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Biopriming with Seaweed Extract: A Sustainable Approach to Augmenting Seed Germination and Vigour

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Seed quality is one of the most important determinants of crop establishment, productivity, and resilience under changing environmental conditions. Conventional seed enhancement techniques have been widely used to improve germination and seedling establishment; however, growing concerns regarding environmental sustainability have encouraged the development of eco-friendly alternatives. Biopriming with seaweed extract has emerged as a promising strategy for improving seed performance by combining the physiological benefits of seed priming with the bioactive properties of marine macroalgae. Seaweed extracts contain a diverse range of compounds, including phytohormones, amino acids, polysaccharides, vitamins, antioxidants, and micronutrients that stimulate metabolic activities during germination. Biopriming enhances water uptake, activates hydrolytic enzymes, improves nutrient mobilization, increases antioxidant activity, and promotes the development of a vigorous root system. These physiological and biochemical changes contribute to improved germination, faster seedling emergence, enhanced stress tolerance, and greater crop productivity. This article reviews the concept, mechanisms, methods, advantages, limitations, and agricultural applications of seaweed extract-based biopriming.

Introduction

Seed quality is the foundation of successful crop production. A seed lot may carry excellent genetic potential, yet poor, uneven, or delayed germination in the field can undermine yield before a single leaf emerges. Farmers and agronomists have long searched for low-cost, eco-friendly methods to improve germination speed, uniformity, and early seedling vigour, especially under the erratic soil moisture and temperature conditions that increasingly characterize field environments. One technique that has moved from research plots into mainstream agronomic practice is seed biopriming with seaweed (macroalgal) extract. Biopriming combines the physiological benefits of seed priming (controlled hydration) with the biological benefits of a bioactive agent, in this case, extract derived from marine algae such as *Ascophyllum nodosum*, *Sargassum*, *Kappaphycus*, *Ecklonia maxima*, or *Ulva* species. The result is a seed treatment that not only pre-activates germination-related metabolism but also delivers a cocktail of natural growth-promoting compounds directly to the embryo and surrounding tissues.

What Is Biopriming?

Biopriming is a two-step seed treatment process:

1. **Hydration/imbibition**: Seeds are soaked or exposed to a controlled-moisture environment, allowing them to absorb water up to a point just short of radicle emergence

(the "lag phase" of germination). This activates enzymes, repairs cellular membranes, and initiates the metabolic machinery required for germination, without letting the seed actually sprout.

2. **Bio-inoculation**: During or after hydration, the seed is treated with a biological agent, a beneficial microorganism (e.g., *Trichoderma*, *Pseudomonas*) or, as discussed here, a seaweed-derived extract rich in bioactive molecules.

Unlike simple soaking, biopriming is time- and temperature-controlled so that seeds are held at the optimal moisture content for a defined period, then surface-dried and either sown immediately or stored briefly before sowing.

Why Seaweed Extract?

Seaweeds are considered biostimulants rather than conventional fertilizers because they contain relatively low amounts of nitrogen, phosphorus, and potassium (NPK) but are rich in biologically active compounds that influence plant growth even at very low concentrations. Seaweed extracts contain phytohormones such as auxins, cytokinins, gibberellins, and abscisic acid-like compounds that regulate cell division, cell elongation, and stress responses. They are also rich in polysaccharides, including alginates, laminarin, fucoidans, and carrageenans, which improve water retention and stimulate plant defense mechanisms. In addition, seaweed extracts provide osmoprotectants such as glycine betaine, micronutrients in readily available forms, and essential amino acids, vitamins, and antioxidants that support enzymatic activity and protect cells from oxidative damage. During biopriming, these bioactive compounds are delivered directly to the seed, where they enhance embryo metabolism and promote the growth of the emerging radicle and plumule during the critical stages of germination.

Mechanisms Behind Improved Germination and Vigour

- **Enhanced Enzyme Activation**

Seaweed extracts stimulate amylase, protease, and dehydrogenase activity during imbibition, accelerating the mobilization of stored starches and proteins in the endosperm/cotyledons into usable sugars and amino acids for the growing embryo.

- **Hormonal Priming**

Cytokinins and gibberellins present in seaweed extracts can substitute for or supplement the seed's own hormone signalling, breaking dormancy faster and promoting more synchronous radicle emergence. Auxin-like compounds support early root initiation.

- **Antioxidant Defence**

Germination is metabolically demanding and generates reactive oxygen species that can damage cell membranes. Seaweed-derived antioxidants and phenolic compounds help neutralize this oxidative burst, protecting membrane integrity in the earliest hours after imbibition.

- **Improved Water and Nutrient Uptake**

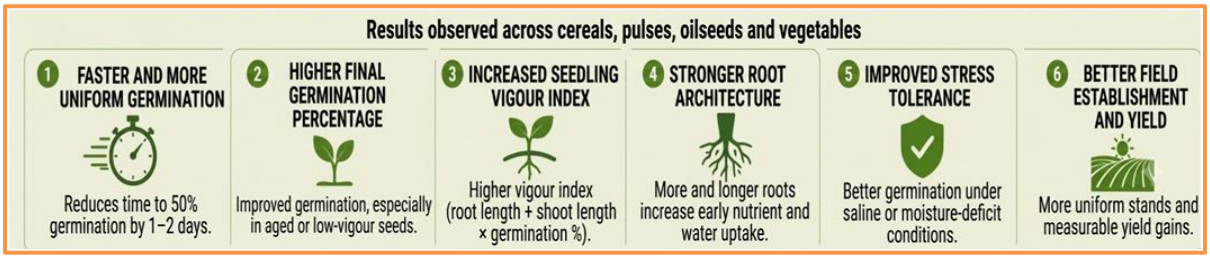
Alginates and other polysaccharides in seaweed extract have hygroscopic properties that can improve water-holding at the seed coat interface, supporting more consistent imbibition, particularly valuable under low soil moisture.

- **Priming of Stress Tolerance**

Osmoprotectant compounds pre-condition seedling tissue to tolerate subsequent abiotic stress (salinity, drought, temperature extremes), a phenomenon often described as "stress memory" or physiological priming.

Demonstrated Benefits in Practice

Across a wide range of crops, starting from cereals (wheat, rice, maize), pulses (chickpea, mungbean, soybean), oilseeds (mustard, sunflower), and vegetables (tomato, okra, onion), biopriming with seaweed extract has been associated for:



Typical Biopriming Protocol

While exact protocols vary by crop, seed size, and extract concentration, a generalized procedure includes:

1. **Extract preparation**: Dilute commercial or laboratory-prepared seaweed extract (commonly 0.1-1.0% concentration, though this varies by product and crop) in water.
2. **Seed treatment**: Soak seeds in the diluted extract solution for a defined period (commonly 6-24 hours depending on seed size and species, smaller seeds need shorter durations).
3. **Controlled incubation**: Hold seeds at a stable temperature (often 20-25°C) to allow metabolic activation without radicle protrusion, sometimes with intermittent aeration.
4. **Surface drying**: Spread seeds in shade to reduce moisture back to near-original levels, restoring free-flowing, sowable condition.
5. **Sowing**: Sow within a short window (typically 24-48 hours) to preserve the physiological gains from priming, or apply a light fungicidal seed coat if storage before sowing is unavoidable.

Concentration and duration should always be optimized for the specific crop and seed lot, as excessive soaking time or overly strong extract concentrations can lead to reduced germination or seedling abnormalities.

Practical and Environmental Advantages

- **Low input cost**: Seaweed extracts require dilution to very low concentrations, making per-hectare treatment costs modest relative to yield benefits.
- **Reduced dependence on synthetic agrochemicals**: As a natural biostimulant, seaweed extract fits well within organic and low-input farming systems.
- **Ease of adoption**: The technique requires no specialized machinery, a simple soaking tank, mesh bags, and shaded drying area suffice for small and marginal farmers.
- **Compatibility**: Seaweed biopriming can often be combined with beneficial microbial inoculants (biofertilizers, biocontrol agents) in an integrated bio-priming approach, provided compatibility is verified.
- **Environmental sustainability**: Seaweed extracts are biodegradable and derived from a renewable marine resource, aligning with sustainable and regenerative agriculture goals.

Limitations and Considerations

Despite its considerable potential, seaweed biopriming cannot be considered a universal solution for improving seed germination and vigour. Its effectiveness varies significantly depending on the seaweed species used, the extraction method employed (alkaline, acidic, enzymatic, or physical), and the crop species or cultivar being treated. A treatment that produces substantial benefits in one crop may have little or no effect in another. In addition, the success of seaweed biopriming is highly dependent on the concentration of the extract and the duration of seed soaking. Both insufficient and excessive concentrations can negatively affect seed performance, emphasizing the need for crop-specific optimization and field-based validation. Another important limitation is the reduced storage life of bioprimed seeds, as the activation of metabolic processes during priming shortens their safe storage period, making immediate sowing preferable. Furthermore, the quality and composition of commercially available seaweed extracts can vary considerably because of differences in raw materials and manufacturing processes, highlighting the importance of using standardized products from

reliable suppliers. Although numerous laboratory and greenhouse studies have demonstrated the positive effects of seaweed biopriming, large-scale, multi-location field studies remain limited. Therefore, additional research is required to establish consistent recommendations and confirm the long-term agronomic and economic benefits of this technology under diverse environmental conditions.

Conclusion

Seed biopriming with seaweed extract represents a convergence of traditional priming physiology and modern biostimulant science. By combining controlled hydration with a natural cocktail of phytohormones, antioxidants, polysaccharides, and micronutrients, this technique offers a practical, low-cost, and environmentally sound way to enhance germination speed, uniformity, and seedling vigour. As climate variability puts increasing pressure on crop establishment, biopriming with seaweed extract stands out as a promising tool for building more resilient, productive, and sustainable cropping systems, provided it is optimized and validated for the specific crop, seed lot, and growing conditions in which it will be used.