

Pioneers of Allelopathy: XVII. Wenxiong Lin

Changxun Fang¹

Fujian Provincial Key Laboratory of Agroecological Processing and
Safety Monitoring, College of Life Sciences, Fujian Agriculture and
Forestry University, Fuzhou 350002, China
E. Mail: changfangxingyx@163.com

(Received in revised form: February 28, 2021)

ABSTRACT

Wenxiong Lin did research for > 30 years in plant molecular ecology and agro-ecology, rice allelopathy and continuous monoculture problems/soil sickness of Chinese medicinal plants. His 20 Patents and most publications (about 100) have focussed on (i). Gene regulation of allelochemicals biosynthesis in allelopathic rice, (ii). allelopathic inhibitory effects on weeds, (iii). continuous monoculture problems/soil sickness in medicinal plants and (iv). the influence of allelochemicals and monoculture practice on the rhizospheric micro-environment. He helped in development of microbial fertilizer to alleviate the autotoxicity problem in continuous cropping of *Radix pseudostellariae* and *Rehmannia glutinosa*, etc. He had been the President of Asian Allelopathy Society, and got the outstanding achievement from the platform of International Allelopathy Foundation. His student, Dr. Changxun Fang got Rice Award and Grodzinsky Award respectively in the 6th and 8th World Congress of International Allelopathy Society. His elucidation of the molecular ecological mechanism of rice allelopathy was awarded the II Class Prize of Fujian Provincial Scientific and Technological Progress Award in 2007. His researches to find the mechanism of development of continuous cropping obstacle/soil sickness in *R. pseudostellariae* and its remedy was awarded the I Class Prize of Fujian Provincial Scientific and Technological Progress Award in 2020.

Keywords: Allelopathy, Chinese medicinal plants, continuous monoculture problems, molecular ecology, Pioneers of Allelopathy, rhizosphere biology, rice, soil sickness

1. PERSONAL LIFE

He was born in a farmer's family on May 14, 1957. His parents Jinyao Lin and Linlan Zeng were hardworking farmers. They are four brothers and sisters. As he was the youngest child in family, hence, his mother worried if he goes to school, that no one would take care of him. Therefore, he started primary school at the age of 9, and only used to attend school for 2-3 hours a day. From his primary to high school, China was in the Cultural Revolution, hence, his basic education was not so good. He also participated in farming operations with his parents and felt the hardships of farmers. After passing high school in 1976, he did 2-Years apprenticeship in carpentry. In 1978, when the higher education examination system was restored in China, he successively passed the National examination and got admission to University. Due to his good Score in National examination, he chose major in agronomy at Fujian Agriculture College (now Fujian

*Correspondence author, ¹ Fujian Provincial Key Laboratory of Agroecological Processing and Safety Monitoring, College of Life Sciences, FAFU, Fuzhou China

Agriculture and Forestry University). He successfully obtained the Bachelor's Degree in 1982. Then he was appointed Teaching Assistant in University. Besides, he was studying part-time and successively obtained the Master's degree and the Doctoral degree in 1989 and 1995, respectively. In May 1988, he married Zheng Hongyan, an administrator of our University. They had one son, Dr. Rui Lin, born in July, 1989 and now postdoctoral fellow in Beijing Institute of Life Sciences, China. During his youth, he was busy with his career and also wrote poems.



Photograph of Prof. Wenxiong Lin

2. EDUCATION

He studied in Fujian Agriculture College (now Fujian Agriculture and Forestry University) and received B.S. (Agronomy) degree in 1982. Thereafter, he worked as Teaching Assistant, Agronomy Department and begun his research on rice allelopathy and its underlying molecular mechanism. In 1986, he got admission in M.S. degree (September, 1986 – July, 1989) and majored in Crop Production and Farming Systems under the supervision of Prof. Wu Zhiqiang. After the M.S. degree, in 1991, he continued his Doctoral studies majoring in Crop Genetics and Breeding (March, 1991-July, 1995). His Ph. D. supervisor was most Eminent Prof. Lu Haoran, expert in Crop Genetics and Breeding.

3. PROFESSIONAL CAREER

After he got the Bachelor's degree in July 1982, he worked as Tutor in College of Agriculture for 2-years, thereafter, he became Teaching Assistant (Agronomy Department) and worked till August 1984. He became Lecturer in 1990 and acted as Director, Agroecology institute. Then, in July 1995, he become the Deputy Director, Agronomy Department. Thereafter his position was changed to Deputy Dean, College of Agriculture (1996.06-1998.09). During this period, he got the postdoctoral position from Agriculture College, Kyungpook National University, Korea (1997.07-1998.07) under Professor, K.U, Kim, which provided him opportunity to work on allelopathy. From 1998.10-2001.02, he was promoted as Director, Scientific Research Division of our University. In 2001, a new College of Life Sciences was established in University. He was appointed the first Dean of this new college, where he had good opportunity to expand his research interests and further explore topics in the allelopathy during the 8-years period. The China Scholarship Council (CSC) sponsored him for 6- Months (August 2007 – February 2008) as a senior visiting scholar in University of California, Los Angeles. From August 2008 to September 2017, he was appointed as Vice President, Fujian Agriculture and Forestry University. Table 1 provides the chronology of his employment, volunteer and elected professional positions, and significant honors and awards.

Table 1. Chronology of Professional Life Events and Awards.

Date	Organization	Duty
1982.07-1984.07	Agronomy Department, Fujian Agriculture College*, Fuzhou, China	Tutor
1984.08-1990.07	Agronomy Department, Fujian Agricultural University*	Teaching Assistant
1990.07-1995.07		Lecturer, Director, Agroecological Institute
1995.07-1998.09	College of Crop Sciences, Fujian Agricultural University*	Associate professor, Supervisor of Master
1995.07-1996.06	Agronomy Department, Fujian Agricultural University*	Deputy Chairman

1996.06-1998.09	College of Crop Sciences Fujian Agricultural University*	Deputy Dean
1997.07-1998.07	College of Agriculture, Kyungpook National University, Korea	Postdoctoral fellow
1998.10-2001.02	Scientific Research Division, Fujian Agricultural University	Director
1999.08-present	College of Agriculture, Fujian Agriculture and Forestry University*	Professor
2007.08-2008.08	University of California, Los Angeles, USA	Senior visiting scholar
2001.08-2008.08	College of Life Sciences, Fujian Agriculture and Forestry University	Dean
2008.09-2017.09	Fujian Agriculture and Forestry University	Vice President
2017.09- present	College of Life Sciences, Fujian Agriculture and Forestry University	Professor

*Both Fujian Agriculture College and Fujian Agricultural University are now the Fujian Agriculture and Forestry University.

Selected Volunteer and Elected Positions

2013-2016	Appointed Editorial Committee member, <i>Acta Ecologica Sinica</i>
2010-present	Appointed Editorial Committee member, <i>Chinese Journal of Applied Ecology</i>
2010-2019	Appointed Editorial Committee member, <i>Acta Agronomica Sinica</i>
2011-2014	Appointed Editorial Committee member, <i>Chinese Journal of Eco-Agriculture</i>
2010-2015	Appointed Editorial Board, <i>PLoS ONE</i>
2010-2017	Elected, President of China Eco-Agriculture Specialized Committee
2015-2018	Elected, President of Asian Allelopathy Society

Selected Honours and Awards

Date	Honors and Awards
1999	Selected man of National Millions of Talent Projects
2015	Fujian Provincial Science and Technology Innovation Leading Talent
2010	Outstanding achievement of Asian Allelopathy Society
2019	Outstanding achievement of China Ecology Society
2008	Outstanding teachers of Fujian Universities
2014, 2018	Outstanding Award of Higher Education and Teaching Achievement of Fujian Province
2005	First Class Award of Higher Education and Teaching Achievement of Fujian Province
2009, 2017	Second Class Award of Higher Education and Teaching Achievement of Fujian Province
2012, 2017, 2019	First class prize of Fujian Provincial Scientific and Technological Progress Award
2017	Second Class Prize, Higher School Scientific and Technological Progress Award, Ministry of Education
2019	Outstanding Contribution Award, Ecological Society of China

4. ALLELOPATHY AND RELATED RESEARCH

He had the great fortune to follow his research interests to a large extent in his career. Although the mechanism of plant allelopathy and its prospect of field application had been his greatest interests, but he have also published in other areas viz., ratoon rice cultivation, different grain-filling stages of superior and inferior rice grains, regulation of rice resistance to heavy metals and UV-B radiations, sustainable agroecology and agricultural management. The almost 200 publications on these topics are not included in the reference section below.

I. General

His earliest purely allelopathy related papers compared different screening methods to evaluate the allelopathic potential of rice and the genetic diversity in allelopathic rice (1-12). Molecular mapping of QTLs associated with allelopathic effects on the banyardgrass (13,18).

Our team developed efficient methods to separate the allelopathy-competition in rice-weed mixture in hydroponics. We found that different survival strategies exist in various allelopathic rice accessions in rice-weed mixed culture system. Allelopathic rice showed better growth by enhancing its allelopathic potential, and non-allelopathic rice struggled to survive by strengthening its nutrients up-take ability under the limited resource conditions (15,21,32). When two rice accessions, one with high allelopathic capacity and another non-allelopathic rice were used as donor rice to explore the underlying mechanism of rice allelopathy (Patent 1-8).

II. Gene regulation of allelopathic rice to inhibit weeds

Our earliest work on the beneficial allelochemicals from allelopathic rice and phenolic acids [p-hydroxybenzoic acid (HA), cinnamic acid (CA) and ferulic acid (FA)] were regarded as vital metabolites during the allelopathic inhibition against weeds (10,16). The gene and proteins involved in the synthesis of these compounds were studied and expression pattern was determined in allelopathic rice under various conditions (14,17,19-35,37,42, his Edited Book Chapter 1). Further, we deeply explored the key gene *PAL* in regulation of rice allelopathic potential and showed that *PAL* has positive role in regulation of rice phenolic acids concentrations and allelopathic capacity against weed (won the Rice award in 2011) (36). The gene expression of *PAL* was directly regulated by *OsWhirly* and the protein activity can be regulated by MAPK11, which is transcriptionally regulated by MYB57 (40). A couple of proteins were identified to interact with *PAL* and these findings demonstrated the regulation network of *PAL* to influence the rice allelopathy potential (43). The change in the *PAL* gene expression in rice plant also greatly affected the rhizospheric microorganisms. Enhanced the gene expression of *PAL* in allelopathic rice accession resulted in increased populations and biodiversity of soil microbes. While, interference in the *PAL* expression, decreased the population number and biodiversity of soil microbes in rhizosphere, implying that there were interactions of plants with microorganism in rhizosphere. Further studies found that *Myxobacteria* is one of the important species contributing to the rice allelopathic potential. The gene expression level

of *PAL* regulates the population of *Myxococcus xanthus* and this species can be increased with ferulic acid to enhance the allelopathic potential in weed inhibition. These allelochemicals and Myxobacteria jointly increase the expression of relevant miRNAs of the co-cultured barnyardgrass, which leads to inhibition of plant hormone signal transduction and decreases the DNA repair capacity in BYG, consequently inhibited the BYG growth (36,41,42). Recently, we developed the weed control technology by using mixture of Myxobacteria and powdered rice straw in paddy field (Patent 13). Our elucidation of the molecular ecological mechanism of rice allelopathy was awarded the II Class Prize of Fujian Provincial Scientific and Technological Progress Award in 2007.

III. Autotoxicity of Chinese medicinal plants in continuous cropping system

It is known that 70 % medicinal plants, especially with tuberous roots and the rhizome as medicine are seriously affected by the continuous cropping obstacle or replanting disease. This is mainly because of autotoxicity of allelochemicals from the first cropping plants to the consecutively cropping plants in the same field, and the bio-interactions of allelochemicals and the soil borne pathogens aggravates the monoculture problems. To find the insights into the phenomenon of indirect allelopathic effects, his group used T-RFLP, high-throughput sequencing of 16srRNA and ITS, metagenomic sequencing and qPCR to systematically study continuous cropping obstacle of *R. Pseudostellariae* and *R. glutinosa*. We found that root exudates of *R. pseudostellariae* were responsible for increasing the population size of pathogenic *Fusarium oxysporum* and *Talaromyces helicus*, and decreasing the abundance of potentially beneficial *Pseudomonas* spp. and *Burkholderia* spp. under continuous monoculture regimes. Soil microbial interactions (including quorum sensing and quorum sensing quenching in microbial community) played an important role in mediating the imbalance of microbial communities in the replanting soil. These findings suggested that microbial community and its structure component play an important role in plant fitness and disease suppression, therefore, organic amendments can be considered as better ecological techniques. Accordingly, we have isolated and screened specific beneficial microorganisms and developed corresponding bacterial fertilizer to explore their amendment effects as microbial fertilizer on the continuous cropping obstacles/soil sickness of medicinal plants (Patent 9-12,14-20). The comprehensive technical system including ecological prevention and control as well as green remediation is successful since 2012. The biological functional bacterial fertilizer technology to overcome the soil sickness problem in *R. pseudostellariae* continuous cropping field developed by us has been continuously successfully used to control continuous cropping problem. It has helped in controlling the occurrence of soil-borne diseases caused by plants root exudates in continuing monoculture system. Besides, it reduced the quantity of chemical fertilizers and pesticides used, thereby, reduced the production cost, improved the yield and quality of *R. pseudostellariae* in various regions of China (44-62,65-71,74-78, Book Chapter 2).

Our achievement was awarded the first class prize of Fujian Provincial Scientific and Technological Progress Award in 2020. In addition, we found that the long-term monoculture of tea plant, also suffers from the soil sickness problems, leading to decreased

soil pH, decreased beneficial microbes and increased the soil pathogenic microbes, which reduced the tea yield. Besides the green manuring of legumes and goat manure also reduced the monoculture problems and it promotes the plant growth and yield in the cropping system (72,73,79,80).

IV. Auto-stimulation of *Achyranthes bidentata* in continuing cropping system

Different from most medicinal plants, a unique medicinal plant named *Achyranthes bidentata* Blumen was found suitable for consecutive monoculture for 30 years or more. Its root dry weight increased and quality was not affected in the consecutively monocultured plants than newly planted crop. This was believed to be attributed to the positive interaction between Plant Growth Promoting Rhinoacteria (PGPR) and the root exudates from the consecutively monocultured medicinal plants in rhizosphere soil ecosystem, in consecutive monoculture system. The detection of naturally occurring microbes such as *Pseudomonas* spp. etc., in the rhizosphere soil of *A. bidentata* can help to develop sustainable consecutive monoculture system. Consecutive monoculture of *A. bidentata* and its root exudates can alter the bacterial and fungal community, increasing the beneficial microbes and replacing the plant-specific pathogenic fungi with plant beneficial fungi. The MCM of *A. bidentata* soil apparently produces some distinct beneficial bacterial communities [*Bacillus*, *Fictibacillus*, *Bradyrhizobium*, *Shinella* and *Herbaspirillum*] and the beneficial fungi *Mortierella* replaced the pathogenic *Fusarium* in monoculture (81,82). This finding opened a new avenue for moderating the root microbiome to improve crop production and sustainability, particularly in continuous cropping system

V. Facilitation between graminaceous and leguminous plants

Intercropping has been widely used to control diseases and improve the yield in agriculture, and the facilitation (mutual benefit) between two species is highly correlated to rhizospheric microorganism diversity. Our team also explored the mutual benefits between the graminaceous and leguminous plants, in the intercropping of maize and peanut. We found that the diversity of bacterial communities was significantly improved in soils via root exudates communication between these two species. The abundance of beneficial bacteria, which helps in P-solubilization, pathogen suppression and N-cycling, was improved in maize and peanut soils due to belowground interactions through intercropping. Among these bacterial population of *Bacillus*, *Brevibacillus brevis* and *Paenibacillus* were increased in maize rhizosphere. While the, *Burkholderia*, *Pseudomonas* and *Rhizobium* were increased in peanut rhizosphere. The belowground interactions of maize and peanut plants increased the number of beneficial bacteria and improved the diversity of the bacterial community in soil, which improves the soil nutrients (N and P) supply and soil micro-ecosystem stability (83).

VI. Future Needs for Allelopathy Research

(i). **Allelopathic microbe collection and application:** In plant allelopathy research, the rhizospheric processes are presently the hotspot. The correlated microorganism species act as the link between donor plant allelochemicals and receptor plants and may play the central role in allelopathic activity. Thus screening these particular microbes

and development of a suitable culture medium and growth condition still needs more work, which will be helpful to develop microbial herbicide or fertilizer for weed control and alleviate the replanting disease in rhizosphere ecosystem.

(ii). Allelopathic cultivars breeding: To breed allelopathic cultivars, there is need to explore the key gene or regulators that participate in the allelochemicals synthesis pathways and requires further in-depth research. Molecular breeding technology could help in developing the strong allelopathic germplasms.

(iii). Field evaluation: The methods and products from the laboratory needs to be tested or applied on bigger scale under the field conditions, to promote the sustainable development of the ecological agriculture.

PUBLICATIONS

He has authored > 300 peer-reviewed publications, Edited over 10 books. The following is the list of his main publications related to rice allelopathy, autotoxicity of consecutively monoculture plants, self-promotion of *Achyranthes bidentate* and facilitation between graminaceous and leguminous plants.

A. Edited Books

1. Lin, W.X. (Ed.) (2015). *Allelopathy in Rice*. Xiamen University Press, Xiamen, 265pp. (Chinese).

B. Book Chapters

1. Shen, L.H., Xiong, J., and Lin, W.X. (2008). Rice allelopathy research in China. In: *Allelopathy in Sustainable Agriculture and Forestry*. (Ed. R.S. Zeng et al). pp. 215-233.
2. Lin, W.X., Fang, C.X., Wu, L.K., and Lin, S. (2016). Research on and application of rice allelopathy and crop allelopathic autotoxicity in China. In: *Agroecology in China: Science, Practice, and Sustainable Management*. (Ed. S.M. Luo, et al). pp. 161-196.

C. Patents

1. Lin, W.X., Xiong, J., and Lin, H.F. (2011). Method for extraction of soil protein and separation of intracellular protein. Patent number: 200910111462.X.
2. He, H.B., Wang, H.B., Chen, R.S., and Lin, W.X. (2011). Preparation method and use method of reagent for determining total phenol in water. Patent number: 200910307754.0.
3. Fang, C.X., Lin, W.X., Wang, Q.S., Yu, Y., Huang, L.K., and Lin, R.Y. (2012). Extraction method of soil microbe genome DNA and total RNA. Patent number: 201010548527.X.
4. Fang, C.X., Lin, W.X., Huang, L.K., Xu, T.C., and Lin, R.Y. (2013). A method for constructing cDNA library of soil microorganisms. Patent number: 201110277886.0.
5. Wang, H.B., Zhang, Z.X., Lin, W.X., He, H.B., Wu, L.K., and Yu, Z.M. (2013). Extraction and separation method for soil extracellular protein. Patent number: 201010585154.3.
6. Wang, H.B., Zhang, Z.X., Lin, W.X., He, H.B., Wu, L.K., and Yu, Z.M. (2013). Extraction and separation method for soil intracellular protein. Patent number: 201010585161.3.
7. Wang, H.B., Fang, C.X., Chen, R.S., Ye, C.Y., Lin, Z.H., He, H.B., and Lin, W.X. (2013). A rapid and efficient method for extracting total RNA from rice tissue. Patent number: 200910310602.6.
8. Fang, C.X., Lin, W.X., Li, C.X., Li, Y.Z., and Lin, W.P. (2016). Method for extracting microbial genomic DNA from hydroponic solution. Patent number: 201410270513.4.
9. Zhao, Y.P., Lin, W.X., Wu, L.K., Zhang, Z.X., Fang, C.X., and Chu, L.X. (2016). A strain of *Bacillus amyloliquefaciens* used to antagonize *Fusarium oxysporum* specialized from the *Radix pseudostellariae*. Patent number: 201410263153.5.
10. Zhao, Y.P., Lin, W.X., Wu, L.K., Zhang, Z.X., Fang, C.X., and Chu, L.X. (2016). A strain of *Bacillus subtilis* used to antagonize *Fusarium oxysporum* specialized from the *Radix pseudostellariae*. Patent number: 201410263152.0.

11. Wu, L.K., Wang, J.Y., Lin, W.X., Chen, J., Wu, H.M., and Lin, H. (2017). An antagonistic strain against *Fusarium oxysporum* specialized from the *Rehmannia glutinosa* and its application. Patent number: 201510317742.1.
12. Wu, L.K., Wang, J.Y., Lin, W.X., Wu, H.M., and Chen, J. (2017). Antagonistic bacteria for root rot of *Radix pseudostellariae* and its application. Patent number: 201610181785.6.
13. Fang, C.X., Lin, W.X., Li, Y.Z., and Li, C.X. (2017). Method of inhibiting the growth of paddy weeds by using rice straw powder plus myxobacteria. Patent number: 201510123478.8.
14. Wu, L.K., Lin, W.X., Wang, J.Y., Chen, J., Wu, H.M., and Lin, H. (2018). An antagonistic strain against *Aspergillus flavus* of *Rehmannia glutinosa* and its application. Patent number: 201510317635.9.
15. Wu, L.K., Chen, J., Lin, W.X., Wu, H.M., and Lin, S. (2019). An antagonistic strain against *Fusarium moniliforme* specialized from the *Radix pseudostellariae* and its application. Patent number: 201610181836.5.
16. Chen, J., Wu, L.K., Lin, W.X., Lin, H., Huang S.Y., Wu, Y.H., and Lin, S. (2019). A strain of *Pseudomonas koreensis* and its application. Patent number: 201610181839.9.
17. Wu, L.K., Chen, J., Lin, W.X., Wu, H.M., and Lin, S. (2019). Antagonistic bacteria for root rot of *Radix pseudostellariae* and its application. Patent number: 201610181785.6.
18. Chen, J., Wu, L.K., Lin, W.X., Lin, H., Liu, B., Song, Y.R., and Wu, H.M. (2019). A new strain of *Burkholderia cepacia* and its application. Patent number: 201610181837.X.
19. Wu, L.K., Chen, J., Lin, W.X., Wu, H.M., and Lin, S. (2019). A complex microbial community fertilizer specially for *Radix Pseudostellariae* and its preparation protocol and application. Patent number: 201610208743.7.
20. Wu, L.K., Lin, W.X., Chen, J., Wu, H.M., and Lin, S. (2020). A complex microbial community agent for eliminating continuous cropping obstacles of *Radix Pseudostellariae* and its preparation protocol. Patent number: 201610190701.5.

D. Peer-Reviewed Publications

(i) Rice allelopathy

1. Lin, W.X., Kim, K.U. and Shin, D.H. (2000). Allelopathic potential in rice (*Oryza sativa* L.) and its modes of action on barnyardgrass (*Echinochloa crusgalli* L.). *Allelopathy Journal* **7**: 215-224.
2. Lin, Q.H., He, H.Q. and Lin, W.X. (2001). Study on the action characteristics of allelochemicals in rice. *Chinese Journal of Eco-Agriculture* **9**: 84-85. (Chinese).
3. Dong, Z.H. and Lin, W.X. (2001). Current status and prospects of allelopathy research in agriculture. *Chinese Journal of Eco-Agriculture* **9**: 79-83. (Chinese).
4. He, H.Q. and Lin W.X. (2001). Preliminary studies on allelopathic potential in rice. *Chinese Journal of Eco-Agriculture* **9**: 47-49. (Chinese).
5. Lin, W.X., He, H.Q., Guo, Y.C., Liang, Y.Y. and Chen, F.Y. (2001). Rice allelopathy and its physiobiochemical characteristics. *Chinese Journal of Applied Ecology* **12**:871-875. (Chinese).
6. He, H.Q., Lin, W.X., Dong, Z.H., Guo, Y.C., Shen, L.H., Liang, Y.Y., Chen F.Y., and Liang K.J. (2002). Genetic ecology of rice allelopathy on receiver plant. *Chinese Journal of Applied Ecology* **13**: 1582-1586. (Chinese).
7. Lin, W.X., He, H.Q., and Kim, K.U. (2003). The performance of allelopathic heterosis in rice (*Oryza sativa* L.). *Allelopath Journal* **2**: 179-188.
8. Lin, W. X., Dong, Z. H., Chen, X. X., He, H. Q., Shen, L. H., Guo, Y. C., Chen F.Y., and Liang, K. J. (2003). Analysis on dynamic heterosis for allelopathy in rice under different environment conditions. *Agricultural Sciences in China* **2**: 707-714. (Chinese).
9. Lin, W.X. (2003). Rhizobiological properties of allelopathic rice in suppression of weeds and its research prospect. *Acta Agronomica Sinica*, **39**: 951-960. (Chinese).
10. He, H. Q., Liang, Y. Y., Jia, X. L., Song, B. Q., Guo, Y. C., Liang, K. J., and Lin, W.X. (2004). Weed-suppressive effect of phenolic acids. *Chinese Journal of Applied Ecology* **15**: 2342-2346. (Chinese).
11. Shen, L.H., Liang, Y.Y., He, H.Q., He, J., Liang, K.J., and Lin, W.X. (2004). Comparative analysis on the evaluation efficiency of allelopathic potential in rice (*Oryza sativa* L.) by using different bioassay methods and its application. *Chinese Journal of Applied Ecology* **9**: 1575-1579. (Chinese).

12. Lin, W.X., He, H.Q., Dong, Z.H., Shen, L.H., Guo, Y.C., Liang, Y.Y., Chen, F.Y., and Liang, K.J. (2004). Study on developmental inheritance of allelopathy in rice (*Oryza sativa* L.) under different environment. *Acta Agronomica Sinica* **30**: 348-353. (Chinese).
13. He, H.Q., Shen, L.H., Xiong, J., Jia, X.L., Lin, W.X., and Wu, H. (2004). Conditional genetic effect of allelopathy in rice (*Oryza sativa* L.) under different environmental conditions. *Plant Growth Regulation* **44**:211-218.
14. He, H.Q., Lin, W.X., Liang, Y.Y., Song, B.Q., Ke, Y.Q., Guo, Y.C., and Liang, K.J. (2005). Analyzing the molecular mechanism of crop allelopathy by using differential proteomics. *Acta Ecologica Sinica* **25**: 3141-3145 (Chinese).
15. Xiong, J., Lin, W.X., Zhou, J.J., Wu, M.H., Chen, X.X., He, H.Q., Guo, Y.Y., and Liang, Y.Y. (2005). Allelopathy and resources competition of rice under different nitrogen supplies. *Chinese Journal of Applied Ecology* **16**: 885-889. (Chinese).
16. He, H.B., Lin, W.X., Wang H.B., Fang, C.X., Gan, Q.F., Wu, W.X., Chen, X.X., and Liang, Y.Y. (2006). Analysis of metabolites in root exudates from allelopathic and non allelopathic rice seedlings. *Allelopathy Journal* **18**: 247-254.
17. Lin, W.X., He, H.B., Xiong, J., Shen, L.H., Wu, M.H., Lin, R.Y., He, H.Q., Liang, Y.Y., Li, Z.W., and Chen, T. (2006). Advances in the investigation of rice allelopathy and its molecular ecology. *Acta Ecologica Sinica* **26**: 2687-2694 (Chinese).
18. Xiong, J., Jia, X.L., Deng, J.Y., Jiang, B.Y., He, H.B., and Lin, W.X. (2007). Analysis of epistatic effect and QTL interactions with environment for allelopathy in rice (*Oryza sativa* L.). *Allelopathy Journal* **20**: 259-268.
19. Xiong, J., Wang, H.B., Fang, C.X., Qiu, L., Wu, W.X., He, H.B., and Lin, W.X. (2007). The differential expression of the genes of the key enzymes involved in phenolic compound metabolism in rice (*Oryza sativa* L.) under different nitrogen supply. *Journal of Plant Physiology and Molecular Biology* **33**: 387-394. (Chinese).
20. Shen, L.H., and Lin, W.X. (2007). Effects of phosphorus levels on allelopathic potential of rice co-cultured with barnyard-grass. *Allelopathy Journal* **19**: 23-32.
21. Song, B.Q., Xiong, J., Fang, C.X., Qiu, L., Lin, R.Y., Liang, Y.Y., and Lin, W.X. (2008). Allelopathic enhancement and differential gene expression in rice under low nitrogen treatment. *Journal of Chemical Ecology* **34**: 688-695.
22. Wang, H.B., He, H.B., Xiong, J., Qiu, L., Fang, C.X., Zeng, C.M., Yan, L., and Lin, W.X. (2008). Effects of potassium stress on allelopathic potential of rice (*Oryza sativa* L.). *Acta Ecologica Sinica* **28**: 6219-6227. (Chinese).
23. Qiu, L., Xiong, J., Wang, H.B., Fang, C.X., He, H.B., Li, Z.W., and Lin, W.X. (2008). The nitrogen nutrient efficiency and the expression analysis of the related genes in different allelopathic potential rice (*Oryza sativa* L.) varieties at seedling stage. *Acta Ecologica Sinica* **28**: 677-684. (Chinese).
24. Qiu, L., Wang, H.B., Xiong, J., Fang, C.X., Wu, W.X., He, H.B., and Lin, W.X. (2008). Regulation effect of exogenous salicylic acid on weed suppression and molecular physiological characteristics of allelopathic rice. *Chinese Journal of Applied Ecology* **19**: 330-336. (Chinese).
25. Fang, C.X., Xiong, J., Qiu, L., Wang, H.B., Song, B.Q., He, H.B., Lin, R.Y., and Lin, W.X. (2009). Analysis of gene expressions associated with increased allelopathy in rice induced by exogenous salicylic acid. *Plant Growth Regulation* **57**: 163-172.
26. He, H.B., Wang, H.B., Fang, C.X., Lin, Y.Y., Zeng, C.M., Wu, L.Z., Guo, W.C., and Lin W.X. (2009). Herbicidal effect of a combination of oxygenic terpenoids on *Echinochloa crus-galli*. *Weed Research* **49**:183-192.
27. Lin, W., Fang, C., Chen, T., Lin, R., Xiong, J., and Wang, H. (2010). Rice allelopathy and its properties of molecular ecology. *Frontiers in Biology* **5**: 255-262.
28. He, H., Wang, H., Wu, H., Guo, X., Liu, C., Chen, R., and Lin, W. (2010). Effects of allelopathic rice on barnyard grass stress: I. Morphological and physiological responses. *Allelopathy Journal* **26**: 185-196.
29. Fang, C.X., He, H.B., Wang, Q.S., Qiu, L., Wang, H.B., Zhuang, Y.E., Xiong, J., and Lin, W.X. (2010). Genomic analysis of allelopathic response to low nitrogen and barnyardgrass competition in rice (*Oryza sativa* L.). *Plant Growth Regulation* **61**: 277-286.

30. He, H.B., Wang, H.B., Lin, Z.H., Chen, R.S., Liu, C.H., Wu, H., and Lin W.X. (2011). Herbicidal effect of mixture of oxygenic terpenoids on paddy weeds. *Allelopathy Journal* **27**:133-142.
 31. Fang, C.X., Wang, Q.S., Yu, Y., Luo, M.R., Huang, L.K., Xiong, J., Shen, L.H., and Lin, W.X. (2011). Differential expression of PAL multi-gene family in allelopathic rice and its counterpart exposed to stressful conditions. *Acta Ecologica Sinica* **31**: 4760-4767. (Chinese).
 32. He, H.B., Wang, H.B., Fang, C.X., Lin, Z.H., Yu, Z.M., and Lin W.X. (2012). Separation of allelopathy from resource competition using rice/barnyardgrass mixed-cultures. *PLoS ONE* **7**: e37201.
 33. Wang, H.B., Yu, Z.M., He, H.B., Guo, X.K., Huang, J.W., Zhou, Y., Xu, Z.B., and Lin, W.X. (2012). Relationship between allelopathic potential and grain yield of different allelopathic rice accessions. *Chinese Journal of Eco-Agriculture* **20**: 75-79. (Chinese).
 34. Xiong, J., Lin, H.F., Li Z.F., Fang, C.X., Han, Q.D., and Lin, W.X. (2012). Analysis of rhizosphere microbial community structure of weak and strong allelopathic rice varieties under dry paddy field. *Acta Ecologica Sinica* **32**: 6100-6109. (Chinese).
 35. He, H.B., Wang, H.B., Fang, C.X., Wu, H., Guo, X.K., Liu, C.H., Lin, Z.H. and Lin, W.X. (2012). Barnyard grass stress up regulates the biosynthesis of phenolic compounds in allelopathic rice. *Journal of Plant Physiology* **169**: 1747-1753.
 36. Fang, C.X., Zhuang, Y.E., Xu, T.C., Li, Y.Z., Li, Y., and Lin, W.X. (2013). Changes in rice allelopathy and rhizosphere microflora by inhibiting rice phenylalanine ammonia-lyase gene expression. *Journal of Chemical Ecology* **39**: 204-212.
 37. Shen, L.H., Li B.L., Ren Y.J., Li C.X., Zhong, Y.J., Fang, C. X., and Lin, W.X. (2015). Phenolic acid synthesis of allelopathic rice regulated by OsMYB and its weed inhibition. *Acta Agronomica Sinica* **41**: 531-538.
 38. Fang, C.X., Li, Y.Z., Li, C.X., Li, B.L., Ren, Y.J., Zheng, H.P., Zeng, X.M., Shen, L.H., and Lin, W.X. (2015). Identification and comparative analysis of microRNAs in barnyardgrass (*Echinochloa crus-galli*) in response to rice allelopathy. *Plant, Cell & Environment* **38**: 1368-1381.
 39. Fang, C.X., Yu, Y., Chen, W.S., Jian, X., Wang, Q.S., Zheng, H.P., and Lin, W.X. (2016). Role of allene oxide cyclase in the regulation of rice phenolic acids synthesis and allelopathic inhibition on barnyardgrass. *Plant Growth Regulation* **79**: 265-273.
 40. Fang, C.X., Yang, L.K., Chen, W.X., Li, L.L., Zhang, P.L., Li, Y.Z., He, H.B., and Lin, W.X. (2020). MYB57 transcriptionally regulates MAPK11 to interact with PAL2;3 and modulate rice allelopathy. *Journal of Experimental Botany* **71**: 2127-2141.
 41. Li, Y., Jian, X., Li, Y., Zeng, X., Xu, L., Khan, M.U., and Lin, W. (2020). OsPAL2-1 mediates allelopathic interactions between rice and specific microorganisms in the rhizosphere ecosystem. *Frontiers in Microbiology* **11**:1411.
 42. Li, Y., Xu, L., Letuma, P., and Lin, W. (2020). Metabolite profiling of rhizosphere soil of different allelopathic potential rice accessions. *BMC Plant Biology* **20**: 265.
 43. Li, L.L., Mu, D., Yan, X., Yang, L.K., Lin, W.X., and Fang, C.X. (2021). Effect of *OsPAL2;3* in regulation of rice allelopathic inhibition on barnyardgrass (*Echinochloa crusgalli* L.). *Acta Agronomica Sinica* **47**: 197-209. (Chinese).
- (ii) Autotoxicity**
44. Wu, L., Wang, H., Zhang, Z., Lin, R., Zhang, Z., and Lin, W. (2011). Comparative metaproteomic analysis on consecutively *Rehmannia glutinosa*-monocultured rhizosphere soil. *PLoS ONE* **6**: e20611.
 45. Wu, L.K., Wang, H.B., You, C.H., Zhang, Z.X., Niu, M.M., Zhang Z.Y, and Lin, W.X. (2011). Establishment of extraction method and 2-dimensional electrophoresis conditions for root tuber proteome analysis of *Rehmannia glutinosa*. *China Journal of Chinese Materia Medica* **36**: 5-8. (Chinese).
 46. Wu, L., Li, Z., Li, J., Khan M.A., Huang, W., Zhang, Z., and Lin, W. (2013). Assessment of shifts in microbial community structure and catabolic diversity in response to *Rehmannia glutinosa* monoculture. *Applied Soil Ecology* **67**: 1-9.
 47. Wu, L.K., Lin, X.M., and Lin W.X. (2014). Advances and perspective in research on plant-soil-microbe interactions mediated by root exudates. *Chinese Journal of Plant Ecology* **38**: 298-310. (Chinese).
 48. Lin, S., Huangpu, J., Chen, T., Wu, L., Zhang, Z., and Lin, W. (2014). Effects of different cropping patterns on the physiology and quality of *Pseudostellaria heterophylla*. *International Journal of Agriculture and Biology* **16**: 981-985.

49. Lin, S., Huangpu, J., Chen, T., Zhang, Z., and Lin, W. (2014). Evaluation of allelopathic potential and identification of allelochemicals in *Pseudostellariae heterophylla* rhizosphere soil of different cropping patterns. *Allelopathy Journal* **33**: 151-162.
50. Wu, L., Wang, J., Huang, W., Wu, H., Chen, J., Yang Y., Zhang Z., and Lin W. (2015). Plant-microbe rhizosphere interactions mediated by *Rehmannia glutinosa* root exudates under consecutive monoculture. *Scientific Reports* **5**: 15871.
51. Lin, S., Huangpu J.J., Chen, T., Wu, L.K., Zhang Z.Y., and Lin W.X. (2015). Analysis of soil microbial community structure and enzyme activities associated with negative effects of *Pseudostellaria heterophylla* consecutive monoculture on yield. *Pakistan Journal of Botany* **47**: 761-769.
52. Lin, S., Dai, L., Chen, T., Li Z., Zhang, Z., and Lin, W. (2015). Screening and identification of harmful and beneficial microorganisms associated with replanting disease in rhizosphere soil of *Pseudostellariae*. *International Journal of Agriculture and Biology* **17**: 458-466. (Chinese).
53. Wu, L.K., Huang, W.M., Wang, J.Y., Wu, H.M., Chen J., Qin X.J., Zhang, Z.Y., and Lin, W.X. (2015). Diversity analysis of rhizosphere microflora of Wild *R. glutinosa* Grown in monocropping for different years. *Acta Agronomica Sinica* **41**: 308-317. (Chinese).
54. Wu, L., Chen, J., Wu, H., Wang, J., Wu, Y., Lin, S., Khan, M.U., Zhang, Z., and Lin, W. (2016). Effects of consecutive monoculture of *Pseudostellaria heterophylla* on soil fungal community as determined by pyrosequencing. *Scientific Reports* **6**: 26601.
55. Wu, L., Wu, H., Chen, J., Wang, J.Y., and Lin W.X. (2016). Microbial community structure and its temporal changes in *Rehmannia glutinosa* rhizospheric soils monocultured for different years. *European Journal of Soil Biology* **72**: 1-5.
56. Zhao Y., Lin S., Chu, L., Gao, J., Azeem, S., and Lin, W. (2016). Insight into structure dynamics of soil microbiota mediated by the richness of replanted *Pseudostellaria heterophylla*. *Scientific Reports* **6**: 26175.
57. Wu, L.K., Chen, J., Wu H.M., Wang, J.Y., Qin, X.J., Zhang, Z.Y., and Lin, W.X. (2016). Comparative proteomics analysis of *R. glutinosa* tuber root in response to consecutive monoculture. *Acta Agronomica Sinica* **42**:243-254. (Chinese).
58. Wu, H., Wu, L., Wang, J., Zhu, Q., Lin, S., Xu, J. Zheng C, Chen J, Qin X, Fang C, Zhang Z, Azeem S, and Lin W. (2016). Mixed phenolic acids mediated proliferation of pathogens *Talaromyces helicus* and *Kosakonia sacchari* in continuously monocultured *Radix pseudostellariae* rhizosphere soil. *Frontiers in Microbiology* **7**: 335.
59. Wu, L., Chen, J., Wu, H., Qin, X., Wang, J., Wu, Y., Khan, M.U., Lin, S., Xiao, Z., Luo, X., Zhang Z and Lin W (2016). Insights into the regulation of rhizosphere bacterial communities by application of bio-organic fertilizer in *Pseudostellaria heterophylla* monoculture regime. *Frontiers in Microbiology* **7**: 1788.
60. Wu, L.K., Wu H.M., Zhu, Q., Chen, J., Wang, J.Y., Wu, Y.H., Lin, S., and Lin W.X. (2016) Effects of different amendments on contents of phenolic acids and specific microbes in rhizosphere of *Pseudostellaria heterophylla*. *Chinese Journal of Applied Ecology* **27**:3623-3630. (Chinese).
61. Wu, H., Xu, J., Wang, J., Qin, X., Wu, L., Li, Z., Lin, S., Lin, W., Zhu, Q., Khan, M.U., and Lin, W. (2017). Insights into the mechanism of proliferation on the special microbes mediated by phenolic acids in the *Radix pseudostellariae* rhizosphere under continuous monoculture regimes. *Frontiers in Plant Science* **8**: 659.
62. Wu, H., Wu, L., Zhu, Q., Wang, J., Qin, X., Xu, J., Kong, L., Chen, J., Lin S., Khan M.U., Amjad, H., and Lin, W. (2017). The role of organic acids on microbial deterioration in the *Radix pseudostellariae* rhizosphere under continuous monoculture regimes. *Scientific Reports* **7**: 3497.
63. Li, Y., Li, Z., Arafat, Y., Lin, W., Jiang, Y., Weng, B., and Lin, W. (2017). Characterizing rhizosphere microbial communities in long-term monoculture tea orchards by fatty acid profiles and substrate utilization. *European Journal of Soil Biology* **81**: 48-54.
64. Jiang, Y.H, Lin S., Lin W.W., Chen T., Yasir A., Wei X.Y., and Lin W.X. (2017). Effects of different fertilizer applications on microbial metabolic activity and community structure in tea rhizosphere soil. *Chinese Journal of Ecology* **36**: 2894-2902. (Chinese).
65. Wu, L., Chen J., Khan M.U., Wang, J., Wu, H., Xiao Z., Zhang Z., and Lin W. (2018). Rhizosphere fungal community dynamics associated with *Rehmannia glutinosa* replant disease in a consecutive monoculture regime. *Phytopathology* **108**: 1493-1500.
66. Wu, L., Wang, J., Wu, H., Chen, J., Xiao, Z., Qin, X., Zhang, Z., and Lin, W. (2018). Comparative metagenomic analysis of rhizosphere microbial community composition and functional potentials under *Rehmannia glutinosa* consecutive monoculture. *International Journal of Molecular Sciences* **19**: 2394.

67. Wu, L., Chen, J., Xiao, Z., Zhu, X., Wang, J., Wu, H., Wu, Y., Zhang, Z., and Lin, W. (2018). Barcoded pyrosequencing reveals a shift in the bacterial community in the rhizosphere and rhizoplane of *Rehmannia glutinosa* under consecutive monoculture. *International Journal of Molecular Sciences* **19**: 850.
68. Wei, X.Y., Lin, Y., Chen, T., Tao Z. X., Zhao, H.Y., Lin S., and Lin W.X. (2018). Effects of plant growth-promoting rhizobacteria on alleviating consecutive monoculture problem of *Pseudostellaria heterophylla* under field conditions. *Chinese Journal of Ecology* **37**: 399-408. (Chinese).
69. Wu, H., Qin, X., Wang, J., Wu, L., Chen, J., Fan, J. Zheng, L., Tangtai H., Arafat, Y., Lin, W., Luo X., Lin S., and Lin, W. (2019). Rhizosphere responses to environmental conditions in *Radix pseudostellariae* under continuous monoculture regimes. *Agriculture, Ecosystems and Environment* **270**: 19-31.
70. Wu, L., Xiao, Z., Li, M., Wang, J.Y., Yang, B., Chen, J., Tong, Q., and Lin, W. (2019). First report of *Sclerotium rolfsii* var. *delphinii* causing southern wilt of *Pseudostellaria heterophylla* in China. *Plant Disease* **103**: 1419.
71. Wu, L.K., Chen, J., Yang, B., Xiao, Z.G., Lu C.H., Wang, J.Y., and Lin, W.X. (2019). Effects of *Rehmannia glutinosa* consecutive monoculture on the community structure and diversity of phyllosphere bacteria. *Chinese Journal of Applied Ecology* **30**: 3509-3517. (Chinese).
72. Arafat, Y., Tayyab, M., Khan, M.U., Chen, T., Amjad, H., Awais, S., Lin, X., Lin, W., and Lin, S. (2019). Long-term monoculture negatively regulates fungal community composition and abundance of tea orchards. *Agronomy* **9**: 466.
73. Jiang, Y., Arafat, Y., Letuma, P., Ali, L., Tayyab, M., Waqas, M., Li, Y., Lin, W., Lin, S., and Lin W. (2019). Restoration of long-term monoculture degraded tea orchard by green and goat manures applications system. *Sustainability* **11**: 1011.
74. Wu, H., Lin, M., Rensing, C., Qin, X., Zhang, S., Chen, J., Wu, L., Zhao, Y., Lin, S., and Lin, W. (2020). Plant-mediated rhizospheric interactions in intraspecific intercropping alleviate the replanting disease of *Radix pseudostellariae*. *Plant and Soil* **454**:411-430.
75. Wu, H., Qin, X., Wu, H., Li, F., Wu, J., Zheng, L., Wang, J.Y., Chen, J., Zhao, Y., Lin S., and Lin, W. (2020). Biochar mediates microbial communities and their metabolic characteristics under continuous monoculture. *Chemosphere*, **246**:125835.
76. Wu, H., Xia, J., Qin, X., Wu, H., Zhang, S., Zhao, Y., Rensing C., and Lin, W. (2020). Underlying mechanism of wild *Radix pseudostellariae* in tolerance to disease under natural forest cover. *Frontiers in Microbiology* **11**:1-16.
77. Li, Q., Wu, Y., Wang, J., Yang, Bo., Chen, J., Wu, H., Zhang, Z., Lu, C., and Lin, W., and Wu, L. (2020). Linking short-chain N-acyl homoserine lactone-mediated quorum sensing and replant disease: A case study of *Rehmannia glutinosa*. *Frontiers in Plant Science* **11**: 787.
78. Wu, L., Yang, B., Li, M., Chen, J., Xiao, Z., Wu, H., Tong, Q., Luo, X., and Lin, W. (2020). Modification of rhizosphere bacterial community structure and functional potentials to control *Pseudostellaria heterophylla* replant disease. *Plant Disease* **104**: 25-34.
79. Arafat, Y., Din, I.U., Tayyab M., Jiang, Y., Chen, T., Cai, Z., Zhao, H., Lin, X., Lin, W., and Lin S. (2020). Soil sickness in aged tea plantation is associated with a shift in microbial communities as a result of plant polyphenol accumulation in the tea gardens. *Frontiers in Plant Science* **11**: 601.
80. Li, Y., Li, Z., Arafat, Y., and Lin, W. (2020). Studies on fungal communities and functional guilds shift in tea continuous cropping soils by high-throughput sequencing. *Annals of Microbiology* **70**: 1-12.
- (iii) Auto-promotion**
81. Wang, J., Wu, L., Tantai, H., Khan M.U., Letuma P., Wu H., Zhang S., Chen, T., Lin, S., and Lin, W. (2019). Properties of bacterial community in the rhizosphere soils of *Achyranthes bidentata* tolerant to consecutive monoculture. *Plant Growth Regulation* **89**: 167-178.
82. Wang, J.Y., Xu, J.H., Wu, L.K., Wu, H.M., Zhu, Q., Kong, L.F., and Lin, W.X. (2017). Analysis of physicochemical properties and microbial diversity in rhizosphere soil of *Achyranthes bidentata* under different cropping years. *Acta Ecologica Sinica* **37**:1-9 (Chinese).
- (iv) Facilitation**
83. Li, Q., Chen J., Wu, L., Luo, X., Li, N., Arafat Y., Lin, S., and Lin W. (2018). Belowground interactions impact the soil bacterial community, soil fertility, and crop yield in maize/peanut intercropping systems. *International Journal of Molecular Sciences* **19**: 622.