Deciphering the signaling pathways underlying the inhibitory effect of elevated CO_2 on root nitrate uptake in Arabidopsis

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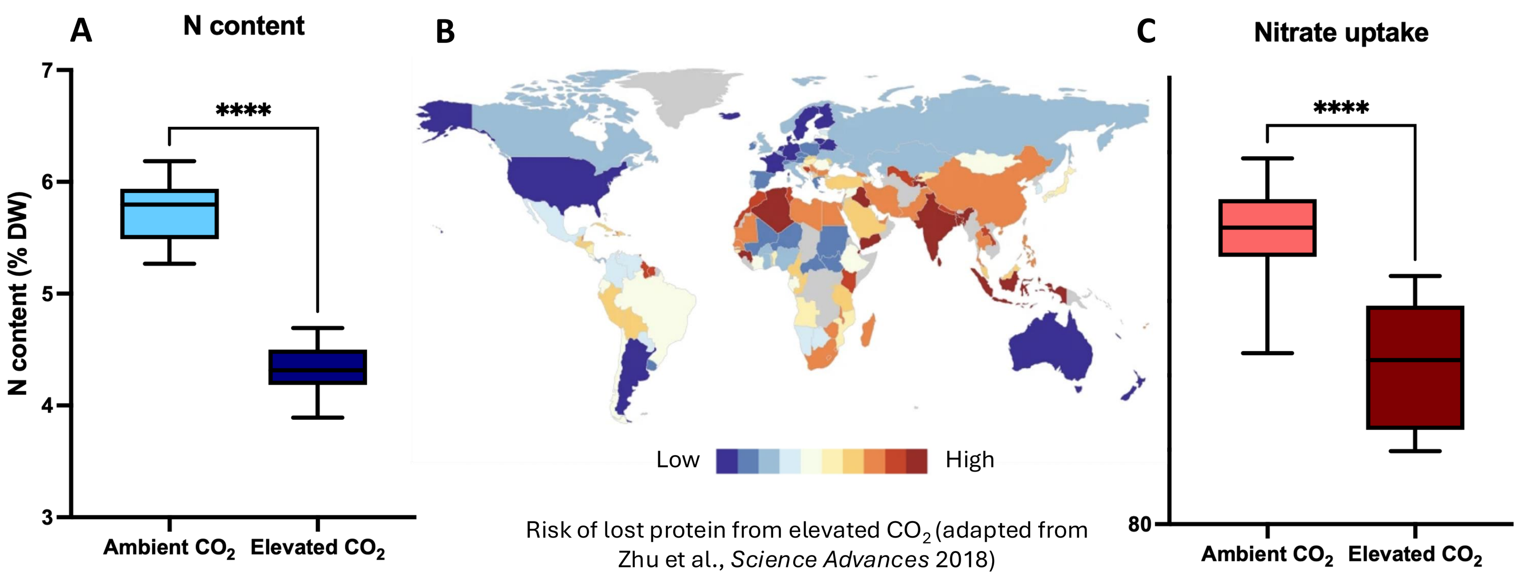
Context

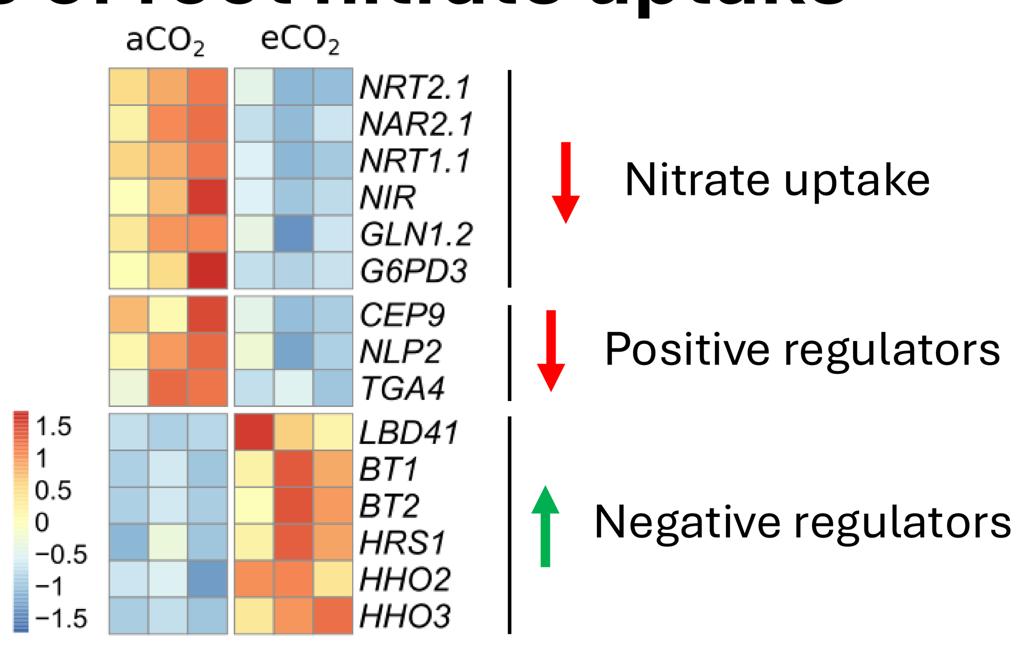
Elevated CO_2 leads to plant N decline associated to inhibition of root nitrate uptake



A. The rising atmospheric CO_2 concentration is causing a decline in plant nitrogen (N) content, a trend observed across most plant species (*Gojon et al., 2023*). **B.** This phenomenon poses a significant threat to human nutrition in the coming decades. **C.** The reduction in plant N content is closely linked to a decrease in nitrate assimilation and uptake efficiency. This inhibitory effect is specific to growth under low nitrate conditions. However, the underlying physiological, cellular, and molecular mechanisms remain poorly understood (*Cassan et al., 2023*).

Elevated CO_2 reprograms expression module of root nitrate uptake

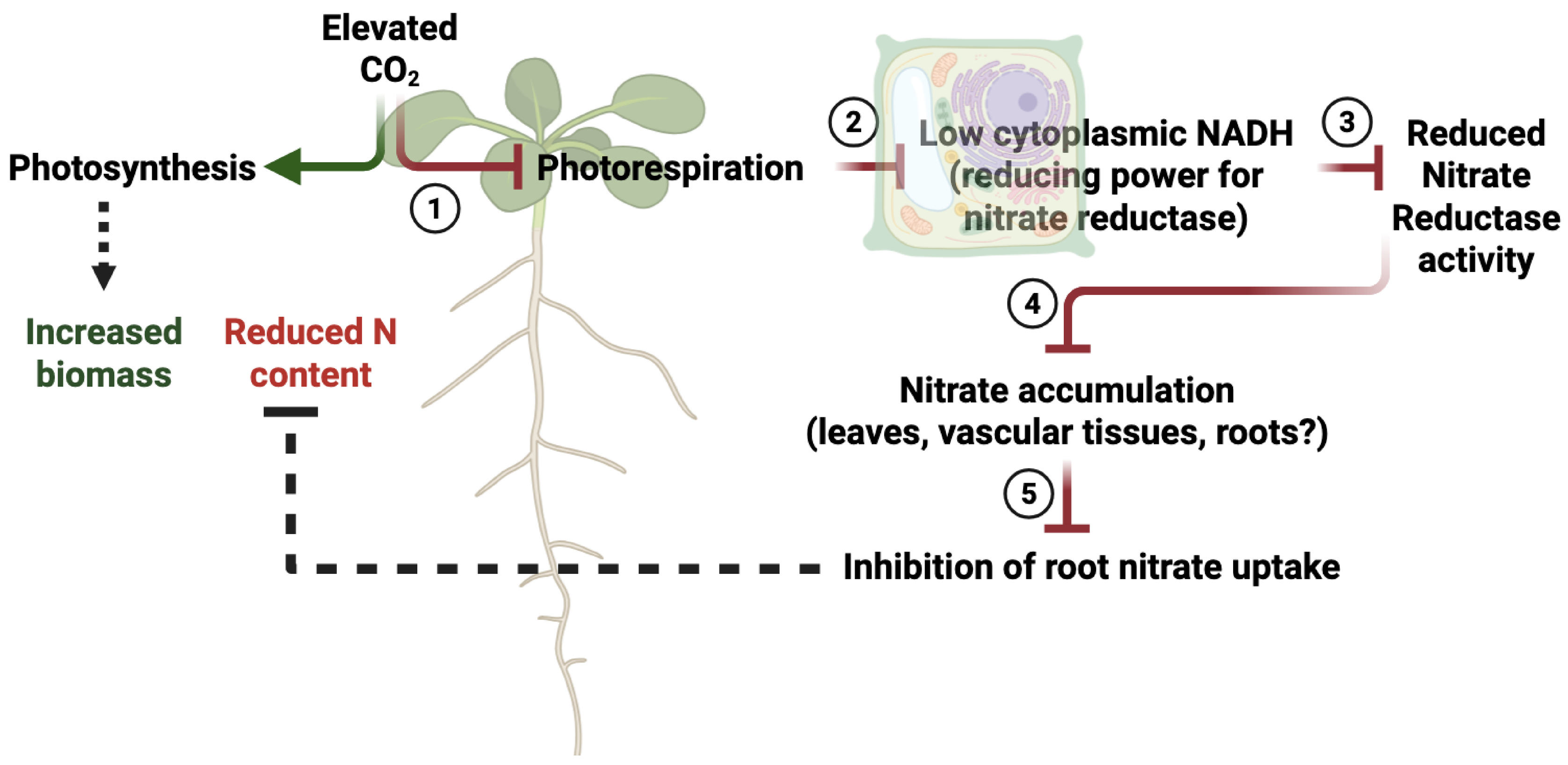
Root transcriptomic data obtained from plants grown under low nitrate conditions, and ambient or elevated CO_2. Blue color represents repression of gene expression by elevated CO_2, red color represents induction of gene expression by elevated CO_2.



Elevated CO_2 represses nitrate uptake gene expression and their positive regulators, while stimulating the experssion of negative regulators of nitrate uptake (*Cassan et al., 2023*). This profile is similar to that observed under high nitrate conditions, suggesting that **plants under elevated CO_2 behave as they would be under high nitrate conditions.**

Working hypothesis

A cell-to-whole plant hypothesis to explain the inhibitory effect of elevated CO_2 on root nitrate uptake



<u>**A Cell-to-Whole Plant Sequential Working Model Explaining the Inhibitory Effect of Elevated CO_2 on Root Nitrate Uptake**</u>

Elevated CO_2 reduces **photorespiration** **(1)**, a process that is thought to supply **nitrate reductase with energy in the form of NADH** **(2)**. As a result, a **reduction in nitrate reductase activity** occurs **(3)**, leading to **nitrate accumulation in leaves, vascular tissues, and/or roots** **(4)**. High nitrate levels are known to **induce feedback inhibition of root nitrate uptake** **(5)**.

To validate this model, **all these steps will be tested using integrative tools**, ranging from **cellular to whole-plant resolution** (see the detailed program below).

Master internship program

First year

- ✓ Determining **nitrate concentration** in different plant tissues under ambient or elevated CO_2, using biochemical assays and $^{15}NO_3^-$ isotopic labelling.
- ✓ Exploring the correlation between internal nitrate concentration and root nitrate uptake **gene expression regulation and root nitrate uptake**.
- ✓ Investigating the **role of nitrate sensors**, involved in root nitrate uptake gene expression regulation, in the inhibition of nitrate uptake by elevated CO_2.

Second year

- ✓ Imaging and **quantifying leaf cytoplasmic NADH** under elevated CO_2 using genetically encoded biosensors.
- ✓ Determining the **efficiency of nitrate reductase** activity under elevated CO_2.
- ✓ Building **a valid cell-to-whole plant model** explaining the inhibitory effect of elevated CO2 on root nitrate uptake, and quantifying the consequence on N content.
- ✓ **Drafting publication**.

About us, and who are we looking for?

The **SIRENE group**, based at **the Institute of Plant Sciences of Montpellier** (IPSIM), focuses on unraveling the molecular mechanisms and signaling pathways that regulate root nitrate transport and root development in response to environmental factors, particularly atmospheric CO_2. Our **multidisciplinary team**, currently comprising 5 researchers, 5 PhD students, 1 postdoc, and 1 engineer, employs integrative approaches—ranging from cell biology to molecular physiology—to address these research questions.

We also leverage **the state-of-the-art facilities** available at IPSIM, including **advanced imaging**, **ionome analyses**, and **gene expression profiling**, to drive our investigations forward.

This project is aimed at students with **a strong interest for integrative approaches** (from cell biology to physiology), willing to **address questions related to plant-environment interactions.**

<u>References of interest:</u>

- *Bloom et al. (2010). Carbon dioxide enrichment inhibits nitrate assimilation in wheat and Arabidopsis. Science 328, 899-903.*
- *Cassan et al. (2024). Natural genetic variation underlying the negative effect of elevated CO_2 on ionome composition in Arabidopsis thaliana. eLife 12, RP90170.*
- *Cassan et al. (2023). A gene regulatory network in Arabidopsis roots reveals features and regulators of the plant response to elevated CO_2. New Phytol 239, 992-1004.*
- *Gojon et al. (2023). The decline of plant mineral nutrition under rising CO_2: physiological and molecular aspects of a bad deal. Trends in Plant Science 28, 185-198.*
- *Zhu et al. (2018). Carbon dioxide (CO_2) levels this century will alter the protein, micronutrients, and vitamin content of rice grains with potential health consequences for the poorest rice-dependent countries. Sci Adv.*