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Synthetic Microbial Community (SynCom) for Sustainable Agriculture

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Agricultural sustainability is possible only when reducing crops' dependency on chemical fertilizers, improving crops' ability to grow on marginal soil types, and improving their resilience against biotic and abiotic stresses. Though bio inoculants play a crucial role in agricultural sustainability, they are still limited due to low reproducibility in fields due to different crops and cultivars, soil types, and agro-ecological conditions. Traditionally, inoculants are developed through a single isolate study model, i.e., *in vitro* screening of strains for plant-growth promotion, omitting their interaction with the host plant and soil ecosystem. Hence, a paradigm shift is needed in developing the inoculant to improve the microbe-mediated crop fitness and productivity. In this paper, we framework the synthetic microbial community (SynCom) as a potential resource for developing ecology-based inoculants to augment nutrient acquisition, drought mitigation, and pathogen resistance of crops to ensure sustainability.

Key Words: Biocontrol agent, Biofertilizer, Core microbiome, Plant holobiont, Plant microbiome, Synthetic microbial community (SynCom)

Introduction

Exploring the soil and plant-associated microbes to improve agriculture productivity is an extremely attractive approach as it ensures sustainability. Till now, the plant-growth promoting bacteria residing in the crop's sphere and soil were isolated, screened, and commercially utilized as 'biofertilizers', or 'biocontrol agents' (collectively referred to as microbial inoculants). This conventional approach-based commercial formulation could ensure a 10-15% yield increase with a 15-20% reduction in chemical fertilizer usage. The inconsistent performance of these inoculants within and between crops and different soil types leads to low farmers' preferences. Though the microbial inoculants have the potential, it is believed that we have not yet explored them to replace the chemical fertilizers completely. Hence, a paradigm shift in developing microbial inoculants is needed to extend its benefits beyond the present scope. Synthetic microbial community (SynCom) is a recently introduced approach that facilitates to design the microbial inoculant using microbial ecology and genetics.

What is SynCom?

The plant recruits its microbial partners through the release of nutrient-rich rhizo-deposits. Upon colonization, a range of microbial functions modulates the phenome of the plant positively to enhance the nutrient and water uptake, growth, and health. These microbial assemblages also mitigate environmental stresses. The plant has a strategy to recruit its core microbiome assemblage. The genetic and physiological traits of the plant are crucial for the recruitment and microbial reservoir of the soil. So, the holobiont (plant with its core microbiome) functioning of crop plants has significance in agricultural sustainability. However, the complexity of plant microbiome in terms of community and functioning often does not allow to proceed the resources for application in agriculture. The synthetic microbial community represents the less-complex consortium selected from the core microbiome of a plant with uncompromised functioning as that of the core microbiome. SynCom is an ecology and genetic-based approach to developing the inoculant.

SynCom Inoculants

Based on the number of strains being used for SynCom development, the SynComs were grouped as small (less than 10), medium (10-100), and large (more than 100) SynComs (Table 1). The large SynComs were tested in Arabidopsis to understand the basic features of SynCom. At the same time, the small and medium SymComs were potentially explored in several crops with a specific beneficial target.

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SynCom Development Strategies

The roadmap for successful SynCom-based inoculant development is (1) understanding the microbiome of a crop through culturable and metagenomic approaches; (2) Identifying and tailoring the microbiome of a crop; (3) screening the potential candidates for persistence and specific benefits; (4) designing the SynCom inoculant, (5) understanding SynCom-crop interaction (6) Assessing the influence of SynCom inoculant on crop's physiology and productivity. This bottom-up approach will develop an efficient SynCom-based inoculant for low-input sustainable rice production (Fig. 1).

Future Prospects

Though SynCom is accepted as a potential alternate for present inoculants to improve sustainability in agriculture, several researchable issues and technological gaps are still to be addressed to make SynCom viable and sustainable technology for agricultural application.

1. **Candidate selection for SynCom:** The plant microbiome comprises rhizospheric, epiphytic, endophytic and phyllospheric microbes, and the abundance and diversity are dynamic. Under this condition, selecting candidates from a plant's core microbiome is challenging. The modern tools, including omic approaches, bioinformatics, and modelling, will pave the way to identifying the possible potential candidates for SynCom.
2. **Number of species in SynCom:** As SynCom is a reductionist approach, using large SynCom (>100) would always ensure better results across the crops, soils, and environmental conditions. However, managing a large number of strains and their equimolar ratio would be a challenging issue.
3. **Microbe-microbe interactions:** The interaction between two strains and among more than two strains would be complex in nature. Understanding the overall interactions of SynCom candidates across the cell density would be a challenging and decisive factor for SynCom's performance.
4. **SynCom as functional representative of the core microbiome:** SynCom should have a limited number of core microbiome candidates. But, it should function in the plant ecosystem like that of the original microbiome without compromising the overall functionality.
5. **Role of each taxon in SynCom:** The contribution of each strain (or taxon) present in the SynCom should be decoded. For this, the drop-out experiment (SynCom without one strain) could be more helpful.
6. **SynCom stability:** SynCom should be robust and prevalent throughout the crop growth stages. The inoculated community should not

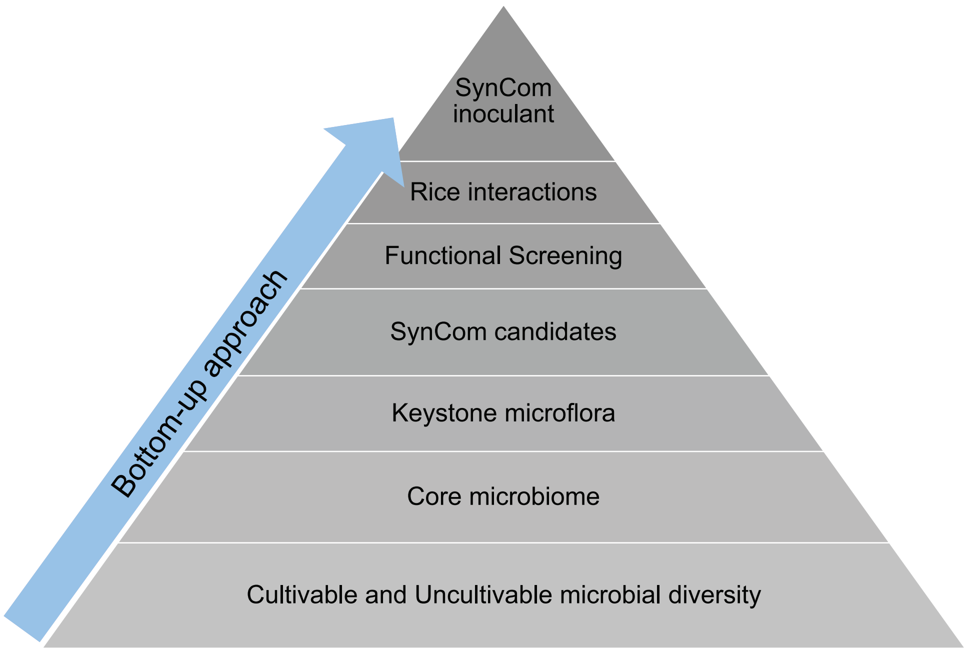

Fig. 1. The proposed model describing the bottom-up approach for SynCom inoculant development

Table 1. Overview of some SynComs and their functioning in plants

Type of SynCom	SynCom candidates		Model plant	Significance	Reference
	No. of species	Candidates			
Small	6	Pseudomonads	Garlic	Plant growth	Zhuang *et al*. (2020)
Small	8	*Williamsia*, *Pantoea*	Alfalfa	Stability of Syncom; Species domination	Moccia *et al.* (2020)
Medium	12	*Bacillus, Paenibacillus, Pantoea, Bradyrhizobium, Kluyvera, Actinobacter, Streptococcus, Chrysobacterium, Spingobium.*	Soybean	Stability of SynCom, N and P acquisition	Wang *et al*. (2021)
Medium	15	Members of Actinobacteria, Alpha, beta and gamma proteobacteria, Firmicutes	Tomato	Salt stress resilience	Schmitz *et al.* (2022)
Large	183	Members of rhizosphere microflora	Arabidopsis	Tryptophan metabolism	Wolinska *et al.* (2021)
Large	188	Leaf and root derived microflora	Arabidopsis	SynCom colonization pattern	Bai *et al.* (2015)

be overcome by the native soil microbiome. Hence, efforts should be taken to identify such candidates during SynCom development.

7. **Validation of SynCom:** To validate the performance of SynCom in terms of stability, robustness in colonization and effectiveness, sequencing techniques and quantitative PCR-based assays can be performed.
8. **Resources for SynCom:** The microbiome of wild species and landraces of a crop have co-evolved with their host plants. These microbes are well-adopted to extreme environments and excel multiple benefits to the plants. Hence, exploring these microbiomes for SynCom development could be a practical approach for agricultural purposes.
9. **SynCom – Crop interactions:** Understanding the molecular talk between the SynCom community and the host plant is essential to assess SynCom's effectiveness. The transcriptomic, proteomic, and metabolomic tools can be explored for this purpose.
10. **Scale up of SynCom:** Industrial scale-up of all the strains of SynCom formulated as a single product is a significant constraint. For this, the use of a minimal number of candidates would be recommended.

Microbial Inoculants versus SynCom Inoculants

Microbial inoculants are inevitable bio-inputs for sustainable agriculture. They are economically viable technology, successfully demonstrated for their nutrient supplementation and stress management in several crops. However, their potential is less explored due to several environmental, scientific, and social issues. SynCom approach will resolve the deficits of current inoculant technology (Table 2).

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Table 2. Comparison between the present microbial inoculants and Syncom inoculants

Microbial inoculant	SynCom inoculant
One or two potential strains	Group of strains as a consortium
Develop through single isolate study model	Develop through ecology-based study
Potential strains from culturable plant microbiome	Involves both culturable and culture-independent tools to identify the strains
Each strain with specific beneficial trait	A Group of strains provides multiple benefits to crop on a labor-sharing basis
No need to be the representative of the core microbiome	Functional representatives of the core microbiome.
Top-down approach and inoculant development and evaluation are easy and quick.	The bottom-up approach needs a robust and methodological approach for inoculant development and evaluation.
Performance varies depending on crops, cultivars, management, soils, and agro-ecological conditions	Consistent performance is possible across varied crops and soils.
Less interaction with soil ecosystem and hence less persistence	High persistence due to high interaction with soil ecosystems
Uncertainty in robust colonization and prevalence throughout the crop's growth stages.	Ensures robust colonization and prevalence.
It can be supplementary for chemical fertilizers and synthetic chemicals.	Potential substitute the chemical fertilizers and synthetic chemicals

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Key Words

Biofertilizer: Commercial preparation containing microorganisms used to provide macro- and micronutrients to the crops.

Biocontrol agent: Commercial microbial preparation applied to crops for pest and disease management.

Core microbiome: Represents the keystone microbes established through evolutionary mechanisms of selection that are important for plant fitness. These species harbor important genes for the fitness of the plant.

Microbial inoculant: The commercial preparation containing microorganisms applied to improve the crop's nutrient uptake, biotic and abiotic stress amelioration and to improve soil health.

Plant holobiont: plant and its associated microbiomes as a single ecological and evolutionary unit.

Plant microbiome: Refers the characteristic microbial community of specific ecological niches of plant. It also includes its functionality. The plant microbiome can be from rhizosphere, phyllosphere, epiphytic and endosphere.

Rhizosphere: The thin layer of soil in close proximity of plant root which is directly influenced by the root.

Synthetic microbial community (SynCom): Represents the consortia of microorganisms designed to mimic, at some scale, the observed function and structure of the microbiome in natural conditions.