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Agricultural Applications of Nanocomposites Superabsorbent Polymers: A Review

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Abstract

A superabsorbent polymer (SAP) can absorb large quantities of water. Hydrophilic materials are known as superabsorbent materials because they can absorb large amounts of aqueous fluid and desorb it under stress. One of the most critical parameters that limit the usefulness of SAP is its absorption capacity. Superabsorbent polymers can be used for water management and to renew arid and desert environments. This review demonstrates that superabsorbent materials can be beneficial to agriculture and the environment by reducing irrigation water consumption, improving fertilizer retention time in soil, decreasing plant mortality, and increasing plant growth. Nanotechnology could play a role in preparing superabsorbent nanocomposite materials by employing superabsorbent polymers. This article introduces superabsorbent/clay nanocomposites and the mechanochemical synthesis approach which are convenient and useful types of superabsorbent nanocomposites..

Keywords: Mechanochemical, Superabsorbent polymers, Nanotechnology, Agricultural, Nanocomposites, Nano clay.

Introduction

In nanotechnology, functional systems are engineered and reorganized by manipulating small molecules and atoms [1]. During the eighteenth and nineteenth centuries, medicine, food, pharmacology, and agriculture evolved into interdisciplinary with the potential to make drastic changes to all these fields [2]. As a result of population growth and its impact on agronomic practices and productivity, there is currently a lack of food supply in developing countries [3]–[5]. Numerous applications in agricultural fields can be enhanced with nanotechnology-based devices [6], [7], from swiftly inspecting diseases to enhancing plant capacity to absorb minerals and promoting the molecular treatment of diseases [8]. Agricultural nanotechnology is growing from a theoretical perspective to a practical one [9]–[12]. An understanding of the experimental tool's capability to work at nanometric levels will create more opportunities for molecular and cellular biology research.

There are roughly 7 billion people on the planet, with about half of them living in Asia. Climate change effects on agriculture, such as storms, droughts, and floods, are leading to a severe food shortage in developing nations due to an increase in the proportion of those living in such areas [13]. Several biotic and abiotic factors similarly limit agricultural production, and insect pests, diseases, and weeds cause significant losses in potential agricultural production [14,15]. Mass production of nanomaterial-based pesticides and insecticides is being developed exclusively to manage insect pests and protect agricultural productivity by releasing nutrients and water molecules slowly, incorporating nanomaterial-mediated genetic material into plants to create insect pest-resistant varieties [16-19]. Precision farming products use these sensors exclusively [10,14]. Superabsorbent polymers (SAPs) are yet another type of polymer that is capable of retaining a great deal of water, usually more than ordinary sponges [20]. In most cases, they are composed of cross-connected polymeric organs. The polymer chains of many sorts of these materials have ionic associations to promote the diffusion of water within the system [21]. As a result, superabsorbent materials are known as hydrophilic building materials that can ingest large volumes of watery fluids in short periods. Then, they can desorb this liquid under anxiety conditions [22].

Currently, superabsorbent polymers have been considered increasingly for water handling, and also for the rehabilitation of parched and additionally abandoned environments [23], [24]. Presented evidence shows that superabsorbent materials can decrease water usage in both farming and environmental water systems. They can also change the time for maintaining compost in the soil, decrease the death rate for plants, and boost the growth rate for plants. Superabsorbent polymers can be adapted using nanotechnology to incorporate the work of nanomaterials[23], [24]. This can help in the development of superabsorbent nanocomposites. Due to their better performance and high surface area utilization, nanoscale superabsorbent materials are used. Similarly, these materials decrease the amount of raw material required and improve productivity [22]. The field of horticulture can make extensive use of nanotechnology. Variety in precipitation sum, distribution, and quality directly affect yield creation in dryland areas. Under rainfed conditions, soil dampness plays the most vital role in affecting the second rice harvest after the first [25].

Hydrogels with super-absorbent properties may provide the most effective results in this area of investigation. The properties of polymeric superabsorbent materials have been experimented with at several scales, from full-scale to miniaturized to nanoscale[24]. Nanotechnology has been used as a perspective for changing the swelling capacity, gelatin quality, and mechanical and warm properties of super absorbents [24]. Many studies have been conducted on the use of nanotechnology to enhance the performance of superabsorbent polymers. The focus of the present article is to shed light on nanocomposites with superabsorbent polymers and their impact on the adjustment of SAP materials. The impact of nanoparticles and nano clay is explored in greater depth as well [4, 22, 26, 27].

A Classification of Saps

Based on their source, SAPs can be divided into two groups:

- Natural one: There are two types of natural polymers: polysaccharides-derived (such as cellulose, starch, alginate, and agarose) and polypeptides-derived (such as gelatin, collagen) are used extensively [28,29].
- Second one is the synthetic chemical types of plastic (vinyl acetate, polyacrylic acid, polyethylene glycol, methacrylic acid) that are developed from petrochemicals.

Like hydrogels, SAPs can be categorized based on several aspects. Depending on whether the cross-linked chains have an electrical charge located in them, SAPs may be divided into four groups [30]:

- ❖ Non-ionic type.
- ❖ Ionic(including anionic and cationic)
- ❖ Amphoteric electrolyte (ampholytic) containing both acidic and basic groups

- ❖ Zwitterionic (polybetaines) that containboth cationic and anionic groups for each repeating structural unit.

For instance, most SAP hydrogels on the market are anionic. In addition, SAPs, as well as their chemical structure, can be grouped into several categories, so the majority of standard SAPs fall into one of the following groups [30–32]:

- cross-linkedpolyacrylatesandpolyacrylamides
- Hydroxy cellulose copolymers with polyacrylonitrile or starch-polyacrylonitrile (PAN)
- Cross-linked maleic anhydride copolymers. Nevertheless, according to sources, SAPs can be classified into two categories, namely synthetic (petrochemical-derived) and natural. Hydrogels based on polysaccharides can be divided into two main groups, i.e. those based on polypeptides (proteins) and those based on polysaccharides. Most SAPs that are derived from natural sources include synthetic components as well, such as vinyl monomers being copolymerized with polysaccharides in graft copolymerization.

A word like "superabsorbent" sometimes means the most conventional form, that of anionic acrylic, which is a copolymer network derived from partially neutralized acetate acid (AA) or acetate amide (AM) [33].

Models of Statistical Analysis

A measurable model for polymer structure design assumes the polymer structure incorporates monomer units, based on probability guidelines. Literature has accounted for several factual computational models, including the recursive strategy [34], the piecing technique, and the production capacity strategy [35]. For the service of identical quantified depictions, the arbitrary cross-linking theory provides the following: (1) Carbon twofold bonds must be equivalent and autonomous; (2) no intramolecular cyclization is permitted; (3) permission of chain exchange or disproportionation; and (4) free energy changes. Transformative subordinate energy, cyclization with inexact treatment, and adjustment of the end components have all been accounted for [36, 37].

As shown in Figure 1, a free radical catalyzes polymerization. through a connection likelihood design. A free radical cross-linking polymerization can be carried out under six different fortified conditions, as shown in figure 1 [21, 23, 30]. There are two properties of the reinforced conditions of a monomer unit: (1) the number of shapes of bonds between different monomers and (2)theType(s) of fortified units.The mono vinyl acrylate monomer, as indicated in the figure, can be bonded in six different ways: not reacted, no bonds with different units, and one bond with another unit. Another monomer of acrylate; another crosslinker; two framed bonds, which may comprise two additional acrylate monomers; an acrylate and a crosslinker; or two crosslinkers[36].

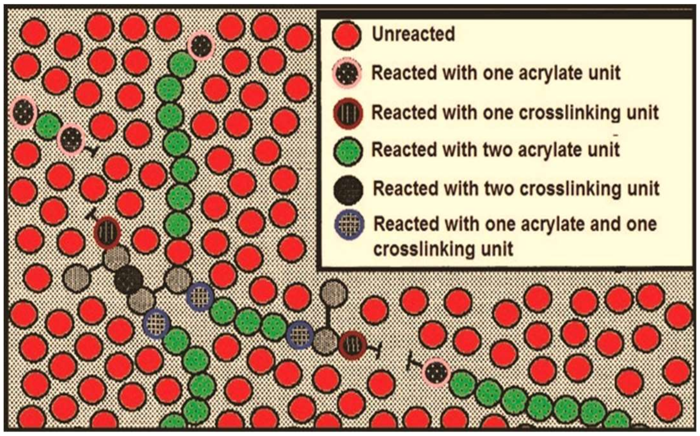

Figure1.An acrylate monomer reacts with a radical free-radical crosslinking polymer during a polymerization process (modified from [36]).

Superabsorbent Clay Nanocomposites

According to Sigma-Aldrich Company, nano clays are dirt minerals that can be used to create polymer-clay nanocomposites having broad properties that can be applied to a wide variety of fields. Nano clay minerals are principally utilized as material components [23]. Montmorillonite is the most usually utilized as a part of these applications [27, 38]. Aluminosilicate layers are deposited on Montmorillonite's surface and are substituted with metal cations, forming stacks of about 10-µm high (Fig. 2).

Nanoparticles of polymer-earth nanocomposite are usually formed by scattering the stacks within the polymer framework. Nanocomposite layers are composed of nanoparticles with a size of approximately 150 nanometers and a thickness of nm-thick clay layers entirely isolated from each other. Moreover, even at low nano clay stacking, Clays are polymers that dwell on a surface connected to nanocomposite, with polymer chains holding a majority of the weight share [23], [39].

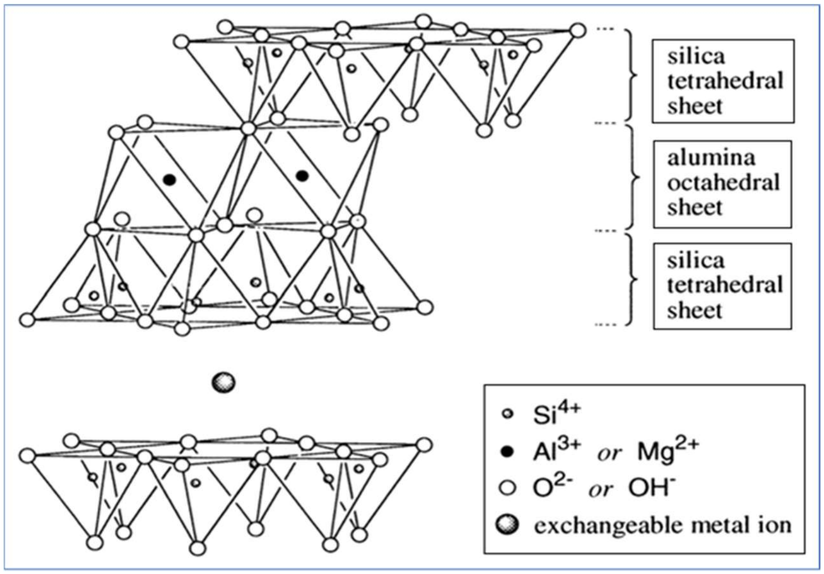

Figure 2. Structure of 2:1 clay mineral (modified from [40]).

The Montmorillonite mineral was discovered in Montmorillon, France, in 1847. In nature, bentonite is a key component of montmorillonite[40]. Montmorillonite is a substance that is mostly found in stones, which are extremely colloidal and plastic. Despite their similarity, kaolin clay particles and Bentonite particles differ on account of their thickness [23]. It is entirely possible that bentonite sodium or potassium salts could be sliced into thin plates with a thickness of 1 nm [41]. Montmorillonite is not the only mineral that may be found in bentonite. The mineral may also consist of crystalline quartz, feldspar, and cristobalite. A significant number of earth minerals-including Bentonite which is an amorphous, high-water-retaining material with thixotropic hydrogel properties, as well as high cation-trading capacity [42]. Dirt minerals may possess properties distinct from soil minerals, such as interstitial water and compatible cations in the interlayer [43].

As part of superabsorbent polymer alteration, montmorillonite (MMT) has been widely used. A superabsorbent made from MMT and NaAlg-g-poly(AA-co-AAm), Rashidzadeh et al. (2014) reported on compost-controlled discharge with the composite [44]. Incorporating montmorillonite into pure superabsorbent created the highly porous structure of Hyd/MMT/NPK, which enhanced water absorption of the composite [44].

Mechanisms Of Swelling in Superabsorbent Polymers

SAP materials swell for a variety of reasons. For swelling to occur, the following components have to be present for the last swelling limit (the amount of surface water that an SAP can hold once surface water has been removed by a centrifuge under free swelling conditions) [10, 22, 25, 43]. SAP polymer arrangements are depicted in Figure 3. Due to its hydrophilic nature and carboxylic acid gatherings (-COOH), SAP is a polymer spine. A polymer/dissolvable association results when watery arrangements are introduced to SAP; one of these is hydration, and another is hydrogen storage [25, 41, 43].

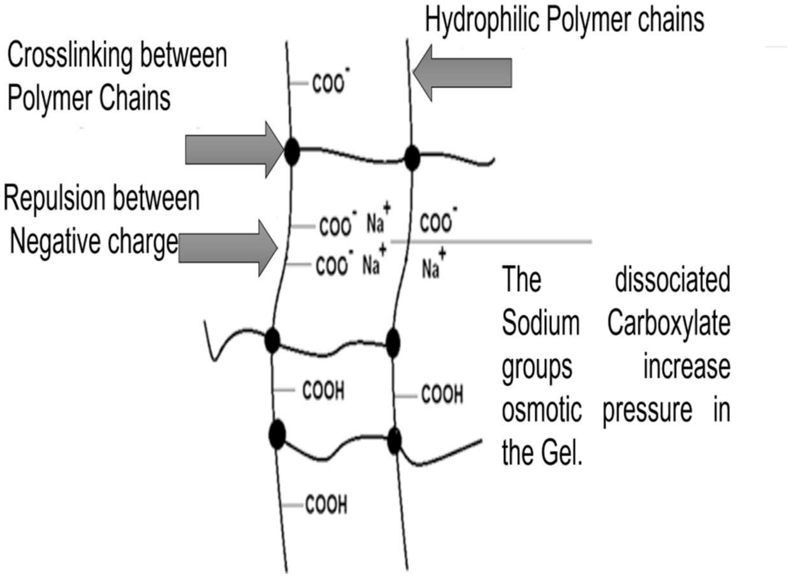

Figure3.Diagram of SAP network during swelling (modified from [10]).

Mechanochemical Synthesis of Superabsorbent Polymers

An efficient mechanochemical process involving the use of a ball mill can be applied for the successful synthesis of different

SAPs with a variety of applications fields such as perovskites like barium titanate[6], [7]. In the crystallographic analysis of the prepared powder, it was demonstrated that mechanically ground BaO and TiO_2 powder are converted fully into barium titanate after 90 minutes of milling [45]. Moreover, EDS analysis concluded that the tested samples contained only barium, oxygen, and titanate. Compared to aqueous suspensions, SAP suspensions of $BaTiO_3$ are more similar to the dry powder of barium titanate[45].

Agricultural Applications

Due to their ability to retain water, SAPs are used in agriculture as a water-saving material and soil conditioner [22]. Due to the expansion and contraction of polymeric particles during moisture cycles, SAPs enhance porosity in clayey soils. Plant growth was significantly moderated by SAP application in drought-stricken areas and irrigation deficit regions [46].

To attain water retention and controlled release properties, superabsorbents are used with fertilizers [47]. In addition to improving plant nutrition and water efficiency, this fertilizer and superabsorbent combination reduce evaporation losses and irrigation frequency [48]. In aquatic and terrestrial areas, SAPs are used to control pest infestations by preventing pests from escaping the granules. For this purpose, superabsorbents based on polyacrylates and polyacrylamides are mainly used. Other polysaccharides used in agriculture and horticulture include sodium alginate, ethyl cellulose, and chitosan [22]. In addition to controlling the release of herbicides, these hydrogels are soil conditioners that encourage plant growth as they are made of agar and starch [22].

Saps as A Source of Nutrition

In agricultural applications, nitrogen fertilizers are employed because it is an essential nutrient for plants [26]. Nitrogen fertilizers, such as urea (46%) are the most widely used [4]. By using slow-release fertilizers, it is possible to minimize nutrient losses observed due to surface runoff, leaching, and vaporization [26]. A slow-release fertilizer is advantageous beyond its reduction of nutrient losses because it provides a controlled and sustained supply of nutrients for a long time, allows the fertilizer to release nutrients more efficiently, reduces the frequency of application, and reduces toxicity and overdose [22].

Hydrogel Sap as Water-Retention Agent

Due to their high-water absorption and retention abilities, superabsorbents conserve water, allowing soils to remain moist [44], [49]. To prevent the soil from drying out, the granules are mixed into it in prescribed amounts. Water is absorbed by the granules by swelling, and they release it as the soil dries by diffusion [22], [50]. This reduces evaporation and irrigation water loss [51]. In the process of absorbing water, the SAP grows and expands, and as a result, the soil becomes a lot more porous, which then increases oxygen availability to the roots. To promote plant growth in areas prone to drought, polyacrylate SAPs were used. The degradation of polyacrylate-based SAPs and the release of toxic chemicals has led to the development of new classes of environmentally friendly bio-based SAPs based on cellulose and starch [50].

Conclusions

Mechanochemical synthesis is an environmentally friendly, highly efficient, and time-saving, economical synthesis technique for creating new and efficient functional materials. This review provides a brief of recent advances in the use of superabsorbent polymers that can be used to replenish arid and desert settings and regulate water. Consequently, superabsorbent materials can benefit agriculture and the environment by using less water for irrigation, increasing the time fertilizer stays in the soil, lowering plant mortality, and promoting plant growth. Superabsorbent polymers could be used in nanotechnology to create superabsorbent nanocomposite materials.

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