



Navigating the future of nano-pesticides: A perspective on design, efficacy, mechanisms, and environmental stewardship

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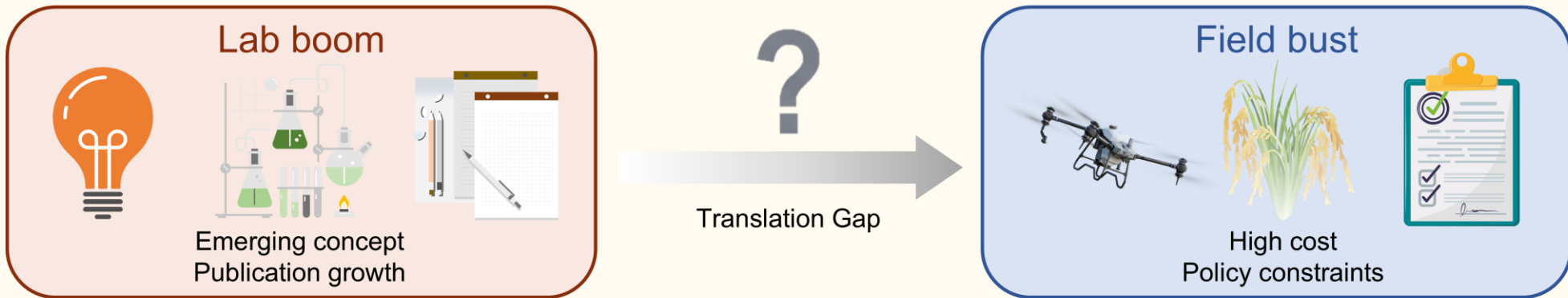


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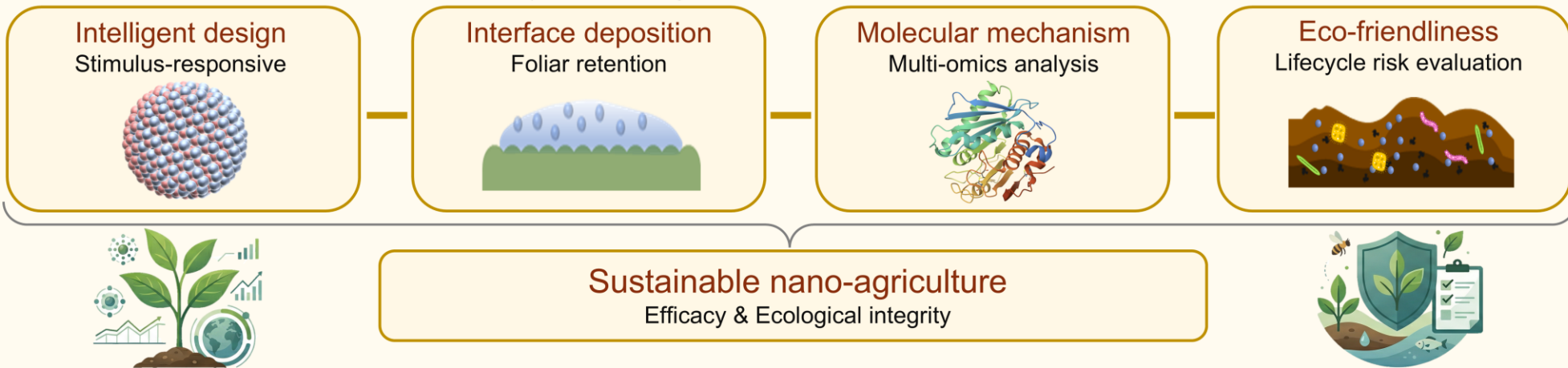


Highlights

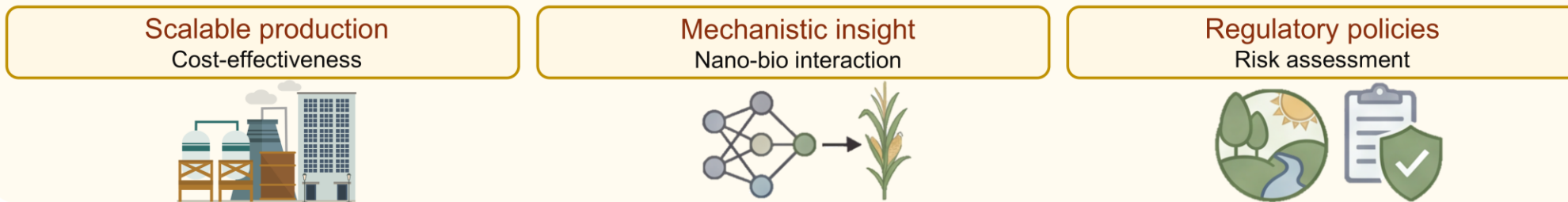
Nano-pesticides: From laboratory boom to field-translation challenge



A cross-disciplinary and integrative framework for nano-pesticide science



Challenges and future prospects





Introduction

Global Challenges



Crop loss: -40%

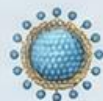


Als, Lost



Low efficiency: 10%-75% loss

Nano-Opportunity



Efficiency boost: ~30%



Controlled delivery



Core Paradox



Innovation gap?



Regulatory gaps



Integrated Systems Framework

Smart-carriers

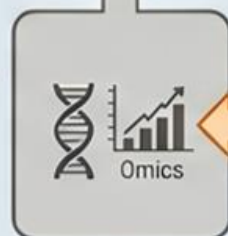


(Controlled release)

Molecular insights



(Decipher insights)



Foliar adhesion
(Retention)

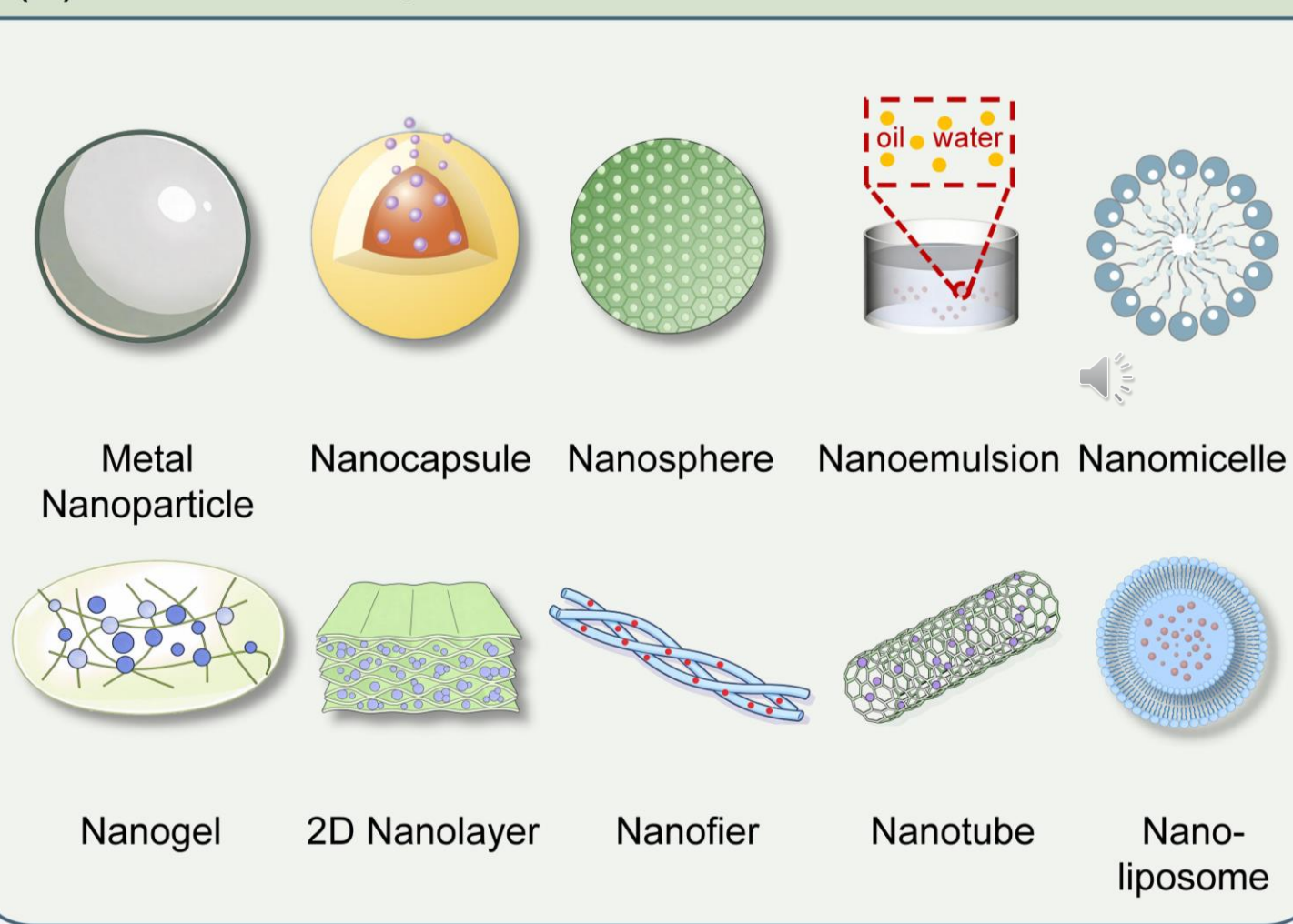


Risk assessment
(safety)

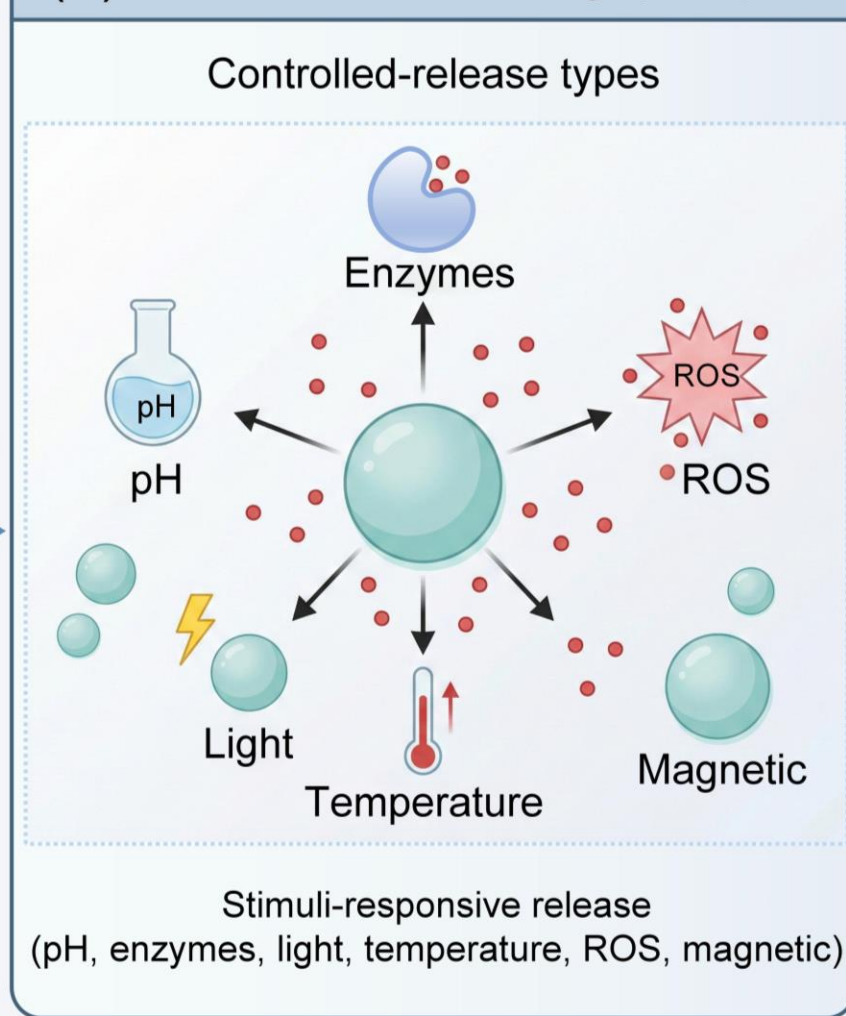


Part I: Classification and intelligent design of nano-pesticide formulations

(A) Nano-pesticide formulations classification

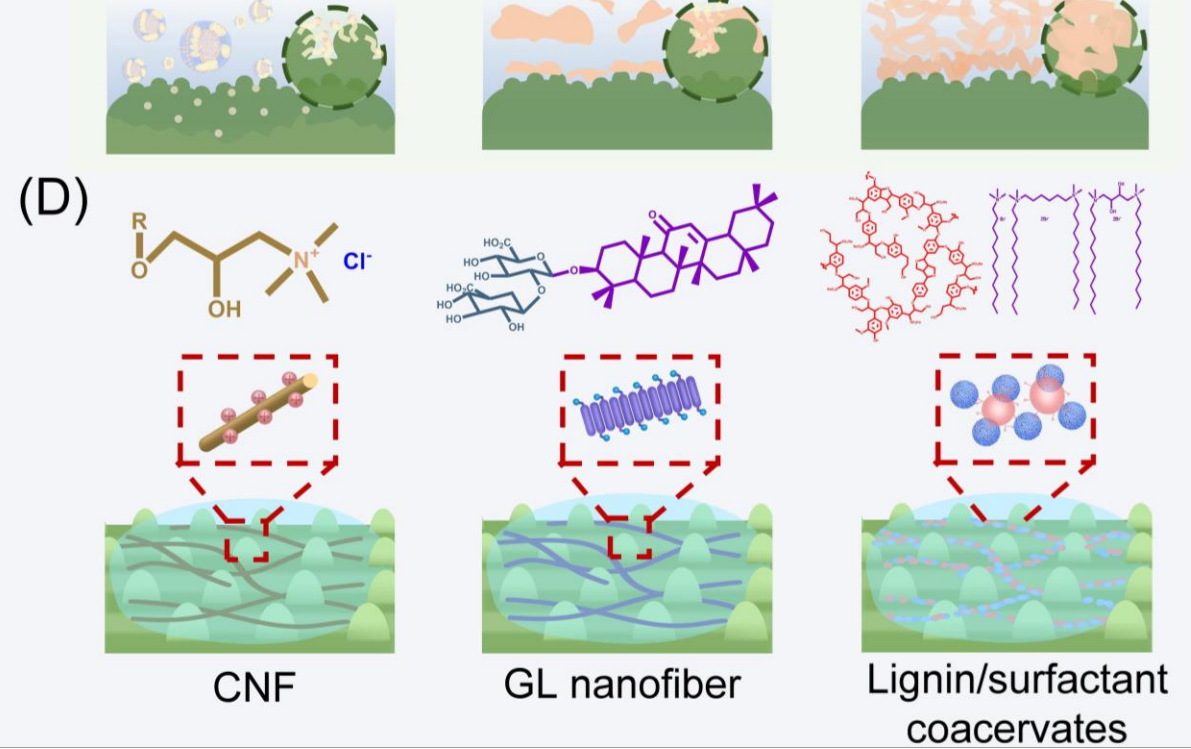
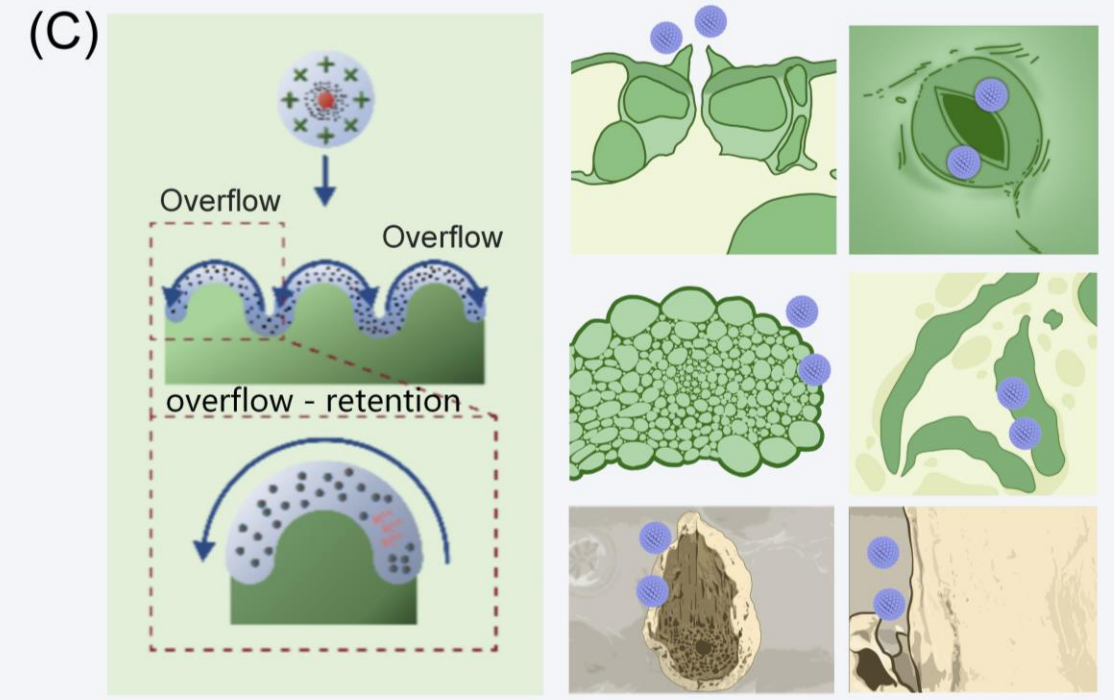
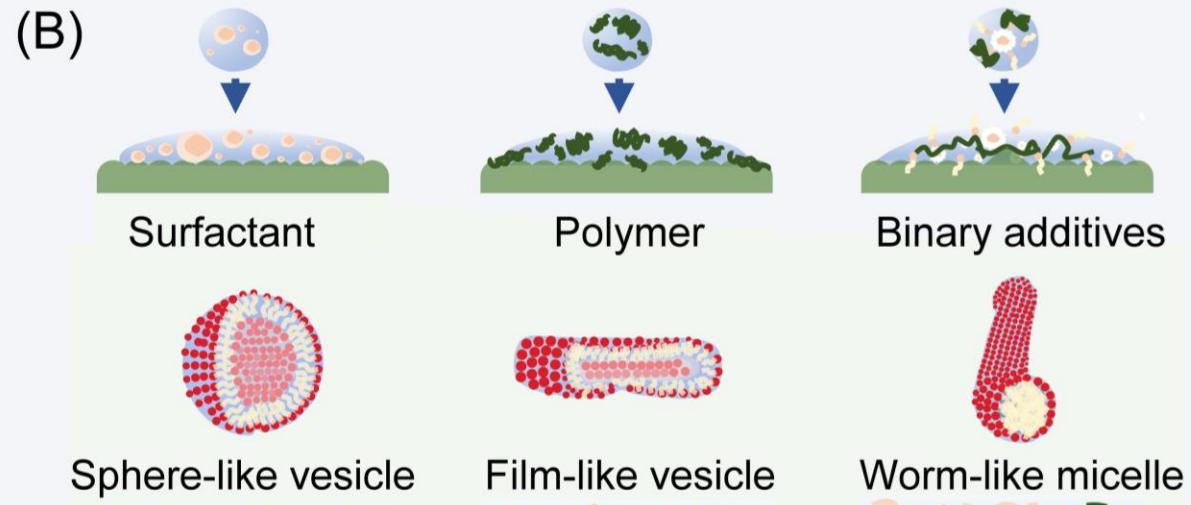
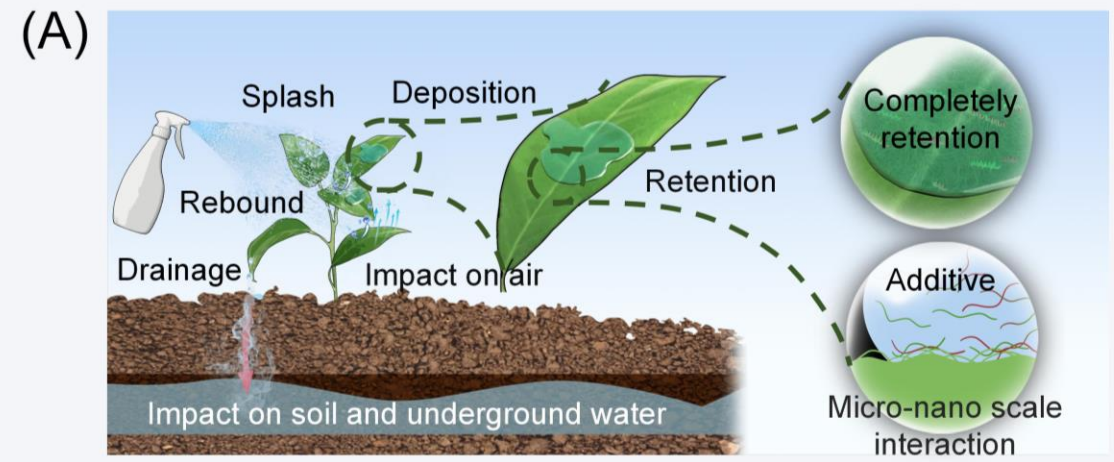


(B) Controlled-release design principles

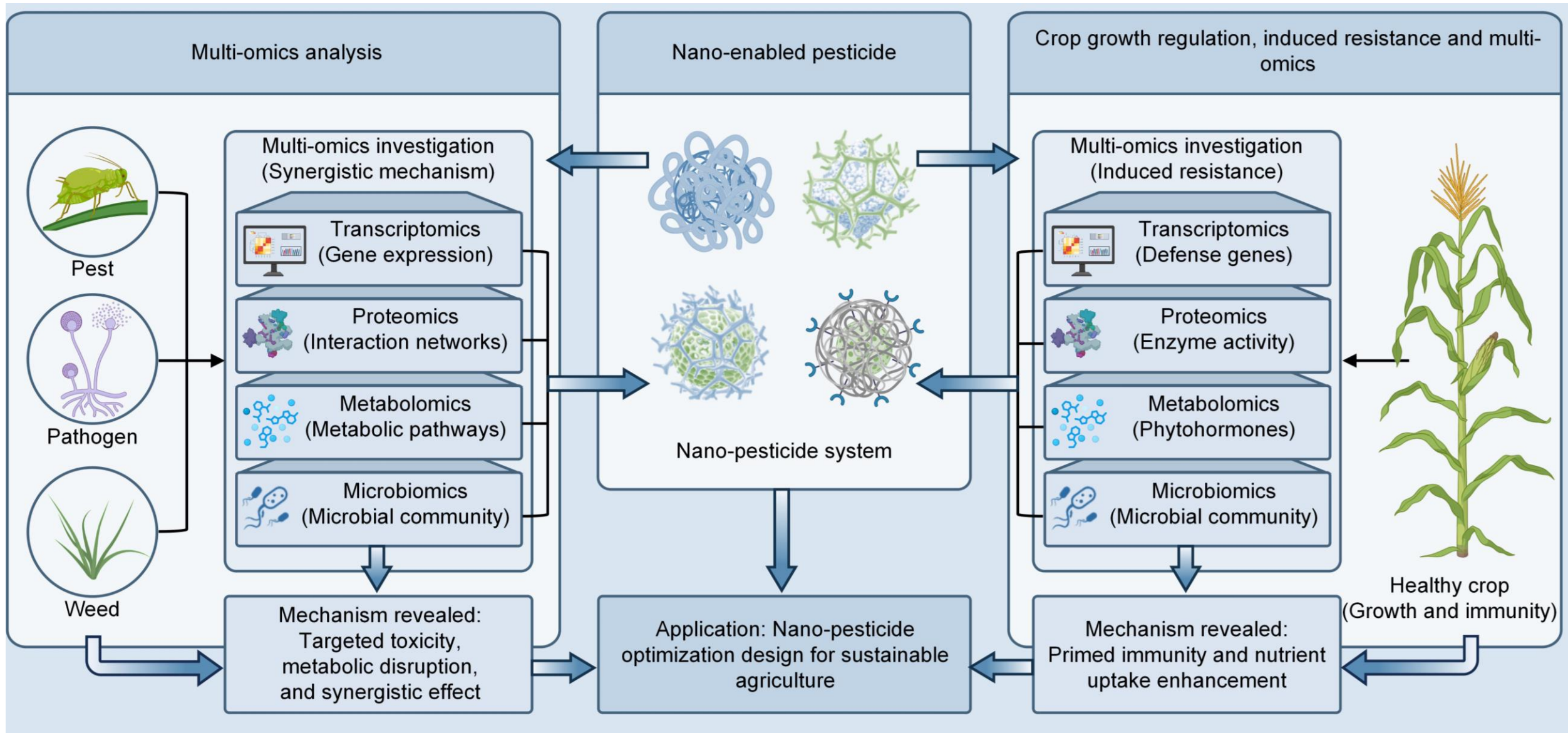




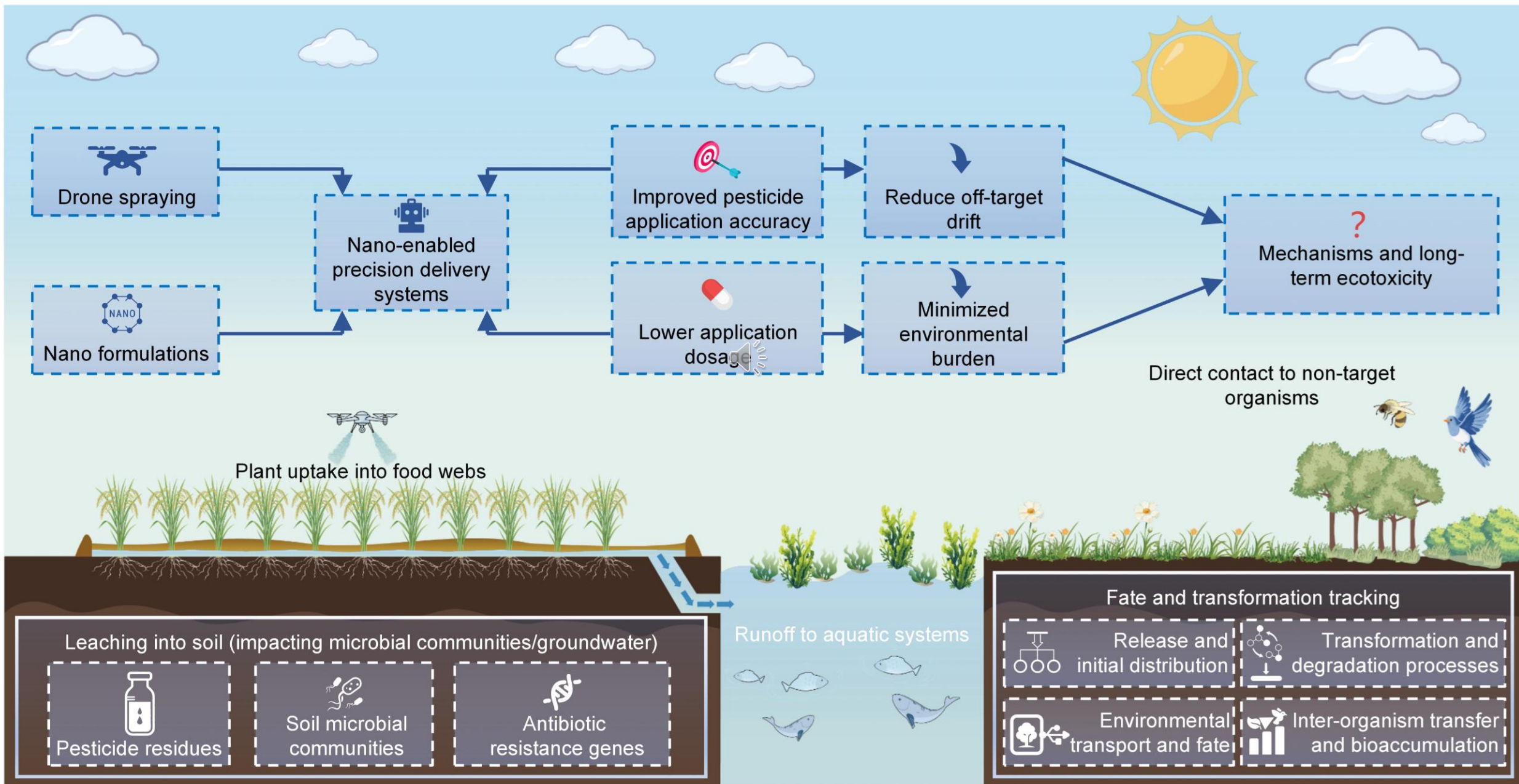
Part II: Interfacial behavior and deposition mechanism of nano-pesticides



Part III: Nano-enabled pesticide acting mechanisms: A multi-omics perspective



Part IV: Eco-risk evaluation of nano-pesticides





Prospects and challenges

- ❑ Widespread adoption of nanopesticides faces challenges in cost, scalability, and carrier safety.
- ❑ Integrated solutions are needed, such as eco-friendly carriers, scalable production, and AI-aided design.
- ❑ Future research should focus on droplet-leaf interaction, post-entry biological mechanisms, and carrier toxicology.
- ❑ Establishing adaptive regulations and international cooperation is key to guiding responsible innovation.

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