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# USE OF HYDROGELS AS A SUSTAINABLE SOLUTION FOR WATER AND NUTRIENTS MANAGEMENT IN PLANT CULTURE

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***Abstract***

*The current climate changes are felt at global level through two primary consequences, namely the increase of day and night temperatures and the decrease of water availability, a fact that determines an important impact in the practices of cultivating plants. Due to this reason, superabsorbent materials such as hydrogels, have been developed to be used especially in plant cultivation systems. The practical relevance of the use of hydrogels in plant substrate could lead to an improvement of water and nutrients management conditions in the field of agriculture. Hydrogels act as a reservoir of water and/or nutrients with gradual release according to plant requirements and in a controlled manner. Thus, a favorable environment for the development of roots and plants is created and maintained throughout their growth. At the same time, this technology brings advantages to the physical characteristics of the soil, by improving the porosity of the soil, thus considerably reducing the undesirable effects observed when applying conventional watering techniques, such as soil drying after sprinkler irrigation and soil erosion during gravity irrigation.*

***Key words****: hydrogels, water and nutrients management, plant culture conditions.*

## INTRODUCTION

Nowadays, the agricultural sector, and therefore the food industry, is facing many problems, but the most important are the challenges due to climate change which causes significant reduction of crop yields (Vicente, 2022); drought affecting the soil being one of the main outcomes of this process. As a result, agricultural production is carried out on arid and semi-arid soils with large pores leading to less water and fertilizer retention, thus affecting their quality and productivity (Oladosu et al., 2022; Singh et al., 2021).

These emerging issues lead to the development of new sustainable and highly efficient agricultural technologies, reducing the negative impact on the environment and providing a suitable growth ecosystem for different plant species (Kassem et al., 2022).

Ecological and sustainable agriculture requires a more intensive use of biological relationships in nature, a more rational use of all natural resources and means of production, and the use of friendly technologies to avoid environmental pollution and increase soil fertility (Liu et al., 2022).

At the same time, organic agriculture, as an alternative to intensive commercial agriculture, is based on a specific agricultural system, which is designed and managed in three directions: ecological, economic and social. Plant cultivation is based on ecological principles such as diversity, stability, equity and productivity, and conventional technological elements are replaced by ecological ones (Ghobashy, 2020).

In this context, the latest development in this field is focused on finding new and sustainable solutions able to respond to these aspects: to assure the water and nutrients for plants with a minimum negative impact on the soil-plants system.

Hydrogels have been defined in various ways and the most precise description refers to hydrogels as water-swollen materials with cross-linked polymeric chains. Also, can be described as materials with remarkable swelling ability that not require structural changes or changes in shape and volume (Oladosu et al., 2022).

In fact, hydrogels are three-dimensional polymer networks, which can be assimilated with a huge macromolecule, with the ability to incorporate large amounts of water or aqueous solutions (Durpekova et al., 2022; Oladosu et al., 2022). In general, the three-dimensional networks of hydrophilic polymers can absorb the amount of water representing at least 20% of the total weight and if water quantity represents more than 95% of the total weight, the hydrogel is called superabsorbent.

The structure and properties of hydrogels depend on their nature, being synthetic as polyesters (non-biodegradable), or natural, based on proteins (for example, gelatine or collagen), or based on polysaccharides (for example, agarose and alginate) and also of the type of bonds between the macromolecular chains, which can be chemical or physical (Ghobashy, 2020; Oladosu et al., 2022).

Chemical gels present interchain covalent bonds, while physical gels present as interchain connections hydrogen bonds, van der Waals bonds (Skrzypczak et al., 2022).

Physical hydrogels are primarily three-dimensional networks formed by secondary bonds, also known as non-covalent bonds (such as hydrophobic interaction, chain entanglement, hydrogen bonding, and electrostatic interaction), between linear molecules to form physical cross-linking joints. The sol-gel appearance for these hydrogels is usually reversible and because no chemical reactions are involved, they are suitable for biomedical applications; (De Kruif et al., 2015; Oladosu et al., 2022).

But then, chemical hydrogels are produced by chemical reactions - irreversible molecular cross-linking that occurs during their formation. They possessed good mechanical properties and stable properties (Oladosu et al., 2022). However, until now, most available hydrogels are produced based on acrylate, so they are non-biodegradable. Moreover, there are some concerns related to the possible toxic effect after their use in the soil (Oladosu et al., 2022).

The most important property of hydrogels is that they swell in the presence of water and contract in its absence. The extent of swelling is determined by the nature of the polymer chain and the crosslinking density.

The higher water content determines the mechanical, diffusion and adsorption properties of hydrogels, giving them the ability to mimic living tissues. Besides that, the higher water content allows the fraction of biomolecules bound to the surface to increase, thus controlling the interactions between the hydrogel and biopolymer (Guilherme et al., 2015).

The development of smart polymeric and biopolymeric materials can help the agricultural sector because of their high water and mineral retention and releasing capacity (Oladosu et al., 2022; Ramli, 2019). Different types of hydrogels are currently developed and studied by researchers as sustainable and eco-friendly biopolymeric materials for agricultural applications (Durpekova et al., 2022).

## MATERIALS AND METHODS

In this paper, a literature review that investigated research articles published in the past decade, regarding the benefits of using hydrogels in order to improve the culture conditions of different plant species was carried out. The review paper presents a synthesis of the properties and characteristics of different types of hydrogels, with special focus on the advantages of their use in relation with their sustainability and eco-friendly benefits. The selection criteria of the reviewed articles were represented by the technologies currently used to obtain hydrogels, their physical characteristics and advantages of the use of hydrogels in improving cultured soil. International databases such as Web of Science, Wiley, Elsevier and Springer were electronically searched for articles and the literature reviews.

## RESULTS AND DISCUSSIONS

Modern agriculture required a large quantity of water and because of the changing climate conditions, the water quantity is dropping from year to year (Koupai et al., 2008; Mantovan et al., 2022). Organic polymers have many properties that allow the optimal use of water in agriculture. The first application covers a wide range of polymers in emulsion, powder or block, suitable for any type of irrigation. Under the action of the polymer, fine surface particles form aggregates. This improves soil porosity, thus considerably reducing soil drying effects as a result of spray irrigation and erosion under gravity irrigation (Oladosu et al., 2022).

Hydrogels are synthesized from various monomers, most of them being hydrophilic, due to the presence in their structure of hydrophilic functional groups of the type: -OH, -COOH, $-CONH_2$, -CONH and $-SO_3H$. However, it was established that by copolymerizing some hydrophilic and hydrophobic monomers hydrogels with increased mechanical resistance can be obtained (Dergunov and Mun, 2009; Ullah et al., 2015).
The need to improve the physical-chemical, biological and mechanical properties of hydrogels has led to the diversification of the range of neutral monomers or carriers of electrical charges (anionic, cationic), as well as with groups susceptible to cross-linking. Obtaining hydrogels by copolymerization (in the presence of a cross-linking agent) is used as a mean of improving the mechanical properties, diffusion through the gel, or limiting the degree of swelling of the obtained gels (Akhtar et al., 2016).
The technologies currently used to obtain hydrogels include different types of polymerizations (in mass, in solution, in suspension, in emulsion), polymerization in the gas phase or induced with plasma, which are very expensive technologies but lead to the formation of very pure and uniform gels (Varaprasad et al., 2017). Another method for hydrogels obtaining is the crosslinking of hydrophilic polymers with crosslinking agents or by exposing them to different types of radiation (Bustamante-Torres et al., 2021).
Hydrogels have a large domain of applicability, in the food (Klein and Poverenov, 2020; Li et al., 2021; Liu et al., 2012; Zhang et al., 2020), biomedical and pharmaceutical domain (Aswathy et al., 2020; Liu et al., 2012; Peppas et al., 2020), agriculture (Koupai et al., 2008; Michalik and Wandzik, 2020; Narjary et al., 2013; Raafat et al., 2012), biosensors (Bae et al., 2020; Herrmann et al., 2021; Sun et al., 2018; Wang et al., 2021) and cosmetics (Mitura et al., 2020; Montesano et al., 2015).
Chitosan based hydrogels are currently used in the agriculture sector in order to deliver valuable bioactive compounds to plants and food products and also to treat the agricultural recycled wastewater (Laftah et al., 2011; Qu and Luo, 2021).
Just as chitosan, alginate is a natural carbohydrate that can be used to produce biodegradable hydrogels. Previous research into the water absorption and retention capacity of alginate-based hydrogels (Davidovich-Pinhas and Bianco-Peled, 2010; Idrissi et al., 2022; Van der Merwe et al., 2022) show potential for using hydrogels in the field of soil amendments. Some key benefits to using alginate as the hydrogel-forming component, as opposed to other synthetic hydrogels such as polyacrylamide, include that alginate is relatively cheap compared to synthetic polymers, alginate is abundant, and alginate is biodegradable within the soil (Michalik and Chojnacka, 2021; Van der Merwe et al., 2022).
Extraction studies, acute systemic toxicity, tissue and blood compatibility, have confirmed the stability and biocompatibility of the hydrogel. The biocompatibility of hydrogels expands the scope of biomedical applications, without risks for the receiving organism (Chai et al., 2017). Much of the research conducted on hydrogels has been directed towards applications such as controlled drug release devices (Gupta et al., 2002).
According to many studies, hydrogels were also obtained from materials such as polyurethane (Tanasić et al., 2021), carboxymethyl cellulose (Bauli et al., 2021), nanocellulose (Li and Chen, 2020), fenugreek galactomannan-borax (Liu et al., 2020), carboxymethyl tamarind kernel gum with sodium-acrylate (Warkar and Kumar, 2019), polyvinylpyrrolidone (Raafat et al., 2012), cassava starch and polyvinyl alcohol (Jungsinyatam et al., 2022) or amphiphilic calcium alginate (Zhang et al., 2022).
Polymer mixtures are composed of two or more polymers, synthetic or natural, which can be thermodynamically compatible or incompatible (Loo et al., 2021).
The possibility of obtaining new materials, with improved properties, by mixing two or more already existing polymers proved to be a much more interesting solution, from an economic point of view, than the design and synthesis of new polymers (Zhang and Khademhosseini, 2017). In the last ten years, the particular importance of a new class of polymers has emerged, that of polymers with biomaterial applications.

The notion of biomaterial mixture of polymers is very broad, but corresponds often to that of a multiphase polymer system (Anstey et al., 2021). The use of these polymer systems to obtain different products requires a processing stage, after which their shape and final structure are fixed. The latter is the one that influences the usage properties of the product (mechanical, optical, dielectric properties, etc.). In this context, the special importance given to the methods of characterizing the morphology of polymer systems is explicable, in order to explain the relationship that exists between the processing parameters, the structure and the properties of the obtained products (Carreau et al., 2021).

The most important beneficial uses for hydrogels made from polysaccharides are the prevention of soil erosion, the controlled nutrient release and the increased water retention properties of sandy soils (Ghobashy, 2020; Oladosu et al., 2022).

Song et al. (2020), studied the effect of a hydrogel obtained from sodium alginate, konjaku flour and lignosulfonate, which was prepared by crosslinking and applied into a soil in order to investigate its influence on the physical-chemical properties of the soil and its degradability. Also, the water holding capacity and retention curve as well as nutrient retention were analysed over tobacco plants under drought stress. The results of the study showed that the hydrogels increased the water capacity of the tested soil and also improved the photosynthetic capability of tobacco plants under drought stress. The proline levels were improved as well and the growth time of the plants were increased.

An eco-friendly and cost-effective hydrogel based on proteins was developed by Hu et al. (2021), by using biomass waste collagen. The scope of the hydrogel was to absorb heavy metals from the soil and have the ability to slowly release nutrients. The results showed that the hydrogels have high water absorbency capacity, are biodegradable and can controlled-release potassium and nitrogen in the soil for a period of up to 40 days. As for the adsorption capacity oh heavy metals, the hydrogels presented good results when teste for Cr (III).

Albalasmeh et al. (2022), studied the effects of a hydrogel based material on corn growth and soil physical properties in laboratory and greenhouse conditions. Ten concentrations of hydrogel were used to evaluate their effect of the hydraulic and physical properties of the soil and four concentrations to monitor the growth of *Zea mays* as a model plant. At a concentration of 0.27% hydrogel, the soil aggregate percentage was 35% and at concentrations of 0.33% hydrogel, the water available in soil was of 49%. The results showed that improvement in soil aggregate percentage was of 35% with 0.27% hydrogel concentration whereas, 0.33% hydrogel concentration increased the soil available water by 49%. Furthermore, water use efficiency was increased for all tested concentrations as well as plant growth.

Hydrogels made of acrylic acid, guar gum and cross-linked with ethylene glycol di methacrylic acid were studied by Thombare et al. (2018), in terms of water absorption and biodegradation properties.

The results showed that the use of hydrogels has significantly improved the porosity, water retention and holding capacity of soil. Furthermore, the hydrogels proved to be biodegradable.

Water-soluble organic polymers are anionic polyacrylamides and their use in improving the culture conditions has the following advantages: up to 95% reduction in soil loss due to leakage; resistance to surface erosion, compaction, and consolidation; the soil is easier to work, especially plowing and the costs are reduced; environmental protection is respected, by reducing the leakage of pesticides and fertilizers; being spread on a surface to be treated, polymers allow the formation of a synthetic mulch that improves both soil cohesion and its permeability (Xiao et al., 2022).

Thanks to the superior hydrophilic properties, the soil is more stable on the surface, so that the seeds germinate more easily and ensures the roots are gripped effectively, they are easy to use and can be spread with seeds and fertilizers and helps to improve soil cohesion and reduce the effects of erosion (Chang et al., 2015; Patra et al., 2022).

A synthesis of the most important results of the literature review regarding the advantages of the use of the hydrogels (with different composition) in different agriculture applications are presented in the Table 1.

Table 1. Characteristics and effects of hydrogels on plant culture and soil conditions

| **Composition of hydrogels** | **Plant culture** | **Effect** | **Reference** |
|---|---|---|---|
| Sodium alginate, konjaku flour and lignosulfonate | Tobacco plants | - Increased the soil water capacity<br>- Improved the photosynthetic capability and reducing sugar<br>- Prolong growth rate | (Song et al., 2020) |
| Biomass waste collagen | *Ensifer* sp.Y1. | - High water absorbency capacity<br>- Highly biodegradable<br>- Excellent adsorption capacity for Cr (III). | (Hu et al., 2021) |
| Commercial hydrogel, cross-linked potassium poly-acrylic acid. | *Zea mays* | - Increase the soil available water and water use efficiency<br>- Plant growth improvement | (Albalasmeh et al., 2022) |
| Superabsorbent hydrogel based on zinc oxide nanoparticles and watermelon peel waste | Pepper plant | - Control of *Fusarium* disease<br>- Decrease the necessary irrigation water quantity | (Abdelaziz et al., 2021) |
| Ativated-carbon-filled agarose hydrogel | Rapeseed | - Improvement water retention<br>- Swelling ratio of rapeseed seedlings decreased<br>- Enhanced rapeseed growth indexes (germination capacity, root and stem length, fresh and dry weight) | (Cao and Li, 2021). |
| Cassava starch (CSt)-g-polyacrylic acid /natural rubber /polyvinyl alcohol | Chili plant | - Slow-released fertilizer capacity which facilitated the growth of chili plant<br>- Improve water retention<br>- Plant growth improvement | (Tanan et al., 2021) |
| Reinforced starch-based hydrogels with natural char nanoparticles | Tomato plant | - Reduced the negative effects of water-deficit stress<br>- Maintain soil moisture content | (Nassaj-Bokharaei et al., 2021) |
| Whey/polysaccharide-based hydrogel with polylactic acid (PLA) | *Raphanus sativus* and *Phaseolus vulgaris* | - Improve water retention capacity of the soil by 30%.<br>- Better plant growth | (Durpekova et al., 2022) |
| Carboxymethyl cellulose and nanocellulose / nanoclays | Cucumber (*Cucumis* L.) | - Potential reduction of fertilizer loss during application<br>- Improve water use in agriculture | (Bauli et al., 2021) |
| Carboxymethyl tamarind kernel gum and sodium-acrylate | Chickpea plants | - Potential use as soil conditioner<br>- Better growth of chickpea plants | (Warkar and Kumar, 2019) |
| Alginate-carboxymethyl cellulose enriched with chitosan and $Cu^{2+}$ | Cucumber (*Cucumis* L.) | - Chitosan may provide an additional source of nitrogen for plants and exhibit antimicrobial activity | (Skrzypczak et al., 2021) |
| Chitosan hydrogel cross linked with Ethylene diamine tetraacetic acid (EDTA) | Soybean plants | - Better soybean plant growth (leaf dimensions and number) | (Ritonga et al., 2019) |
| Chitosan, gelatin and polyvinyl alcohol (PVA) | Chili plants | - Antimicrobial activity on *Phytophthora capsici* | (López-Velázquez et al., 2019) |
| Carboxymethyl tamarind kernel gum with sodium-acrylate | Chickpea plants | - Potential use as soil conditioner<br>- Significant improvement of the moisture absorption (35%), porosity (7%) and water retention capacity | (Warkar and Kumar, 2019) |
| Chitin, NaOH/urea aqueous solution, crosslinking with epichlorohydrin | Rapeseed (*Brassica napus*) | - Safe and biodegradable<br>- Promote seed germination and growth | (Tang et al., 2014) |
| Superabsorbent hydrogel type Suprab A200 (commercial grade) | *Ligustrum ovalifolium* | - Increased residual and saturated water content | (Koupai et al., 2008) |
| Sodium carboxymethylcellulose and hydroxyethyl cellulose cross-linked with citric acid | Cucumber and sweet basil | - Overall enhancement of plant growth<br>- Increased water retention properties | (Montesano et al., 2015) |
| Polyacrylic acid, sodium polyacrylate, cellulose, starch | Maize plants | - Enhanced growth of maize<br>- Improved water availability in the soil | (Mazen et al., 2015) |
| Superabsorbent hydrogel type Belsap (commercial grade) | *Cajanus cajan* seedlings | - Improved growth in both the height and root collar diameter<br>- Increased soil moisture | (Gilbert et al., 2014) |

There are important advantages that hydrogels have when used in agriculture domain, such as the ability to stabilize the soil even on steep slopes, to reduce the costs of improving soil characteristics, the ease of use and the possibility to spread them with seeds and fertilizers and also help improve soil cohesion and reduce the effects of erosion (Vundavalli et al., 2015).

## CONCLUSIONS

The characteristics of hydrogels, composed from different materials such as chitosan, carboxymethyl cellulose, nanocellulose, polyvinylpyrrolidone, polyvinyl alcohol, etc., combine three properties that are consistent with current priorities regarding the sustainable development requirements of the agricultural system: biodegradability, recycling of residual materials and suitability for multiple processing techniques.

The application of hydrogels at culture substrate level, ensure a sustainable solution for water management in agriculture and controlled fertilization of the soil, thus improving the yield by stimulating the germination of the seeds and the metabolic processes of the plants. Because of these properties adding hydrogels to soil could contribute to produce large and constant harvests in variable environmental conditions.

The beneficial effects of hydrogels use in improving culture conditions of different plant species highlighted by the current research are the improved growth rate, photosynthetic capability and adsorption capabilities. Another advantage of using hydrogels is the reduction of the negative effects of water-deficit stress and slow release of fertilizers.

In addition, acting as a soil conditioner, it contributes to increasing soil water availability and water use efficiency, improving water retention potential and the antimicrobial properties, effects also highlighted in the reviewed research studies.

One major drawback of hydrogels is the lack of mechanical strength, so researchers need to find ways to improve the mechanical integrity and 3-dimensional hydrogels structures. Further research is also needed in the field of application technology which depends on both the structure of the hydrogels and the plant culture and soil type.

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