Cross species metabolic complementation of vitamin K2 biosynthesis determines emergent suppression of tomato *Fusarium* wilt

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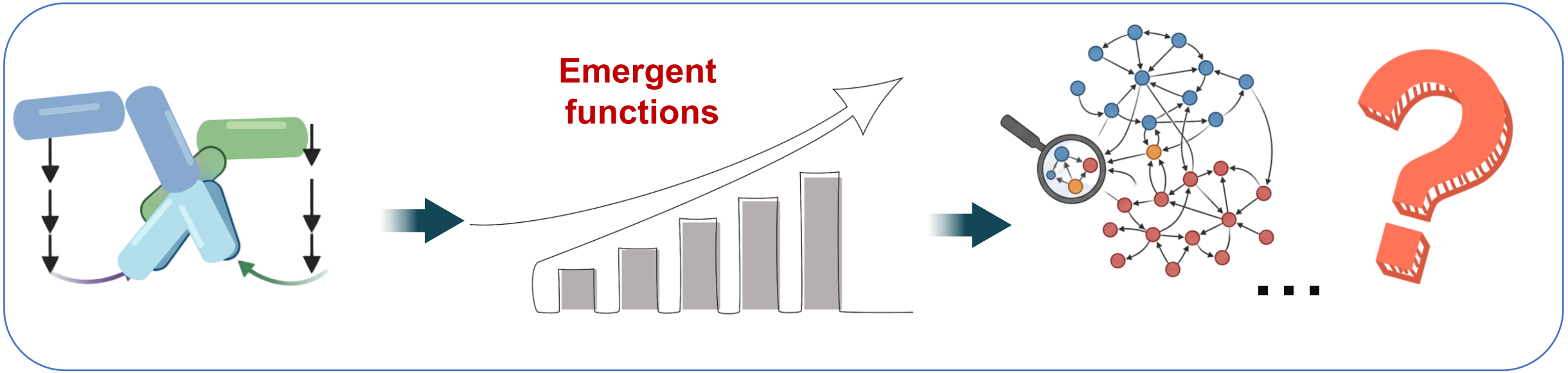


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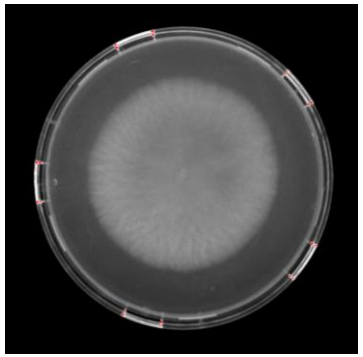
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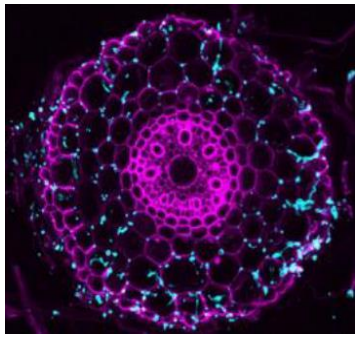
The mechanisms underlying emergent functional phenomena in microbial communities remain unclear.



- The mechanisms underlying emergent functional phenomena in microbial communities remain unclear.
- The origin of emergent functions in microbial communities is still a matter of debate.

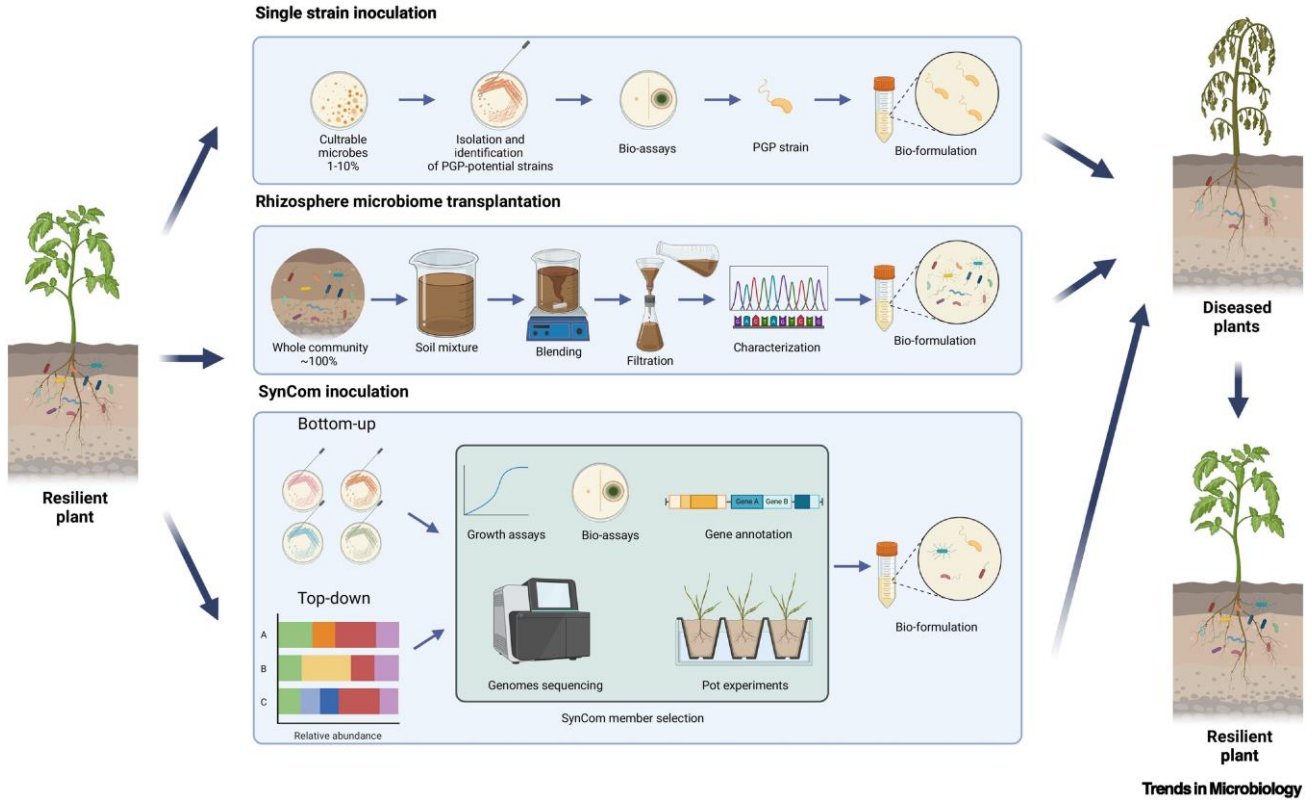
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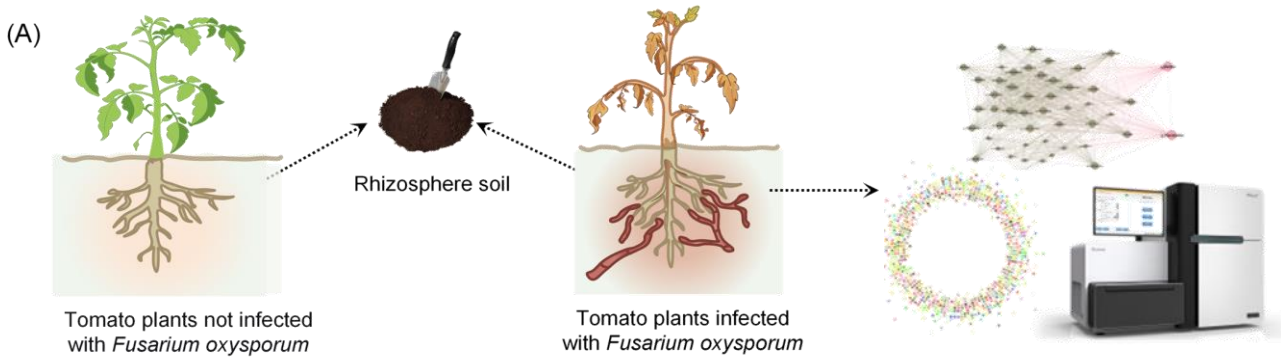




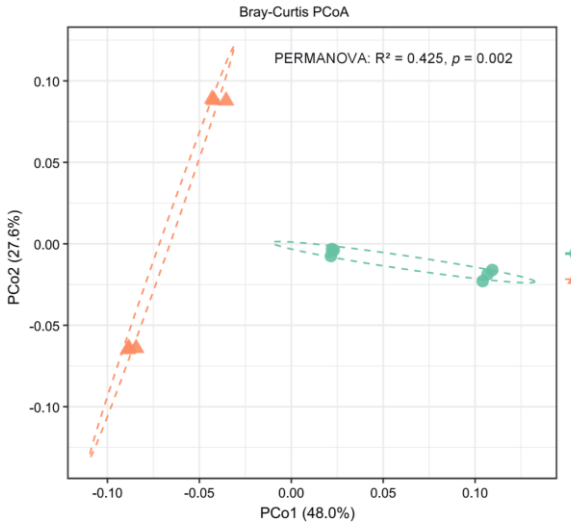
(Xu et al. 2025)

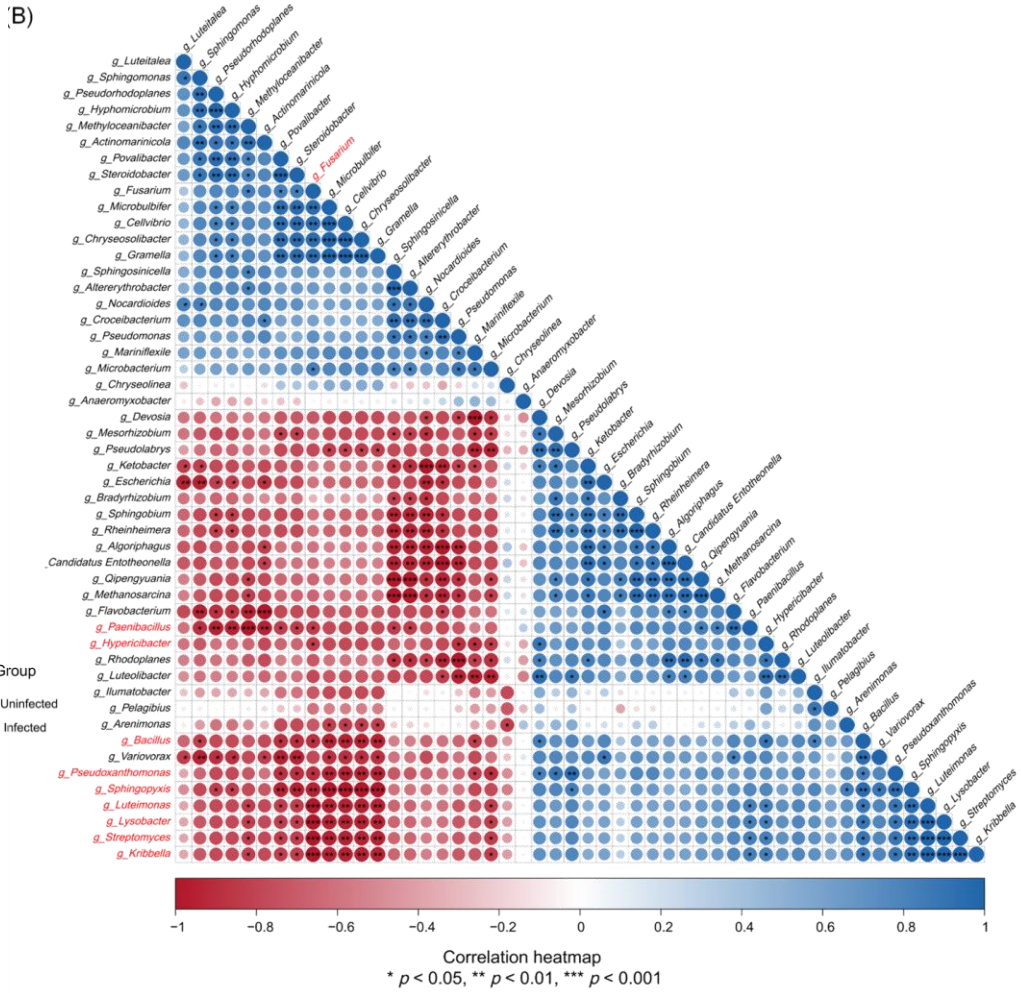
- *Fusarium* can cause wilt diseases in various crops, and such diseases have been reported in multiple countries.
- Synthetic microbial community (SynCom) have emerged as powerful experimental systems to study such emergence.

Results

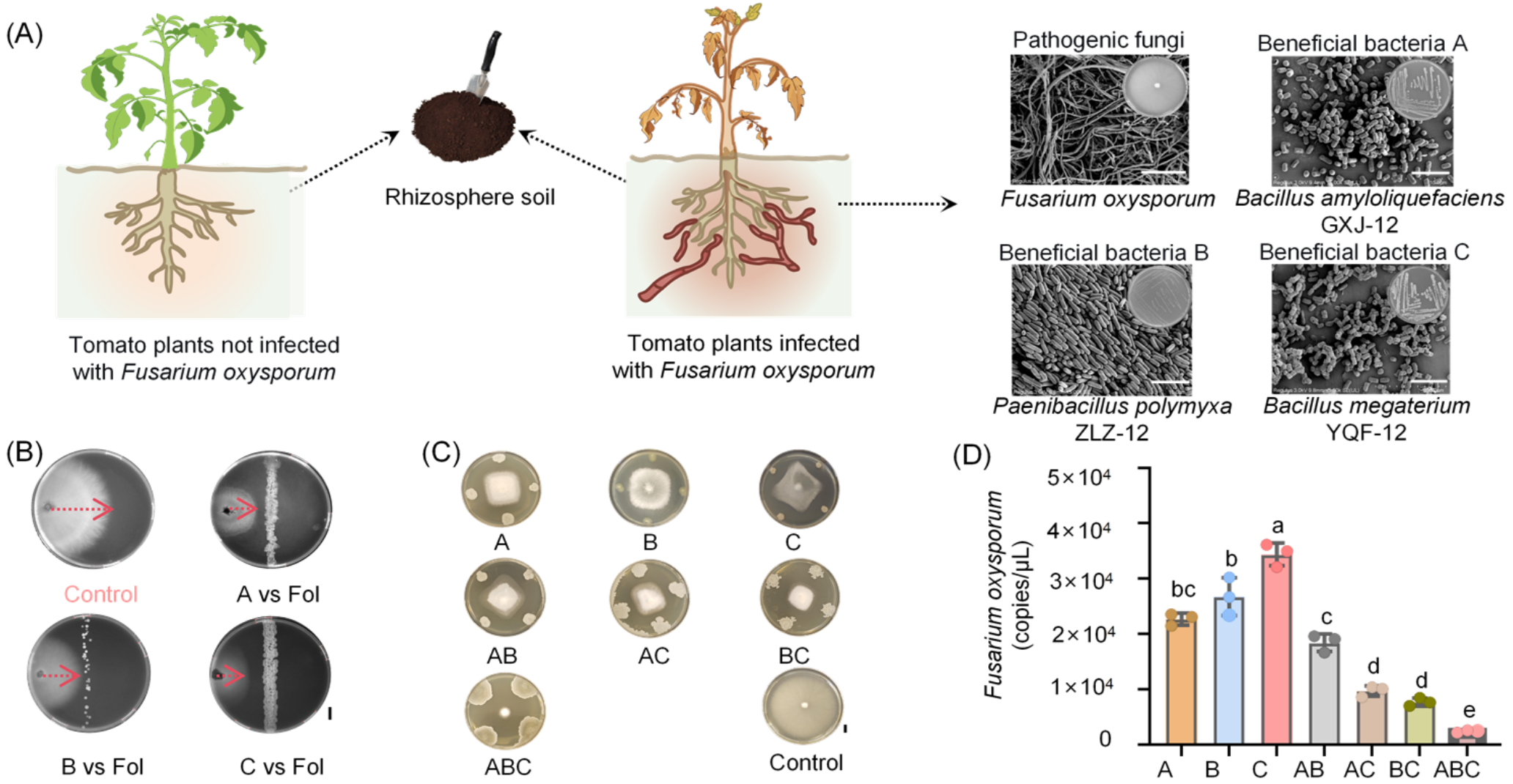


- The microbial community structure in the rhizosphere soil of tomato plants infected with *Fusarium oxysporum* f. sp. *lycopersici* (Fol) changed markedly.
- *Paenibacillus, Bacillus, Streptomyces, Lysobacter*, and other microbial genera showed significant negative correlations with Fusarium.



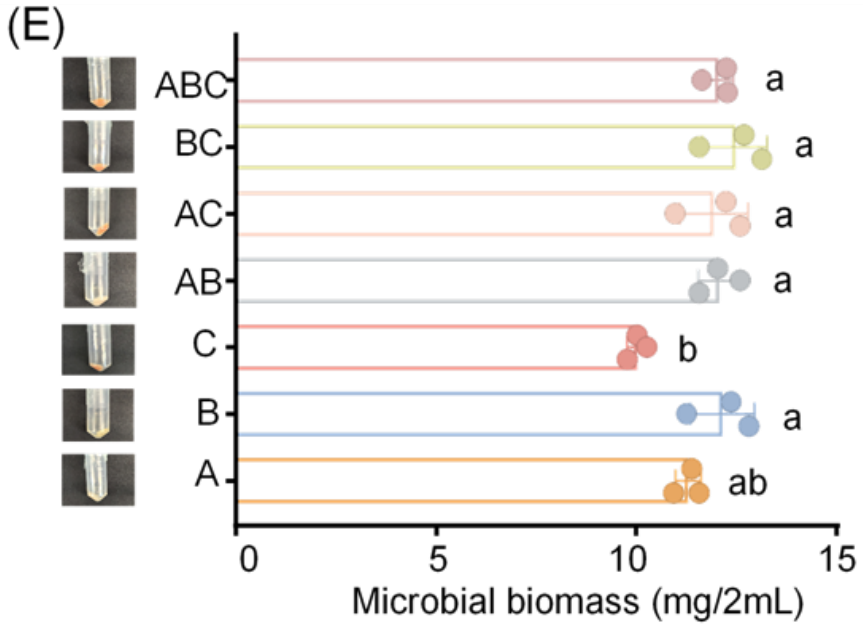


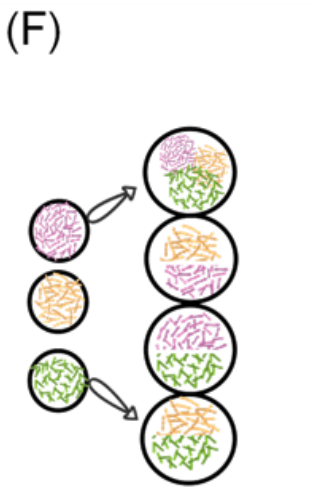
Emergent suppression of Fol in a defined tri-strain SynCom

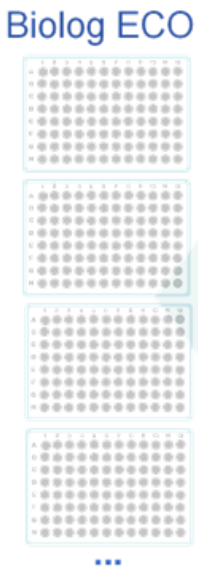


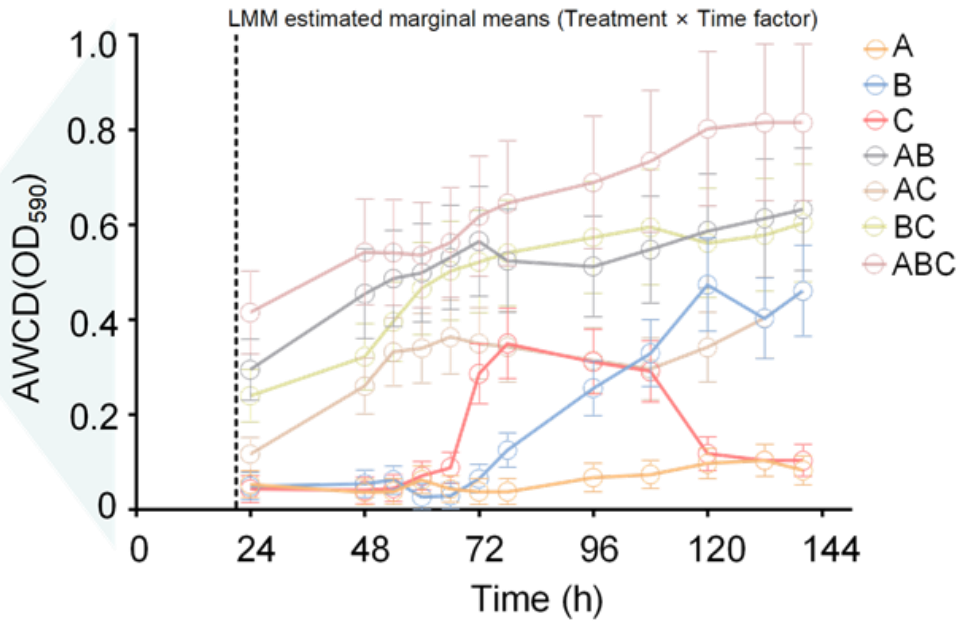
- From these taxa, three culturable strains that exhibited in vitro antagonism against Fol were isolated.
- Confrontation assays showed emergent suppression of Fol by the tri-strain SynCom.

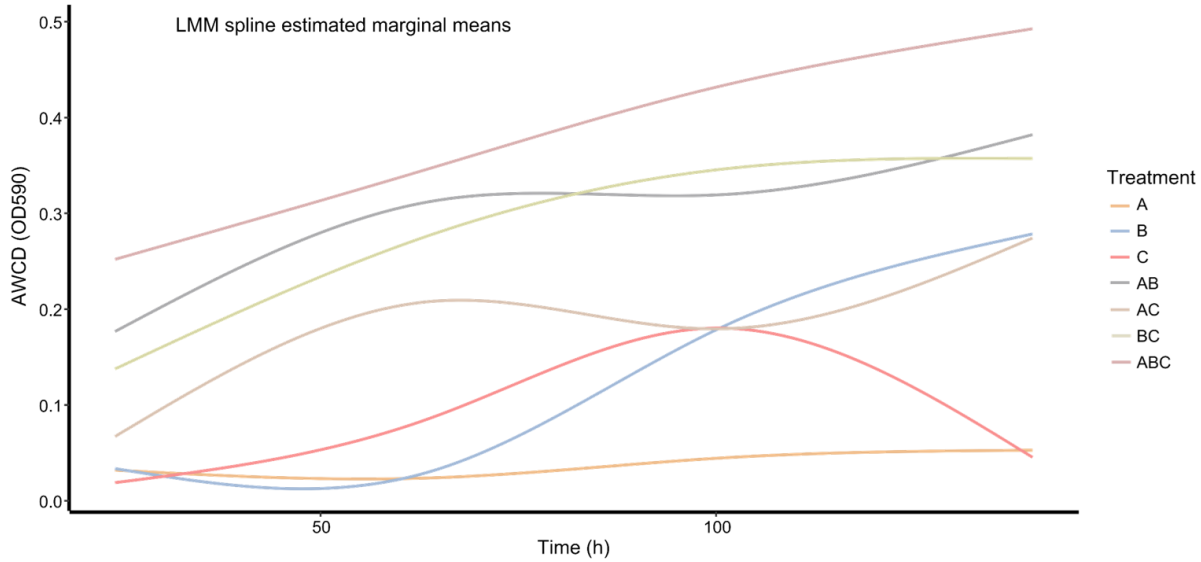
The tri-strain SynCom showed an overall trend toward superior resource utilization capacity.





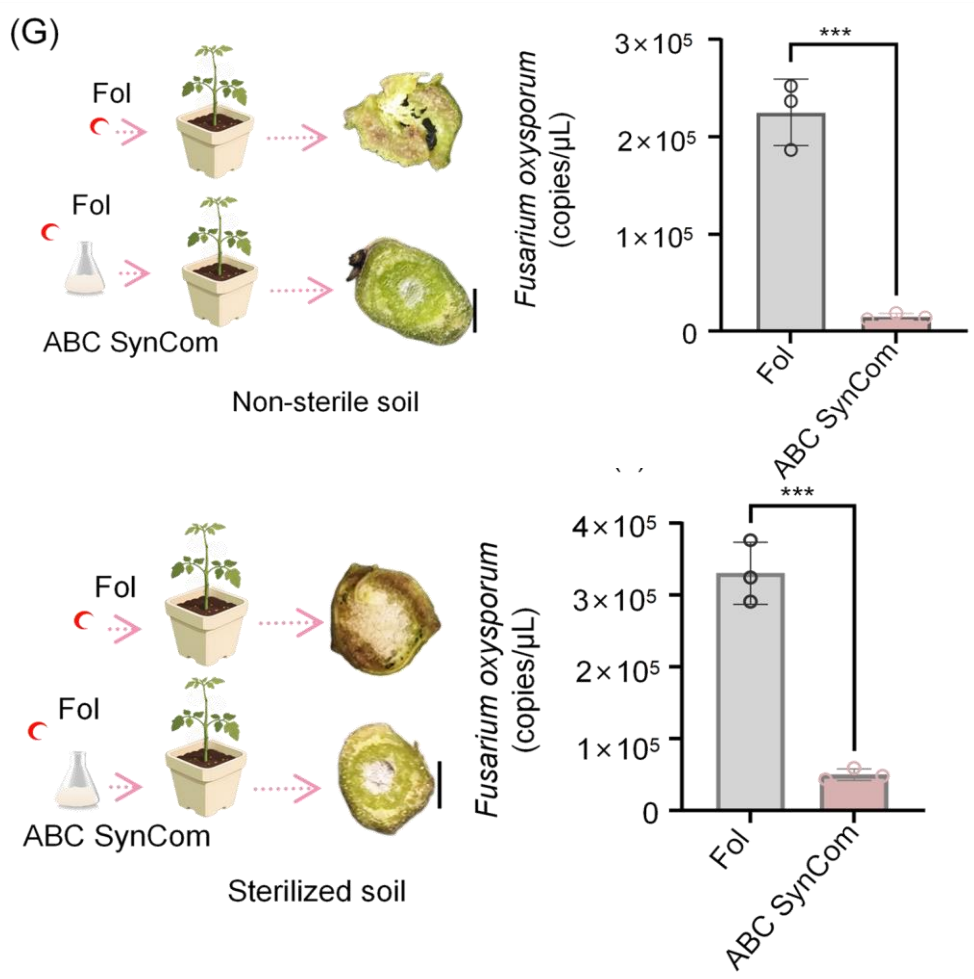


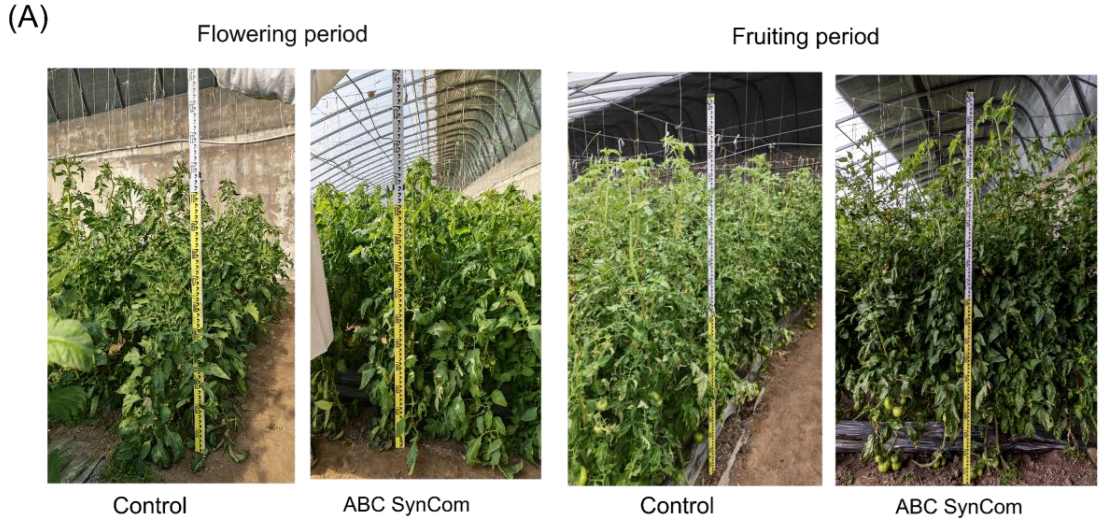


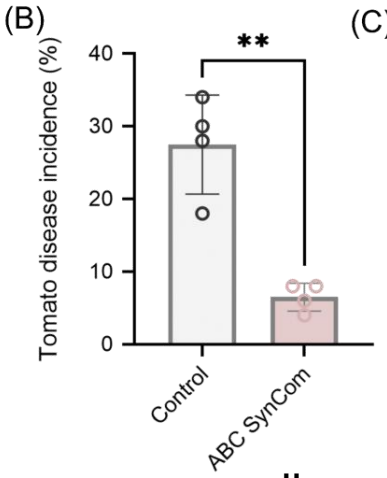


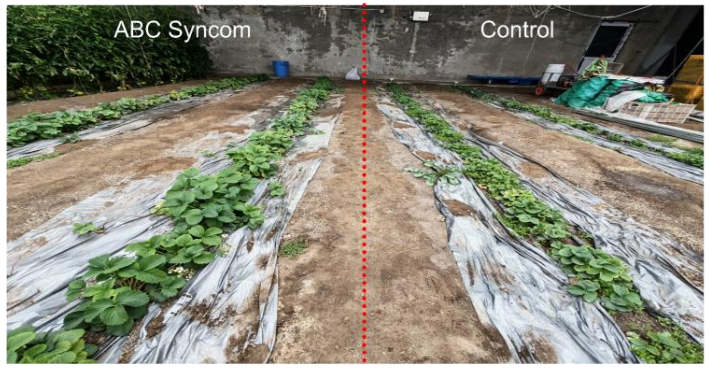
- The tri-strain SynCom showed an overall trend of superior resource utilization capacity, further indicating that it may have stronger metabolic capacity.

Emergent suppression of Fol was maintained under multiple simulated conditions



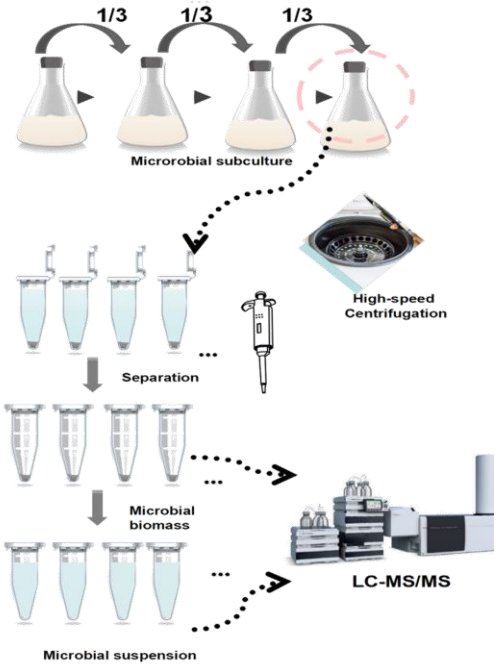


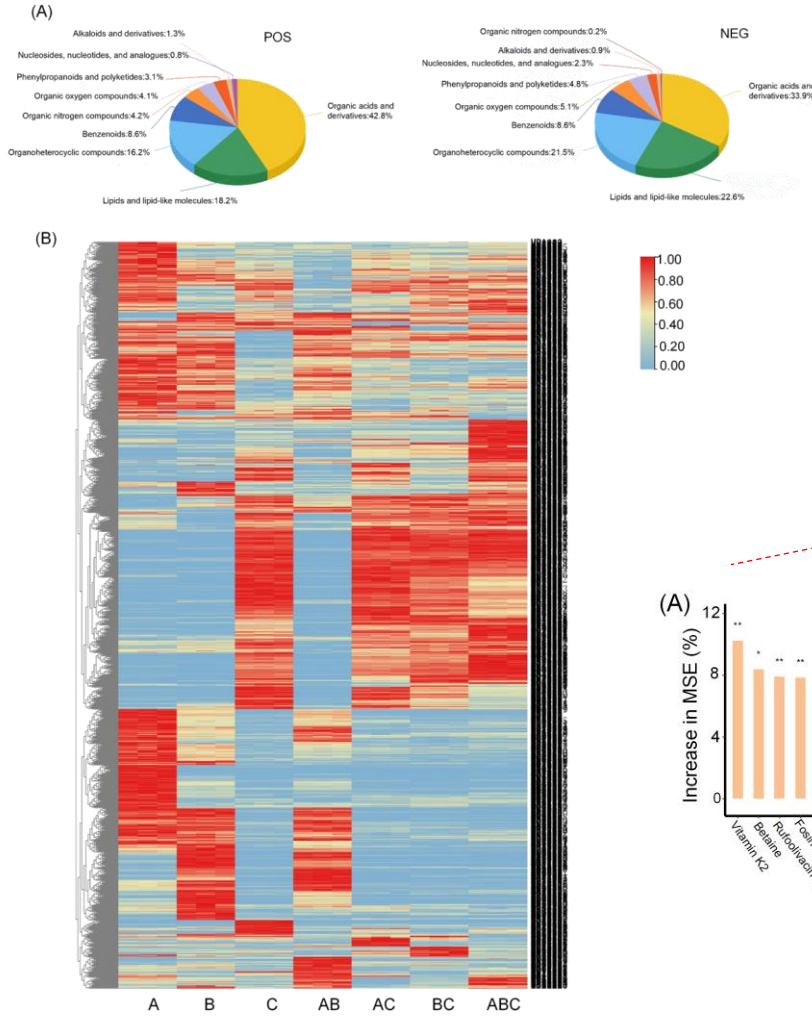


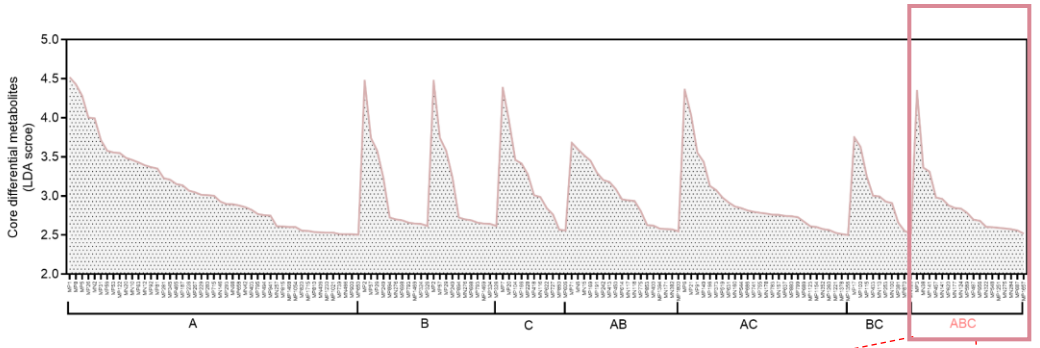


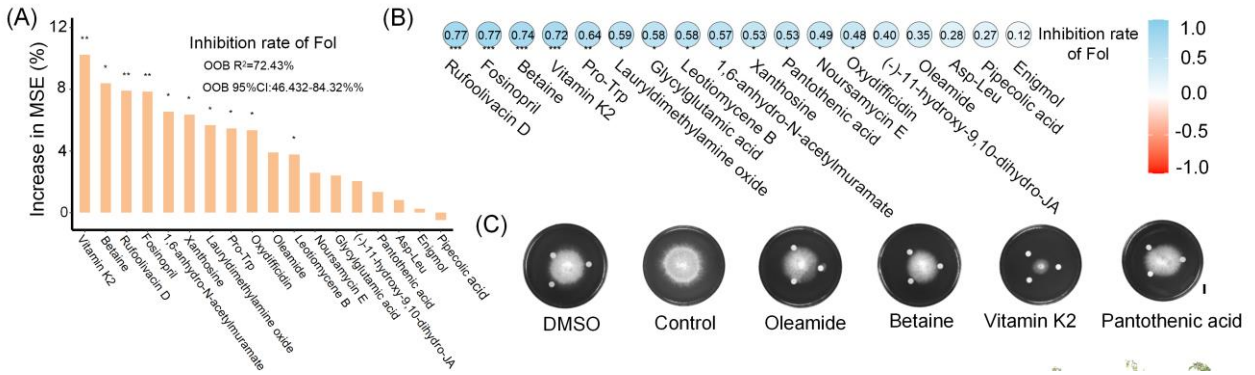
- The tri-strain SynCom exhibited robust performance across soil suspension assays, tomato pot experiments, and preliminary field trials.
- The SynCom exhibits good broad-spectrum crop adaptability and field application potential.

Vitamin K2 is a key effector metabolite underlying emergent FoI suppression



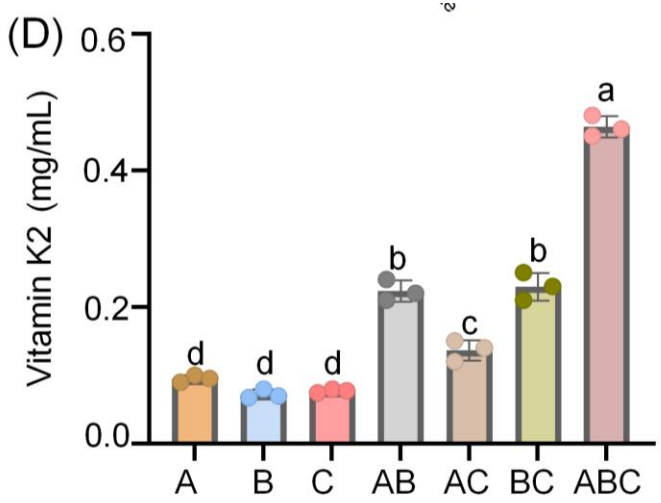


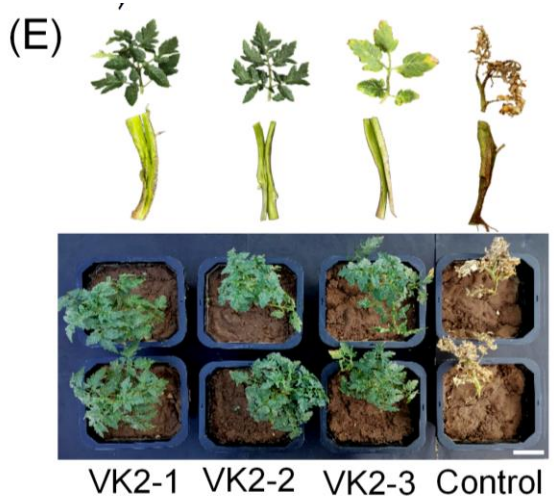


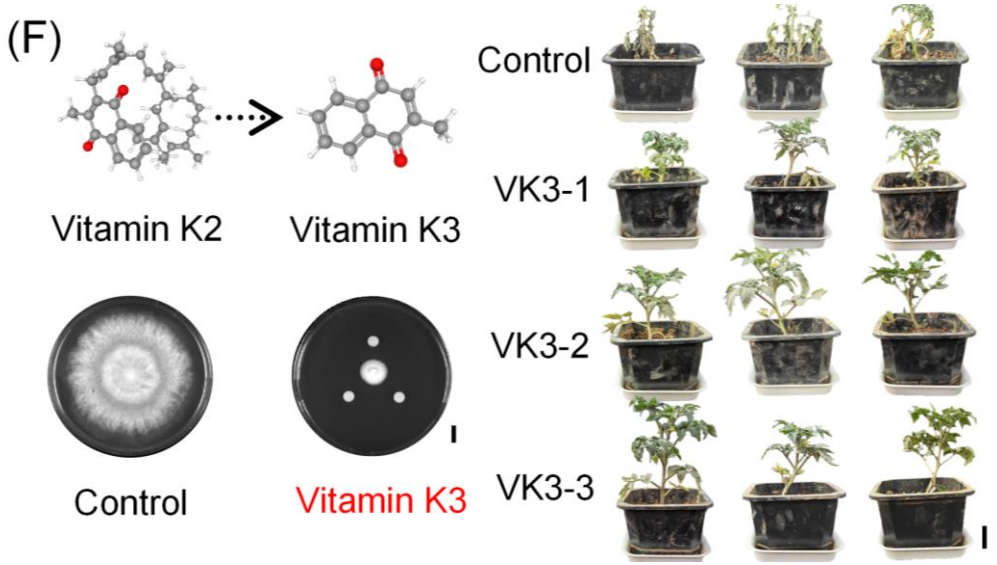


- Relative to single-strain and two-strain SynComs, the tri-strain SynCom exhibited extensive metabolic reprogramming.

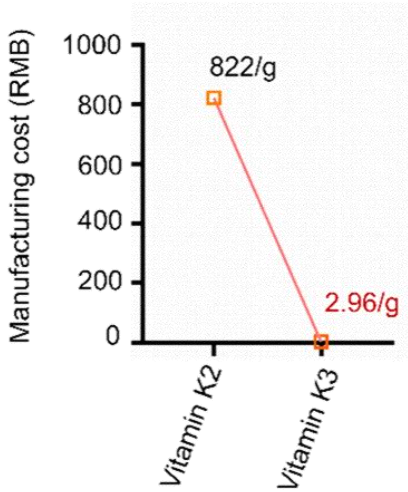
A low-cost vitamin K-type quinone recapitulates the emergent antifungal function





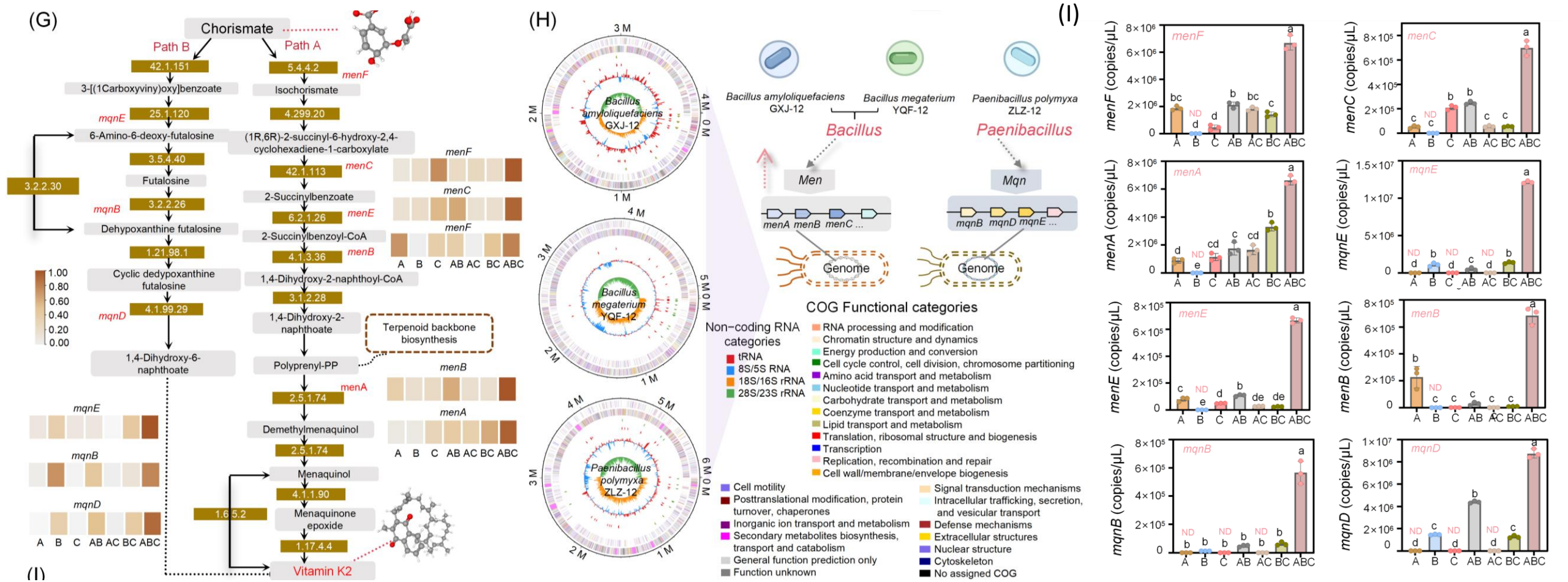


- A low-cost vitamin K-type quinone (vitamin K3) reproduced the emergent antifungal activity, with a cost only about 1/277th that of vitamin K2, indicating its potential for scalable application as an alternative to community-derived metabolites.





Distributed dual biosynthetic pathways enable high-level vitamin K2 production in the tri-strain SynCom



- The coordinated activation of two phylogenetically distinct vitamin K2 biosynthetic pathways (the *Men* and *Mqn* pathways) distributed across *Bacillus* and *Paenibacillus* species.

Conclusion

- This study demonstrates that the tri-strain SynCom suppresses the fungal pathogen *Fusarium oxysporum* through a strictly emergent mechanism.

- Vitamin K2 is a key effector metabolite underlying the emergent suppression, and a low-cost analogue, the vitamin K-type quinone vitamin K3, recapitulated the emergent antifungal function.

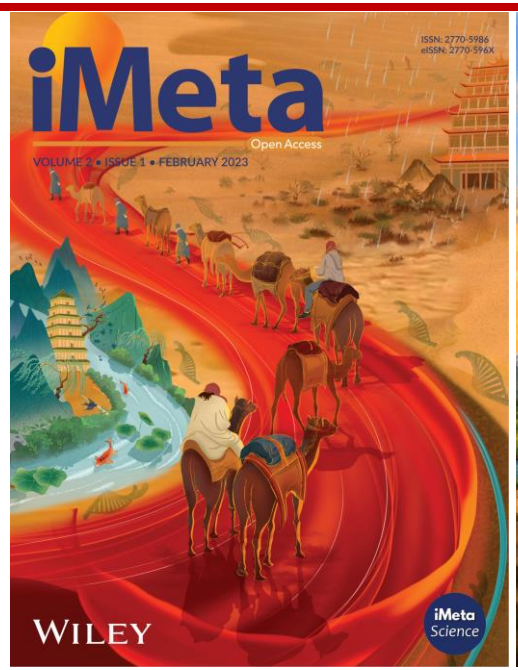
- Complementary *Men* and *Mqn* pathways enable cross-species vitamin K2 biosynthesis, indicating that microbiome emergent functions can rely on interspecies-interaction-triggered activation of latent metabolism rather than on simple constitutive metabolite exchange or additive effects.

- These findings establish cross species metabolic complementation as a mechanism for functional emergence. Future work should determine whether these metabolites act directly on plant defense or indirectly via pathogen inhibition, using spatially resolved approaches such as split-root systems and metabolite tracing.

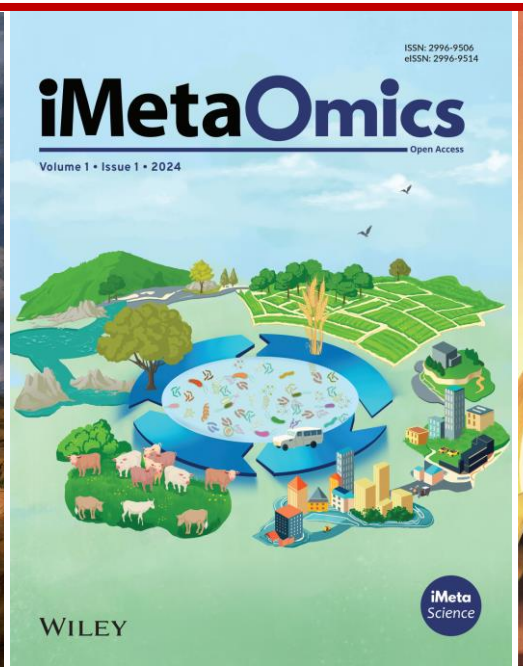
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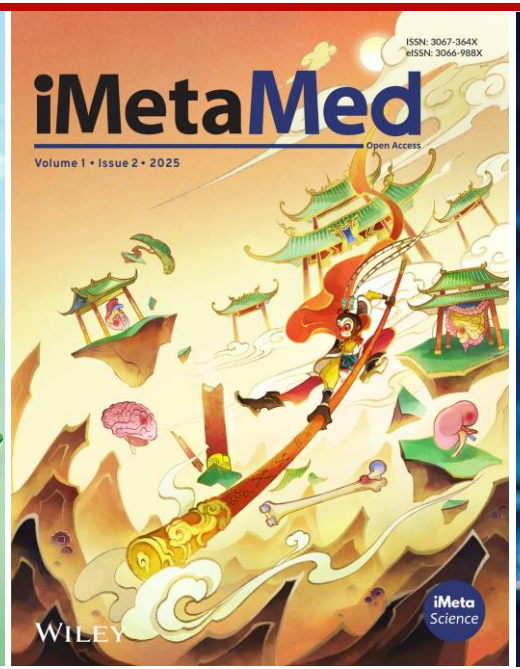
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