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ROLE OF CARBON DOTS AND THEIR APPLICATIONS IN AGRICULTURE

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ABSTRACT

Carbon Dots exhibit exceptional size-dependent optical properties that can be adjusted through surface alterations, thus broadening their applicability across various domains. Furthermore, their facile synthesis, excellent dispersibility, solubility, hydrophilic characteristics, biocompatibility, environmental sustainability, cellular permeability, low toxicity, high photostability, and cost-effectiveness have garnered interest across a wide range of applications, from materials chemistry to nanotechnology.

Carbon Dots have long been utilized as growth enhancers by improving the photosynthesis process in agricultural systems. In this approach, the manufactured Carbon Dots of the specified size are distributed on the plant, where the leaf adsorbs the CDs onto its surface. Consequently, Carbon Dots enhance the absorption rate of sunlight and carbon dioxide. Consequently, the rate of photosynthesis escalates. Consequently, the crop's growth and yield may rise by 10%-20%. Moreover, Carbon Dots possess disease-resistant qualities that safeguard them against many ailments.

The substantial incorporation of Carbon Dots in plants significantly enhances seed germination, root development, leaf quantity, and enzymatic activity for the conversion of CO2 into carbohydrates via an accelerated rate of photosynthesis. Consequently, rice crop productivity rises by 14.8%. Furthermore, it possesses disease resistance that safeguards plants from damage. Moreover, Carbon Dots can transform detrimental UV light into photosynthetically active radiation, hence promoting enhanced plant growth. This study elucidates the physiological roles of carbon dots in crop growth and development, photosynthesis, and their uses in enhancing agriculture.

Keywords: Synthesis, CDs, Nanotechnology, Biocompatibility, Carbon dioxide, UV radiation

1. INTRODUCTION

Carbon dots (CDs) are carbon-based nanomaterials characterized by their fluorescent characteristics, comprising quasi-spherical carbon nanoparticles measuring less than 10 nm in size. Since their discovery in 2004, carbon dots (C-dots) have garnered considerable interest and are currently being investigated for several applications, including agriculture, energy storage and conversion, molecular sensing, nanoforensics, bioimaging, drug delivery, and antimicrobial therapies. C-dots are generally comprised of carbon, hydrogen, and oxygen, however nitrogen, phosphorus, and additional elements may be incorporated during or subsequent to the synthesis process.

Sustainable agricultural practices can substantially contribute to fulfilling global food requirements while preserving environmental integrity. Nanotechnology has attracted significant interest as a sustainable solution to the difficulties confronting the agricultural sector. Carbon dots (CDs) are innovative carbon nanostructures possessing distinctive features. Carbon Dots exhibit significant aqueous solubility, biocompatibility, and minimal toxicity. Due to their exceptional bio-compatibility, Carbon Dots are comparatively safer nanomaterials for agricultural applications. In recent years, Carbon Dots have demonstrated substantial growth-promoting benefits on plants. Given that agricultural outputs depend on the photosynthetic efficiency of plants, Carbon Dots, with their photoluminescence, can promote photosynthesis and optimize solar energy utilization to boost crop productivity, rendering them ideal photosynthetic enhancers. Besides PL, the hydrophilicity of Carbon Dots further promotes plant growth by expediting seed germination and enhancing water absorption in plants. Furthermore, their antibacterial and antioxidant characteristics enable them to alleviate biotic and abiotic stressors, thereby enhancing plant health.

Carbon Dots, a collective term for various nanosized luminous carbon materials, specifically encompass graphene quantum dots, carbon quantum dots, carbon nanodots, and carbonized polymer dots, categorized based on their distinct carbon core structure, surface groups, and characteristics.

Applications of Carbon Dots in Agriculture Crop Production

Enhancing agricultural output is essential for sustaining the burgeoning human population. Recent studies have demonstrated the beneficial impact of Carbon Dots on the growth of monocotyledonous plants (such as wheat, rice, and maize), dicotyledonous plants, and various other species, including mung beans, tomatoes, lettuce, tobacco, soybeans, eggplants, chili peppers, watermelons, radishes, celery, coriander, and cabbage. Carbon Dots are extensively utilized in agriculture for seed priming, enhancing photosynthesis, alleviating plant stress, and serving as sensors. The beneficial effects of Carbon Dots on many plants suggest their significant application potential in agriculture, contributing to enhanced crop development and increased sustainability in agricultural production.

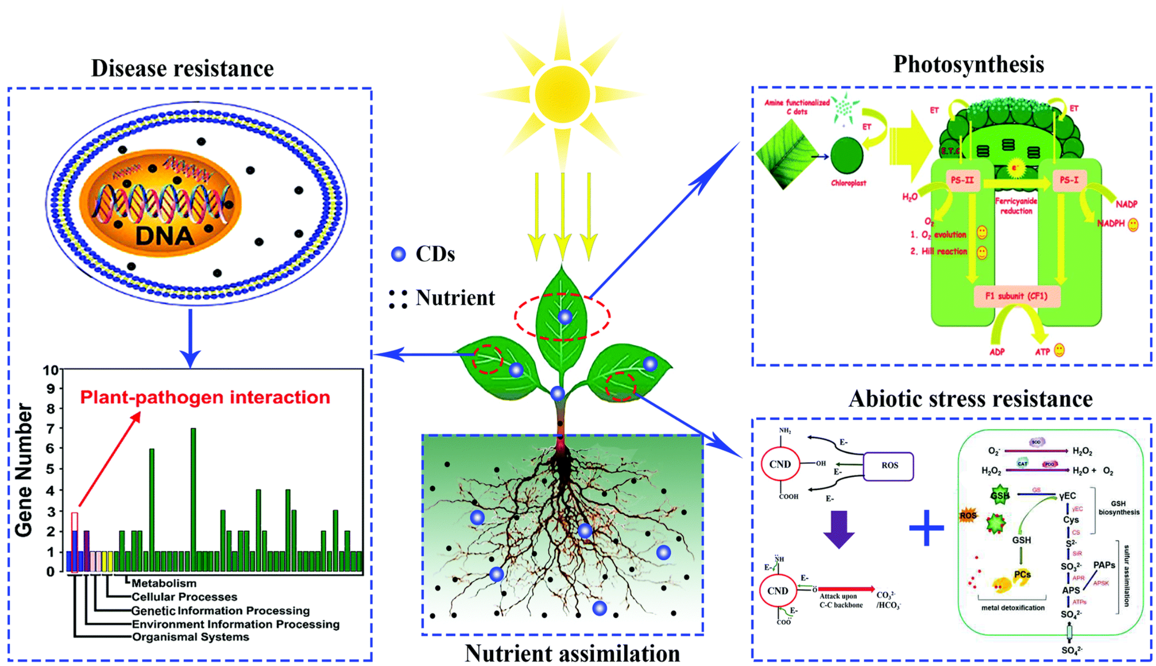

Figure: 1 Applications of CDs in Agriculture.

Due to their minimal toxicity and superior fluorescent characteristics, Carbon Dots were initially employed for the biological imaging of agricultural systems. The amino-functionalized Carbon Dots were synthesized utilizing p-phenylenediamine as a precursor. The influence of Carbon Dots on the complete life cycle of rice demonstrated that Carbon Dots enhanced plant development by facilitating seed germination, root expansion, and carbohydrate accumulation. The yield rose by 14.8%. Ultimately, Carbon Dots transformed into plant hormone analogs that stimulated plant growth and carbon dioxide, which was subsequently turned into carbohydrates via the Calvin cycle. They subsequently achieved same results by examining the complete life cycle of Carbon Dots on the dicotyledons Arabidopsis thaliana and Trifolium repens L.

The function of Carbon Dots throughout the entire crop life cycle encompasses the pre-harvest phase (seed germination, nano-fertilizers, plant growth regulators, targeted delivery of fertilizers, pesticides, and biomolecules, photosynthesis, and stress tolerance) and the post-harvest phase (antibacterial preservation of harvested fruits and intelligent anti-counterfeit packaging). At the conclusion of the crop life cycle, they transform into agricultural waste, which serves as valuable biomass materials that may be utilized to produce compost and reintegrate into the crop life cycle, so establishing a closed loop.

Carbon Dots promote the growth and development of agriculture crops

The primary routes for Carbon Dots to infiltrate plants are root absorption from soil or water and leaf absorption. Research indicates that Carbon Dots can infiltrate plant cells and subsequently be conveyed with water and minerals from the roots to the stems and leaves; they are assimilated through cell walls and plasmodesmata via extracellular routes in intercellular and extracellular spaces, then traverse the cortex and enter the xylem through the plastid pathway. Carbon Dots exhibit durable and distinctive fluorescence signals, offering an effective means for tracking in plants. The absorption of Carbon Dots by plants can be illustrated by techniques such as fluorescence imaging, transmission electron microscopy, or Raman spectroscopic analysis.

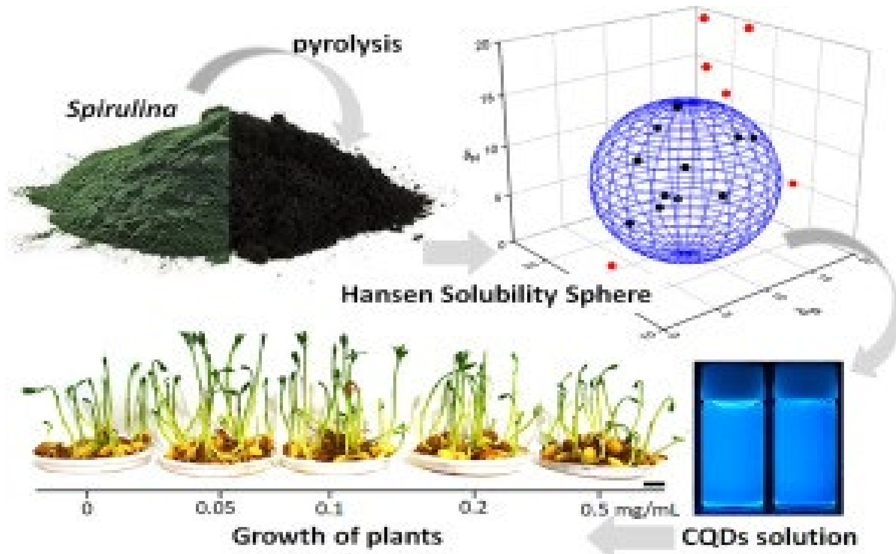

Figure: 2 Carbon Dots promote the growth and development of crops

Confocal laser scanning microscopy was employed to examine the roots, stems, and leaves of early seedlings, revealing that Carbon Dots predominantly reside within the vascular system. Transmission electron microscopy was employed to examine the transverse sections of roots, stems, and leaves, revealing substantial aggregation clusters of CDs in the intercellular gaps. Consequently, Carbon Dots are absorbed by the roots, enter the root vascular bundle, and are then transferred to the vascular bundles of the stem and leaves, ultimately entering the intercellular space for aggregation. The growth and production of crops rely on efficient photosynthesis, the primary source of materials for plant development and biomass accumulation, accounting for about 90% of crop biomass. A significant physiological role of Carbon Dots is to augment plant photosynthesis.

The principal physiological roles of Carbon Dots include facilitating seed germination and root development,1049nhance uptake, promoting overall plant growth, augmenting biomass accumulation, improving photosynthesis, and elevating carbohydrate content, as well as enhancing plant resilience to abiotic stress and disease; these processes are vital for plant development and crop yield.

The Role of Carbon Dots as Biosensors in Agriculture

As pesticide dosage rises, the fluorescence intensity of Carbon Dots markedly diminishes due to the fluorescence-quenching phenomena. Tafreshi et al. devised a fluorescence-based technique for the detection of three pesticides: diazinon, glyphosate, and semicarbazide. This sensor exhibits strong selectivity despite the presence of other herbicides and has shown outstanding performance with tomato samples. It can additionally be employed in various agricultural items to attain ultrasensitive fluorescence detection of pesticides in actual samples utilizing green Carbon Dots. Electrostatic interactions between functional groups on the surfaces of Carbon Dots and isothio pesticides result in fluorescence quenching of the Carbon Dots. Ghosh et al. created a sensor for detecting isothio pesticides utilizing this fluorescence-quenching phenomenon of Carbon Dots. The detection limit reaches nanomolar amounts in water, fruit, and rice samples, while maintaining great selectivity amidst different interfering chemicals and other pesticides.

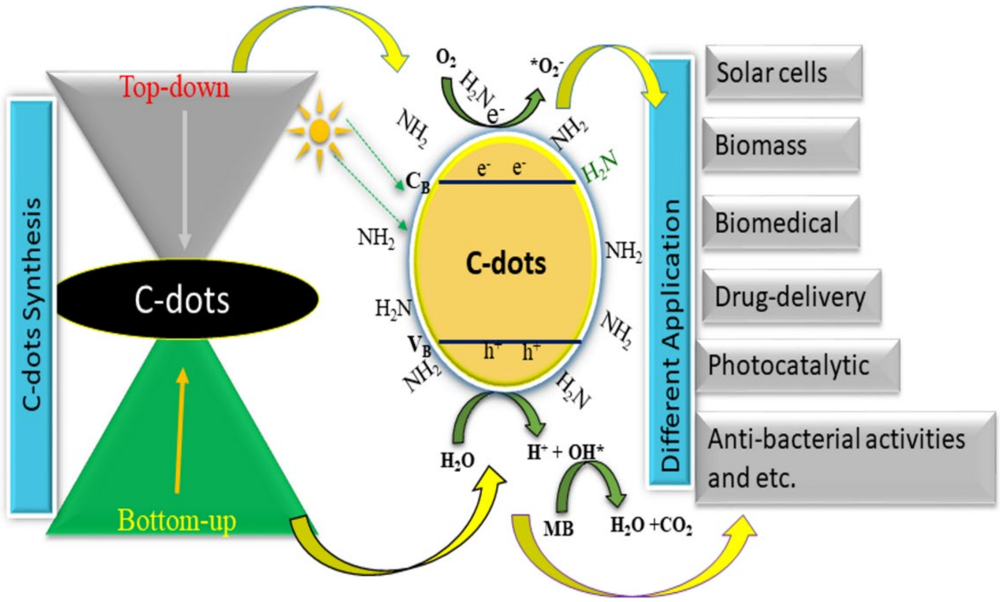

Figure: 3 Carbon Dots as Biosensors in Agriculture

The fluorescence characteristics of Carbon Dots can be markedly controlled via atomic doping or surface functionalization. Doped Carbon Dots may be either single-element or multi-element doped, which boosts their fluorescence properties and markedly improves their efficacy in sensing applications. Yahyai et al. produced sulfur- and nitrogen-doped Carbon Dots and created a paper-based chemiluminescence sensor employing these Carbon Dots for the detection of oxfamil pesticide in fruit juice and water.

The Protective Effect of Carbon Dots on Agriculture

An optimal ecological environment is essential for food security production. Due to their low toxicity, chemical inertness, biodegradability, and affordability, Carbon Dots are regarded as an exceptional option for the degradation of organic contaminants. Pesticides, industrial chemicals, by-products of industrial processes, and aromatic hydrocarbons that enter the environment can stimulate and accumulate pathogenic microorganisms in the food chain, so converting them into organic pollutants. These contaminants possess mutagenic, carcinogenic, and endocrine-disrupting effects that adversely affect human health. Current study has identified the significant significance of Carbon Dots in the photodegradation of organic contaminants, including residual pesticides and endocrine disruptors. Cruz et al. discovered that Carbon Dots were utilized alongside a photosensitizer for the photodegradation of organic dyes and hazardous gasses. The incorporation of Carbon Dots significantly enhanced the degradation rate relative to the original photocatalysts. Carbon Dots possess the capability to function as photocatalysts for the breakdown of tetracycline. Moreover, Carbon Dots can diminish the uptake of heavy metal ions by crops, thereby mitigating the detrimental effects of heavy metals on crop development, as heavy metal ions can be sequestered between the functional groups on the surface of Carbon Dots, consequently lowering the concentration of heavy metal ions in crops.

Carbon Dots Enhance Agriculture Crop Photosynthesis

The growth and production of crops rely on efficient photosynthesis, the primary source of materials for plant development and biomass accumulation, accounting for about 90% of crop biomass. A significant physiological role of Carbon Dots is to augment plant photosynthesis. Photosynthesis encompasses two energy conversion processes: the transformation of light energy into electrical energy and the conversion of electrical energy into chemical energy. This process involves light absorption, electron transfer, photophosphorylation, carbon assimilation, and other critical reaction steps.

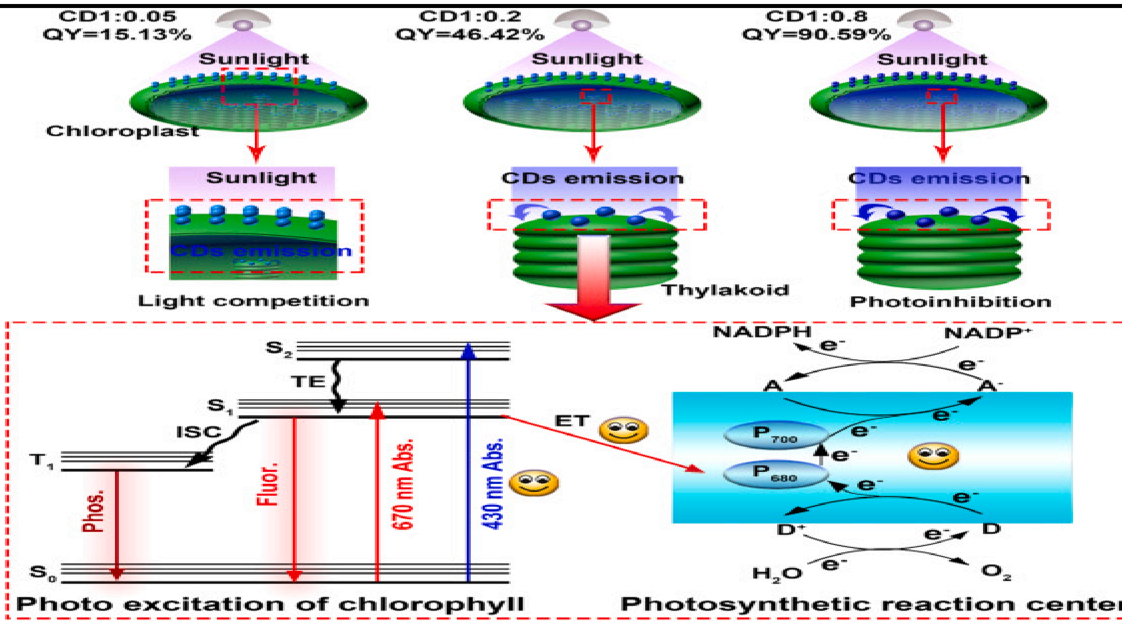

Figure: 4 Carbon Dots Enhance Crop Photosynthesis

Carbon Dots generally demonstrate robust absorption in the ultraviolet spectrum (200–400 nm), although their light absorption can be broadened into the visible spectrum depending on the nature and quantity of surface functional groups, along with variations in the oxygen/nitrogen composition within the carbon matrix. Carbon Dots offer greater advantages for boosting photosynthesis in monocotyledonous plants compared to dicotyledonous plants. The structural distinctions in the vascular system and root architecture of monocotyledonous and dicotyledonous plants account for the heightened photosynthesis. Carbon Dots exert varying effects on the photosynthesis of C3 plants (rice) and C4 plants (corn), with a more pronounced impact on CO2 assimilation in rice compared to corn. This disparity arises from corn's C4 metabolic pathway, which effectively mitigates photorespiration and enhances CO2 fixation rates. Additionally, Carbon Dots markedly enhance the stomatal conductance of rice.

Improving Agriculture Crop Quality with Carbon Dots

Photosynthesis serves as the primary mechanism for assimilation in crop yield creation, with the yield level contingent upon the accumulation and dispersion of photosynthetic products. The consistent application of CDs (50 mg L−1) during the vegetative development phase of maize can enhance carbohydrate accumulation in the reproductive growth phase, leading to an increase in the 1000-grain weight and a final yield augmentation of 24.50%. The expression of sucrose transporter (SUT) genes in leaves increased 1.61 times following treatment with Carbon Dots, and this upregulation augmented the sucrose transportation capacity in the phloem.

Consequently, an increased quantity of carbohydrates is conveyed from leaves to grains, thereby enhancing grain filling and augmenting yield. Fertilizer, as the primary source of crop nutrients in contemporary agriculture, directly influences or regulates nutrient metabolism and cycling, significantly impacting crop yield and quality. The incorporation of Carbon Dots as fertilizer enhancers into various fertilizers can expedite chemical reactions, enhance nutrient decomposition, improve fertilizer release characteristics, increase fertilizer utilization efficiency, and foster crop growth and development.

Effects of CDs on nutrition assimilation by plants

In addition to photosynthesis, nutrient absorption is a crucial component influencing plant growth. The hydrophilic groups (hydroxyl and carboxyl groups) on the surface of Carbon Dots offer numerous binding sites for water molecules, which are absorbed by the plant with the Carbon Dots. Ultimately, sufficient moisture in plant seeds might enhance germination and expedite the growth of seedlings. In a seed germination experiment, Carbon Dots-treated mung bean seeds exhibited moisture levels that were 34.9% more than those of the control group, suggesting that Carbon Dots enhance the water absorption ability of seeds. Water absorption by plants is concomitant with the absorption of nutrients. A 2007 report by the Food and Agriculture Organization of the United Nations (FAO) indicates that over 96%

of global rural land is impacted by various abiotic stresses (such as drought, cold, salinity, excessive solar radiation, and pesticide misuse), resulting in an annual loss of approximately 50% of global crop yields.

CONCLUSION

The utilization of Carbon Dots in agriculture has emerged as a prominent issue in recent years. This article examines current advancements in the application of Carbon Dots in agriculture, with a detailed focus on the interactions between crops and Carbon Dots. Carbon Dots exhibit significant potential in mitigating climate change, accommodating population increase, and enhancing agricultural productivity. This review elucidates the function of Carbon Dots throughout the whole crop life cycle and their reintroduction into the cycle as precursors derived from agricultural waste. The conditions for crop growth, encompassing temperature, soil quality, water availability, and cultivation practices, profoundly influence crop development and yield production. Research on the impact of Carbon Dots on agricultural applications is still insufficient. Temperature significantly influences the biological activity and metabolic activities of crops. Optimal temperature can enhance crop growth and development, augment photosynthetic efficiency, and elevate nutrient absorption and usage efficacy. Simultaneously, temperature can influence the activity of soil microorganisms, thereby impacting the breakdown and usage of carbon quantum dots. The characteristics of soil directly influence crop development. Various soil types possess distinct fertility and water retention capacities, influencing crop growth and yield. Significant advancements have been made in the domain of Carbon Dots; however, further efforts are necessary to enhance their uses in agriculture.

CONFLICT OF INTERESTS

None

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None

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