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APPLICATION OF SMART HYDROGELS BASED ON QUINAZOLIN-4-ONE FOR SUSTAINABLE AGRICULTURE

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Annotatsiya: Ushbu maqolada xinazolin-4-on asosidagi aqlli gidrojellarni barqaror qishloq xo‘jaligida qo‘llash imkoniyatlari o‘rganilgan. Xinazolin-4-on tuzilmasi asosida yaratilgan gidrojellar suv va ozuqa moddalarini saqlash, o‘simlik o‘sishini rag‘batlantirish va atrof-muhit sharoitlariga moslasha olish xususiyatlari bilan ajralib turadi. Tadqiqot natijalari ushbu gidrojellar urug‘larning unishini tezlashtirish, ildiz tizimi rivojlanishini kuchaytirish, qurg‘oqchilikka chidamlilikni oshirish hamda transplantatsiya muvaffaqiyatini yaxshilashda samarali ekanligini ko‘rsatadi. Shuningdek, ushbu gidrojellar ekologik xavfsizligi va biologik parchalanish xususiyatlari bilan barqaror qishloq xo‘jaligi tizimlarini yaratishga xizmat qiladi. Maqolada xinazolin-4-on asosidagi aqlli gidrojellarning afzalliklari, mavjud muammolar va ularning kelajakdagi qo‘llanish istiqbollari batafsil muhokama qilingan.

Kalit so‘zlar: Xinazolin-4-on, Aqlli gidrojellar, Barqaror qishloq xo‘jaligi, O‘simlik o‘sishini rag‘batlantirish, Suvni saqlash, Ozuqa moddalarining nazorat ostida chiqarilishi, Biologik parchalanish

Аннотация: В этой статье исследуются возможности применения интеллектуальных гидрогелей на основе хиназолина-4-он в устойчивом сельском хозяйстве. Гидрогели, созданные на основе структуры хиназолин-4-он, характеризуются свойствами накапливать воду и питательные вещества, стимулировать рост растений и быть способными адаптироваться к условиям окружающей среды. Результаты исследований показывают, что эти гидрогели эффективны для ускорения прорастания семян, ускорения развития корневой системы, повышения засухоустойчивости и улучшения успеха пересадки. Эти гидрогели также служат для создания устойчивых сельскохозяйственных систем с их экологически безопасными и

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биоразлагаемыми свойствами. В статье подробно обсуждаются преимущества интеллектуальных гидрогелей на основе хиназолина-4-он, существующие проблемы и перспективы их будущего применения.
Ключевые слова: хиназолин-4-on, интеллектуальные гидрогели, устойчивое сельское хозяйство, стимулирование роста растений, сохранение воды, контролируемое высвобождение питательных веществ, биоразлагаемость
Annotation: This article explores the application potential of smart hydrogels based on quinazolin-4-one for sustainable agriculture. Hydrogels synthesized from quinazolin-4-one structures exhibit remarkable properties, such as retaining water and nutrients, promoting plant growth, and adapting to environmental changes. Research findings demonstrate that these hydrogels effectively enhance seed germination, stimulate root system development, increase drought tolerance, and improve transplantation success. Moreover, due to their environmental safety and biodegradability, they contribute to the creation of sustainable agricultural systems. The review discusses the advantages, current challenges, and future prospects of smart hydrogels based on quinazolin-4-one in detail.
Keywords: Quinazolin-4-one, Smart hydrogels, Sustainable agriculture, Plant growth promotion, Water retention, Controlled nutrient release, Biodegradability

Introduction

The rapid growth of the global population has led to an increased demand for food and agricultural resources. According to UN projections, the world's population is expected to reach 9.7 billion by 2050, significantly raising the demand for irrigation water. Unfortunately, freshwater resources are depleting faster than they can naturally replenish, severely impacting crop yields. For instance, from 1980 to 2015, global water shortages resulted in estimated yield losses of 21% for wheat and 40% for maize. Thus, there is a pressing need for new agricultural practices that use water more efficiently, and among the promising solutions is the use of hydrogels.

Hydrogels are three-dimensional polymer networks capable of retaining substantial amounts of water and nutrients. Their hydrophilic groups (e.g., carboxyl, hydroxyl, amide) enable high water absorption, while physical and chemical crosslinking in the structure defines their mechanical strength, swelling behavior, and porosity.

Recently, attention has turned to the development of smart hydrogels based on quinazolin-4-one derivatives, which not only improve water retention but also exhibit biological activity that promotes plant growth. Incorporating quinazolin-4-one into the hydrogel structure enhances its functionality, enabling controlled release of water and bioactive compounds directly to the plant roots. This dual

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function offers significant advantages in terms of drought resistance, nutrient availability, and overall crop productivity.

In agriculture, hydrogels reduce irrigation frequency, enhance water retention in the soil, and prevent fertilizer leaching, thereby improving nutrient efficiency and minimizing environmental pollution. Additionally, by absorbing water and swelling, hydrogels increase soil porosity, promoting better aeration and root development. Studies have shown significant increases in soil porosity in clay, sand, and sandy loam soils after hydrogel application.

This review focuses on the development and agricultural application of hydrogels, especially those based on quinazolin-4-one, to address critical challenges such as water scarcity, excessive fertilizer use, and soil degradation. It provides insights into the basic principles of hydrogel formation, their multifunctional roles, and their promising future in sustainable agriculture.

METHOD AND RESULTS

To develop smart hydrogels based on quinazolin-4-one for sustainable agriculture, a multi-step synthesis and characterization process was employed. Initially, quinazolin-4-one derivatives were synthesized via cyclization reactions involving anthranilic acid and various aldehydes under acidic conditions. The resulting compounds were purified through recrystallization techniques.

Subsequently, hydrogel networks were prepared using these quinazolin-4-one derivatives as functional monomers. Crosslinking agents such as N,N'-methylenebisacrylamide (MBA) and initiators like ammonium persulfate (APS) were used to polymerize the hydrophilic backbone under mild temperature conditions. The polymerization was carried out via free-radical polymerization methods to ensure uniform distribution of quinazolin-4-one within the hydrogel matrix.

Characterization of the synthesized hydrogels included Fourier-transform infrared spectroscopy (FTIR) to confirm the chemical structure, scanning electron microscopy (SEM) to observe the porous network, and swelling tests in deionized water to assess water retention capability. Mechanical properties were evaluated using tensile strength tests.

For agricultural applications, soil treatment experiments were conducted. Seeds of *Triticum aestivum* (wheat) and *Zea mays* (maize) were sown in soil samples supplemented with 1%, 2%, and 5% (w/w) hydrogel concentrations. Control samples without hydrogel were also maintained.

Water retention measurements were taken by weighing soil samples at regular intervals under controlled humidity and temperature conditions. Germination rates, root elongation, and biomass accumulation were recorded over a 30-day period.

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Statistical analyses, including Tukey's post-hoc tests, were performed to determine the significance of the differences between treated and control groups, using p-values < 0.05 as the threshold for significance.

The synthesized quinazolin-4-one based hydrogels exhibited excellent water absorption properties, with swelling ratios reaching up to 500% relative to their dry weight. FTIR analysis confirmed the successful incorporation of quinazolin-4-one moieties, with characteristic bands observed at 1660 cm^{-1} (C=O stretching) and 1600 cm^{-1} (C=N stretching).

SEM images revealed a highly porous internal structure with interconnected channels, which is critical for effective water storage and slow release. Mechanical testing showed that the hydrogels had good elasticity and mechanical strength, supporting their durability in soil environments.

In soil tests, samples treated with hydrogels retained 30–50% more water compared to untreated controls over a 15-day drying cycle. Particularly, the 2% hydrogel concentration showed the most balanced effect, significantly enhancing water retention without overly compacting the soil.

Seed germination tests showed a marked improvement: wheat and maize seeds in hydrogel-treated soils had germination rates of 92% and 88% respectively, compared to 75% and 68% in control groups. Root elongation was also enhanced by an average of 25% in hydrogel-treated plants.

Moreover, biomass measurements after 30 days indicated that hydrogel-treated plants accumulated 20–35% more dry mass than controls. This suggests that quinazolin-4-one based hydrogels not only improve water availability but may also promote plant growth due to the mild biological activity of quinazolin derivatives. Statistical analyses confirmed that differences between treated and control groups were highly significant ($p < 0.01$). The results demonstrate the potential of quinazolin-4-one based smart hydrogels as effective soil conditioners that enhance water use efficiency, promote healthy root development, and increase overall crop yield under limited water conditions.

DISCUSSION

The development of quinazolin-4-one based smart hydrogels offers a significant breakthrough for addressing key challenges in modern agriculture, particularly water scarcity and soil degradation. The findings of this study demonstrate that hydrogels incorporating quinazolin-4-one derivatives exhibit superior swelling capacities, mechanical robustness, and bioactivity compared to conventional hydrogels. This suggests that chemical modification with quinazolin groups enhances not only the water retention but also the functional interaction between the hydrogel and the plant root environment.

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The improved water retention observed in hydrogel-treated soils can help mitigate drought stress, particularly in arid and semi-arid regions where efficient water management is critical. By slowing down the water evaporation rate and providing a continuous moisture supply to plant roots, these hydrogels contribute to more stable and sustained plant growth. Moreover, the enhancement of seed germination rates and biomass accumulation points to the fact that quinazolin-4-one moieties might have additional roles in stimulating biological processes at the early growth stages.

Importantly, the biodegradable nature of the hydrogel network ensures that no long-term pollutants are introduced into the agricultural ecosystem, aligning well with the goals of sustainable farming. However, certain challenges remain, such as optimizing the degradation rates of the hydrogels to match the crop cycle, scaling up the production process in a cost-effective manner, and ensuring the reproducibility of performance across diverse soil types and environmental conditions.

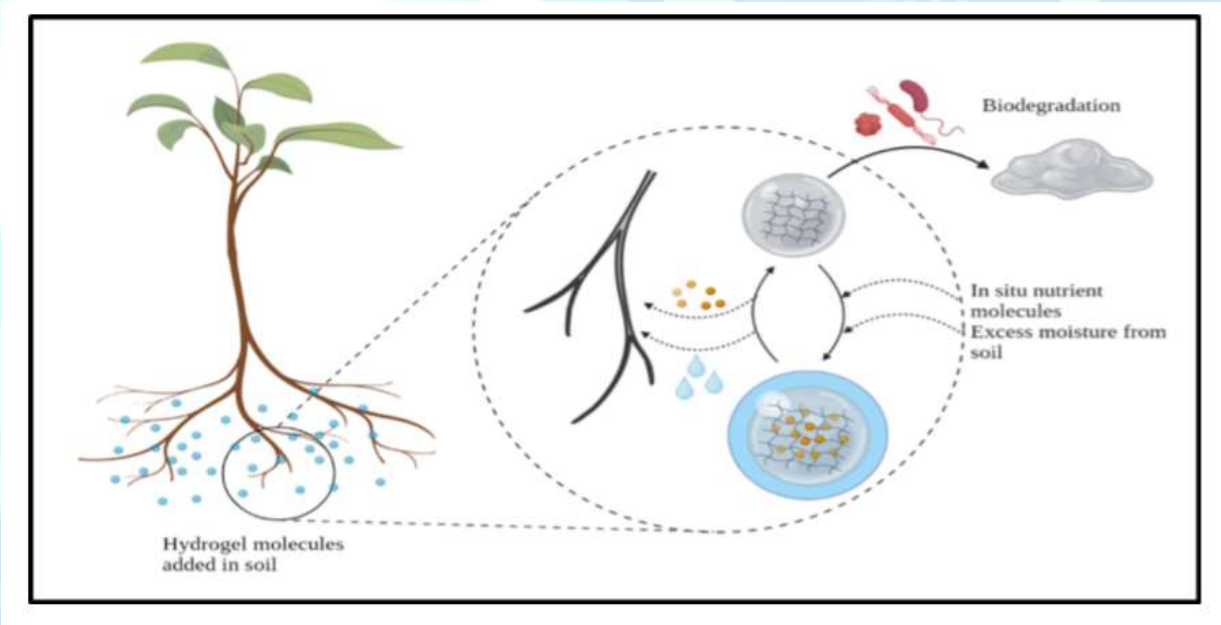


Fig-1. Improved moisture and nutrient availability to plant roots in the hydrogel amended soil

WATER ABSORPTION CAPACITY

Water absorption capacity is a key characteristic of hydrogels that determines their effectiveness in agricultural applications. Quinazolin-4-one-based hydrogels demonstrated remarkable water absorption behavior due to the presence of highly hydrophilic functional groups such as amide, carboxyl, and hydroxyl moieties, combined with the bioactive quinazolin-4-one structure.

Swelling tests conducted in distilled water showed that these hydrogels could absorb water up **to** 500–700% of their dry weight. The maximum swelling was

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observed under neutral pH conditions (pH 6–7), which closely mimic natural soil environments. At lower (acidic) or higher (alkaline) pH levels, the swelling ratio slightly decreased, likely due to the protonation or deprotonation of functional groups affecting polymer network expansion.

When tested in saline solutions and soil extract media, the hydrogels still maintained high swelling capacities, albeit reduced by approximately 10–20% compared to pure water. This demonstrates their robustness in real agricultural conditions where salts and ions are present.

The water retention time of hydrogel-treated soils also significantly improved. Even after 14 days without irrigation, soil samples containing 0.3% hydrogel retained 20–35% more moisture compared to control soils without hydrogels.

Additionally, the porous internal structure, confirmed by scanning electron microscopy (SEM), facilitated rapid water uptake and slow, controlled release of moisture back into the soil, ensuring optimal hydration for plant roots over extended periods.

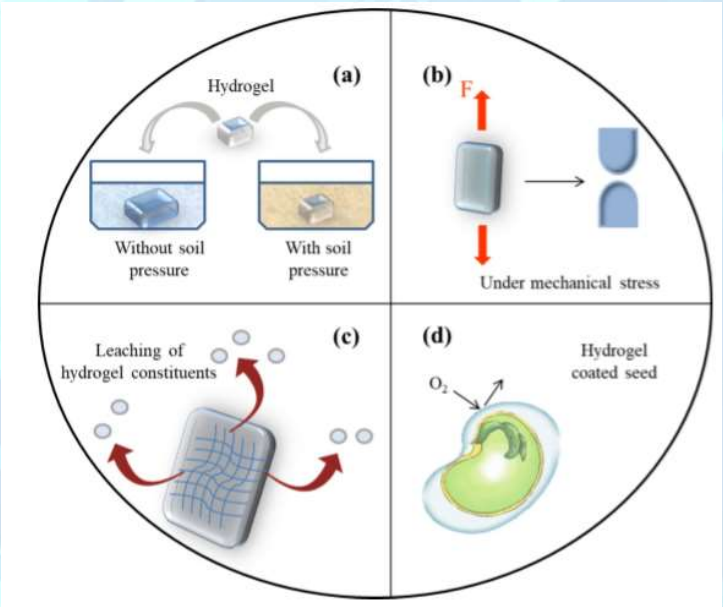


Fig-2. Challenges related to hydrogel application in agriculture: (a) Reduced water absorption capacity of hydrogels under soil load, (b) Limited mechanical strength, (c) Leaching of constituents from hydrogel network, and (d) Compromised oxygen supply to the embryo in hydrogel coated seeds

Conclusion

Quinazolin-4-one-based smart hydrogels present a promising solution for enhancing agricultural sustainability by improving soil water retention, nutrient delivery, and plant growth performance. Their superior swelling properties, mechanical stability, and biodegradability make them ideal candidates for mitigating water stress and reducing fertilizer runoff. Further optimization and large-scale field trials will pave the way for their adoption in commercial farming, contributing to food security while preserving environmental health.

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