河南農業大學
Henan Agricultural University

## 1st China–Australia Symposium on Crop Stress and Climate Adaptation

# Responses of Maize Rhizosphere Microecology to Combined High Temperature and Drought Stress

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**2026-3-13**

**Australia · Tasmanian**

# Report Outline

## 一、Research Background

## 二、Research Result

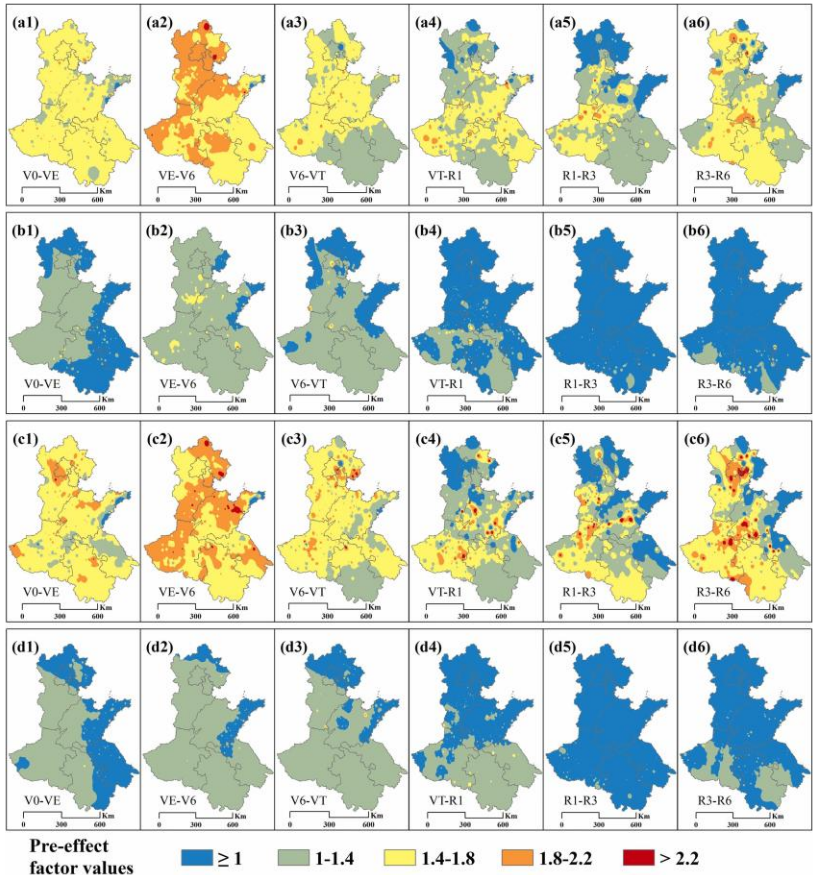
1. Impact of combined high-temperature and drought stress on the growth and yield of maize
2. Changes in soil nitrogen, phosphorus and organic carbon contents
3. Changes in the microbial community at rhizosphere
4. Rhizosphere soil non-targeted metabolomics analysis
5. Association between microbiome and metabolome
6. Relationship between microorganisms and maize growth / soil nutrients
7. Regulation of metabolic substances in maize response to stress

## 三、Ongoing Work

# PART.01

# Research Background

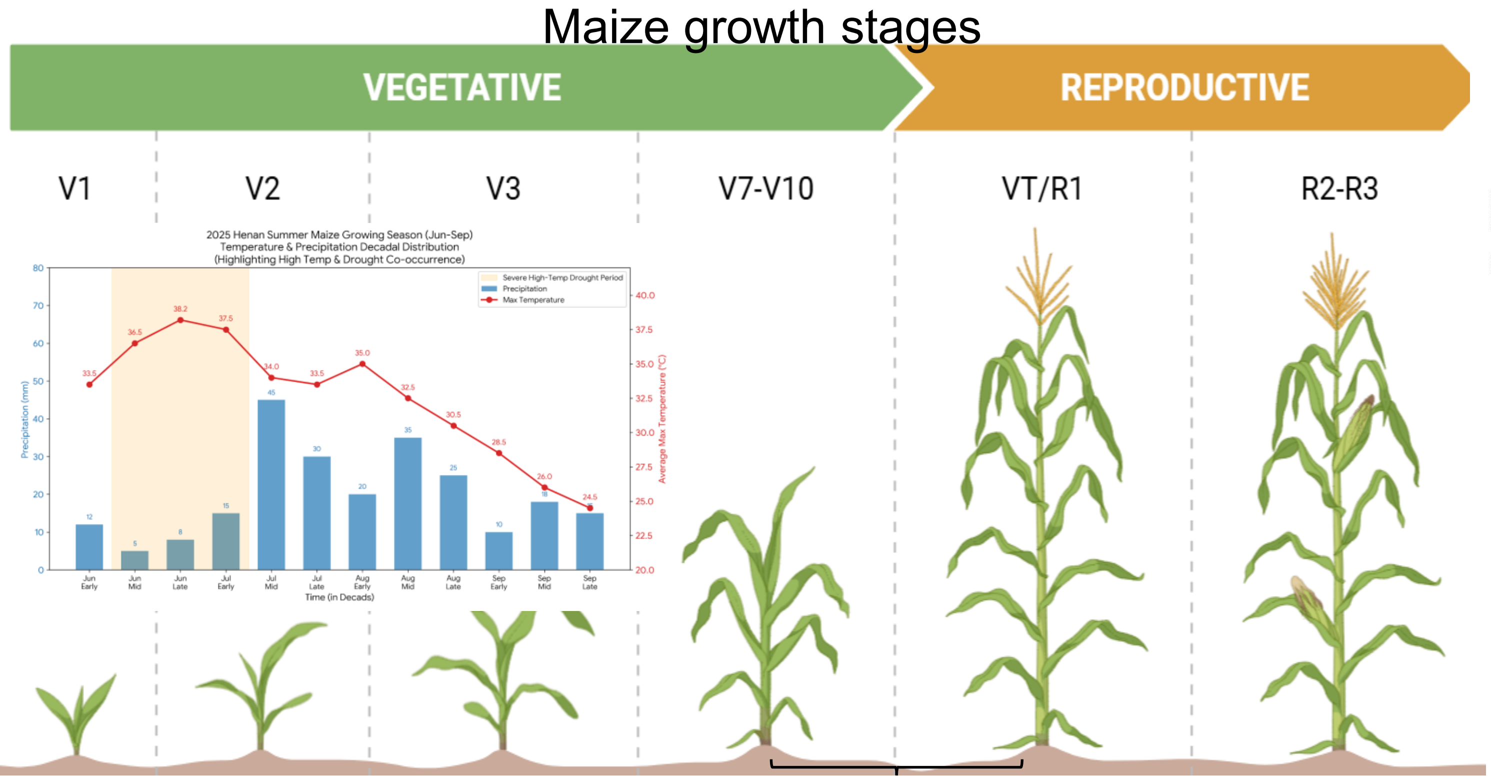
01

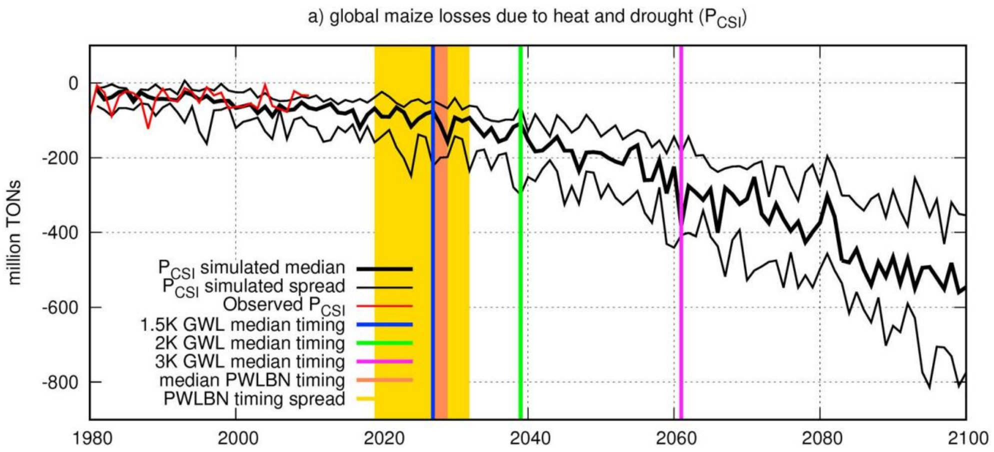

(Li et al. 2025)

- China's maize production accounts for 23.2% of the global production. Among this, the Huang-huai-hai summer maize region contributes 35% of the China's total production.
- The summer maize in the Huang-Huai-Hai region is usually sown in June and harvested in September. Its whole growing period is easy to be affected by high temperature and drought.

# Research Background



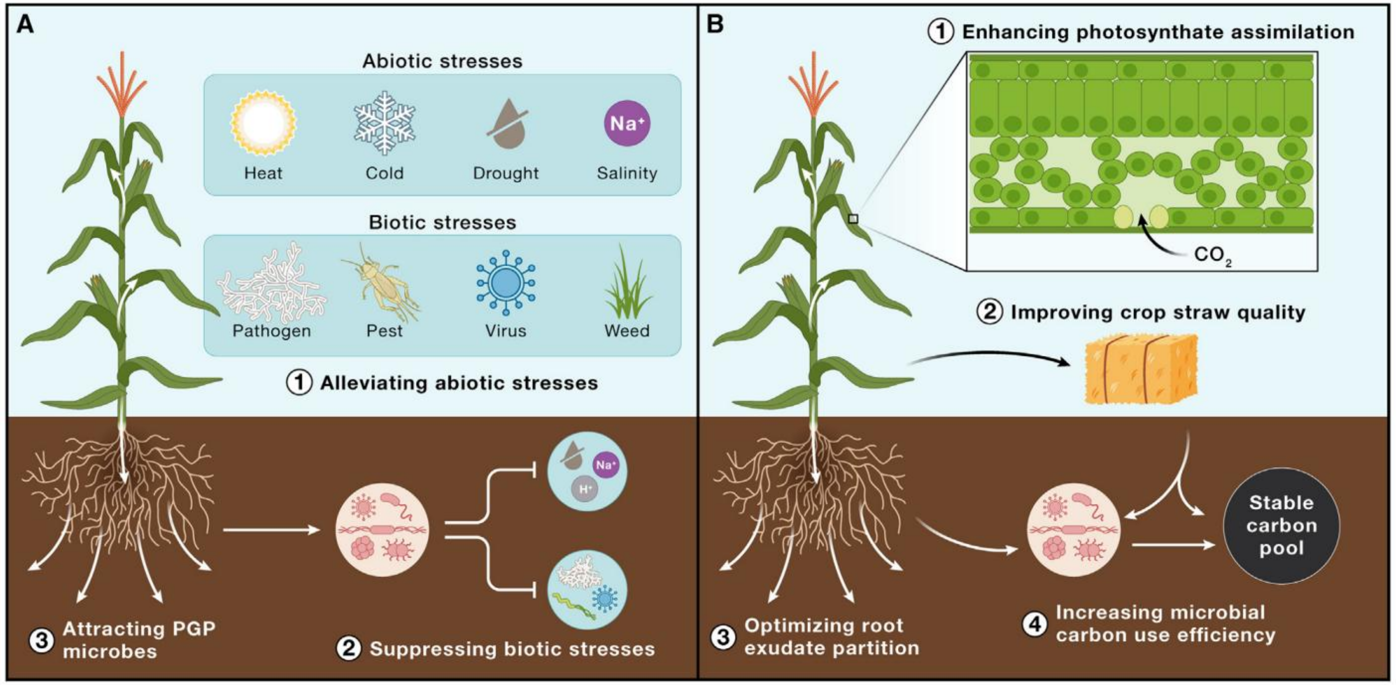

Water shortage critical period &
Temperature-sensitive period



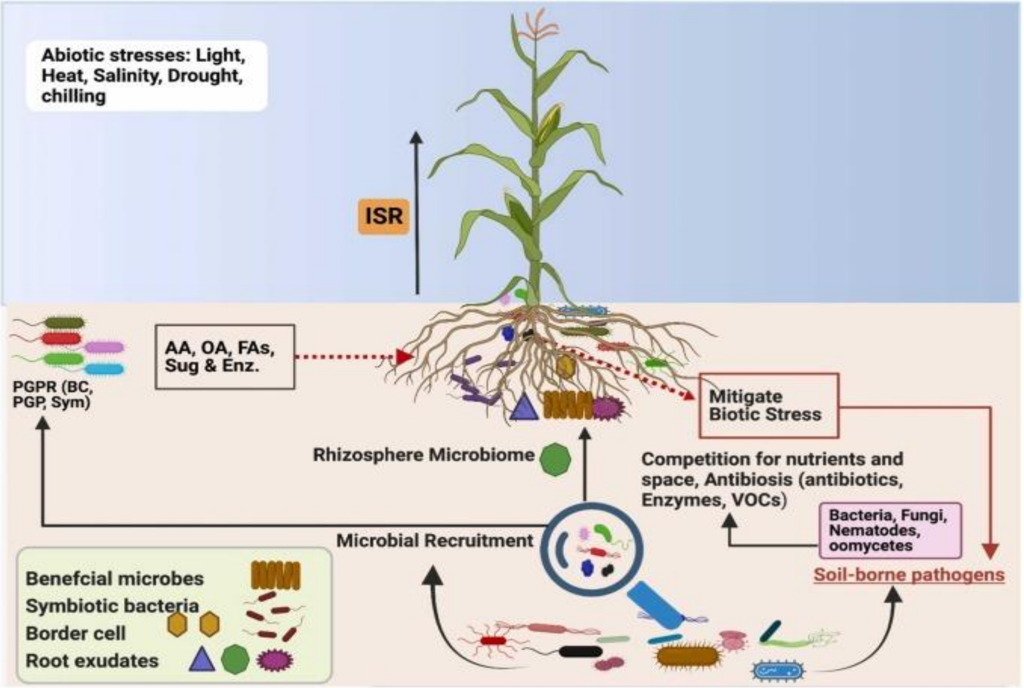

(Zampieri et al. 2019)

- The consecutive hot weather combined with extremely low rainfall will cause a **combined stress of high temperature and drought**. Especialiy the V10-VT stage of maize growth, it is **the most sensitive period to water and temperature**.
- For every 1°C increase in the global average temperature, the average yield of maize will decrease by approximately 7.4%.

# Research Background




The strategies that plants adopt to cope with global climate change（Ge et al., 2025）




Plant-microbe interactions mediated by root exudates and their functions（Fan et al., 2025）

- The **rhizosphere microecosystem** is an integrated whole formed by the close interaction between plant roots, soil and microorganisms, and it is **extremely sensitive** to environmental changes.
- The rhizosphere microorganisms are the "**second genome**" of plants. When the plants are under stress, they will specifically recruit **plant growth-promoting bacteria (PGPB)** to resist the stress.

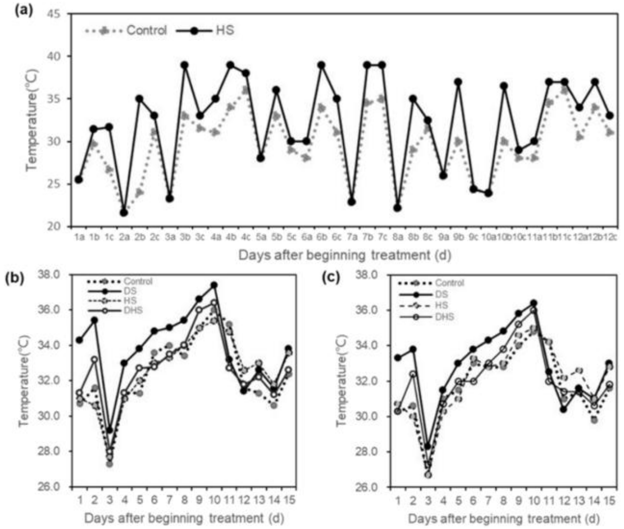
# Scientific Problems and Research Implications

**Therefore, understanding the effects of combined high temperature and drought stress on rhizosphere microecology of summer maize is of great practical significance for improving the yield of summer maize and ensuring food security.**

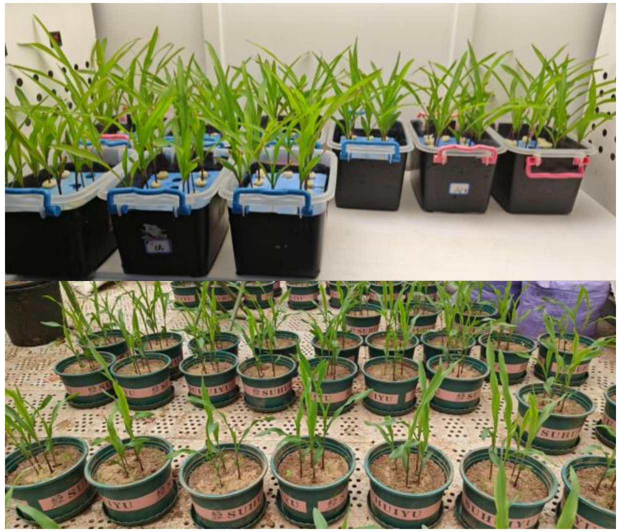
- **Scientific hypothesis: Maize roots were stimulated to secrete specific metabolites under combined high temperature and drought stress, which could enhance the tolerance of maize by recruiting beneficial microorganisms to assist in nutrient uptake and initiating stress resistance.**

# Experiment Design


Overview of the experimental site



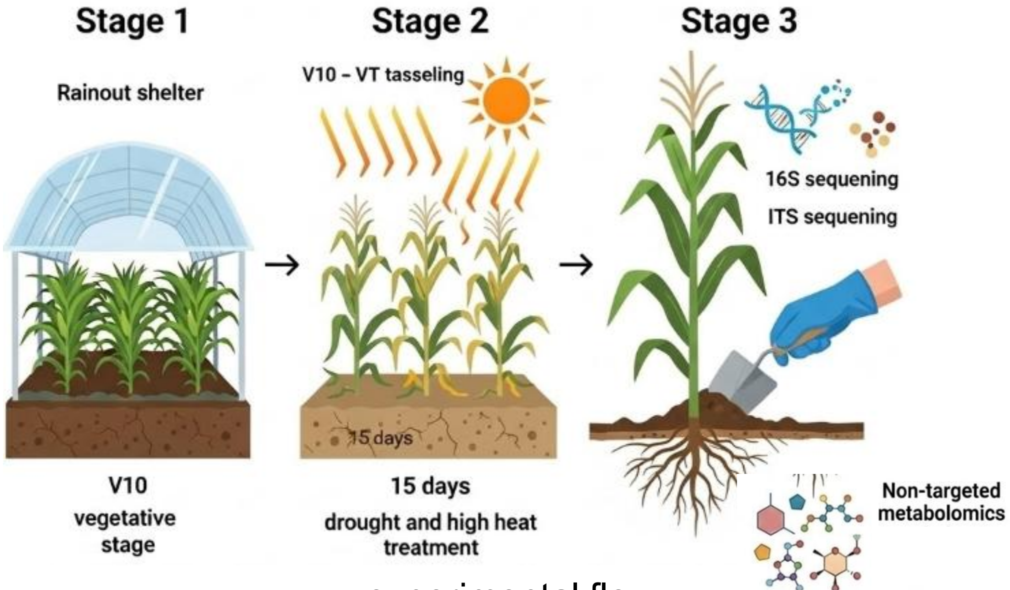

Distribution of plant and soil temperatures



Verification of metabolite application

| Treatment | Temperature（°C） | Field Moisture Capacity (FMC) |
|---|---|---|
| Drought Stress（DS） | Atmospheric Temperature | 45±5% |
| Heat Stress（HS） | Atmospheric Temperature +6.5°C（±1.4°C） | 80±5% |
| Combined Drought and Heat Stress（DHS） | Atmospheric Temperature +6.5°C（±1.4°C） | 45±5% |
| Control | Atmospheric Temperature | 80±5% |

Experiment involved four treatments



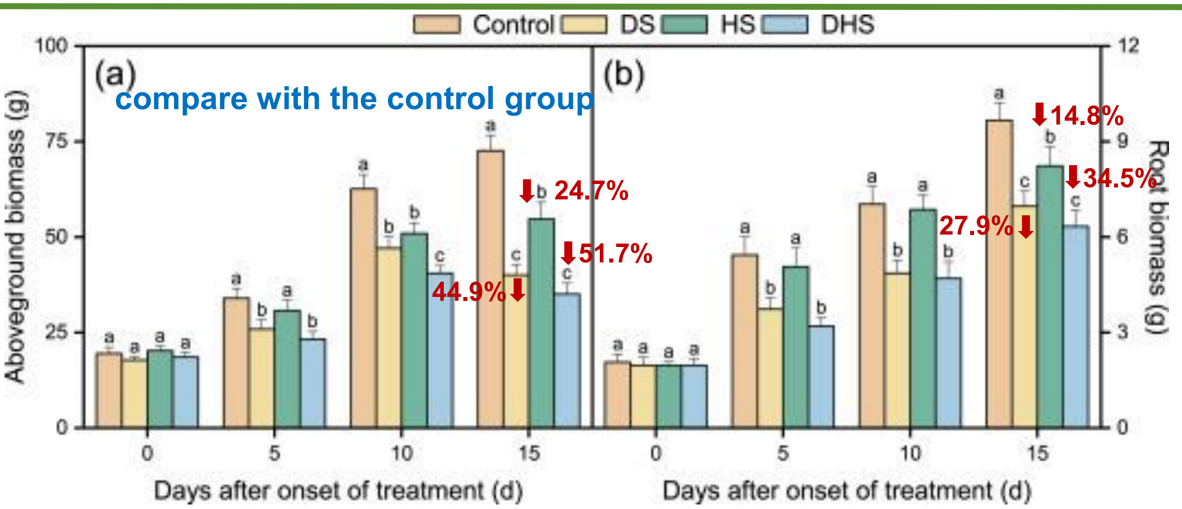

experimental flow

# PART.02

# Research Result

02

# 1. Maize growth and yield




Dry weight of aboveground and root biomass

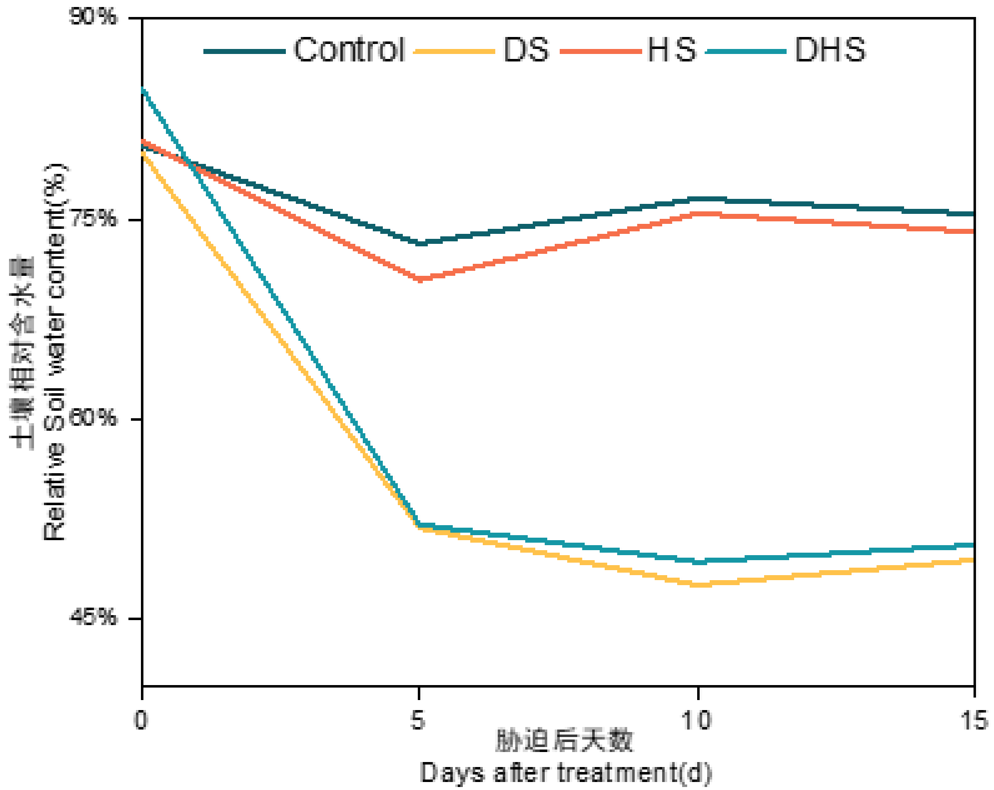

Maize plant phenotype

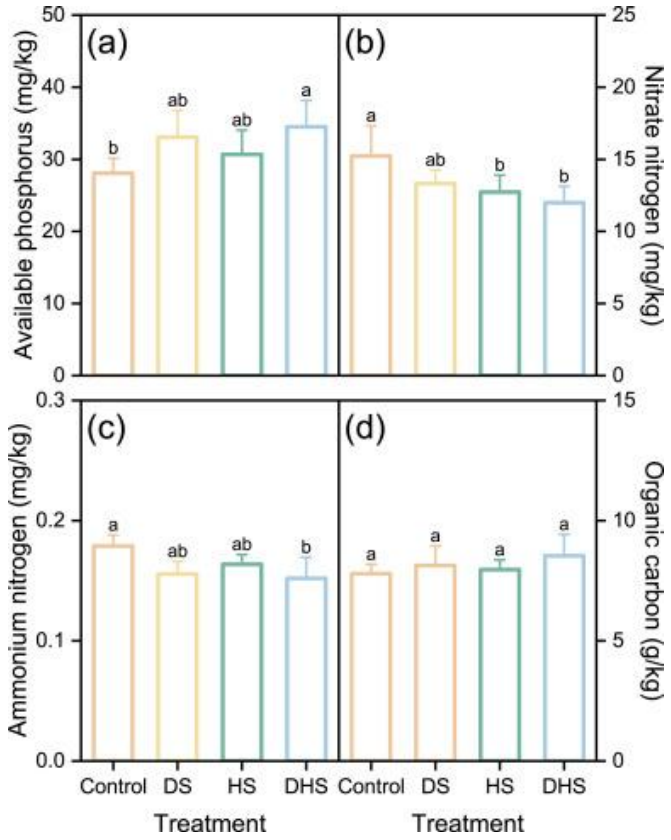
| 处理 Treatment | 穗长 Ear length (cm) | 穗粗 Ear diameter (mm) | 穗行数 Ear row | 行粒数 Grain number per row | 秃尖长 Bald tip length(cm) | 败育率 The abortive rate (%) | 穗粒数 Grain number per ear | 百粒重 Hundred seeds weight(g) | 产量 Yield (g/plant) |
|---|---|---|---|---|---|---|---|---|---|
| Control | 18.47±1.35a | 43.34±1.92a | 13.87±1.19ab | 35.86±1.68a | 1.39±0.47a | 0.15±0.03c | 489.83±40.16a | 27.47±1.12a | 143.77±15.86a |
| DS | 17.29±1.33b | 42.60±1.72a | 14.40±1.35a | 31.29±1.80b | 1.51±0.52a | 0.22±0.02b | 448.25±34.42ab | 25.29±1.19b | 113.13±14.60b |
| HS | 17.80±1.11ab | 42.38±2.17a | 13.33±1.23b | 31.57±2.44b | 1.50±0.31a | 0.37±0.05a | 459.78±36.68a | 26.78±1.32a | 110.78±10.21b |
| DHS | 16.18±1.07c | 40.70±2.60b | 13.20±1.01b | 27.00±2.58c | 1.83±0.26a | 0.38±0.05a | 381.33±36.96b | 26.61±1.02a | 96.34±10.53c |

⬆ 153.20%  ⬇ 32.99%

- **Compared with the control group, the DHS treatment significantly reduced aboveground biomass 51.7%, root biomass 34.5% and yield 32.55%.**

# 2. Changes in soil nitrogen, phosphorus and organic carbon contents

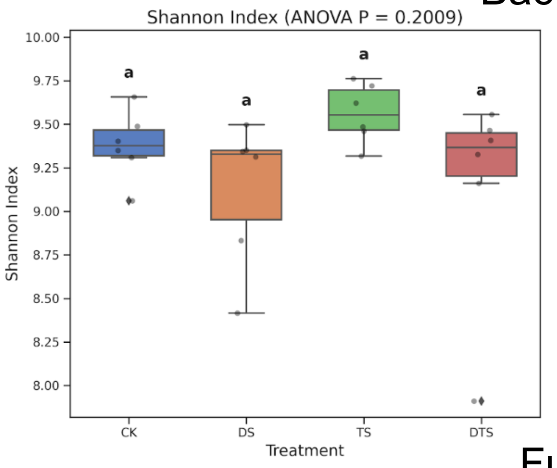


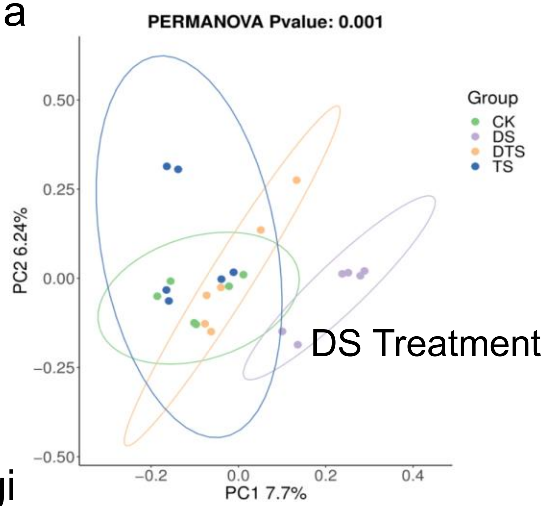




- Compared with Control, the available phosphorus content of DHS significantly increased by 22.91%, while the available phosphorus contents of DS and HS increased by 17.92% and 9.34% respectively.
- Different stress factors all have a significant impact on the soil nutrients.

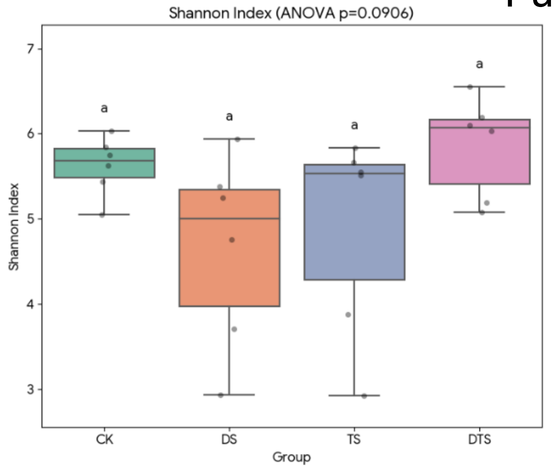
# 3. Changes in the microbial community at rhizosphere

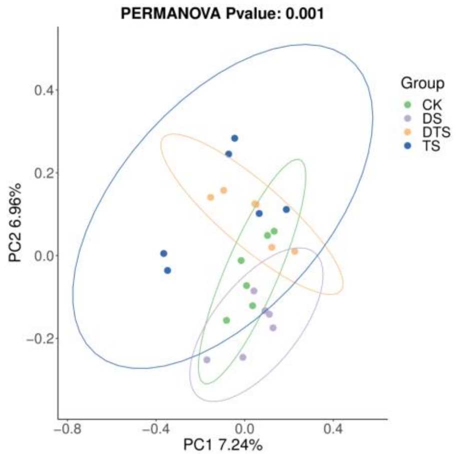
Bacteria




Fungi




Bacteria PERMANOVA analyse (adonis2)

| | Df | SumOfSqs | $R^2$ | F | Pr(>F) | Signif |
|---|---|---|---|---|---|---|
| Temperature | 1 | 0.24532 | 0.08240 | 2.2231 | 0.002 | ** |
| Drought | 1 | 0.31691 | 0.10644 | 2.8719 | 0.001 | *** |
| Temperature:Drought | 1 | 0.20808 | 0.06989 | 1.8857 | 0.010 | ** |
| Residual | 20 | 2.20698 | 0.74127 | | | |
| Total | 23 | 2.97729 | 1.00000 | | | |

Fungi PERMANOVA analyse (adonis2)

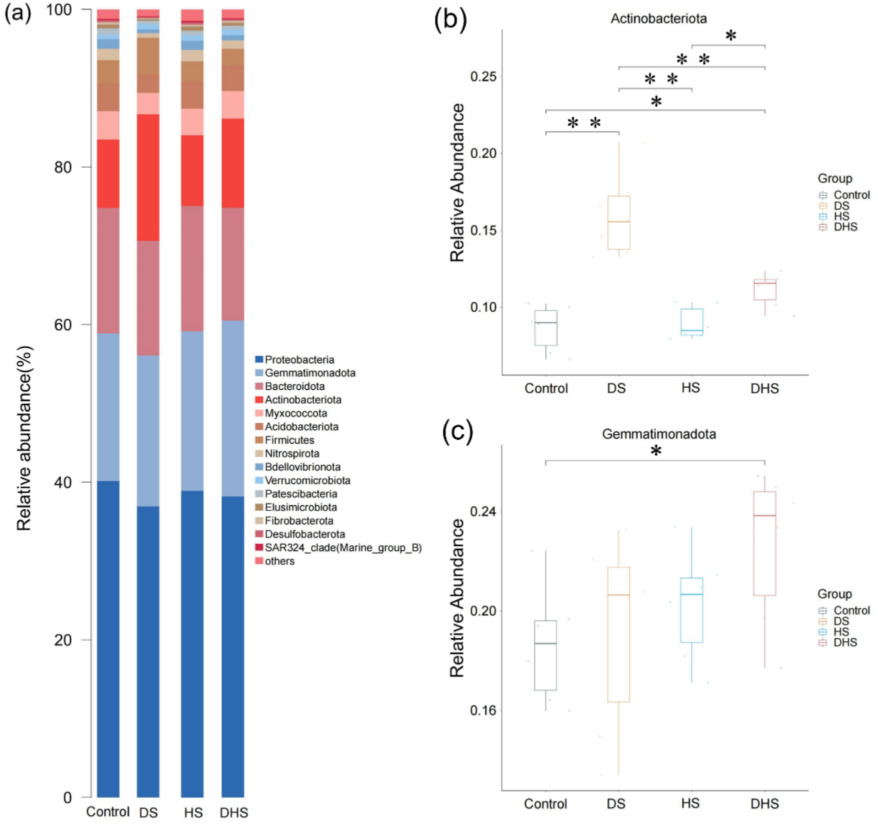
| | Df | SumOfSqs | R2 | F | Pr(>F) | Signif |
|---|---|---|---|---|---|---|
| Temperature | 1 | 0.4390 | 0.06779 | 1.7040 | 0.003 | ** |
| Drought | 1 | 0.31691 | 0.07248 | 1.8218 | 0.003 | ** |
| Temperature:Drought | 1 | 0.06402 | 0.06402 | 1.6090 | 0.011 | ** |
| Residual | 20 | 5.1527 | 0.79571 | | | |
| Total | 23 | 6.4756 | 1.00000 | | | |

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

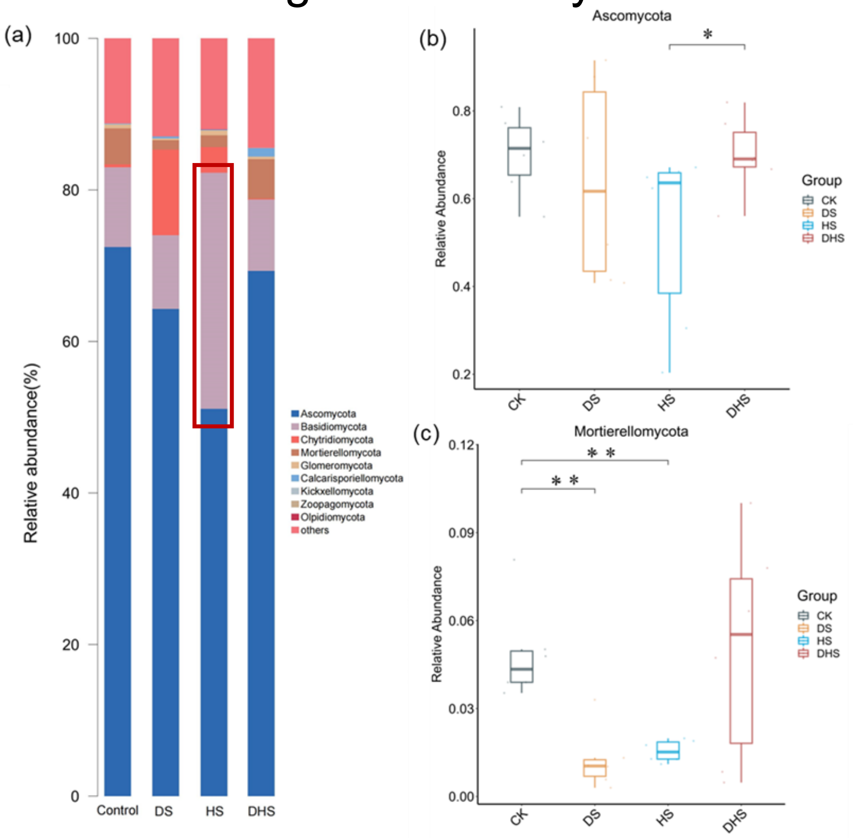
- **The impact on the α diversity of the microbial community was not significant, which might be due to the short duration of the treatment. Bacterial community undergoes more drastic changes than fungal community.**
- **PERMANOVA analysis revealed that for the bacterial community, drought had the most significant impact, explaining 10.64% of the variation. And there is a similar trend in the fungal community.**

# 3. Changes in the microbial community at rhizosphere

Bacterial Community



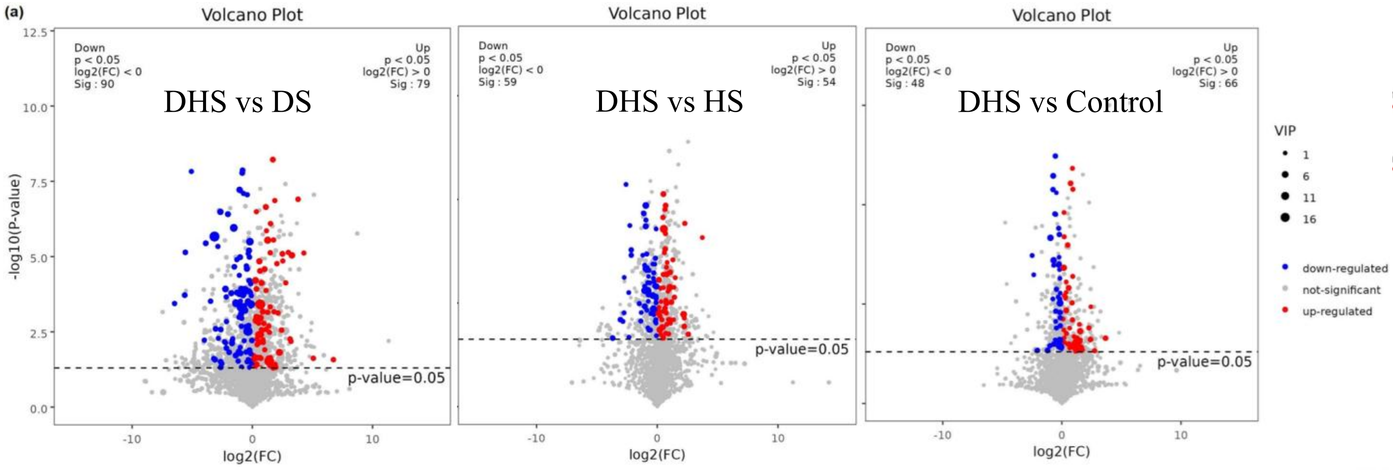

Fungal community



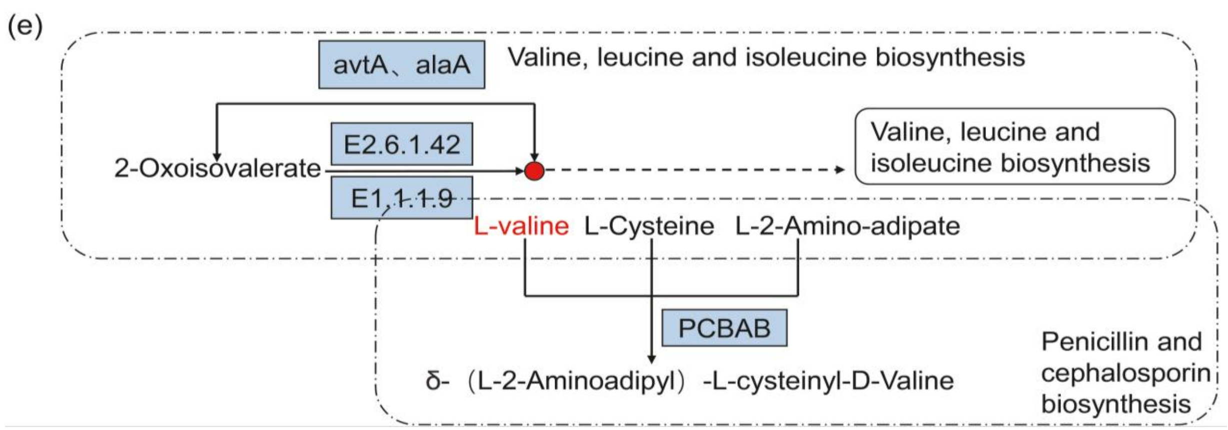

- Microbial communities of bacteria and fungi have undergone **significant changes**.
- Compared with Control, under **DS conditions**, the relative abundance of **Actinobacteriota was the highest**; the relative abundance of the **Gemmatimonadota in DHS significantly increased.**
- Under the HS treatment, the relative abundance of **Basidiomycetes significantly increased**.

(Yuan A.,...Shao R. et al., Soil Biology and Biochemistry. 2024)

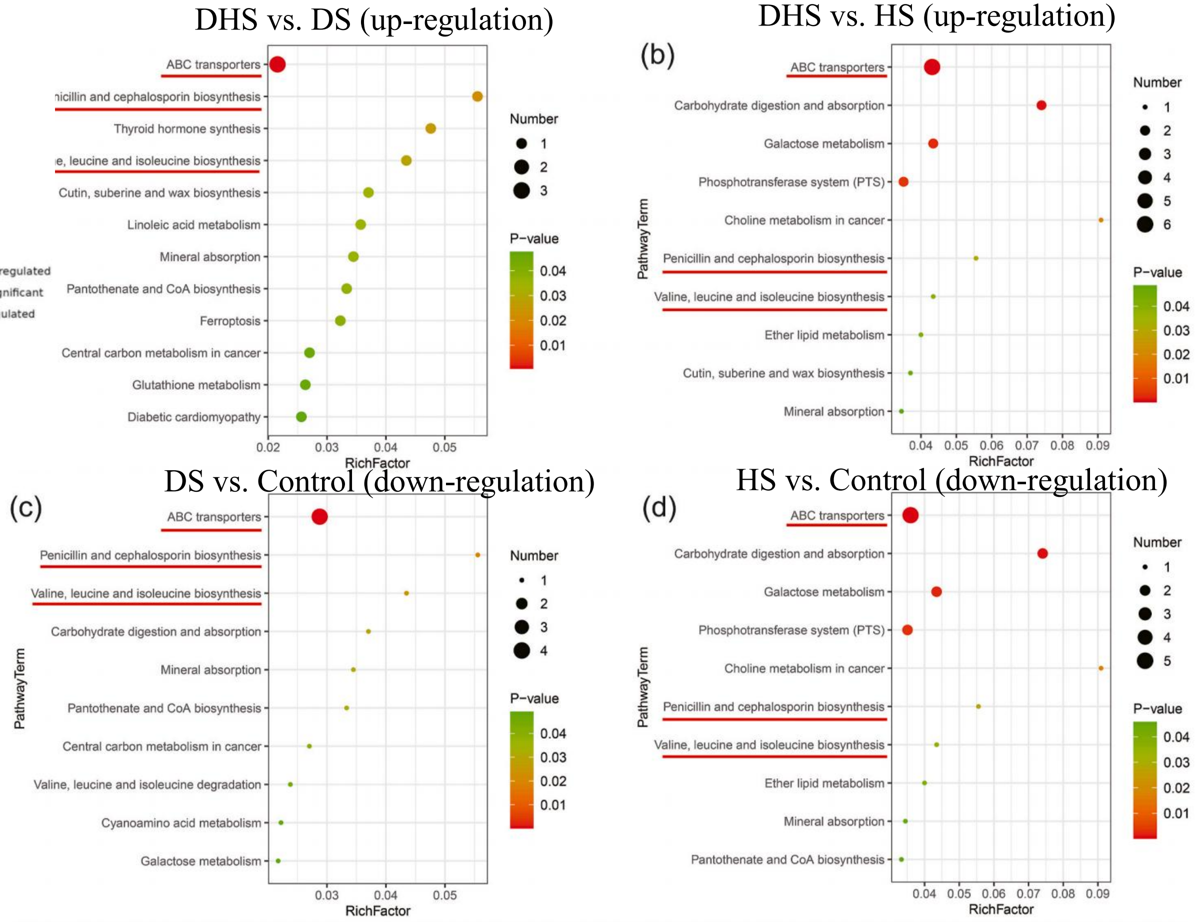
# 4. Rhizosphere soil non-targeted metabolomics analysis




Screening of differential metabolites




Location of the key metabolite L-valine



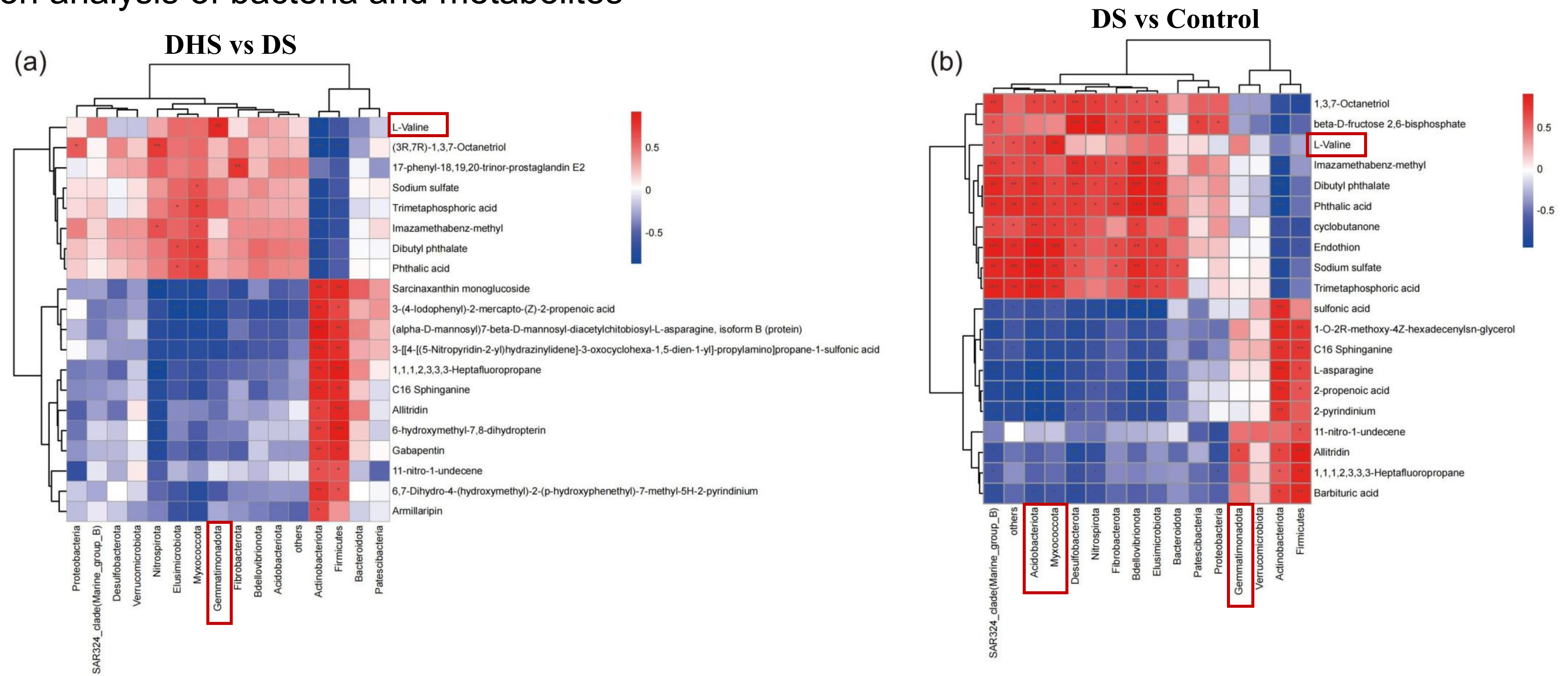

Metabolic pathway enrichment

- Under combined stress, the biosynthesis pathways of **ABC transporters**, **Penicillin and cephalosporin biosynthesis**, and **Valine, leucine and isoleucine biosynthesis** were all significantly upregulated. The significantly upregulated metabolite: **L-valine**.

**(Yuan A.,...Shao R. et al., Soil Biology and Biochemistry. 2024)**

# 5. Association between microbiome and metabolome

Correlation analysis of bacteria and metabolites

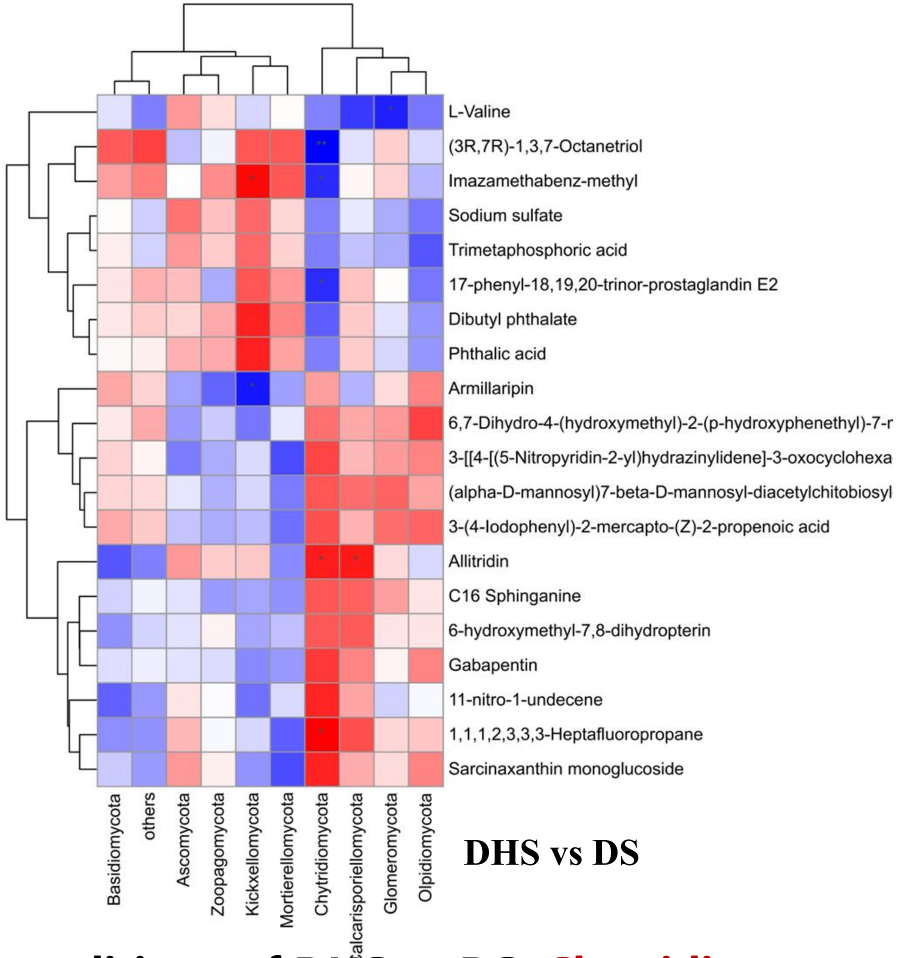



- **Under the conditions of DHS vs DS, the Actinobacteria and the Firmicutes showed a significant negative correlation with L-valine. Gemmatimonadota showed a significant positive correlation with L-valine.**
- **Under the DS vs Control conditions, the Actinobacteria and L-valine showed a significant positive correlation.**
- **The combined stress of corn involves unique metabolic-microbial interactions.**

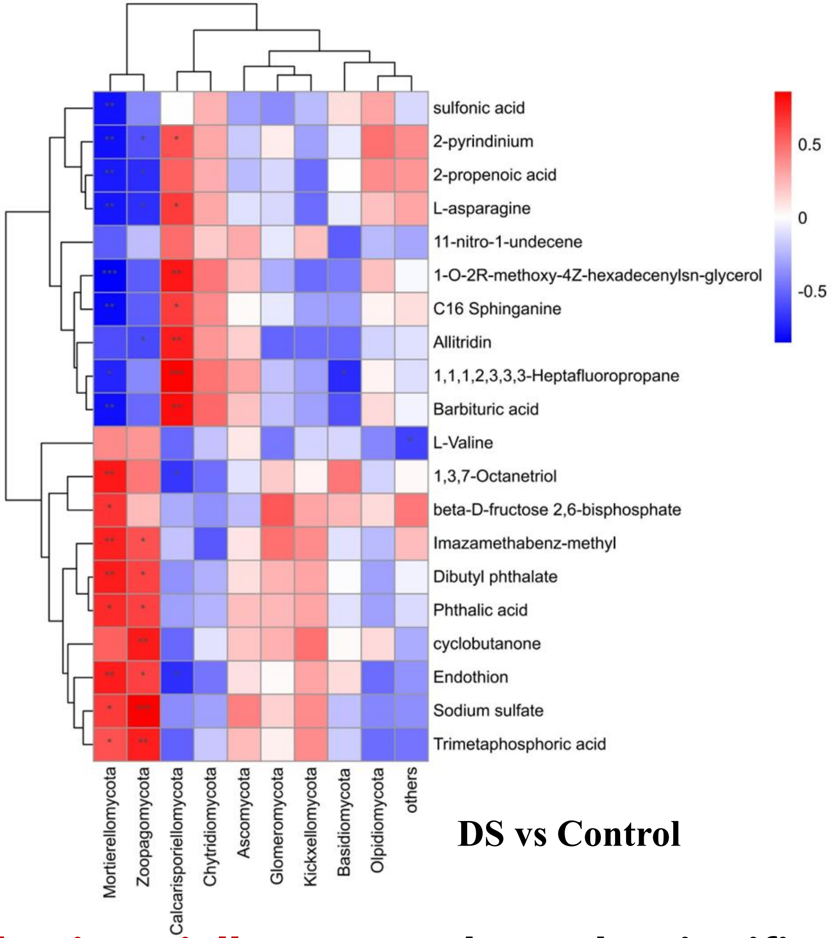
(Yuan A.,...Shao R. et al., Soil Biology and Biochemistry. 2024)

# 5. Association between microbiome and metabolome

Correlation analysis of fungi and metabolites




DHS vs DS

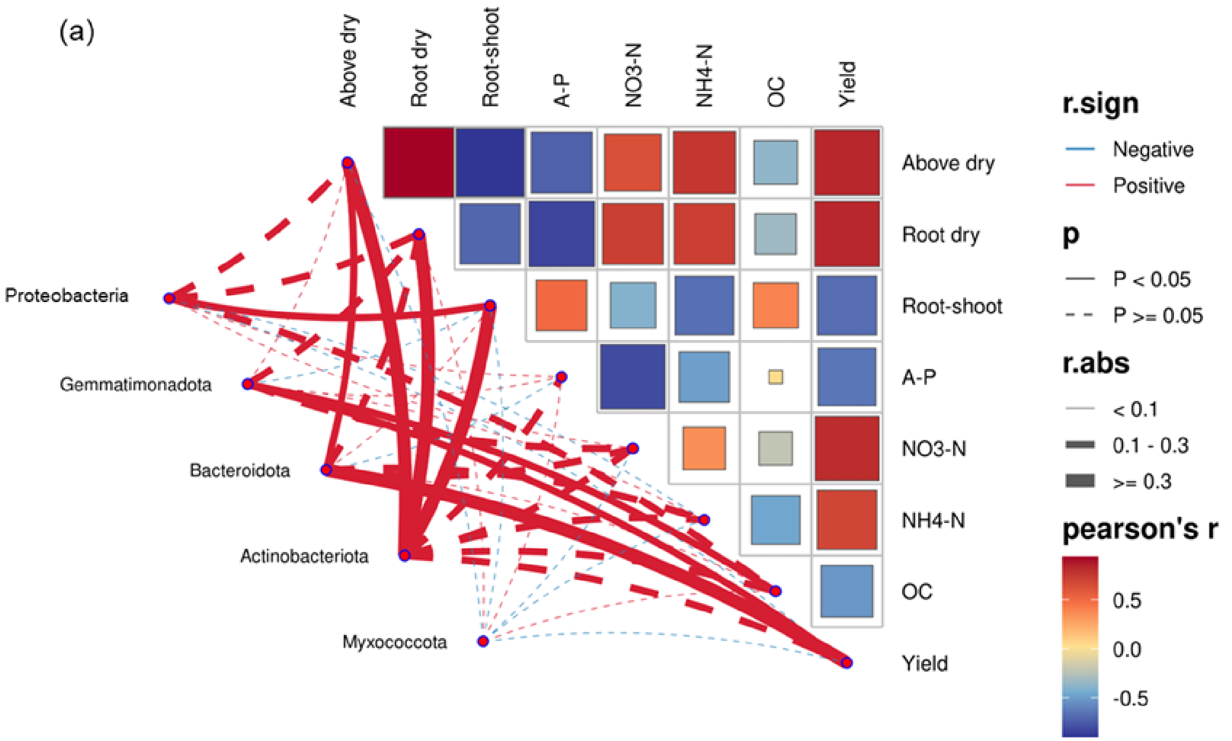



DS vs Control

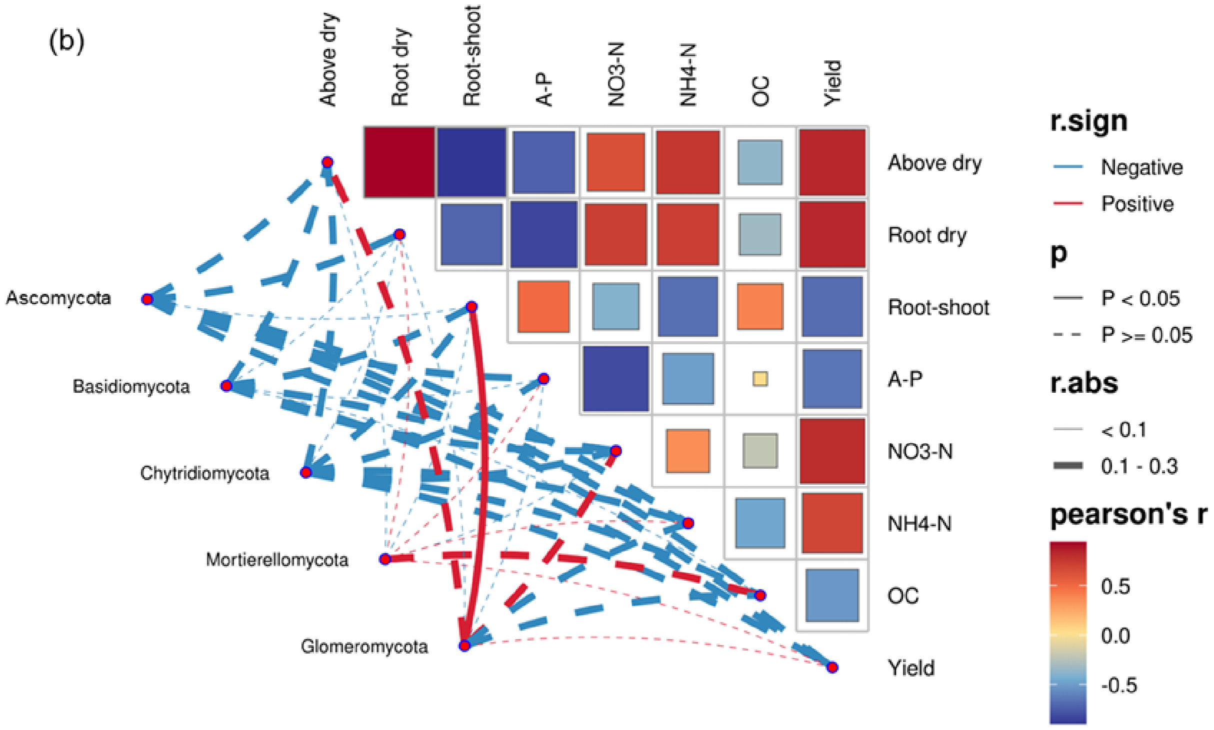
- Under the conditions of DHS vs DS, **Chytridiomycota and Calcarisporiellomycota** showed a significant positive correlation with **Allitridin**.
- Same as bacteria, under stress conditions, the fungal community is profoundly influenced by metabolites.

# 6. Relationship between microorganisms and maize growth / soil nutrients

Bacteria



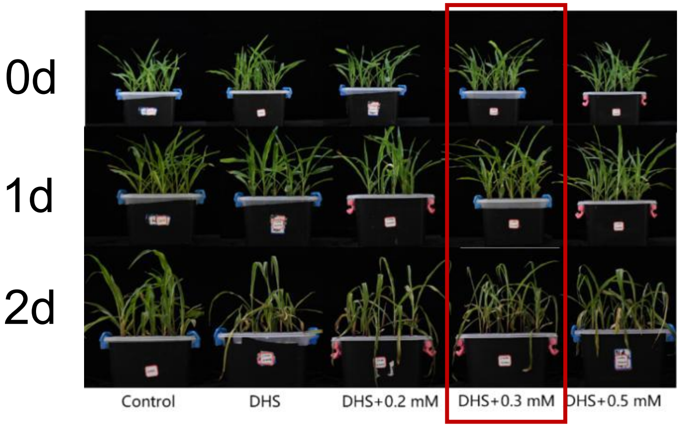

Fungus



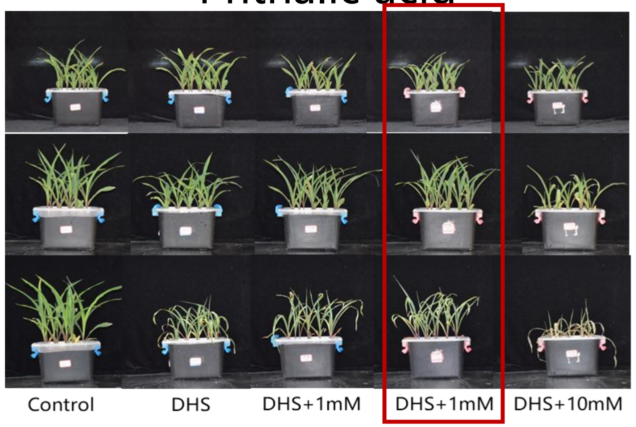

- **Among bacteria, Proteobacteria, Gemmatimonadota, and Actinobacteriota have significant positive correlations with biomass, yield, root-shoot ratio, and soil nutrients.**
- **Only the Glomeromycota of fungi showed a significantly positive correlation with the root-shoot ratio.**

# 7. Regulation of metabolic substances in maize response to stress

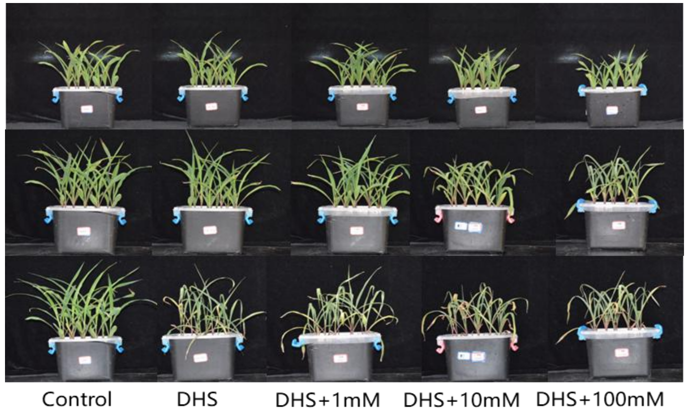
L-valine



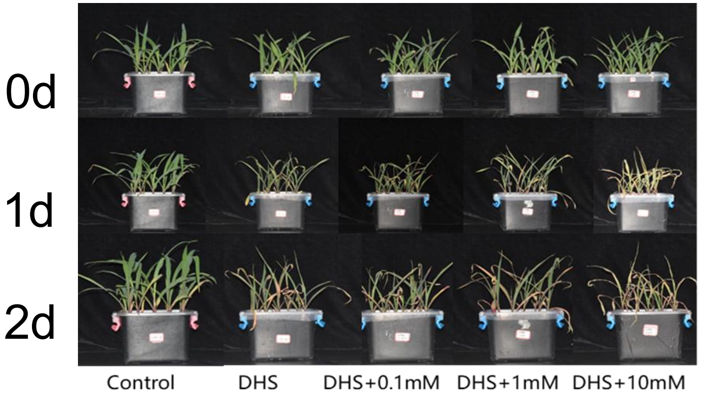

Phthalic acid



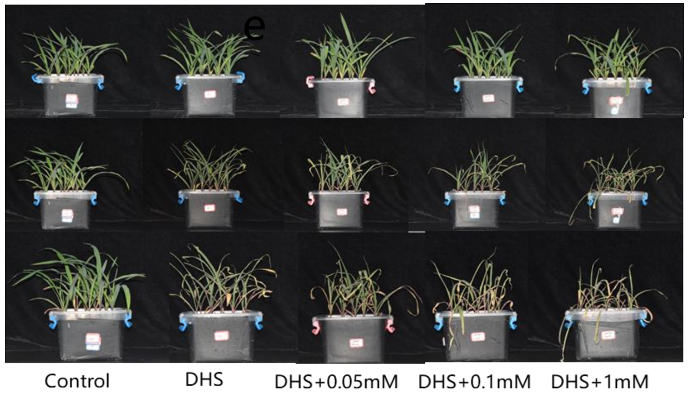

D-fructose




Orotic acid



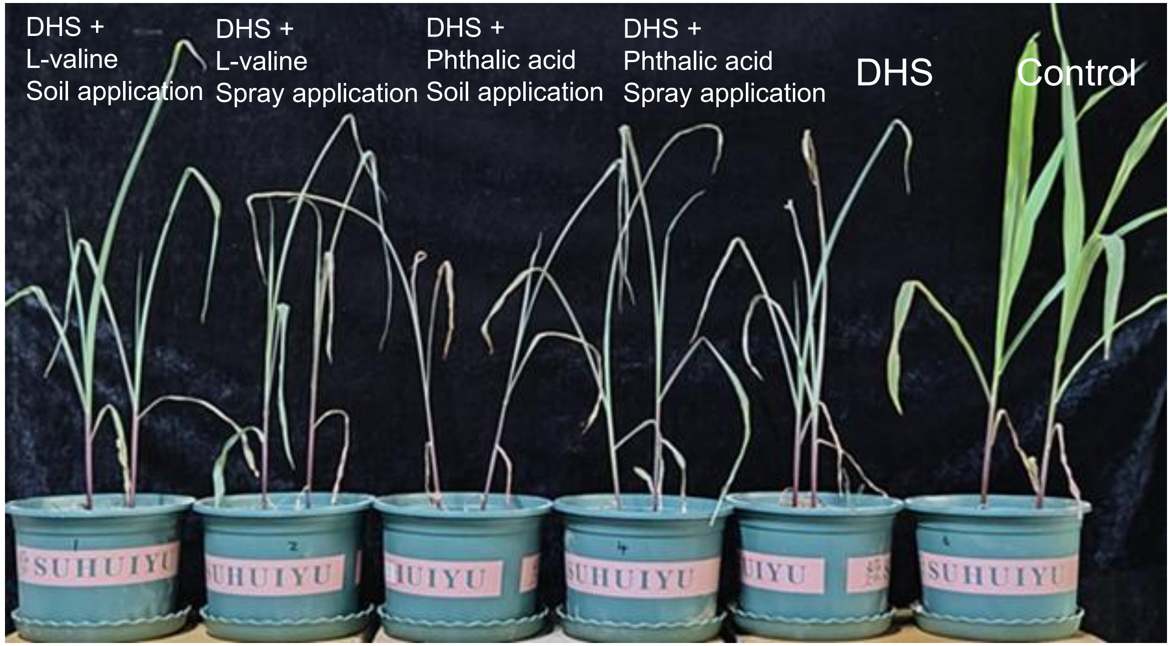

Glutathione




- **The promoting effect of applying 0.3 mM L-valine and 1 mM Phthalic acid under DHS was determined to be the best， through biomass measurement and root scanning methods.**

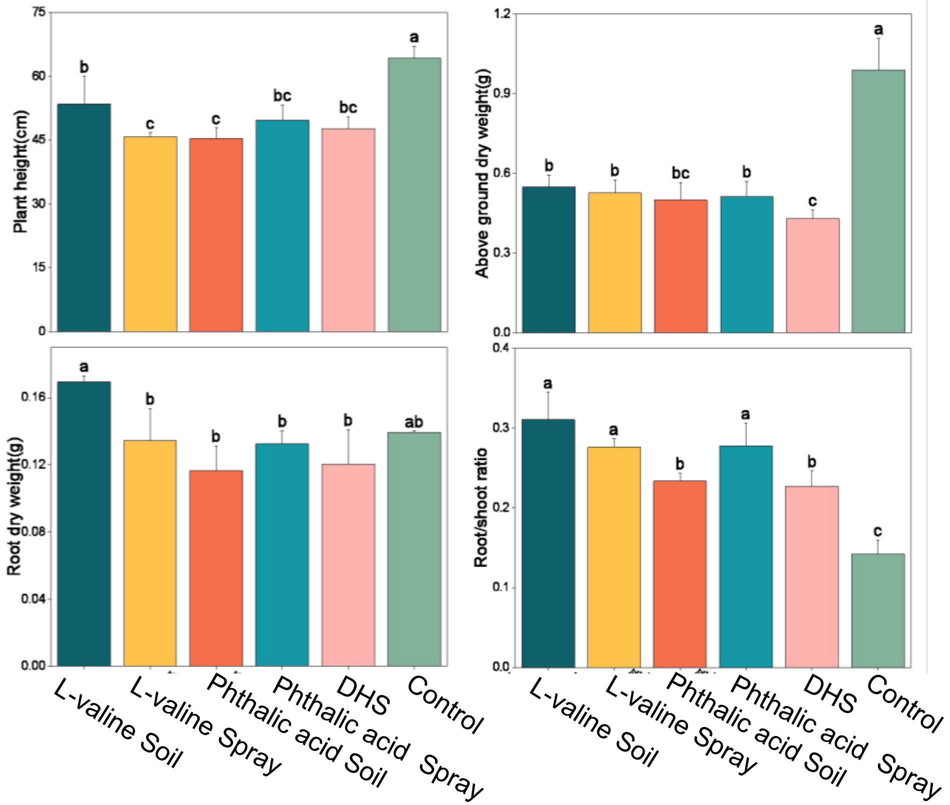
# 7. Regulation of metabolic substances in maize response to stress

## Application methods and regulatory effects of L-valine and phthalic acid




| Treatment | Total root length | Total surface area | Average root diameter | Total root volume | Number of root tips |
|---|---|---|---|---|---|
| L-valine Soil | 510.20±105.91a | 51.43±7.41ab | 0.38±0.06b | 0.48±0.04ab | 1757±104.6a ↑20.18% |
| L-valine Spray | 329.97±46.49bc | 40.99±4.64ab | 0.41±0.02ab | 0.42±0.05b | 1254.5±45.96c |
| Phthalic acid Soil | 224.90±0.58c | 34.78±9.18b | 0.41±0.02ab | 0.35±0.07b | 1022±52.32d |
| Phthalic acid Spray | 394.37±16.07ab | 38.82±12.27ab | 0.38±0.009b | 0.36±0.1b | 1430±39.6b |
| DHS | 398.78±31.79ab | 39.89±4.29ab | 0.35±0.03b | 0.35±0.02b | 1462±70.71b |
| Control | 421.72±26.40ab | 54.09±11.10a | 0.45±0.01a | 0.62±0.13a | 1484.5±36.1b |

Effects of different metabolite application methods on maize root growth




- Compared with DHS, L-valine soil significantly increased the root dry weight by 40.66%.
- In conclusion, L-valine Soil achieved the best results, effectively enhancing the resistance of maize to DHS.

# PART.03

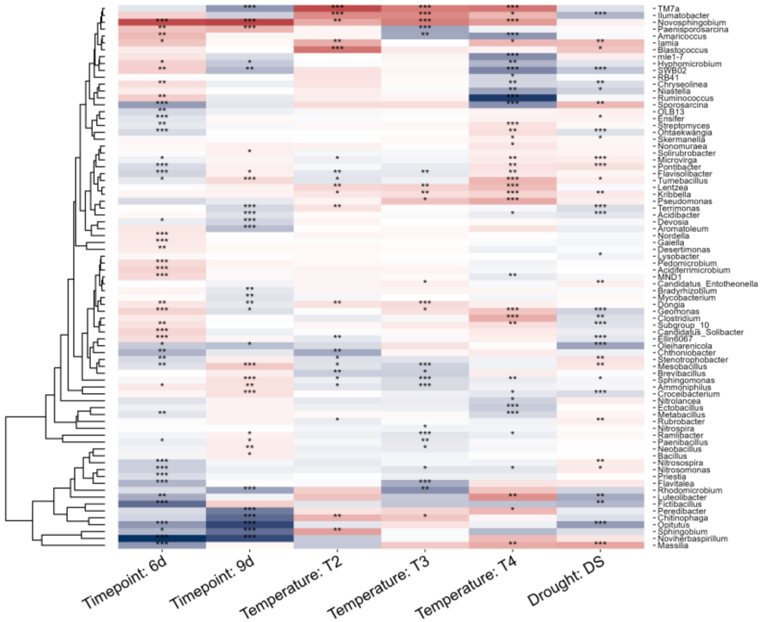
# Ongoing Work

03

# Ongoing Work

- Analysis of the mechanism by which L-valine in the maize rhizosphere drives the enrichment of Gemmatimonadota and enhances maize's resistance to combined stress of high temperature and drought.
- Using the resistant variety MY73 as the experimental material. Decoding the mechanism of drought resistance from the perspective of rhizosphere microecology.
- Isolation, identification and stress resistance function verification of plant growth-promoting bacteria (PGPB).

Filter PGPB




Linear Mixed Model represents the changes in the microbial community

Microbial isolation and identification


Microbial functional genes

PGPB application verification

# Paper and Patent

- This research was published in **Soil Biology and Biochemistry** under the title of "Dynamic interplay among soil nutrients, rhizosphere metabolites, and microbes shape drought and heat stress responses in summer maize." (Selected as an **ESI highly cited** paper)
- Granted an international patent (Netherlands).

Contents lists available at ScienceDirect
Soil Biology and Biochemistry
journal homepage: www.elsevier.com/locate/soilbio

Dynamic interplay among soil nutrients, rhizosphere metabolites, and microbes shape drought and heat stress responses in summer maize

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ARTICLE INFO

ABSTRACT



abundances. When exposed to HS in contrast to the other two stress treatments, the Basidiomycota (31.2%) relative abundance became significantly elevated. Metabolites, consisting of phenol ethers, fatty acyls, organo-oxygen compounds, allyl-type 1,3-dipolar organic molecules and organic nitro compounds, were differentially abundant across different treatments. Pathway analysis highlighted the up-regulation of ABC transporters, penicillin/cephalosporin biosynthesis, and valine/leucine/isoleucine biosynthesis pathways when exposed to either DHS compared to DS or HS. Overall, these findings suggest that DHS would stimulate the secretion of L-valine by the roots, thereby facilitating the recruitment of Gemmatimonadota and improving nitrate and ammonium absorption by roots under DHS. In brief, the results offer significant insights into the interactions between microbes and plants, as well as the potential to harness beneficial microbial communities to improve maize resilience and productivity under different types of abiotic stress.

1. Introduction

In the context of global warming, drought stress (DS) and heat stress (HS) have become major challenges for agricultural production (Jägermeyr et al., 2021). These abiotic stress factors not only directly affect crop yield and quality, but may also have a long-term impact on the overall health and stability of agroecological system (Iqbal et al., 2024). As an important global food and feed source, maize (*Zea mays* L.) has high water requirement and high sensitivity to environmental change (Jia et al., 2022). Huang-Huai-Hai region is one of the most important maize producing regions in China, with the planting area of summer maize accounting for more than 35% of the total planting area in the entire country (Ren et al., 2020). However, they often suffer from the combined drought and heat stress (DHS) in August, which coincides with the critical stage for the formation of production (Ling et al., 2023). Therefore, a deeper understanding of how summer maize responds to these adverse conditions is critical for developing effective agricultural management strategies to address the challenges posed by climate

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[1] Ao Yuan, Saini Dinesh Kumar and Haotian Wang contributed equally to this work.

OCTROOINUMMER 2032775

Octrooicentrum Nederland verklaart dat op grond van octrooiaanvraag 2032775 , ingediend op 17 augustus 2022 octrooi is verleend aan:

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Yifei Sun te Zhengzhou, China
Jiameng Guo te Zhengzhou, China
Yulou Tang te Zhengzhou, China
Lijuan Wang te Zhengzhou, China
Qinghua Yang te Zhengzhou, China
Krishna Jagadish te Manhattan, Kansas, Verenigde Staten van Amerika

Voor: Method for Improving Drought Resistance of Maize

Een recht van voorrang werd ingeroepen, gebaseerd op octrooiaanvraag: 202210920580.0, ingediend op 2 augustus 2022 in China.

Aan dit bewijs is een exemplaar van het octrooischrift gehecht met nummer 2032775 en dagtekening 13 januari 2026.

De maximale beschermingsduur van dit octrooi loopt tot en met 16 augustus 2042.

Uitgereikt te Den Haag, 15 januari 2026

De Directeur van Octrooicentrum Nederland,

dr. Maja Schmitt

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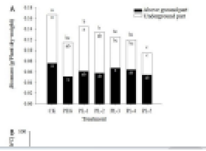
(54) Method for Improving Drought Resistance of Maize

(57) Disclosed is a method for improving drought resistance of maize, and relates to the technical field of planting. The method comprises the steps of applying exogenous L-arginine solution to maize plants; the concentration of the exogenous L-arginine solution is 50 - 500 μmol·L⁻¹, and the application amount of L-arginine in the exogenous L-arginine solution is 440 – 4400 mg/mu. Under drought stress, the dry matter weight, leaf relative water content, SPAD value and photosynthetic performance



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# Thank you for your attention!