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Research article

Waste-derived nutritional seed balls coated with mycorrhizal inoculum: a one health perspective

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ABSTRACT

The fast-paced agriculture development has increased risks to human and environmental health due to over use of chemical fertilizers and pesticides. We are at the verge of finding sustainable solution to this problem. Nutritional seed balls constructed from oil seed meals and waste-derived binders, and coated with Arbuscular Mycorrhizal Fungi (AMF) and Ectomycorrhiza (ECM), present a promising solution. A nutrient-rich carriers and biodegradable binders ensure stability and environmental compatibility. The fungal inoculation of both AMF and ECM enhances plant nutrient uptake, stress tolerance, and root health that reduces fertilizer dependency. The vital role of this system is in its alignment with the One Health paradigm by supporting human, animal, plant, and environmental well-being. T hese seed ball will not only be useful in agriculture but also in nurseries, agroforestry, and reforestation programs that shows that they are versatile and has great potential for large-scale application. This review synthesizes current evidence on their agronomic benefits, waste valorization potential, and role in advancing sustainable agriculture and food security.

Keywords: Nutritional seed balls, Waste-derived binders, Oilseed meals, AMF, ECM, Mycorrhizal inoculum, Biodegradable seed coating, Sustainable agriculture, One Health, Soil health, Circular bioeconomy, Food security.

INTRODUCTION

The food production demand is expected to increase over the next decade. The main reason is population growth and changing dietary preferences [1]. Synthetic fertilizers and pesticides are an inevitable part of the conventional agricultural system [2]. This approach has delivered yield gains but also produced unintentional consequences. Nutrient leaching, eutrophication of aquatic systems, biodiversity decline, soil degradation, and greenhouse gas emissions are now recognized as unintended and uncompensated side effects [2,3]. Apart from environmental concerns, there are significant public health implications that harm the environment and the public, but are not reflected in the market price of the food produced. [4,5]. Endocrine disruption, cancer risk, and antimicrobial resistance are prominent health hazards of Prolonged exposure to chemical residues through food and water. Even today, the agricultural runoff continues to contaminate water sources vital for both humans and animals [4,5].

Due to growth in environmental challenges, the need for sustainable and ecologically responsible options in all sectors has never been more important. Among the most promising approaches are plant–microbe partnerships, particularly the symbioses formed with mycorrhizal fungi. Arbuscular mycorrhizal fungi (AMF) and ectomycorrhizal fungi (ECM) establish close associations with roots. It helps expand the functional capacity of root systems and eventually improves nutrient acquisition, water uptake, and stress tolerance [6,7]. A recently published meta-analysis study covering more than 180 trials confirmed that inoculation with AMF increases plant biomass by almost 50% and doubles phosphorus uptake, providing solid evidence of their agricultural potential [8].

Seed coating is emerging as an efficient delivery system for microbial inoculation beneficial to crops [9]. Root colonization is enhanced by placing microbial propagules, such as spores, cysts, and vegetative cells, directly on the seed surface. This also reduced the need for bulk soil inoculation of seeds [9]. However, many current coatings rely on synthetic polymers or refrigeration to maintain viability, which limits adoption in low-resource settings [10]. Therefore, there is a strong case for developing biodegradable and

low-cost carriers that can maintain inoculum stability at room temperature.

This article explores the rationale and potential of nutritional seed balls composed of oil-seed meals and waste-derived binders, coated with AMF and ECM. It further tries to find whether this innovative idea fits within the One Health framework, which emphasizes the interconnected health of humans, animals, plants, and the environment.

Mycorrhizal seed coating: benefits and evidence

Mycorrhizal fungi are well known for their characteristics of plant growth-promoting symbiotic association. Using their external hyphae to explore more soil that finally boosts the uptake of immobile nutrients such as phosphorus, as well as nitrogen, zinc, and copper [11]. In addition to enhanced nutrition, colonized plants exhibit improved tolerance to abiotic stress, including drought, salinity, and heavy metal contamination [12]. AMF are associated primarily with herbaceous crops, while ECM play an essential role in forest ecosystems, supporting tree species such as pine, oak, and eucalyptus [13].

Findings from previous experiments reveal the effectiveness of seed coating as a delivery technique. In phosphorus-deficient Ultisols, maize seeds coated with AMF produced higher biomass along with more grain yield with limited fertilizer application [14]. In another example, cowpea coated with AMF and bio-char showed a seventy-six per cent increase in shoot biomass and over fifty per cent improvement in yield without fertilizer supplementation [15]. These findings highlight the potential of seed coatings to partially substitute mineral fertilizers, thereby reducing input costs and environmental burdens.

Waste-derived carriers and binders

The stability and efficiency of microbial coatings is primarily dependent on Carriers and binders. Peat, vermiculite, and synthetic polymers are widely used but face limitations in terms of cost, sustainability, and biodegradability [16]. Agro-industrial residues present an attractive alternative [17]. Oil-seed meals such as peanut, flax-seed, and soybean are rich in proteins and micro-nutrients, offering both structural support and supplementary nutrition for seedlings [17]. Paper-making sludge provides a biodegradable matrix capable of binding pellets and gradually decomposing in the soil, and comes with the benefit of readily available cellulose and lignin [18]. Tapioca starch waste is another viable option, functioning as a natural adhesive while maintaining compatibility with microbial inocula [19].

Studies indicate that such biodegradable binders are effective in supporting mycorrhizal viability and colonization [19, 20]. Seed coatings based on tapioca starch have successfully maintained spore activity and ensured root colonisation, while simultaneously supporting the principle of a circular bioeconomy by transforming waste streams into valuable agricultural inputs [20].

Nutritional seed balls: concept and process

The proposed product involves embedding seeds in a matrix composed of oil-seed meal and biodegradable binders, followed by coating with AMF and ECM spores. To prevent microbial contamination during storage, natural preservatives such as neem extract can be incorporated, which possess anti-fungal activity without harming beneficial organisms [21]. Drying is carried out in shaded, low-temperature conditions to maintain inoculum viability, and storage can occur at room temperature in breathable containers.

This integrated system offers multiple advantages. The oilseed meal acts as an immediate nutrient source [17], the waste-derived binder ensures structural integrity and biodegradability [18,19], and the mycorrhizal coating provides long-term agronomic benefits [6,7,8]. The design is adaptable for use in crop nurseries, agroforestry, and reforestation projects [13,14,15], making it a versatile tool for both smallholder farmers and large-scale initiatives.

One health perspective

The development of biodegradable, mycorrhiza-coated seed balls is directly aligned with the principles of One Health, which recognizes the interdependence of human, animal, plant, and environmental health. By reducing the need for chemical fertilizers, the technology contributes to safer water supplies and reduces nitrate-related health risks in humans [22]. Minimizing agrochemical runoff also protects livestock and aquatic biodiversity, while indirectly supporting pollinator populations vital for food production [23]. Plants benefit from improved nutrient uptake, enhanced resilience, and reduced dependence on external inputs [24]. Environmentally, the recycling of waste materials such as paper sludge and tapioca starch prevents landfill accumulation and lowers carbon emissions, while the activity of mycorrhizal fungi enriches soil biodiversity and contributes to carbon sequestration [25].

The holistic benefits that emerge from this single intervention illustrate its relevance not only for food security but also for broader sustainability and public health agendas.

Challenges and future directions

Although promising, this approach faces challenges that need to be addressed before large-scale adoption. The shelf-life of mycorrhizal spores under ambient storage remains a limitation, requiring optimization of drying techniques and packaging strategies [26]. The concentrations of AMF and ECM inoculum must be standardized across crops and environments, and the scalability of production requires the development of cost-effective yet quality-assured manufacturing processes. Finally, awareness and training among farmers are critical to ensure successful implementation and adoption in diverse agricultural systems.

Future work should focus on refining preservation methods that extend the viability of inoculum without refrigeration, developing multifunctional coatings that combine nutrition with pest

protection, and conducting multi-location field trials to confirm performance across agro-ecological contexts [27, 28].

CONCLUSION

A sustainable solution for modern agriculture can be nutritional seed balls made from oilseed meals and waste-derived binders, coated with AMF and ECM. These eco-friendly carriers improve plant growth, nutrient uptake, and resilience while reducing dependence on chemical fertilizers. They also improve soil health and promote circular economy practices by recycling agricultural and industrial residues. If one tries to find a solution to modern agriculture, these seed balls safeguard human, animal, plant, and environmental well-being. Simple yet impactful, mycorrhiza-coated seed balls represent a transformative innovation for food security and ecological sustainability.

Conflicts of Interest: No conflict of interest

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