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(REVIEW ARTICLE)

A review: Revealing the important of bio stimulant coated microbeads biofertilizers for improving the effectiveness of inoculant for enhancing the agronomic traits and productivity of crops

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Abstract

The utilization of biofertilizers and inoculants has emerged as a promising strategy in modern agriculture to bolster crop productivity sustainably. However, maximizing the effectiveness of these microbial agents remains a challenge. To address this, biostimulant-coated microbeads biofertilizers have been introduced, aiming to enhance the interaction between microorganisms and plants. These innovative formulations combine biofertilizers with biostimulants, substances that stimulate biological activity in the soil and enhance plant nutrient absorption. Biostimulant-coated microbeads are designed to improve agronomic traits such as root growth, disease resistance, and stress tolerance, ultimately leading to increased crop yields. Various studies have demonstrated the efficacy of biostimulant-coated microbeads in enhancing nutrient uptake, promoting plant growth, and reducing the reliance on chemical fertilizers. However, several challenges persist in their implementation, including ensuring efficacy and consistency, navigating regulatory frameworks, achieving cost-effectiveness, and promoting awareness among farmers. Addressing these challenges through research, innovation, and education is crucial for the successful integration and widespread adoption of biostimulant-coated microbeads in sustainable agriculture.

Keyword: Sustainable agriculture; Microbial biostimulants; Crop productivity; Encapsulation technology

1. Introduction

Modern agriculture faces significant challenges in maintaining and enhancing the sustainable productivity of crops. One of the approaches utilized to optimize agricultural yields is through the use of biofertilizers and inoculants [1]. Biofertilizers, containing beneficial microorganisms for plants, have immense potential to improve soil health and enhance nutrient efficiency for crops. On the other hand, inoculants, which consist of bacteria or fungi cultures that benefit plants, are applied to expedite symbiotic processes with plants, aiding in nutrient absorption and increasing resilience to environmental stress [2].

Despite the promising benefits of biofertilizers and inoculants, there are still limitations in their effectiveness. One major constraint is the challenge of maximizing the interaction between these microorganisms and plants. To address this, research and innovation are continually evolving, and one prominent approach is the use of biostimulant-coated microbeads biofertilizers.

Biostimulant-coated microbeads are special formulations that combine biofertilizers with biostimulants, substances that stimulate biological activity in the soil and enhance plant nutrient absorption [3]. The application of biostimulant-coated microbeads is expected to enhance the effectiveness of inoculants, providing an additional advantage in

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improving agronomic traits such as root growth, disease resistance, and environmental stress tolerance(Lobo et al., 2019). The use of microbeads biofertilizers containing biostimulants with encapsulation methods offers several significant advantages. Microbeads produced through encapsulation provide protection to microorganisms in biofertilizers from adverse environmental influences, enhancing their survival and biological activity [4]. The gradual release from encapsulation creates a stable environment, improving the efficiency of biofertilizer use and supporting plant growth [5]. These advantages also include increased resilience of microorganisms to external pressures, such as chemicals and weather changes. Biostimulants in encapsulation stimulate the plant's root system to enhance nutrient absorption, while reducing the use of chemical fertilizers supports sustainable agriculture [6]. With ease of application, this method provides an innovative solution to enhance the performance of biofertilizers in supporting modern and sustainable agriculture.

Previous studies have provided evidence that the combination of biofertilizer and inoculant can enhance agricultural yields. However, the role of biostimulant-coated microbeads in improving the effectiveness of inoculants needs further exploration. Therefore, this research aims to reveal the importance of using biostimulant-coated microbeads biofertilizers in enhancing the effectiveness of inoculants to improve agronomic traits and productivity of crops. The findings of this study are expected to offer new insights and make a significant contribution to the development of sustainable agriculture.

2. Biostimulant Coated Microbeads Biofertilizers

Biostimulant coated microbeads biofertilizers are innovative agricultural products that combine biostimulants, microorganisms, and fertilizers to enhance plant growth and productivity. Biostimulants are substances that stimulate plant physiological processes, while biofertilizers contain natural derivatives and/or microorganisms that benefit plant growth [7]. The use of biostimulant coated microbeads biofertilizers has been shown to improve nutrient uptake, increase crop yields, and enhance plant tolerance to abiotic stress. These products are designed to promote sustainable agriculture by reducing the dependency on chemical fertilizers and contributing to soil regeneration. The specific composition and application of biostimulant coated microbeads biofertilizers may vary, but they generally aim to optimize plant nutrition, improve soil fertility, and support ecological functioning in agricultural systems [8].

Microbial coated with biostimulants are substances or microorganisms that stimulate natural processes in plants or the rhizosphere to benefit nutrient uptake, nutrient use efficiency, tolerance to abiotic stress, and/or crop quality, independently of its nutrient content. They are designed to promote plant growth and development by stimulating natural biochemical processes, optimizing the absorption of water and nutrients by the plant, and increasing the plants' tolerance to drought and salinity [9]. Microbial biostimulants can be formulated using a single plant growth-promoting microbe (PGPM) strain, an arbuscular mycorrhizal fungi (AMF)/PGPR multispecies consortia, or a combination of PGPMs with organic and inorganic chemicals. They work by enhancing the plant's natural processes, such as nutrient uptake, photosynthesis, and hormone production, and by improving the physical and microbiological properties of the soil [10]. The use of microbial biostimulants is a promising approach to sustainable agriculture, as it reduces the dependency on chemical fertilizers and contributes to soil regeneration [7].

Table 1 Various Biostimulant Coated Microbeads Biofertilzers

Microbes	**Biostimulant**	**Plant**	**Encapsulation methods**	**Reference**
Streptomyces fulvissimus-Uts22	Chitosan	Wheat	Spray Drying	[11]
Azosprillum brasilense DSM 1690	Clay, Alginate	Wheat	Ionic gelation	[12]
Enterobacter ludwigii-PS10	Zinc (Zn), Alginate	*Solanum lycopersicum*	Ionic Gelation	[13]
Pseudomonas putida	Alginate	*Capsicum annuum*	Ionic Gelation	[14]
Pantoea agglomerans	Alginate	*Zea mays*	Ionic Gelation	[15]
Metarhizium brunneum-BIPESCO5	Alginate	*Solanum lycopersicum*	Ionic Gelation	[16]

Enterobacter (SA-10)	Vermicast, Cow Manure, Alginate	*Ocimum basilicum*	Ionic Gelation	[17]
Acinetobacter calcoaceticus, Bacillus proteolyticus, Stenotrophomonas pavanii	Alginate	*Zea mays*	Ionic Gelation	[18]
Bacillus velezensis	Alginate, zedo gum, mastic gum, tragacanth gum	Wheat	Layer-by-layer	[19]
Bacillus licheniformis	Chitosan, Rice Starch	*Capsicum annuum* (L.)	Ionic Gelation	[20]
Bacillus velezensis	Alginate, SiO_2	Bean	Ionic Gelation	[22]
Azotobacter sp.	Alginate	Wheat	Ionic Gelation	[21]
Myroid gitamensis	Alginate, Gum Arabic	Wheat	Ionic Gelation	[23]

3. Improvement Of Agronomic Properties And Crop Productivity by Biostimulant-Coated Microbeads Biofertilizers

Innovative agricultural products known as biostimulant-coated microbeads biofertilizers have garnered considerable interest due to their capacity to enhance agronomic characteristics and boost the productivity of crops. These formulations incorporate a blend of biostimulants, microorganisms, and fertilizers, synergistically promoting plant growth, elevating crop yields, and enhancing soil fertility [24]. The utilization of biostimulant-coated microbeads biofertilizers has demonstrated numerous advantages, including:

- Enhancing nutrient uptake and improving soil fertility, microorganisms in these products can improve the availability of nutrients in the soil, allowing plants to better absorb essential elements such as nitrogen, phosphorus, and potassium. The use of *Metarhizium brunneum* encapsulated with biostimulant can enhance the availability of nitrogen and phosphorus in both nutrient-poor and nutrient-rich conditions because these microbes can transfer insect-derived nitrogen to plants, serving as a pathway for nitrogen availability. *Metarhizium* species can also solubilize phosphorus, making it more accessible to plants by breaking down phosphorus-containing compounds in the soil [25]. In a study conducted by Aeron et al., (2021), it was shown that *Enterobacter turicensis* encapsulated with biostimulant can enhance the availability of phosphorus, zinc and potassium because these microorganisms can solubilize phosphorus, zinc and potassium.
- Increasing crop yields: By promoting plant growth and nutrient uptake, biostimulant coated microbeads biofertilizers can contribute to higher crop yields. The use of *Pseudomonas fluorescens* coated with biostimulant can enhance the availability of nitrogen, phosphorus, and potassium for tomato plants, leading to increased shoot length and root length, fruit weight, and the number of branches and fruits per plant, thus improving crop yields [27]. The experiment conducted on okra plants by Roslan et al., (2022) showed that the use of *Enterobacter hormaechei* encapsulated with biostimulant resulted in an increased yield of up to 75.6% by altering soil characteristics, which indirectly enhanced okra phosphorus (P) and potassium (K) uptake. This was achieved by elevating soil available phosphorus and soil available potassium, along with acid excretion, even under low P and K fertilizer inputs.
- Enhancing stress tolerance: Some microorganisms in these products can help plants to better cope with abiotic stress, such as drought and high temperatures. In a study conducted by Saad & Ahmed Abokoura (2020), it was shown that using biostimulant-coated microbeads can enhance the resilience of bacteria under 60% irrigation conditions because the biostimulant used can protect and strengthen the cell walls. The use of biostimulant beads can increase wheat yields compared to those not inoculated with bacteria. In research conducted by Bhise & Dandge (2019b), the inoculation of *Pantoea agglomerans* encapsulated with biostimulant was shown to enhance shoot length by 130.36%, root length by 128.20%, fresh weight by 127.10%, and dry weight by 136.39% when compared to non-inoculated rice plants under salt stress conditions ranging from 0-8%
- Reducing the need for chemical fertilizers: The use of biostimulant coated microbeads biofertilizers can help to reduce the reliance on chemical fertilizers, which can have negative environmental impact. The microencapsulated biofertilizer offers a direct application method to the soil, decreasing the necessity for frequent applications and averting leaching into the nearby environment. Its gradual release characteristic

ensures prolonged nutrient availability to plants, leading to enhanced plant growth, amplified crop yields, and minimized nutrient runoff [23].

In conclusion, the utilization of biostimulant-coated microbeads biofertilizers represents a significant advancement in modern agriculture, offering a comprehensive solution to enhance crop productivity while promoting sustainability. By integrating biostimulants, microorganisms, and fertilizers, these innovative formulations synergistically facilitate plant growth, elevate crop yields, and enhance soil fertility. The demonstrated advantages of biostimulant-coated microbeads biofertilizers, including improved nutrient uptake, increased stress tolerance, and reduced reliance on chemical fertilizers, highlight their potential to revolutionize farming practices worldwide. Through their gradual release mechanism and direct application to the soil, these biofertilizers ensure prolonged nutrient availability, thereby minimizing environmental impact and contributing to the long-term health of agricultural ecosystems. As such, the widespread adoption of biostimulant-coated microbeads biofertilizers holds promise for addressing global food security challenges and advancing sustainable agricultural practices into the future.

4. Challenges and Future in Implementation

The use of biostimulant coated microbeads brings forth opportunities as well as hurdles in the domain of sustainable agriculture. Despite offering a hopeful approach to improve plant development and decrease dependency on synthetic fertilizers, there are various obstacles that must be overcome to effectively introduce and widely accept these innovative products. Challenges in the implementation of biostimulant coated microbeads span various fronts. Firstly, ensuring the efficacy and consistency of these microbeads presents a formidable challenge, given factors such as microorganism stability, nutrient release dynamics, and interactions with soil microbiota. Secondly, navigating the regulatory landscape poses a significant hurdle, as differing regulations across regions can impact market availability and acceptance. Establishing harmonized regulations and clear guidelines will be pivotal for their widespread adoption. Research efforts must prioritize optimizing formulations to maximize effectiveness across diverse soil types and crops. Moreover, achieving cost-effectiveness compared to traditional fertilizers is imperative. Striking a balance between production costs and benefits is essential to incentivize farmers to adopt these innovative products on a larger scale. Educating farmers about the benefits and proper application methods is also crucial. Increasing awareness regarding the advantages of biostimulant coated microbeads in terms of soil health, crop productivity, and environmental sustainability will be key to driving adoption. Lastly, continuous research and development efforts are necessary to enhance performance. Exploring novel encapsulation technologies and optimizing microbial strains through rigorous field trials are essential for future implementation. In conclusion, while biostimulant coated microbeads hold immense promise for sustainable agriculture, addressing the challenges related to regulation, efficacy, cost-effectiveness, education, and research is vital for their successful integration and widespread use in enhancing crop productivity and soil health.

5. Conclusion

The integration of biostimulant-coated microbeads biofertilizers into modern agricultural practices presents a promising avenue for addressing the challenges of maintaining sustainable crop productivity. By combining biofertilizers with biostimulants, these innovative formulations offer multifaceted benefits including enhanced nutrient uptake, increased crop yields, and improved stress tolerance. The utilization of biostimulant-coated microbeads has shown significant potential in optimizing plant growth, reducing the dependency on chemical fertilizers, and promoting soil health. However, several hurdles must be overcome for their successful implementation. These challenges encompass ensuring efficacy and consistency, navigating regulatory frameworks, achieving cost-effectiveness, promoting farmer education and awareness, and advancing research and development efforts. Addressing these challenges will be instrumental in realizing the full potential of biostimulant-coated microbeads biofertilizers in enhancing crop productivity and soil sustainability. With concerted efforts in research, innovation, and education, biostimulant-coated microbeads can emerge as a valuable tool in promoting sustainable agriculture and addressing global food security challenges.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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