Bioformulations: The Path to Sustainable Agriculture

Vrinda Sehgal[1], Mamrutha HM[1], Rinki[1*], Vanita Panday[1], Gopalareddy K[2], Vanishree Girimalla[3], Preety Rani[1], Zeenat Wadhwa[1] and Yogesh Kumar[1]

[1]ICAR-Indian Institute of Wheat and Barley research, Karnal, Haryana, India

[2]ICAR- Sugarcane Breeding Institute, Coimbatore, Tamil Nadu, India

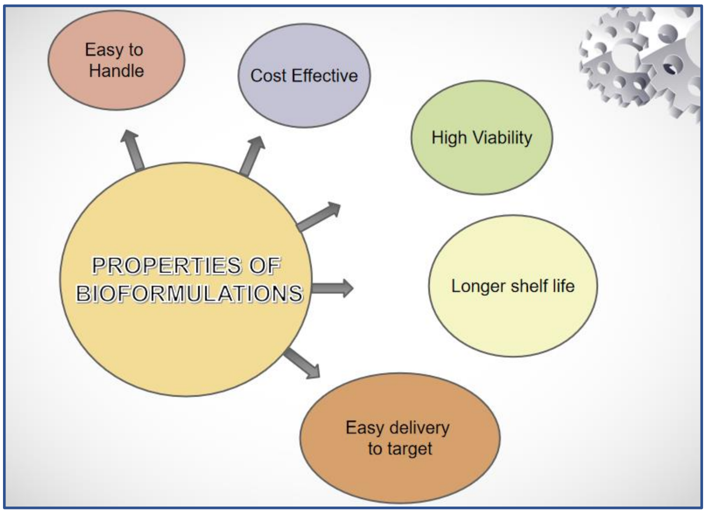
[3]ICAR- Indian institute of Seed Science, RS, GKVJ Campus, Bengaluru, Karnataka, India

*Corresponding Author: rinki@icar.gov.in

The increasing awareness of the public regarding the environment is causing them to feel concerned about the chemical substances utilized in producing food, leading to a greater preference for organic food. Globally, chemical pesticides and fertilizers have been extensively employed to enhance agricultural productivity and safeguard plants and their harvests from diseases. However, environmentalists are now taking a closer look at the significant negative impacts linked to these methods. Thankfully today, we have options available for replacing or at least minimizing the use of these chemicals. Another option as a substitute is the use of bio-formulations, which are comprised of living microorganisms such as fungi and bacteria. These bio-formulations are available for purchase globally, and can be used as alternatives to chemical pesticides, fungicides, and fertilizers. They can be used either on their own or in conjunction with chemical fertilizers. This information has provided fresh perspectives in the field of agricultural economics, as researchers have recently created microbial bio-inoculants to enhance plant growth and eliminate disease as a new alternative. However, this environmentally friendly method is facing challenges because the bio-formulations currently available for certain crops do not consistently yield results that are similar to those achieved in controlled laboratory conditions. Scientists across the globe are continuously working hard to develop formulations that are easier for users, possess enhanced abilities to combat plant diseases, and potentially protect a wider variety of crops. It is important to thoroughly examine the entire process of bio-formulation development, including screening microorganisms, developing and executing products, to ensure they are used in the most effective way.

Scientifically bio-formulations refer to the products derived from microbial sources, which can include whole microorganisms or their byproducts (metabolites), designed to enhance plant growth, nutrient acquisition, and disease control in an environmentally friendly manner. These formulations could be mixed solutions containing many bio-inoculants (microbial strains), sticking agents and nutrients which can leverage the beneficial interactions between plants and specific microorganisms to improve agricultural sustainability.

Fig.1. Properties of Bio-formulations



Different types of bio-formulations include bio-fertilizers and bio-pesticides which comprise of bacteria and fungi as its main components (Fig. 2). Additionally, these bio-formulations contain fungus and bacteria, either alone or in combination. These can be applied similarly as chemicals, for example, as seed dressing, soil treatment or foliar spray. Those bio-formulations that do not possess any living organism have been focused majorly via this article. However, the formulation procedure may differ based on many factors like inoculant type, soil type, available resources and type of application etc.

Another bio-formulation of biochar acts as a potential inoculant carrier for sustainable agriculture. Understanding how biochar affects agriculture and the potential for increasing cell immobilization can shed light on how biochar functions as an effective inoculant carrier. It found its application in improving maize productivity and soil fertility.

Types of Bio-formulations		
SOLID CARRIER BASED FORMULATIONS	**LIQUID BIOFORMULATIONS**	**POLYMER ENTRAPPED FORMULATIONS**
Inoculants are mixed with solid carriers in appropriate proportions . Carriers are the delievery agents which are inert materials used for microbes transportation. Types : 1. Soils - Peat, Coal 2. Plant Wastes - Composts, manure 3. Inert materials - Polyacrylamide Gel, Alginate Beads	Solution contains micro-organisms along with nutrients, cell protectants and additives which can promote plant growth and survivability. For example aqueous or oil based products Ensures product stability Prevention from osmolysis Inoculants protection from extreme conditions	Contains polymer entrapped inoculants along with other essential components. For example alginate based formulations • Non Toxic • Storage at ambient temperature for long duration • Easy to produce and handle • Chemical solidification • Beads formation with live cells inside

Fig. 2. Types of Bio-formulations

Nano-formulations, a new addition to the realm of bio-formulation in high-tech "smart" farming, involve combining nanoparticles with biofertilizers to create nano-biofertilizers (NBFs). The introduction of NBFs into plants holds the potential to enhance their growth and increase their ability to withstand external pressures. By utilizing microbe-driven environmentally-friendly production, metallic nanoparticles and organic substances like polysaccharide and chitosan can be enclosed in order to create these formulations e.g. improving the effectiveness of insecticide by using a nano-bio-formulation of etofenprox

Among other foliar chemical bio-formulations, it is found that effect of proline has been studied on almost all the abiotic stresses like salinity, temperature, drought, osmotic etc. for different crops like common beans, chickpea, wheat cultivars etc (Fig. 3).

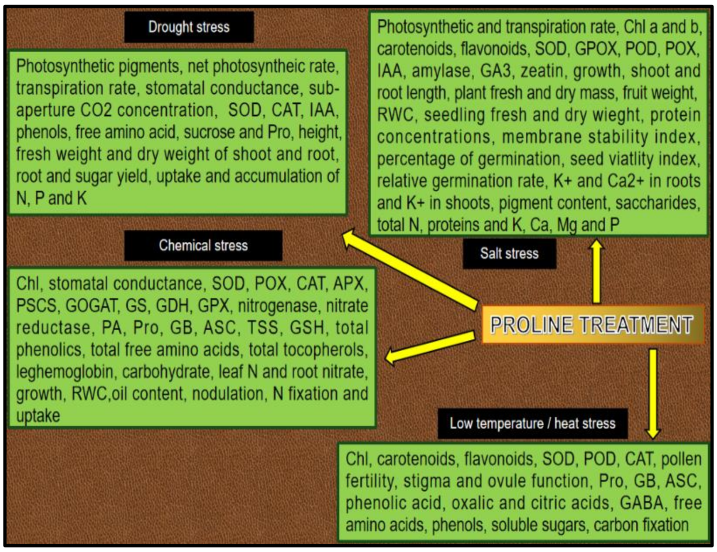


Fig. 3. The summarized physiological and biochemical changes observed under the influence of exogenous proline in plants (Up-regulated processes and/or biochemicals are marked in green)

Table 1: Different types of bioformulations and their mode of action

S. No.	Spray	Bio-formulation applied	Crop	Improved trait	Mechanism of action
1	Foliar spray	Silica	Rice (*Oryza sativa* L.)	Water stress tolerance	Regulates stress through mantaining RWC, net photosynthetic ratio, intercellular CO_2 level, stomatal conductance, and transpiration rate. In addition, silica plays a vital role in improving the physiological activities and enhancing the cellular metabolic rates in plants in response to drought stress, thus enhancing water use efficiency, growth, and biomass
2	Foliar spray	Melatonin	Strawberry (*Fragaria × ananassa Duch.*)	Salinity stress tolerance and enhance fruit yield and quality	Increases yield of strawberry fruit and quality, in plants grown under salinity. Melatonin is associated with boost in leaf antioxidant enzymes and abscisic acid

3	Foliar spray	Naphthyl acetic acid	Maize (*Zea Mays* L.)	Drought stress tolerance	Increased Seed vigor index, root–shoot ratio, leaf area index, leaf area ratio, Total biomass, chlorophyll 'a', chlorophyll 'b', carotenoid content, peroxidase and Superoxide dismutases content under high drought stress
4	Foliar spray	Calcium	Maize (*Zea Mays* L.)	Drought stress tolerance	Increased plant growth, water relations, proline content and hydrogen peroxide activity
5	Foliar spray	HBL (28-homobrassinol)	Rapeseed (*Brassica napus*)	salinity stress tolerance	Lowers the concentrations of NH_4+ and NO_3^- ions significantly, and the consequent enhancement in photosynthesis, efficient utilization of nitrogen
6	Foliar spray on the shoots	Proline	Lettuce (*Lactuca sativa*)	Temperature stress tolerance	Effective foliar application of proline up to 5 µM improves lettuce yield in response to temperature and salinity stress
7	Foliar spray	Proline	Quinoa (*Chenopodium quinoa*)	Drought stress tolerance	Increased proline content, total phenolic compounds, and antioxidant enzyme activity
8	Foliar spray	Proline	Common beans (*Phaseolus vulgaris*)		Increased the concentrations of carotenoids, ascorbic acid, endogenous proline, phosphorus and potassium in plants exposed to stress
9	Foliar spray	Proline	Wheat (*Triticum aestivum*)		Reduces the Na^+:K^+ ratio and oxidative stress and increasing the content of the internal proline improve growth and yield
10	Foliar application	Proline	Chickpea (*Cicer arietinum*)	Heavy metal stress tolerance	Increased nodulation, hemoglobin, carbohydrate content, leaf and root nitrogen content, the enzymatic activity of enzymes related to nitrogen fixation
11	Foliar spraying and root application	Melatonin	Soybean (*Glycine max* (L.) Merrill)	Water deficit stress tolerance	Improved PSII efficiency, improved the leaf area index and the accumulation of dry matter, slowed down oxidative stress and damage to leaves by increasing the activity of antioxidant enzymes, reduced the content of malondialdehyde
12	Foliar spray	Spermidine	Oat Seedlings	Reduces the negative effects of salt stress	Increased the activities of superoxide dismutase, peroxidase catalase, and ascorbate peroxidase, and

					reduced the rate of O_2 production and the accumulation of H_2O_2 and malondialdehyde
13	Foliar spray	Myo-inositol	Creeping bent grass (*Agrostis stolonifera* L.)	Enhances drought tolerance	Protected plants from drought damage by improving OA and water use efficiency, the decline in chl loss for photosynthetic maintenance, and improvement in antioxidant enzymes activity and gene expression contributing to less oxidative damage under drought stress and contributed to better plant water status
14	Foliar spray	Glycine betaine and potassium	Wheat	Enhances drought tolerance	Improved spike length, number of grain per spike and grain yields, leaf water potential, osmotic potential and turgor potential to maintain plant water potential gradient under stress.
15	Foliar spray	Trinexapac-ethyl	Creeping Bent grass (*Agrostis stolonifera* L.)	Enhances drought tolerance	Higher soil water content, lower evapo-transpiration rates, and higher leaf relative water content, greater osmotic adjustment, which was associated with increased accumulation of soluble sugars and inorganic ions (Ca and K) in leaves of TE-treated plants. TE-treated plants maintained significantly higher turf quality and leaf photochemical efficiency under stress
16	A label-free nano-liquid chromatography-mass spectrometry	Nitric oxide	Banana (*Musa acuminate*)	Osmotic stress	Antioxidant enzyme activities, such as superoxide dismutase and ascorbate peroxidase

Conclusion

The use of bio-formulations as a solution to reduce crop yield losses has become a more sustainable option compared to chemicals. However, the formulation of these bio-pesticides is often inadequate and does not meet the necessary regulatory standards, thus hindering their successful commercialization. Compiled information on bio-formulations as common bio-fertilizers and bio-pesticides with their mode of action is available in the researched texts but until now not much research is done to compile the information present on chemical bio-formulations. Only after thorough research can globally available bio-formulations that are “in use”, would be considered for the process of commercialization. In this article, we propose creating a framework for methods to achieve better formulations. This framework could be valuable for developing more effective products.

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