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# Structural characterization and water turbidity removing efficacy of *Portulaca* mucilage–alginate (PMA) beads

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ABSTRACT

The focus of the present study includes the isolation, characterization, and a correlation of water clarification efficacy of mucilage from *Portulaca oleracea* leaves, a food-grade polysaccharide and its encapsulated calcium alginate beads. The characterization of mucilage powder was conducted for its physical and chemical properties. *Portulaca* mucilage was encapsulated in calcium alginate to develop *Portulaca* mucilage–alginate (PMA) beads. The developed beads were characterized by scanning electron microscopy, energy dispersive X-ray analysis, thermo gravimetric analysis, differential scanning calorimetric analysis, and fourier transform infrared spectroscopy techniques to study various physicochemical aspects. Efficiency of PMA beads for water clarification in low as well as high turbid water was investigated. Percentage turbidity removal was found to be 97 and 87%, respectively, in high and low turbid waters. Efficiency of recycled beads was also studied. Mucilage and PMA beads showed varied surface morphologies before and after treatment with turbid water. Relevancy of these variations to the turbidity removal is discussed. Swelling studies revealed that the beads were swelled at low pH range (pH < 5) and at higher pH range (pH > 9). The findings of this study lead to the potential production of new environmentally friendly composite beads for water clarification.

*Keywords:* *Portulaca* mucilage; PMA beads; Sodium alginate; Water turbidity removal; Swelling behavior; Natural coagulant

## 1. Introduction

Mucilage is a polysaccharide macro molecule that dissolves more or less upon contact with water and forms a colloidal solution [1]. In recent years, plant mucilage has raised tremendous interest due to its diverse application in pharmacy in the formulation of both solid and liquid dosage forms as thickeners, water retention agents, emulsion stabilizers, suspending agents, binders, and film formers [2]. With the increase in demand for natural mucilage, it has become necessary to isolate and evaluate the newer sources of mucilage to meet the needs. Vast application of plant mucilage in various industries is because of low cost, ready availability, and important properties which they confer on products.

*Portulaca* mucilage was isolated from the leaves of *Portulaca oleracea* Linn, which belongs to the family Portulacaceae. It is commonly known as purslane and

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is an annual succulent weed native to India. Purslane is a good leafy vegetable and eaten throughout much of Europe and Asia. Its mucilage is of great use for soups and stews.

*Portulaca* is a rich source of omega-3 fatty acids, which are thought to be important in preventing heart attacks and strengthening the immune system [3]. *Portulaca oleracea* leaves mucilage has a complex arabinogalactan structure similar to gum arabic and contains d-galactose:l-arabinose:d-galacturonic acid:d-xylose:l-rhamnose at a ratio of 40:20:5:1:31 [4]. It can spread in water easily and change to thermal-resistant mucilaginous liquid when heated. Its gel can be used as a mucoadhesive agent for gastric retention purposes [5]. The use of various plant extracts as natural coagulants for water clarification was reported earlier [6–8]. In recent works, plant polysaccharides such as chitosan and mercaptoacetyl chitosan [9,10] were also used for turbidity removal. However, reports are lacking on *Portulaca* mucilage in this regard. Isolated reports are available on physicochemical characterization of the *Portulaca* mucilage, but comprehensive studies on *Portulaca* mucilage-alginate (PMA) composite beads with respect to their morphological physicochemical characterization in relation to water clarification efficiency has not been done.

The objective of the present study was isolation and characterization of *Portulaca* mucilage and PMA beads with respect to water clarification. The beads were assessed for their morphological properties and elemental composition before and after using for water turbidity removal. Alginate is a nontoxic hydrophilic polysaccharide, consists of 1,4-linked β-D-mannuronate and α-L-guluronate residues, chosen as the polymeric vehicle due to its useful properties and versatility and the relative ease with which they undergo gelation with divalent cations suitable for biomacromolecules and living cells [11,12]. The gel-forming property of mucilage leads to the present investigation. Thus, in this study composite micro spheres were developed and characterized. $CaCl_2$ was used as both cross-linking and coagulating agent to sodium alginate. $Na_2B_4O_7$ solution was used to lower the rapid solubility of mucilage and thereby expelling water to form semi-transparent solid. This process retains the elasticity and mechanical strength of the beads. The properties of *Portulaca* mucilage and PMA beads, such as functional groups, morphology, elemental composition, and pH-sensitive behavior of the beads, were evaluated and correlated with their water clarification activity.

## 2. Materials and methods

### 2.1. Materials

Mucilage was isolated from the leaves of *Portulaca oleracea* L. using hot aqueous extraction method developed by Garti et al. [4]. Sodium alginate, $CaCl_2$, and $Na_2B_4O_7$ were purchased from Sigma-Aldrich Chemicals (Hyderabad, India). All chemicals were of analytical grade.

### 2.2. Preparation of PMA beads

Preparation of PMA beads was carried out using the method of Mohamadnia et al. [13] with some modifications. Various concentrations of sodium alginate were used to optimize the concentration. Fifty milliliters of 0.5, 1.0, 2.0, 3.0, and 4.0% solutions of sodium alginate were prepared by dissolving 0.25, 0.5, 1.0, 1.5, and 2.0 g of sodium alginate in 50 ml of distilled water, respectively. Fifty milliliters of 0.5, 1.0, 2.0, 3.0, and 4.0% solutions of mucilage were also prepared by dissolving 0.25, 0.5, 1.0, 1.5, and 2.0 g of mucilage powder in 50 ml of distilled water, respectively, under stirring. Prepared sodium alginate solutions were mixed with an equal volume of mucilage solution to get the final concentration of sodium alginate 0.25, 0.5, 1.0, 1.5, and 2.0%, respectively. Different concentrations of sodium alginate mixed with mucilage solution were added separately from a height of nearly 1–2 cm into excess of $CaCl_2$ solution. For 10 ml of sodium alginate-mucilage mixture, 100 ml of $CaCl_2$ solution was required. The formed beads (Fig. 4) were left to harden for 2 h in the same $CaCl_2$ solution. The beads were washed with Tris-buffer (7.5 pH, 0.05 M) to remove the loosely bound mucilage and allowed to dry the beads at room temperature.

### 2.3. Jar test experiments for synthetic water turbidity removal

High turbid water of 450 NTU (Nephelometric Turbidity Units) was treated with mucilage concentrations of 20, 40, and 60 mg/1; and 500, 1,000, and 1,500 mg/1 dosage of PMA beads. Whereas, low turbid water of 35 NTU was treated with 6, 12, and 20 mg/1 concentrations of unentrapped mucilage and 150, 300, and 500 mg/1 concentrations of PMA beads. Kaolin clay was used for synthetic turbid water preparation. Systronic Digital Nephelo-turbidity meter 132 was used for turbidity measurement.

In each experiment, 500 ml aliquots of turbid water in 1 L beakers were placed on a magnetic stirrer. Mixing was started at 100 RPM (rotations per minute).

After addition of requisite doses of coagulant, the mixing was continued for 1 min to ensure proper dispersion of coagulant in water. The stirring was continued for 9 min at a speed of 40 RPM. At the end of the mixing period, the beakers were removed and the contents were allowed to settle for 1 h. For turbidity measurements, 30 ml of settled water sample was withdrawn.

The optimum concentrations and particular reaction time were chosen based on highest observable efficiency. Details were discussed in previous reports [14].

### 2.4. Characterization of mucilage powder and developed mucilage/alginate beads

(1) *Physical characterization*: isolated mucilage powder was evaluated for its physical characteristics viz. appearance, odor, solubility, percentage yield, swelling ratio (SR), weight loss on drying, pH, density, surface morphology, and viscosity, according to the method of Wolfe et al. [15].
(2) *Chemical characterization*: mucilage powder was subjected to chemical identification tests for carbohydrates, steroids, terpenoids, alkaloids, flavanoids, tannins, and saponins, according to the method of Harborne [16].
(3) *Flow Properties*: the dried *Portulaca* mucilage powder was investigated for the flow properties viz. bulk density, compressibility index, and Hausner's ratio, according to the method of British pharmacopeia [17].
(4) *Morphology*: mucilage powder and beads, those treated with 450 NTU were processed for SEM observation. Samples were mounted on a metal stub with a double-sided adhesive tape, coated with gold, using HUS-5GB vacuum evaporator, and the images were taken at an accelerating voltage of 10 kV using Hitachi S-3000N Scanning Electron Microscope.

### 2.5. pH-sensitive properties of the composite gel beads

The swelling behavior of a support under specified experimental conditions is an important parameter for immobilized cell carriers [18]. Swelling characteristics of the beads were determined by immersing dried test beads in various aqueous media (pure water and buffer solutions with pH 2, 4, 6, 8, 10, 12, and 14) at room temperature. Accurately weighed amounts of beads (1 g) were immersed in 50 ml buffer solutions and the beads were removed from the swelling medium at specific time intervals. They were blotted with filter paper and weighed immediately.

SR of the sample was calculated according to the following expression.

$$\mathrm{SR}(\%) = \left[\frac{W_s - W_d}{W_d}\right] \times 100 \quad (1)$$

where $W_s$ is the weight of the swollen beads at each predetermined buffer solution under the equilibrium state, $W_d$ is the weight of the beads at dried state.

### 2.6. Fourier transform infrared spectroscopy (FTIR)

The FTIR spectra of the native sodium alginate, dry mucilage powder, and mucilage/alginate composite gel beads over the wavelength range 4,000–400 $cm^{-1}$ were recorded using Thermo Nicolet, NEXUS, and TM, USA FTIR spectrometer. Individual beads were crushed with pestle in a mortar; the crushed material was mixed with potassium bromide. The mixture was compressed to a 1 mm semi-transparent disk by applying a pressure of 20 MPa (FW-4A pelleter) for 5 min.

### 2.7. Elemental analysis

Elemental analysis was carried out employing INCAx-sight Oxford Energy Dispersive X-ray Analysis (EDAX) detector fitted to Hitachi S-520 Scanning Electron Microscope.

### 2.8. Thermal analysis

Thermo gravimetric analysis (TGA) and Differential scanning calorimetric (DSC) studies were carried out on *Portulaca* mucilage powder, PMA beads, and sodium alginate as well. TGA was performed using a TGA/SDTA 851$^e$ (METTLER TOLEDO, Switzerland) with a TS0801RO Sample Robot. DSC was performed using a DSC 821$^e$ (METTLER TOLEDO). Each powdered sample was sealed in an aluminum pan and heated at a constant rate of 10 °C $min^{-1}$ over a temperature range of 25–800 °C, under N2 atmosphere (10 ml $min^{-1}$), and evaluated using STAR$^e$ 8.10 Software.

## 3. Results and discussion

### 3.1. Physical and chemical characterization of mucilage powder

The extracted mucilage was brownish in color with a pleasant odor. The mucilage was slowly soluble in water produces viscous solution and practically not soluble in organic solvents. The percentage yield was 9.5 ± 1.35%. The weight loss on drying was 2.08 ± 0.148%. The swelling index was found to be 54 ± 1.087. The density, pH, and viscosity of 1% w/v solution of the mucilage powder in distilled water were found to be 1.018 ± 0.015 g/ml, 3.6 ± 0.10, and 8.48 ± 0.10 cPs, respectively. All the physical properties were represented in (Table 1). When the mucilage was treated with Iodine solution, particles stained blue. Angular masses were observed when the mucilage was treated with 96% ethanol. This is a characteristic feature of mucilage. The chemical tests of mucilage for carbohydrates gave a positive result and negative results for other phyto chemical tests (Table 2).

Angle of repose of extracted mucilage was found to be 23.56° ± 1.45°, indicates the powdered mucilage has excellent flow properties. The bulk densities of the dried mucilage were utilized for calculating the Carr's index which was 21.18 ± 0.05%, which indicates good compression properties. The flow properties of *Portulaca oleracea* leaves mucilage were shown (Table 3).

### 3.2. SEM analysis

Dry mucilage powder and dry PMA beads were observed in scanning electron microscope. The SEM photograph of the beads shows rough surface with large wrinkles and flakes (Fig. 1(a)). These flakes and wrinkles might be caused by partly collapsing the polymeric gel network during dehydration [18]. The shape of beads in wet state was spherical and smooth. Air drying resulted in an irregular shape and a rough surface. Whereas after the treatment, beads showed smaller flakes with more compact surface due to the deposition of turbid particles on their surface (Fig. 1(b)), which appears to have a different structure after the treatment.

Whereas, the surface of mucilage powder shows amorphous porous structure before treatment (Fig. 2(a)) and it showed less pores due to the adsorption of turbid particles. Fig. 2(b) clearly indicates the presence of new shiny, bulky particles over the surface of mucilage powder after the treatment. A comparative study of the scanning electron micrographs of *Portulaca* mucilage and its alginate beads before and after the treatment with turbid water are used as a supportive evidence for our previous reports on water clarification [11]. The deposition of more turbid particles on surface of both the mucilage powder and beads might be due to the more acidic nature of *Potulaca* mucilage (pH 3.6) which is near to the pH of 1% solution of Alum (pH 3.4), the most commonly used primary coagulant for water clarification. The acidic pH of mucilage results in more adsorptive nature toward turbid particles. EDAX studies revealed the

Table 1
Physical characterization of mucilage from *Portulaca oleracea* leaves

| Physical properties | Observation |
|---|---|
| Appearance | Brownish powder |
| Odor | Characteristic |
| Solubility | Slowly soluble in water and produces viscous solution, insoluble in organic solvents |
| Percent yield (g/kg) | 9.5 ± 1.35 |
| Weight loss on drying (mg) | 2.08 ± 0.148 |
| Swelling index (%) | 54.0 ± 1.087 |
| Density of liquid (1.0% w/v) | 1.018 ± 0.015 |
| pH | 3.6 ± 0.10 |
| Viscosity (cPs) | 8.48 ± 0.10 |

Table 2
Phytochemical characterization of mucilage powder

| Tests | Observation |
|---|---|
| Mounted in iodine solution | Particles stained blue |
| Mounted in 96% ethanol | Angular masses |
| Wagner's test for alkaloids | −ve |
| Salkowski test for steroids and terpenoids | −ve |
| Molisch's test for carbohydrates | +ve |
| Foam test for saponins | −ve |
| Alkaline reagent test for tannins and Phenolic compounds | −ve |
| Alkaline reagent test for flavonoids | −ve |

Table 3
Flow properties of *Portulaca oleracea* leaf mucilage

| Flow properties | Observation |
|---|---|
| Angle of repose ($\theta^{\circ}$) | 23.56 ± 1.45 |
| Loose bulk density (g/cm$^3$) | 0.625 ± 0.04 |
| Tapped bulk density (g/cm$^3$) | 0.793 ± 0.03 |
| Carr's index (%) | 21.18 ± 0.05 |
| Hausner's ratio | 1.269 ± 0.04 |

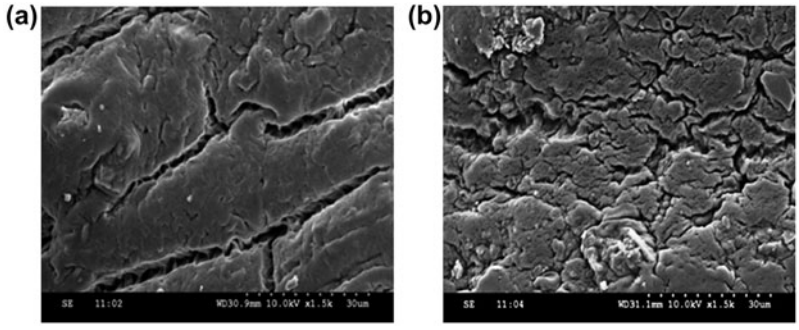


Fig. 1. SEM images of PMA beads (a) before treatment with (450 NTU) turbid water and (b) after treatment with (450 NTU) turbid water.

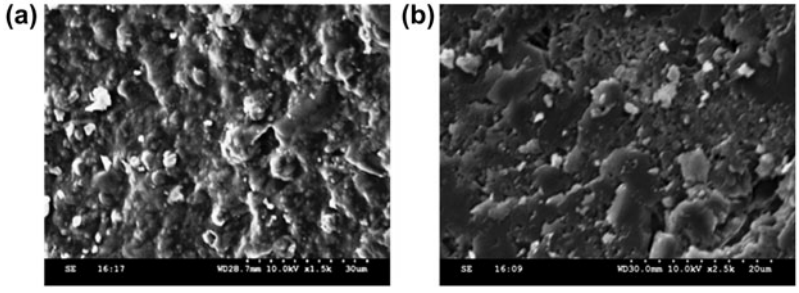


Fig. 2. SEM images of *portulaca* dry mucilage powder (a) before treatment with (450 NTU) turbid water and (b) after treatment with (450 NTU) turbid water.

presence of new elements after the treatment, which is an indication of their adsorption (Table 4).

### 3.3. EDAX analysis

The relative proportions of the elements in the mucilage powder and the beads before and after the treatment with turbid water are presented in (Table 4). There was a complex collection of elements in the mucilage powder and the mucilage/alginate beads. The elements present in the mucilage powder were oxygen (O), magnesium (Mg), aluminum (Al), silicon (Si), and calcium (Ca). After the treatment, the mucilage powder showed more adsorption of carbon (C),

Table 4
Elemental composition of mucilage powder and its alginate beads before and after the treatment with turbid water

| | | Mucilage powder | | | | Mucilage powder | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Atom% | | Weight% | | Atom% | | Weight% | |
| S. no | Element | BT | AT | BT | AT | BT | AT | BT | AT |
| 1 | C | – | 44.74 | – | 36.63 | – | 35.45 | – | 27.89 |
| 2 | O | 79.75 | 52.05 | 67.52 | 56.77 | 77.89 | 60.94 | 60.48 | 63.87 |
| 3 | Na | – | 0.71 | – | 1.12 | 0.14 | – | 0.16 | – |
| 4 | Mg | 0.27 | 0.6 | 0.35 | 0.99 | – | – | – | – |
| 5 | Al | 7.92 | 0.43 | 11.31 | 0.79 | 0.26 | 0.68 | 0.35 | 1.2 |
| 6 | Si | 7.49 | 0.25 | 11.13 | 0.48 | 0.16 | 0.77 | 0.21 | 1.41 |
| 7 | P | – | – | – | – | – | 0.06 | – | 0.12 |
| 8 | S | – | 0.05 | – | 0.11 | 0.09 | 0.02 | 0.14 | 0.04 |
| 9 | Cl | – | 0.04 | – | 0.1 | 13.76 | 0.05 | 23.67 | 0.12 |
| 10 | K | – | 0.96 | – | 2.56 | – | 0.04 | – | 0.1 |
| 11 | Ca | 4.57 | 0.16 | 9.69 | 0.44 | 7.7 | 2 | 14.99 | 5.24 |

sodium (Na), and potassium (K) in addition to the elements present before the treatment. Before the treatment, oxygen content was high.

After the treatment, O, Al, and Si were decreased. The elements that were present in mucilage powder after treatment and absent before treatment with turbid water were C, Na, and K. Mg content also increased in the mucilage powder after the treatment relative to BT. Only traces of sulfur (S) and chlorine (Cl) were found after the treatment. EDAX of mucilage/alginate beads showed the presence of O, Na, Al, Si, S, Cl, and Ca before the treatment with turbid water. After the treatment it showed C, P, and K elements in addition to the elements present before treatment; O, S, and Ca were decreased after treatment and the percentage composition of Al and Si were increased. The percentage decrease and increase of elements in the mucilage powder and its alginate beads after the treatment suggest a possible involvement of ion-exchange mechanism interaction. The comparative result of SEM/EDX showed that the concentration and distribution of elements in the mucilage and the beads were different before and after turbid water treatment. This could be due to the adsorption/

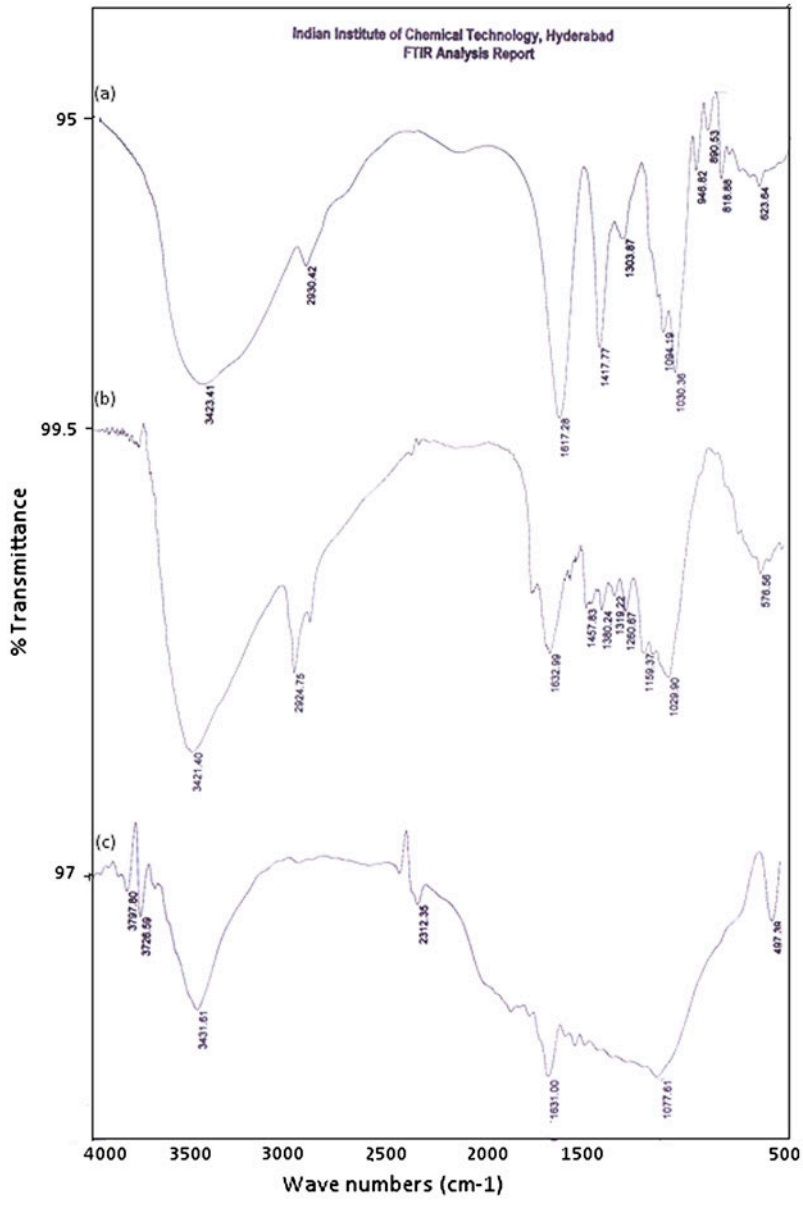


Fig. 3. FTIR spectra of (a) sodium alginate (b) *Portulaca* mucilage (c) PMA beads.

desorption of the elements during treatment with *Portulaca* mucilage powder as well as mucilage/alginate beads.

### 3.4. FTIR

The −OH groups present in all the forms are clearly seen in the region of 3,421–3,424 $cm^{-1}$ and they are also present in the case of the beads form at 3431.61 $cm^{-1}$. The peaks attributed to the $-CH_2$ stretching are present at 2,924.75 and 2,930.42 $cm^{-1}$ in *Portulaca* mucilage and sodium alginate, respectively (Fig. 3(a) and (b)).

Some distinct strong absorption bands were observed at 1,617.28 and 1,417.77 $cm^{-1}$ in sodium alginate due to asymmetric and symmetric stretching of carboxyl anions, respectively [19,20]. This absorption peak has become weak in *Portulaca* mucilage/alginate beads (Fig. 3(c)). This may be due to multiinteractions such as hydrogen bonding and electrostatic interactions among mucilage and alginate molecules in the mucilage/alginate beads. Absorption at 1,632.99 $cm^{-1}$ in *Portulaca* mucilage is attributed to C–O stretching of the uronic acid residues, which are the repeating units that are present in it. Finger print region bands are different in all the three forms. The other peaks at 1,029.90 and 1,030.36 $cm^{-1}$ were assigned to the stretching vibration of (C–OH) for mucilage and sodium alginate beads, respectively. $CH_2$ stretching peak becomes weak in mucilage/alginate beads and a new absorption peak appears at 2,312.35 $cm^{-1}$, which were not present in mucilage and sodium alginate.

### 3.5. Swelling behavior of beads in response to pH variations

The swelling property generally involves (1) the diffusion of water molecules into polymeric network, (2) the relaxation of the hydrated polymer chains, and (3) the expansion of the polymer network into the surrounding aqueous solution [21,22]. Before the swelling, there exist strong intermolecular interactions, such as hydrogen bonds and hydrophobic interactions in the dried mucilage/alginate beads, which remained in the hard state. In this case, free water penetrates inside the beads to fill the inert pores among the polymer chains, contributing to a greater degree of swelling.

Water absorption by beads was determined as a function of pH. When immersed in buffer solutions, mucilage/alginate beads were readily swollen up to a size that depended on the degree of ionization of the carboxylic acid groups of alginate and mucilage. The swelling and shrinking kinetics of beads measured in buffer solutions of pH 2–14 are shown (Fig. 5). The swelling behavior of the beads is a function of its network structure, degree of ionization of functional groups, and hydration of the hydrophilic groups of mucilage and alginate [23]. The beads swell in the buffer solutions of low pH range (pH 2–5) and at higher pH range (pH 9–14). Whereas, shrinking of PMA beads was observed in the pH range of 5–9.

Beads shrank and aggregated due to the disappearance of electrostatic repulsion and the generation

Fig. 4. Photographs of developed *Portulaca* mucilage–alginate beads.

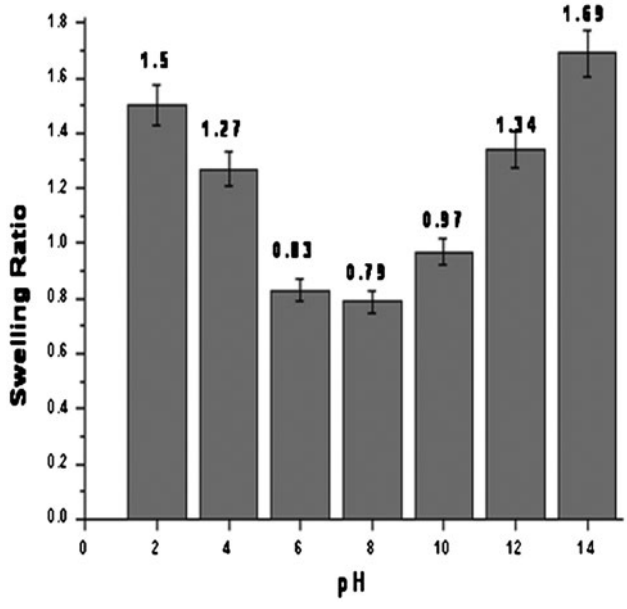


Fig. 5. Effect of pH on swelling behavior of PMA beads.

of hydrophobic interactions, owing to hydrogen bond formation between unionized carboxylic acid groups of alginate and the OH groups of mucilage. In the buffer solution of pH 9, the carboxylic groups of alginate transform into the ionized form ($COO^-$) and the electrostatic repulsion between ionized groups causes the beads to swell. Similar findings were observed in the swelling behavior of composite gel beads of tamarind gum and sodium alginate [24].

### 3.6. Performance of PMA beads for water clarification

The efficiency of PMA beads in terms of turbidity removal appears promising. Residual turbidites went on decreasing by increasing the concentration of PMA beads (coagulant) in both the low and high turbid water.

The optimum dose of PMA beads required was found to be 0.3 g/l to obtain maximum turbidity removal in the case of low turbid water (35 NTU) and

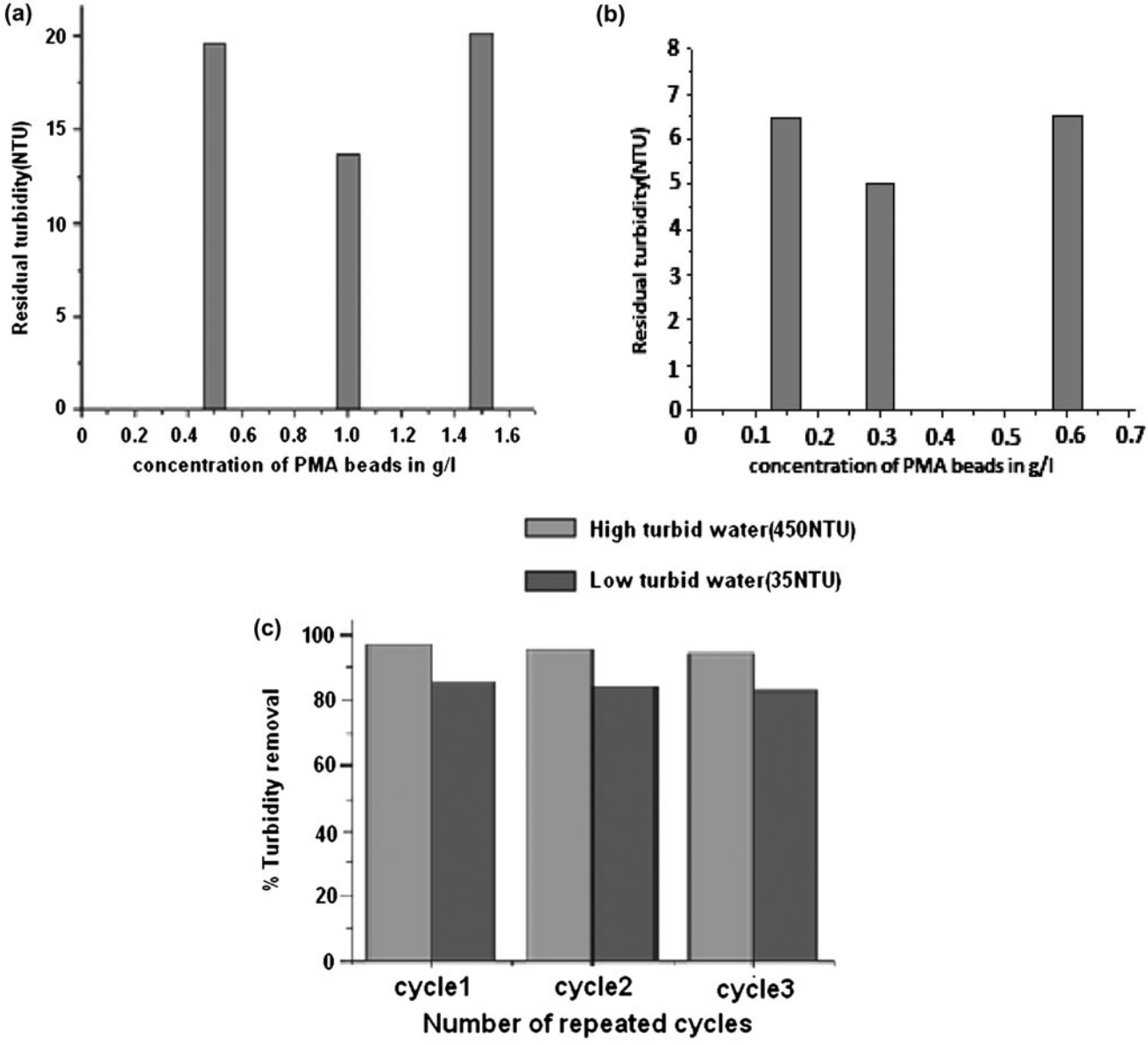


Fig. 6. Water clarifications by PMA beads (a) in high turbid water (450 NTU) (b) in low turbid water (35 NTU) levels (c) capability (%turbidity removal) of recycled PMA beads.

reduces the turbidity to 5.5 NTU (Fig. 6(a)). Turbidity removal was found to be effective when high turbid water was used. Treatment with 1 g/l of PMA beads reduced the turbidity to 13.5 NTU (Fig. 6(b)). Filtration of so clarified water through Whatmann No. 1 filter paper produced a very clear filtrate of less than one unit turbidity, which is in the range of WHO standard limits of drinking water. A turbidity removal of about 97% was achieved in high turbid water, which is more similar with the turbidity removal by natural coagulants assessed in previous studies [25], while 87% was observed for low turbid water without filtration.

The results obtained by dry mucilage powder were almost in the similar range of NTU that was obtained by PMA beads, but the potentiality of PMA beads is that they can be recycled and reused. The optimum dose of mucilage was found to be 12 and 40 mg/l in low and high turbid waters, respectively (Fig. 7(a) and (b)). PMA beads were recycled, thoroughly washed with demineralized water and used in three repetitive cycles to check out their effectiveness in low as well as high turbid water levels. The percentage turbidity removal was same in first two cycles, but the capability was found decreased slightly in third cycle (Fig. 6(c)). This may be due to that some suspended particles remain attached on to the beads even after thorough washing and no free space on beads surface to accommodate more particles.

The optimal dose of each coagulant varies according to the initial turbidity of water. It was observed that by increasing the concentration of coagulant, turbidity removal also increased initially, but after attaining the optimum dosage level, it shows no remarkable decrease in turbidity. Several studies reported that up to particular dosage flocculation increases and beyond that flocculation diminish [26,27]. This could be explained by the fact that the higher dose of flocculent would create the steric hindrance among the agglomerates to disturb the settling of particles.

### 3.7. Thermal behavior

Thermo gravimetric and DSC analyses were performed simultaneously on the mucilage powder, PMA beads, and sodium alginate.

The first stage is assigned to loss of water from the polysaccharide and the proportion of weight loss was about 3.07 and 14.12% in mucilage powder and sodium alginate beads, respectively. Whereas, it was found to be 0.17% in the case of PMA beads, which are correlated to three endothermic peaks in the DSC curves in Fig. 8(a)–(c). The endothermic peak strength of composite beads has increased, as shown in Fig. 8(c), which is due to the dehydration. The second and third stages of TG curve are possibly due to molecular scission and decomposition reactions of polysaccharide. The components of long chain backbone of the polysaccharide can begin to separate. The initial decomposition temperature of mucilage is observed at 203˚C, whereas final decomposition temperature is observed at 806˚C, which correlates with the main exothermal peaks at 220–806˚C (Fig. 8(a)). The weight loss is 25.17%, indicating energy release through the weight loss.

The melting temperatures of sodium alginate are 240–630 and 630–806˚C (Fig. 8(b)) where the weight losses are 41.2, 59.8, and 67.8%, respectively. They correspond to two of DSC peaks at 260 and 630˚C, respectively. However, the initial decomposition temperatures of PMA beads observed at 290–462 and

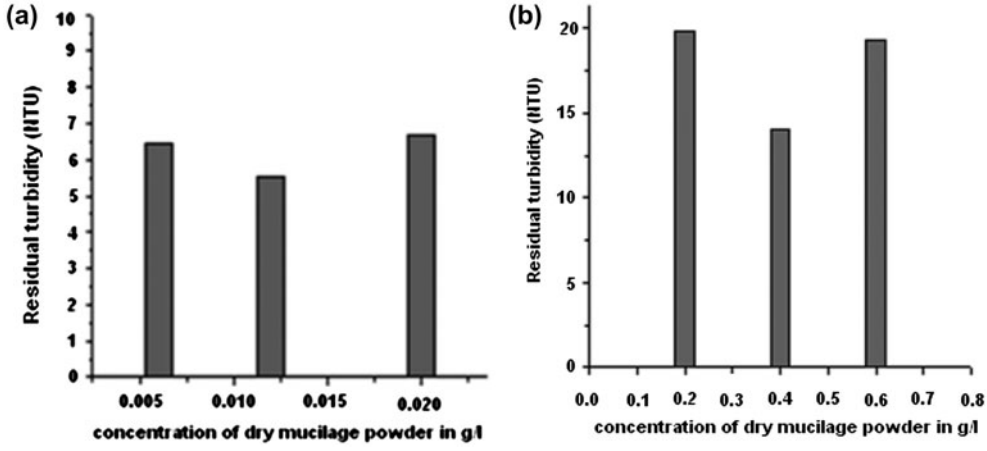


Fig. 7. Water clarifications by *Portulaca* mucilage powder (a) in low turbid water (35 NTU) and (b) in high turbid water (450 NTU).

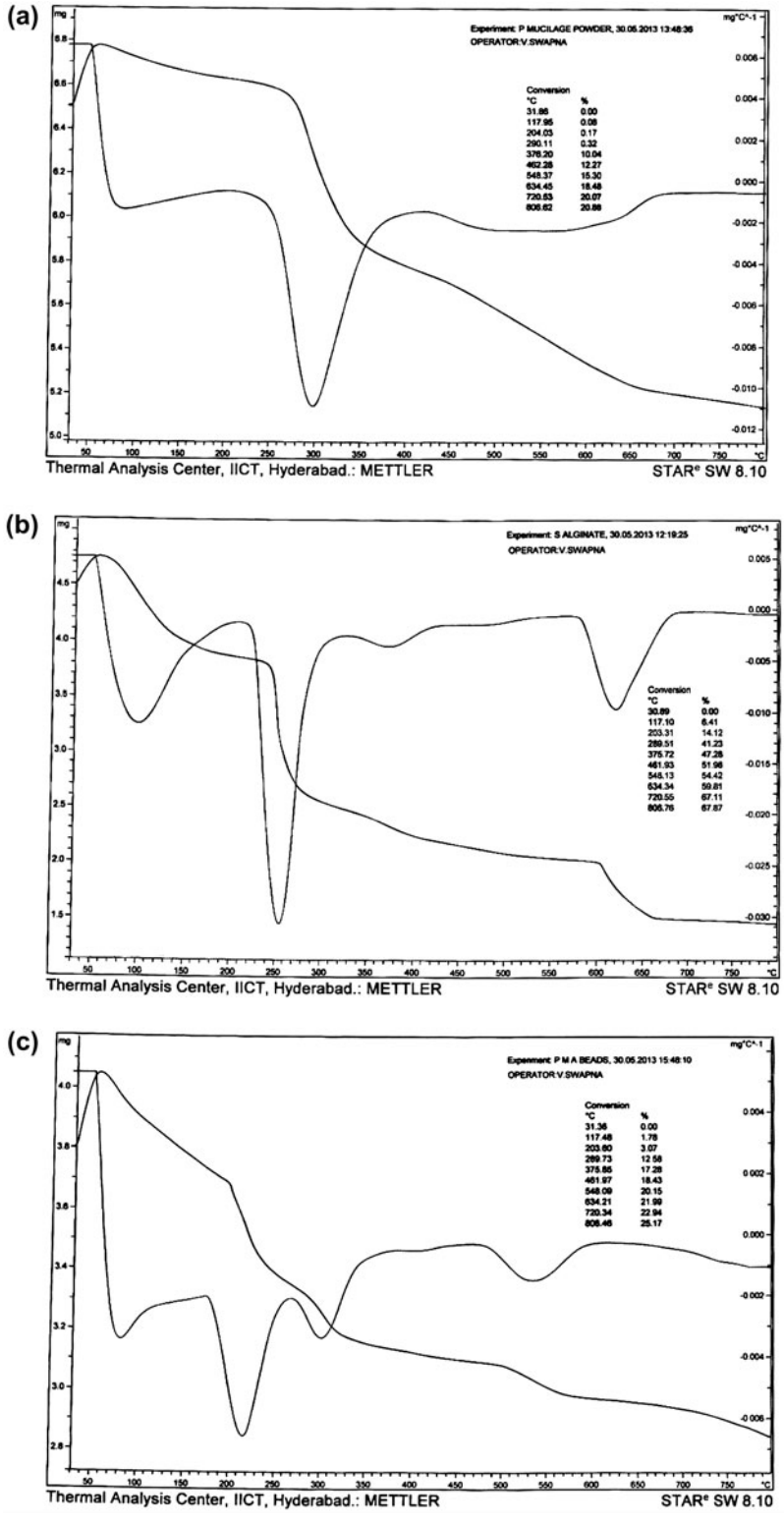


Fig. 8. TGA & DSC curves of (a) mucilage, (b) sodium alginate, and (c) PMA beads.

462–806˚C and correlates with the DSC curves at 300 and 650˚C, the corresponding weight losses are 12.2 and 20.8%, respectively. Compared with mucilage and native alginate, PMA beads are observed to show high decomposition temperatures (Fig. 8(c)); there are two exothermic peaks at 300 and 650˚C. Moreover percentage weight losses are less (20.8% only) in the case of beads compared to mucilage (25.17%) and sodium alginate (67.8%). This tendency shows the improved stability of composite beads than that of each mucilage and sodium alginate and has confirmed the cross-linking between mucilage and sodium alginate to form PMA composite beads. The results obtained from sodium alginate were in agreement with the findings of [28,29]. These observations show greater thermal stability of PMA beads.

## 4. Conclusions

Morphological variations found from SEM studies and the variations in the elemental composition are clear indications of the water clarification process. Flow property of mucilage powder was found suitable in pharmaceutical and biomedical application. The pH plays a greater role in the swelling process of PMA beads. Thermal stability of beads revealed that they are potential supporters to be employed for immobilization of mucilage with good economical feasibility. Present study proved that they are potential, recyclable, and reusable natural coagulants for water clarification.

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