the network structure of the crosslinked (CTS/Cell)-g-PAA superabsorbent (Fig. 4d).

3.4 Grafting onto crosslinked (CTS/Cell)

![Graphs showing grafting yield (A) and efficiency (B) of CTS-g-PAA, CTS-g-PAA/Cell and crosslinked (CTS/Cell)-g-PAA.]

The grafting efficiency and yield of neat chitosan and in presence of cellulose as filler are compared in Fig. 5 with the same parameters for the chemically linked hybrid. It is obvious that the efficiency for the CTS-g-PAA, CTS-g-PAA/Cell and crosslinked (CTS/Cell)-g-PAA were all in the same level (83% in average). Interestingly, the grafting yield was more suggestive and revealed that obtained hybrid attained the highest yield (750%) as compared to either neat chitosan (472%) or cellulose filled chitosan (692%). This means that the inclusion of the cellulose by any means improved the grafting process especially in the case of the chemically linked hybrid. This can be explained on the light of the higher capability of the cellulose to respond to the initiator attack by free radical formation which generates higher number of grafting sites. This finding may be considered as another proof for the hybridization of chitosan and cellulose and that the grafting on this hybrid was not influenced by their chemical coupling.
3.5 Water sorption potential of the superabsorbent composites

The water absorption potential of the prepared superabsorbents was investigated in distilled water and saline. The distilled water absorption of CTS-g-PAA was in the range 140 g/g, almost doubled and acquired water absorption of 275 g/g when the cellulose was incorporated as filler (CTS-g-PAA/Cell). In case of the crosslinked hybrid (CTS/Cell)-g-PAA) the enhancement in the water absorption reached 178% with respect to the chitosan as a sole backbone for grafting (390 g/g). In case of saline (0.9 wt. % of NaCl solution) the absorption lessened dramatically. It is known that with increasing the ionic strength diminish of the ionic charges on the polymeric network which results in intensive shrinkage and passage of the stored water to outside the network41.

3.6 Effect of pH on the swelling

The swelling behavior of the superabsorbent samples at various pH values between 2 and 12 is displayed in Fig. 6 which shows that the swelling of the superabsorbent was increased with increasing pH from 2 to 7. In the pH region above 7, it decreases again continuously until pH 12. The maximum water absorbency of the hybrid (CTS/Cell)-g-PAA was reached at pH 7. In acidic solutions, due to the presence of high concentration of H+, greatest number of the carboxylate anions are in the protonated form, thereby the anion-anion electrostatic repulsion was impaired almost completely.

Further, it is supposed that the –NH2 groups protonation at the same pH range will give rise to enhanced repulsion therefore works against the diminished repulsion on the protonated –COO groups. At pH 7, COOH groups are in the COO− form which results greater anion-anion repulsion and consequently higher swelling capacity. Above pH 8 the swelling of hybrid (CTS/Cell)-g-PAA decreases due to the presence of high content of K+ cations emerging from KOH in the solution. This shields the –COO- groups and inhibits perfect anion-anion repulsion. The accumulation of carboxylic ions inside the hybrid (CTS/Cell)-g-PAA network increases the water discharge from the network as a result of the weakening of the hydrogen bonding between the water and carboxylic groups thus the hybrid (CTS/Cell)-g-PAA shrinks42, 43.
3.7 Water retention behavior of crosslinked (CTS/Cell)-g-PAA-NPK superabsorbent composite in soil

![Water retention behavior of water](image)

Due to the superiority of the crosslinked (CTS/Cell)-g-PAA as compared to the prepared superabsorbents, it was selected to be loaded with NPK as fertilizer thus it was necessary to follow its water retention behavior in the soil at room temperature and 31% humidity after the loading as clear from Fig. 7a. The water retention behavior of the soil alone was also studied for comparison (Fig. 7b). Within 4 weeks, the capability of the soil containing the superabsorbent composite to retain water was noticeably greater than that of the soil alone. It was 58 and 24% on the 12th and 24th days, respectively. For the neat soil, it reached 49 and 8% after the same time interval. This proves that the superabsorbent in the soil could evidently increase its water retention and decrease the evaporation rate.

3.8 Fertilizer release

In order to follow the release of the loaded nutrients, conductivity measurements were performed in aqueous media as a function of time at 25 °C for fertilizer loading of 19% (curve b) and for the same amount of the nutrients alone as a control (curve a) as demonstrated in Fig. 8. The release from the free nutrients was very fast and immediately attained a plateau within 16 min. due to the rapid dissociation of the soluble salts in the water.

![Cumulative release](image)

Fig. 8: Monitoring of nutrient release at 25 °C using conductivity measurements as a function of time for (a) NPK fertilizer, (b) crosslinked (CTS/Cell)-g-PAA/NPK superabsorbent composite.
On the other hand, the release from the crosslinked (CTS/Cell)-g-PAA/NPK system was started slower within the first 15 min. and continued much slower up to 40 min. Further ahead the release was faster but stepped steadily for the next 3 h. which indicates that the release exhibited a sustained behavior as dominated by its interaction with the superabsorbent. The conductivity measurements are reflecting the total concentration of the electrolytes in solution thereby differentiation between N, P and K was not possible.

Fig. 9: Release behaviors of nitrogen, phosphorous and potassium from (A) crosslinked (CTS/Cell)-g-PAA-NPK superabsorbent composite, and (B) free NPK fertilizer without superabsorbent polymer.

The release of each component of the fertilizer is displayed individually in Fig. 9 from the crosslinked (CTS/Cell)-g-PAA/NPK composite (Fig. 9a) as compared to the free forms (Fig. 9b). The corresponding profiles point out that the cumulative released amount increased much slower from the polymeric system as a function of time (especially during the first hours) as compared to the free NPK sample. The release was completed within 16 min. from the free fertilizer sample while prolonged to almost 3 h from the superabsorbent. To be more specific, the release of fertilizer from the crosslinked (CTS/Cell)-g-PAA/NPK reached 42.24%, 54.34% and 89.03% in 10, 20 and 90 min., respectively. The slower release of fertilizer from crosslinked (CTS/Cell)-g-PAA/NPK can be related to some interaction with the ionic sites of the polymeric network. Interestingly, the N release was significantly faster than the other elements from the free sample while the polymer matrix helped to provide more control and simultaneous liberation of all components which is thought to be advantageous for the plants.

ACKNOWLEDGMENT

We express our sincere thanks to Delta Agrochemicals Company for providing financial support for this work.

4. CONCLUSIONS

Chemical combination of chitosan and cellulose in one stable backbone, suitable for post grafting polymerization of acrylic acid, gives better contribution to the mechanical
strength of resulting superabsorbent than the equivalent graft copolymer obtained from chitosan alone. Improved resistance to acidic conditions and broadening of the chemical activity over a wide range of pH are additional advantages that give rise to higher water absorption and prolonged retention. These characteristics make these superabsorbents promising for tailoring devices for controlled release applications of soil nutrients.

REFERENCES


