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Targeted Prevention and Control of Crop Pests and Diseases: Inter-organism Information Flow and Behavior Manipulation Postprint

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Abstract

Life sciences research can generally be divided into two major directions: the study of life entities themselves and the study of interactions among living organisms. Regarding the latter, life on Earth has, through long-term evolutionary processes, established relationships characterized by mutual struggle, mutual dependence, and mutual interaction. The information flow between organisms determines the direction of energy flow and material flow among species, while interactions among organisms constitute ecological relationships such as parasitism, mutualism, symbiosis, competition, and antagonism. The laws governing the transmission of information flow among them represent fundamental principles of life existence and constitute the most crucial environmental conditions for life's interdependence, encompassing exceptionally rich scientific questions.

Full Text

Preamble

Strategic Priority Research Programs (Category B) of the Chinese Academy of Sciences

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Targeted Prevention and Control of Crop Pests and Diseases—Inter-organism Information Flow and Behavioral Manipulation

1. Project Background and Significance

Life sciences research can be broadly divided into two major directions: the study of living entities themselves and the study of interactions among living organisms. Regarding the latter, life on Earth has evolved complex relationships of conflict, interdependence, and interaction over long evolutionary timescales.

Information flow between organisms determines the direction of energy and material flow among species, while these interactions constitute ecological relationships such as parasitism, mutualism, symbiosis, competition, and antagonism. The patterns governing information transfer represent fundamental principles of life and create the most important environmental conditions for organismal interdependence, harboring exceptionally rich scientific questions.

To date, human understanding of the mechanisms underlying information generation, mutual recognition, and transmission between organisms remains rudimentary. Over the past three decades, however, rapid advances in molecular biology and omics have endowed humanity with the capacity to explore complex inter-organism information flows, enabling the elucidation of processes involved in information generation, recognition, decoding, response, and interaction. This field is poised to become one of the major breakthrough directions in modern life sciences research. The Strategic Priority Research Program on “Targeted Prevention and Control of Crop Pests and Diseases” establishes and develops innovative research organizational models to convene CAS’ s advantaged research teams for collaborative 攻关. The program’ s overarching goal is to systematically analyze and identify inter-species information and its transmission processes related to the occurrence, development, and devastation of crop pests and diseases, establish finely tuned signaling networks for inter-organism information flow, and identify novel technologies targeting critical regulatory nodes in information transmission processes [Figure 2: see original paper]. Under this overarching objective, the program has achieved a series of internationally visible scientific accomplishments since its inception.

The program’ s academic thinking represents a fundamental shift from traditional pest control strategies. Conventional approaches focus on individual organism elimination, targeting pest nervous systems and basic metabolic pathways, resulting in high toxicity to humans and the environment and promoting resistance development. In contrast, the new strategy of targeted prevention and control based on information flow aims at critical information nodes that determine pathogenicity or invasiveness, offering specificity, environmental friendliness, and safety [Figure 1: see original paper]. By decoding and artificially manipulating information flow among crops, insects, and pathogenic microorganisms, the program will break through current fundamental academic thinking in pest control, providing major guidance and strategic significance for ensuring food and food safety.

2. Progress Achieved

The program has organized collaborative 攻关 among CAS’ s advantaged research teams in relevant fields, focusing on crop-pathogen-insect interactions as a scientific model system. Through systematic analysis of the molecular and informational basis of information flow recognition, decoding, and natural manipulation, the program has revealed new biological processes and explored principles for artificial simulation and manipulation of inter-species relationships.

This has provided a scientific foundation and technology development platform for breakthroughs in targeted prevention and control technologies.

Key achievements include:

The program discovered that the locust gregarization process is strongly regulated by epigenetic mechanisms exhibiting transgenerational inheritance effects. Parental crowding effects significantly influence offspring hatching time, with miR-276 participating in transgenerational regulation to control hatching synchrony. Additionally, miR-71 and miR-263 were found to regulate locust cuticle metabolism, providing targets for developing strategies to control locust aggregation [Figure 3: see original paper]. These findings were published as original articles in *PNAS* and featured on the cover of *PLoS Genetics*.

In plant immunity research, the program identified novel mechanisms by which host plants recognize bacterial effector proteins AvrAC and AvrB and their information flow. The research resolved new transcription factor BES1 and novel functional gene EDR4 in crop disease resistance pathways, 完善了作物抗病信息网络. The program also discovered connections between intracellular immune receptors and exocytosis mechanisms, revealing new plant innate immunity and pathogen virulence mechanisms.

A groundbreaking discovery showed that natural plant non-coding RNAs can enter fungal cells and control the expression of fungal pathogenicity genes. This enabled specific intervention targeting information flow molecules in major cotton pests and diseases (cotton bollworm and cotton verticillium wilt). The program also discovered that vector insects can produce nematode pheromones that control nematode development and behavior, with insect-derived pheromones attracting nematodes into tracheae for transport to new hosts, playing a crucial role in the spread of pine wilt disease.

Using TALEN and CRISPR/Cas9 genome editing technologies, the program achieved the first simultaneous modification of all three copies of the *MLO* gene in hexaploid wheat internationally, obtaining wheat materials with broad-spectrum resistance to powdery mildew [Figure 4: see original paper]. Published in *Nature Biotechnology* in 2014, this work was featured in special commentaries by *Nature* and *Nature Biotechnology*, reported by CCTV's "News Live Room," and praised by the Vice Minister of Agriculture as a "major breakthrough" in disease resistance breeding technology.

The program has established close cooperative relationships with over 30 domestic and international universities and research institutions, focusing on areas such as differential behavioral responses of locust phases to aggregation pheromones, impacts of climate change on global plague occurrence, and synergistic invasion mechanisms of exotic invasive species. Commissioned assessments by the Shanghai Library and Information Center concluded that the program is "internationally first-class, domestically leading," with citation rates per paper in plant science and entomology exceeding those of UC Davis, INRA, and the University of Florida.

3. Originality

The program integrates organizational management innovation with research funding system innovation. Since its launch, it has successfully achieved its intended goals, establishing a foundation for developing novel technologies to artificially manipulate insect and pathogenic microorganism behavior and pathogenic processes, while demonstrating originality in theory, methodology, and technology.

Theoretical Innovation: “Recognition, decoding, and manipulation of inter-organism information” represents a key frontier in modern life sciences. The program integrates domestic advantaged research teams, using crop-pathogen-insect interactions as a model system to systematically analyze molecular foundations of information flow generation, recognition, transmission, and natural manipulation. This has elucidated novel phenomena and mechanisms in inter-organism communication, establishing finely tuned signaling networks for information flow and identifying critical regulatory nodes. Major breakthroughs have been achieved in understanding molecular bases of parasitic, symbiotic, and antagonistic relationships, cross-species and cross-kingdom signal transmission processes, novel epigenetic regulatory mechanisms, and evolutionary dynamics of information flow in relation to environmental factors.

Technical Innovation: The program has invented major new technologies and innovative methods for artificially manipulating insect and pathogenic microorganism behavior and pathogenic processes. Using TALEN and CRISPR-Cas9 genome editing, the program achieved the first simultaneous mutation of three *MLO* gene copies in hexaploid wheat, obtaining broad-spectrum powdery mildew-resistant materials. This provides the only currently available strategy and starting material for breeding powdery mildew-resistant wheat varieties and was listed among the top ten technological breakthroughs of 2016 by *MIT Technology Review*. Additionally, RNAi technology development enabled specific intervention targeting information flow molecules in major cotton pests and diseases, achieving important breakthroughs in agricultural biotechnology.

Management Innovation: The program leadership and management office adhere to the philosophy of “lean team, stable support, strict evaluation, first-class results,” implementing a differentiated funding system to encourage major scientific achievements. The program has established a series of regulations including supplementary reward funding management, intellectual property management, and evaluation protocols. It sponsors youth academic forums on biological interactions in Beijing and Shanghai, has compiled promotional materials, and established a program website, WeChat, and Weibo presence [Figure 6: see original paper]. A shared database and public research platform based on mature pipelines have also been constructed, providing institutional guarantees and professional platforms for collaborative innovation.

4. Significance for Industry

As the world's most populous nation and a major agricultural country, China faces crop pests and diseases as major natural disasters threatening agricultural production and causing social instability and population reduction. Current pest control still relies on chemical pesticides targeting basic metabolic processes, ignoring inter-organism relationships and information transmission, leading to serious problems including pesticide abuse and environmental pollution. By decoding and artificially manipulating information flow among crops, insects, and pathogens, the program will break through current fundamental academic thinking in pest control, providing major guidance and strategic significance for ensuring food and food safety. The program's achievements will make outstanding contributions to field pest control.

5. Recommendations for Future Development

5.1 Discipline Development

Since its launch, the program has achieved internationally influential progress in fields such as “biological disaster outbreak mechanisms and control” and “crop-microbe-insect interactions,” advancing the discipline of biological interaction research and consolidating China's international position in this field. Continued funding is recommended to promote multidisciplinary collaboration from upstream molecular model exploration to downstream field applications, fostering innovative major achievements.

5.2 Industry Impact

After two years of effort, the program has produced multiple original achievements in “targeted regulation of inter-organism information flow,” with plant genome editing technology selected among *MIT Technology Review*'s “Top Ten Breakthrough Technologies of 2016.” The project “Biological Disaster Outbreak Mechanisms and Control” was selected as one of only 20 landmark major progress projects in CAS' s “12th Five-Year” general domain, and the only one in agriculture. Continued support is recommended to advance the development of major new technologies for artificially manipulating insect and pathogenic microorganism behavior, providing fundamental academic thinking and next-generation control strategies for global food and food safety.

5.3 Talent Cultivation

The program has consolidated CAS' s advantaged research forces in plant pathology, plant microbiology, and entomology to build an internationally first-class innovation team. While gathering academic leaders, the program emphasizes youth talent cultivation. Since its launch, the program has added one NSFC innovation team, one foreign member of the Norwegian Academy of Sciences, two “Ten Thousand Talents” recipients, one “Distinguished Young Scholar,” one

young science and technology innovation leader, and three “Excellent Young Scholars.” Academician Kang Le received the Tan Jiazhen Life Science Achievement Award, Academician Fang Rongxiang received the Chinese Society of Plant Pathology Lifetime Achievement Award, Academician Chen Xiaoya received the International Cotton Genome Initiative (ICGI) Outstanding Contribution Award, and researcher Guo Huishan received the State Council Special Government Allowance. Researchers Zhou Jianmin and Li Chuanyou lead two major scientific research program projects. Additional funding is recommended to recruit research groups in urgently needed directions and expand the program’s research team.

Expert Perspectives:

He Shengyang, Member of the U.S. National Academy of Sciences:

“Every year, up to 30% of major global crops are lost to pest outbreaks and pathogen infections. Pathogens, pests, and abiotic stresses undoubtedly constitute the most significant threats to sustainable crop production. Developing innovative and environmentally friendly control strategies represents the greatest challenge for 21st-century agriculture. Addressing these challenges requires global scientists to accelerate understanding of the molecular mechanisms by which pathogens and pests infect crops and translate basic research into major innovative technologies for pest management. If Chinese scientists could take the lead in this field, would that not be a great achievement? If you had asked me this question ten years ago, I would have said it was a beautiful dream. But today, with CAS establishing this large-scale, multidisciplinary ‘Targeted Prevention and Control of Crop Pests and Diseases’ pilot program, I can proudly say we are witnessing this dream become reality. This ambitious program uniquely features large scale and multidisciplinary collaboration among distinguished scientists. In just two years, the program has produced multiple impressive achievements that I believe have propelled China’s entomology and plant pathology research to world-class levels.”

John G. Hildebrand, Member of the U.S. National Academy of Sciences:

“The extensive use of chemical fertilizers and pesticides has significantly improved crop yield and quality but has severely disrupted agricultural ecosystems and harmed human health. Comprehensively understanding the mechanisms of inter-organism information exchange and interactions to develop environmentally friendly advanced pest control technologies represents the frontier of global agricultural science. This program’s establishment is therefore of great significance, possibly CAS’s first large-scale multidisciplinary collaboration project in this field. The program has achieved remarkable results in the past two years, with each project producing rich, valuable scientific output. Many original research articles have been published in high-level comprehensive and specialized journals, demonstrating that the program’s research has entered the international frontier and possesses competitiveness. Particularly noteworthy are the artificial modifications of disease and pest resistance traits in staple crops using

genome editing and RNAi technologies based on newly discovered mechanisms. These technological developments have already generated tremendous international impact and will continuously support plant protection and crop yield improvement.”

Note: Figure translations are in progress. See original paper for figures.

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