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Effect of formulations of microbial consortia on the nutrient uptake by maize (*Zea mays* L.)

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Abstract
A pot experiment was conducted to study the effect of five formulations of two microbial consortia on the nutrient uptake by maize. The results revealed that uptake of nitrogen was found to be higher in plants treated with liquid as well as Na-alginate formulation (0.51 g plant $^{-1}$ respectively) at 45 and at 90 DAS in plants treated with Na-alginate formulation (2.19 g plant^{-1}), Phosphorus uptake in plants treated with liquid as well as Na-alginate formulation at 45 (0.07 g plant^{-1}) and 90 DAS (0.22 g plant^{-1}). Potassium its uptake were found to be higher in plants inoculated with liquid formulation at 45 (0.21 g plant^{-1}) and 90 DAS (1.63 g plant^{-1}). However, the application of two different microbial consortia did not significantly influence nutrient uptake by maize suggesting the importance of carrier material on the effectiveness of the consortia.

Keywords: Microbial consortia, nutrient uptake, maize, *Zea mays* L.

Introduction

Maize, a widely cultivated crop known for its high nutritional value and economic importance, has been a focus of research study. Maize, is one of the world's most important cereal crops, serving as a staple food for millions of people and a vital feedstock for livestock. However, the optimal growth and yield of maize depend on the availability of essential nutrients in the soil, including macronutrients (such as nitrogen, phosphorus and potassium) and micronutrients (such as zinc, iron, and manganese). Traditional agricultural practices often rely on synthetic fertilizers to enhance nutrient availability. Still, these practices can have detrimental effects on the environment and long-term soil health.

Formulating microbial consortia involves the deliberate selection of carrier material and combination of specific microorganisms with complementary functions, such as nitrogen-fixing, phosphate-solubilizing and plant growth-promoting rhizobacteria. These microbial consortia can be applied to enhance nutrient cycling and make nutrients more accessible to plants (Amalraj *et al*., 2012, Sivasakthivelan and Saranraj 2013; Suman *et al*., 2008) [4, 13, 14]. When applied to the soil, these consortia interact with plant roots, forming symbiotic relationships that can lead to a range of benefits, including increased nutrient uptake (Akthar and Siddiqui, 2008) [2].

The effects of microbial consortia on nutrient uptake by plants are multifaceted. These microbial communities can help solubilize otherwise inaccessible nutrients, produce growth-promoting compounds and also protect plants from pathogens (Harman, 1991 and Vessey, 2003) [6, 17]. By creating a more favorable rhizosphere environment, they improve the overall nutrient acquisition efficiency of plants (Yadav *et al*., 2015b; Suman *et al*., 2015) [18, 15]. This approach not only enhances crop yields but also promotes sustainable and environmentally friendly agricultural practices by reducing the reliance on synthetic fertilizers and mitigating their associated negative impacts.

Hence, the present experiment was conducted to study the effect of different formulations of microbial consortia on the nutrient uptake by maize under pot culture.

Materials and Methods

In this study, one of N_2 fixer (*Azospirillum* ACD-15 or *Gluconacetobacter* G_1), *Pseudomonas striata* (PSB) and K-solubilizing bacterium (KSB) collected from the Agricultural Microbiology Laboratory at the Institute of Organic Farming (IOF), University of Agricultural Sciences, Dharwad were used in preparation of two microbial consortia (MC) in 1:1:1 ratio. A five different formulations namely lignite, kaolinite, bentonite, Na-alginate and liquid formulations of these two MC were formulated following 1:3 ratio of culture and carrier material for carrier based formulations. For Na-alginate formulation encapsulation technique was followed as proposed by Saxena (2013) [12] and for liquid formulation different additives were used as cell protectants (Nisarga and Patil, 2018; Prakash, 2018 and Sandesh, 2017) [7, 8, 11].

These formulations of microbial consortia were tested for their effectiveness on nutrient uptake by maize (hybrid Super 900 M Gold) in a greenhouse pot experiment at UAS, Dharwad along with dual inoculation of recommended biofertilizers (*Azospirillum* ACD-15 and PSB) and uninoculated control. Maize seeds of Super 900 M Gold were procured from All India Co-ordinated Research Project on Maize, Main Agricultural Research Station (MARS), University of Agricultural Sciences, Dharwad, India.

Plastic pots of 9 kg capacity were filled with 7.5 kg soil of 4mm sieve size and subjected for two cycles of alternate wetting and drying was mixed well after each cycle. Pre-germinated seeds were treated with consortia formulated in lignite, kaolinite, bentonite (20 g/kg seeds), Na-alginate encapsulated beads (4 g/kg seeds) and in liquid (4 ml/kg seeds). Simultaneously, control with dual inoculation and a un-inoculated control were maintained in five replications. Recommended dose of fertilizer at 1.2:1.5:1.2 g N:P:K pot^{-1} was applied to all the treatments. Four pre-germinated seeds per pot were sown and seedlings were thinned to two plants in each pot after 15 days after sowing and grown for 90 days.

Nutrient uptake by maize was assessed after 45and 90 days of sowing.

Results and Discussion

Application of five formulations of two different microbial consortia on the maize crop in pot culture significantly influenced nutrient uptake. Among the five formulations used, the nitrogen uptake by maize plant was recorded significantly superior values in treatment T_3 having liquid formulation and treatment T_4 having Na-alginate formulation (0.51 g plant^{-1} respectively), the phosphorus uptake (0.07 g plant^{-1}) and potassium uptake (0.21 g plant^{-1}) were found significantly higher in treatment T_3 having liquid formulation than other treatments at 45 DAS. Whereas at 90 DAS, maize plants treated with treatment T_4 receiving Na-alginate formulation (2.19 g plant^{-1}) for nitrogen uptake, plants treated with treatment T_4 receiving Na-alginate formulation for phosphorus uptake (0.22 g plant^{-1}) and plants treated treatment T_3 receiving liquid formulation for potassium uptake (1.63 g plant^{-1}) were found to significantly superior than other treatments. The results of this study are in accordance with the findings of Thilagar *et al*., (2016) [16]; Abou and Abdel, (2012) [1]. This increase in the nutrient uptake is attributed to the increase in the nutrient availibility by multiple mechanisms exerted by the microorganisms in the consortia as well as increased enzymatic action. This increase is also attributed to formulation i.e., Na-alginate and liquid form supporting the survivability and effectiveness of microorganisms in microbial consortia (Amalraj *et al.,* 2015) [3]. However, the application of two different microbial consortia found to non-significantly influence with respect to nutrient uptake by maize.

Microbial consortia, which consist of a group of different microorganisms working synergistically, play a crucial role in facilitating nutrient uptake by maize (Akthar and Siddiqui, 2008) [2]. These consortia typically including beneficial microorganisms that establish intricate symbiotic relationships with the plant roots, forming what is commonly known as the rhizosphere. Through mechanisms such as nitrogen fixation, phosphorus solubilization, potassium solubilization and the production of plant growth-promoting substances, these microbial consortia contribute to the improved availability and absorption of essential nutrients by maize (Raja *et al.,* 2006; Rajasekar and Elango, 2011) [9, 10]. By fostering a more efficient nutrient uptake process, these formulations can potentially lead to increased crop yields, improved resistance to stressors, and a reduction in the need for synthetic fertilizers, thereby promoting sustainable agricultural practices (Desai *et al.*, 2013) [5].

Table 1: Nitrogen uptake by maize plant as influenced by inoculation with formulations of microbial consortia

Formulations	Nitrogen uptake (g plant^{-1}) at 45 DAS								Nitrogen uptake (g plant^{-1}) at 90 DAS							
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	Mean A	T_1	T_2	T_3	T_4	T_5	T_6	T_7	Mean A
MC1	0.28^{de}	0.26^{e}	0.39^{b}	0.60^{a}	0.32^{cd}	0.27^{b}	0.23^{c}	0.38^{a}	1.58^{g}	1.71^{e}	2.01^{c}	2.34^{a}	1.69^{e}	1.48^{f}	1.30^{g}	1.86^{a}
MC2	0.29^{de}	0.36^{bc}	0.63^{a}	0.42^{b}	0.27^{e}	0.27^{b}	0.23^{c}	0.39^{a}	1.59^{g}	1.79^{d}	2.29^{b}	2.04^{c}	1.64^{f}	1.48^{f}	1.30^{g}	1.87^{a}
Mean B	0.29^{b}	0.31^{b}	0.51^{a}	0.51^{a}	0.29^{b}	0.27^{b}	0.23^{c}		1.58^{e}	1.75^{c}	2.15^{b}	2.19^{a}	1.67^{d}	1.48^{f}	1.3^{g}	
Comparison of	S. Em (±)				L.S.D (p=0.05)				S. Em (±)				L.S.D (p=0.05)			
A	0.005				NS				0.01				NS			
B	0.008				0.02				0.01				0.03			
Interaction (A×B)	0.011				0.03				0.01				0.04			

Table 2: Phosphorus uptake by maize plant as influenced by inoculation with formulations of microbial consortia

Formulations	Phosphorus uptake (g plant^{-1}) at 45 DAS								Phosphorus uptake (g plant^{-1}) at 90 DAS							
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	Mean A	T_1	T_2	T_3	T_4	T_5	T_6	T_7	Mean A
MC1	0.03^{e}	0.03^{e}	0.05^{c}	0.07^{a}	0.04^{d}	0.04^{b}	0.03^{c}	0.05^{a}	0.14^{e}	0.16^{d}	0.20^{b}	0.24^{ab}	0.16^{d}	0.15^{d}	0.13^{e}	0.18^{b}
MC2	0.04^{d}	0.05^{c}	0.09^{a}	0.06^{b}	0.04^{d}	0.04^{b}	0.03^{c}	0.05^{a}	0.15^{de}	0.18^{c}	0.25^{a}	0.21^{b}	0.16^{d}	0.15^{d}	0.13^{e}	0.19^{a}
Mean B	0.04^{b}	0.04^{b}	0.07^{a}	0.06^{a}	0.04^{b}	0.04^{b}	0.03^{c}		0.15^{d}	0.17^{b}	0.22^{a}	0.22^{a}	0.16^{c}	0.15^{d}	0.13^{e}	
Comparison of	S. Em (±)				L.S.D (p=0.05)				S. Em (±)				L.S.D (p=0.05)			
A	0.001				0.003				0.002				0.005			
B	0.001				0.004				0.003				0.008			
Interaction (A×B)	0.002				0.006				0.004				0.011			

Table 3: Potassium uptake by maize plant as influenced by inoculation with formulations of microbial consortia.

Formulations	Potassium uptake (g plant^{-1}) at 45 DAS								Potassium uptake (g plant^{-1}) at 90 DAS							
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	Mean A	T_1	T_2	T_3	T_4	T_5	T_6	T_7	Mean A
MC1	0.12^{f}	0.13^{ef}	0.18^{c}	0.22^{b}	0.14^{de}	0.12^{d}	0.10^{e}	0.16^{a}	1.02^{h}	1.16^{ef}	1.46^{c}	1.66^{b}	1.15^{f}	0.79^{f}	0.64^{g}	1.29^{b}
MC2	0.12^{f}	0.15^{d}	0.24^{a}	0.18^{c}	0.14^{de}	0.12^{d}	0.10^{e}	0.16^{a}	1.10^{g}	1.28^{d}	1.80^{a}	1.51^{c}	1.20^{e}	0.79^{f}	0.64^{g}	1.38^{a}
Mean B	0.12^{d}	0.14^{c}	0.21^{a}	0.20^{b}	0.14^{c}	0.12^{d}	0.1^{e}		1.06^{e}	1.22^{c}	1.63^{a}	1.58^{b}	1.17^{d}	0.79^{f}	0.64^{g}	
Comparison of	S. Em (±)				L.S.D (p=0.05)				S. Em (±)				L.S.D (p=0.05)			
A	0.002				0.005				0.005				0.014			
B	0.003				0.009				0.008				0.022			
Interaction (A×B)	0.004				0.012				0.110				0.032			

Note: **MC_1**: Microbial consortia-1, **MC_2**: Microbial consortia-2, **T_1**: Lignite formulation, **T_2**: Kaolinite formulation, **T_3**: Liquid formulation, **T_4**: Na-alginate formulation, **T_5**: Bentonite formulation, **T_6**: Dual inoculation of ACD-15+PSB, **T_7**: Un-inoculated control.
A = Microbial Consortia and **B =** Formulations of Microbial consortia.
Means followed by the same superscript within factors (A and B) and their interaction (A × B) do not vary significantly at P = 0.05 by DMRT.

Conclusion

In conclusion, application of microbial consortia in the Na-alginate and liquid formulation represent a promising avenue for improving nutrient uptake by maize. These complex communities of microorganisms offer a sustainable and eco-friendly solution to the challenges of modern agriculture. As we continue to explore and understand the intricate interactions within microbial consortia, we can develop innovative strategies to enhance maize productivity while promoting the health of our ecosystems. Furthermore, the use of microbial consortia formulations offers a promising alternative to chemical fertilizers, addressing concerns related to environmental pollution and the detrimental impact of excessive synthetic inputs on soil health and microbial diversity. With ongoing research and advancements in this field, the development of formulations targeting specific nutrient requirements of maize holds great potential for enhancing agricultural productivity while minimizing ecological consequences.

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