RISING LEVELS OF ATMOSPHERIC CARBON DIOXIDE (CO_2) INTENSIFY MALNUTRITION

IRAKLI LOLADZE, PHD

BRYAN COLLEGE OF HEALTH SCIENCES, BRYAN MEDICAL CENTER, LINCOLN NEBRASKA

SCHOOL OF MATHEMATICAL & STATISTICAL SCIENCES, ARIZONA STATE UNIVERSITY

RURAL DEVELOPMENT AND FOOD SECURITY FORUM

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THE GLOBAL BURDEN OF MALNUTRITION

Hunger:

- 821 million people are food insecure

Mineral Undernutrition:

- 1.1 billion people at risk of dietary zinc (Zn) deficiency
- 1.2 billion people at risk of dietary iron (Fe) deficiency
- 3.5 billion people at risk of dietary calcium (Ca) deficiency

Caloric Overnutrition:

- Over 2 billion people are overweight
- Over 600 million people are obese

FAO, International Fund for Agricultural Development, UNICEF, World Food Programme, WHO (2018) The state of food security and nutrition in the world. Building climate resilience for food security and nutrition. Rome: FAO: 202

Grosbois et al (2005). Human iron deficiency. *Bulletin de l'Academie Nationale de Medecine*, *189*, 1649–1663.

Kumssa et al (2015). Dietary calcium and zinc deficiency risks are decreasing but remain prevalent. *Scientific Reports*, *5*, 1–11.

Ng et al (2014) Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet*. 384: 766–781.

MALNUTRITION IN ASIA AND THE PACIFIC

- The fastest rise in overweight rates is found in South East Asia and the Pacific.

- Nearly half of the world's population experiencing a double burden of stunting among children under 5 & overweight adult females lives in SE Asia and the Pacific.

- The prevalence of double burden (% stunting, % overweight): Philippines (32, 29), Indonesia (36, 26) , Papua New Guinea (43, 50)

"high availability and promotion of processed, low-cost, energy-dense foodstuffs (e.g. via fast-food outlets, supermarket chains) can result in overconsumption."

Haddad et al (2015). The double burden of malnutrition in SE Asia and the Pacific: priorities, policies and politics. *Health Policy and Planning*, *30*(9), 1193–1206.

ELEMENTAL (STOICHIOMETRIC) TAKE ON "JUNK FOOD"

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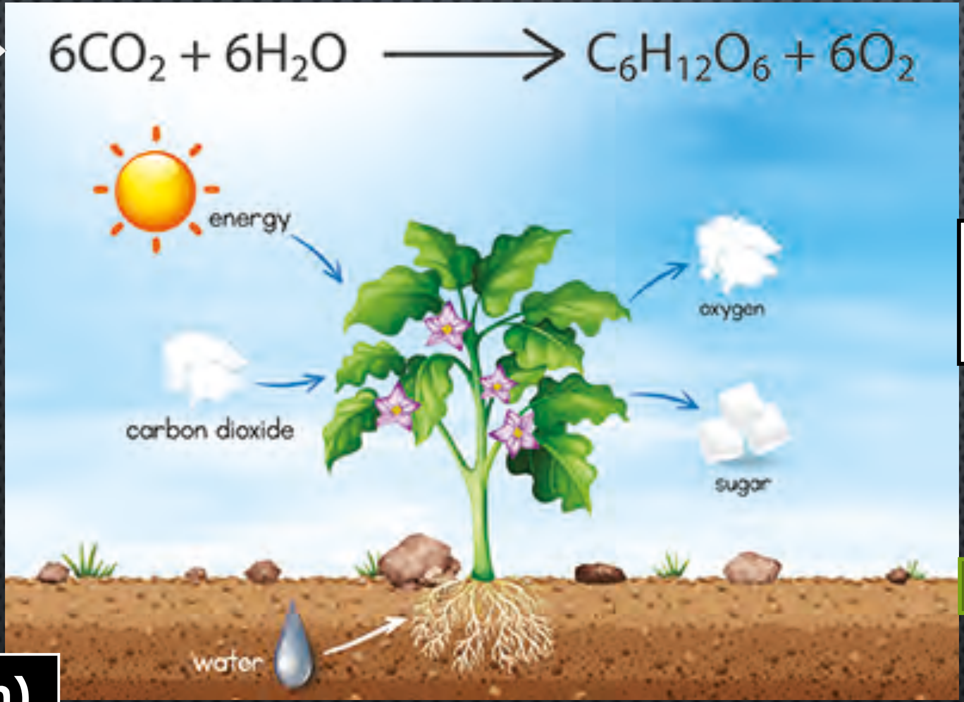
THE QUALITY OF STAPLE CROPS, VEGETABLES, FRUITS?

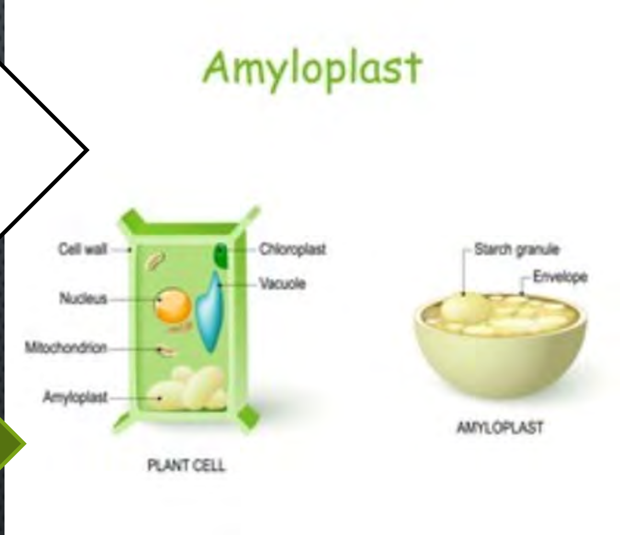
ELEMENTAL (STOICHIOMETRIC) TAKE ON PHOTOSYNTHESIS AND RISING ATMOSPHERIC CO_2 LEVELS

CO_2



C, H, O

Fe,Zn,Mg,Ca,K,Se...



Dilution of minerals by C,H,O!

Year	CO_2 (ppm)
1900	296
1950	311
2000	370
2019	411
2100	420-960

Opinion TRENDS in Ecology & Evolution Vol.17 No.10 October 2002 457

Rising atmospheric CO_2 and human nutrition: toward globally imbalanced plant stoichiometry?

Irakli Loladze
Dept of Ecology and Evolutionary Biology, Princeton University, Princeton, NJ 08544, USA.
e-mail: iloladze@princeton.edu

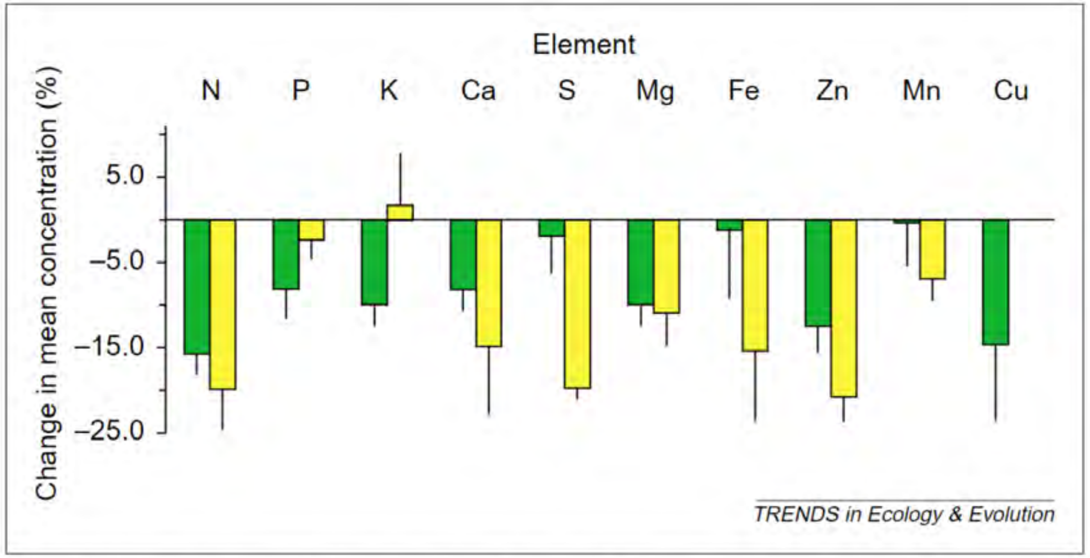


Fig. 1. Changes (%) in the mean concentration of essential elements in plants grown in twice-ambient atmospheric [CO_2] relative to those grown at ambient levels [all plants (foliar), green; wheat (grains), yellow]. The figure is based on 25 studies covering 19 herbaceous and 11 woody plant species, and five wheat cultivars

"high [CO2], as a rule, should alter the elemental composition of plants, thus affecting the quality of human nutrition."

"high [CO2] could intensify the already acute problem of micronutrient malnutrition."

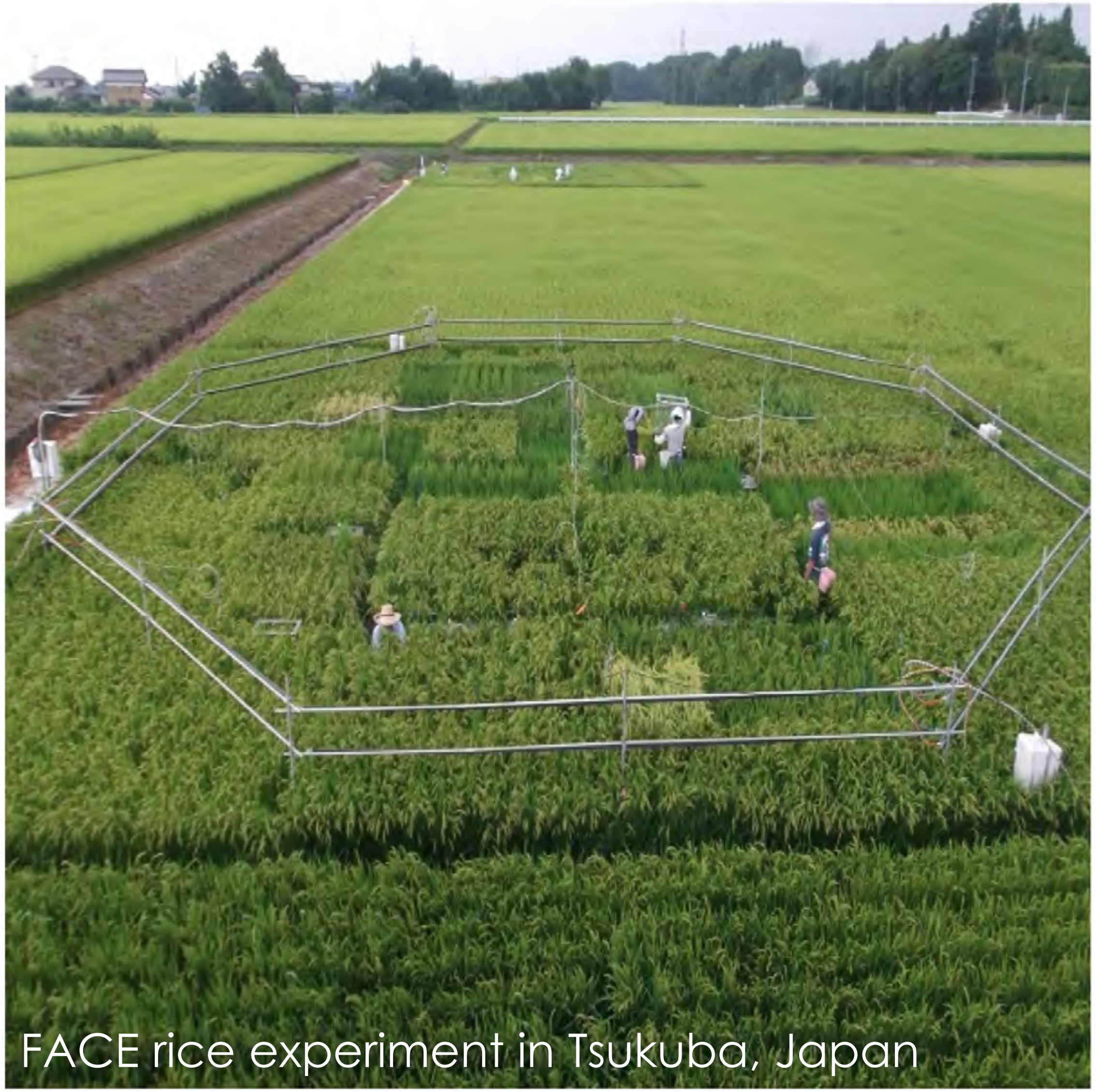
Loladze (2002) Rising atmospheric CO2 and human nutrition: toward globally imbalanced plant stoichiometry? *Trends in Ecology & Evolution*, *17*(10), 457–461.

ELEVATED CO_2 EXPERIMENTS AROUND THE WORLD

Greenhouses

Open-Top Chamber
Photo credit: R. Gottsberger

Mini-FACE (Free-Air CO_2 Enrichment)
University of Hohenheim, Germany



FACE rice experiment in Tsukuba, Japan

Experimental rice field near Tsukuba, Japan Rice within the octagon in this field is part of an experiment started by a University of Tokyo professor and designed to grow rice under different atmospheric conditions. The experiment was conducted by researchers of National Agriculture and Food Research Organization of Japan. Rice grown under the higher carbon dioxide concentrations expected in the second half of this century (568 to 590 parts per million) is less nutritious, with lower amounts of protein, vitamins, and minerals. © 2018 Dr. Toshihiro HASEGAWA (National Agriculture and Food Research Organization of Japan)

THE EFFECT OF ELEVATED CO_2 ON PROTEIN IN STAPLE CROPS

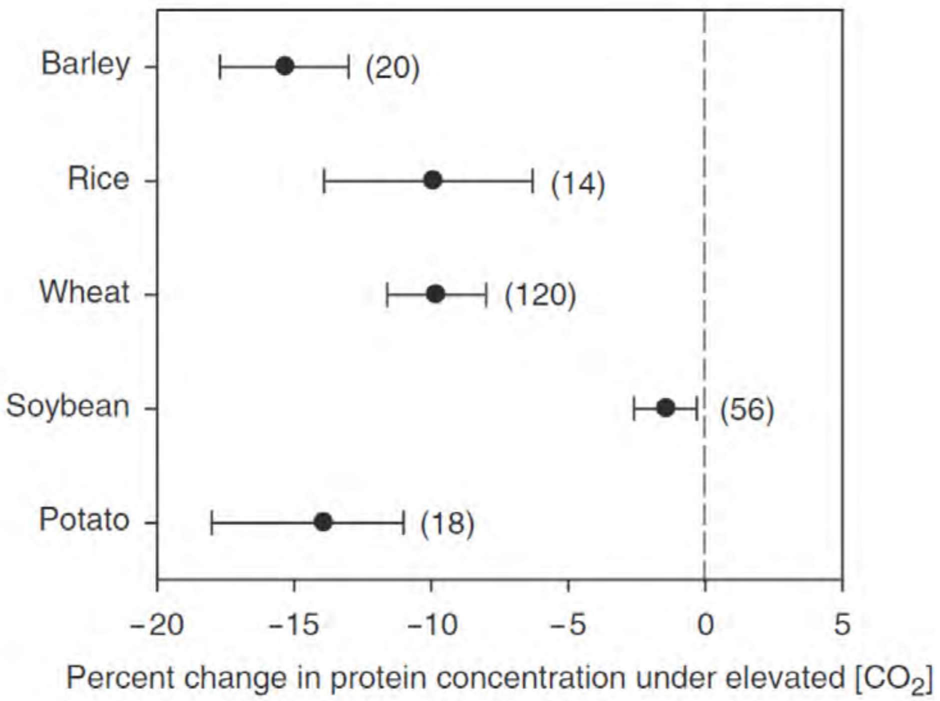
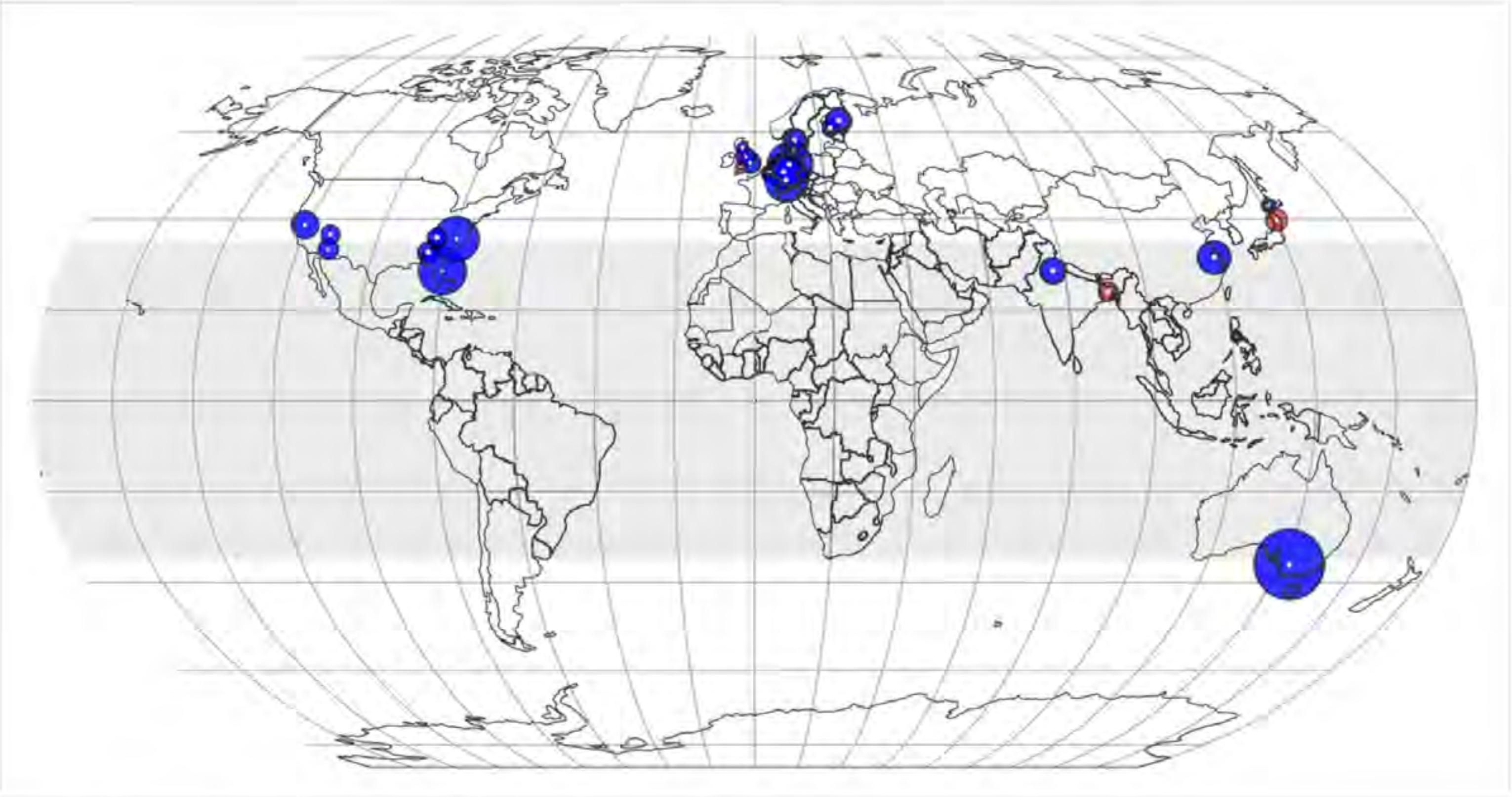


Fig. 1 Response of crop protein concentrations to growth at elevated CO_2 for five major crops. Means and 95% confidence limits are depicted. Numbers of experimental observations for each species are in parentheses.

Taub et al (2008). Effects of elevated CO2 on the protein concentration of food crops: a meta-analysis. *Global Change Biology, 14*(3), 565–575.

- 7,761 *pairs* of observations from elevated CO2 experiments from Asia, Australia, Europe and North America

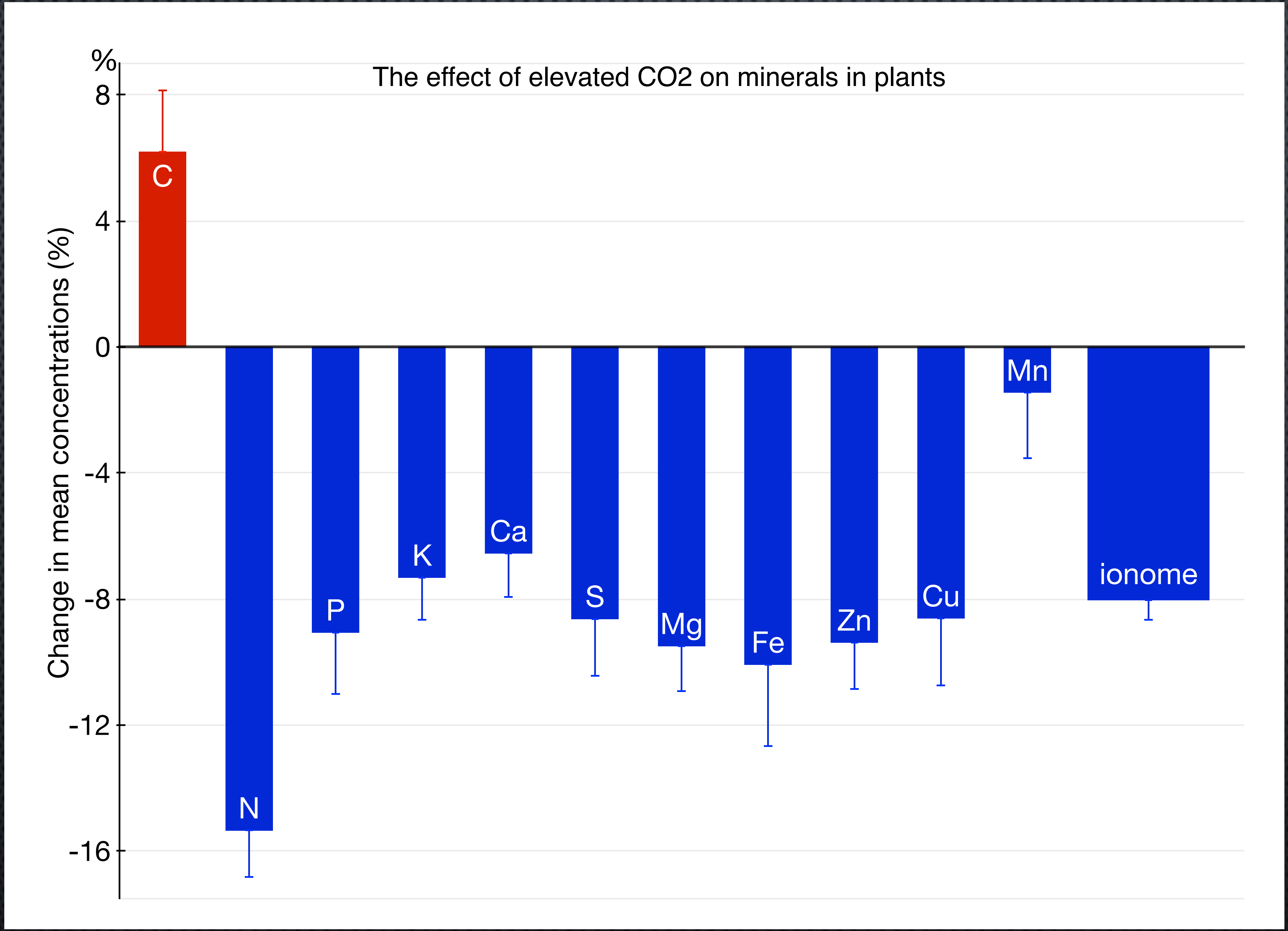
- Observations cover 25 minerals and 130 plant varieties of crops and wild plants



The effect of CO_2 at various locations and latitudes.

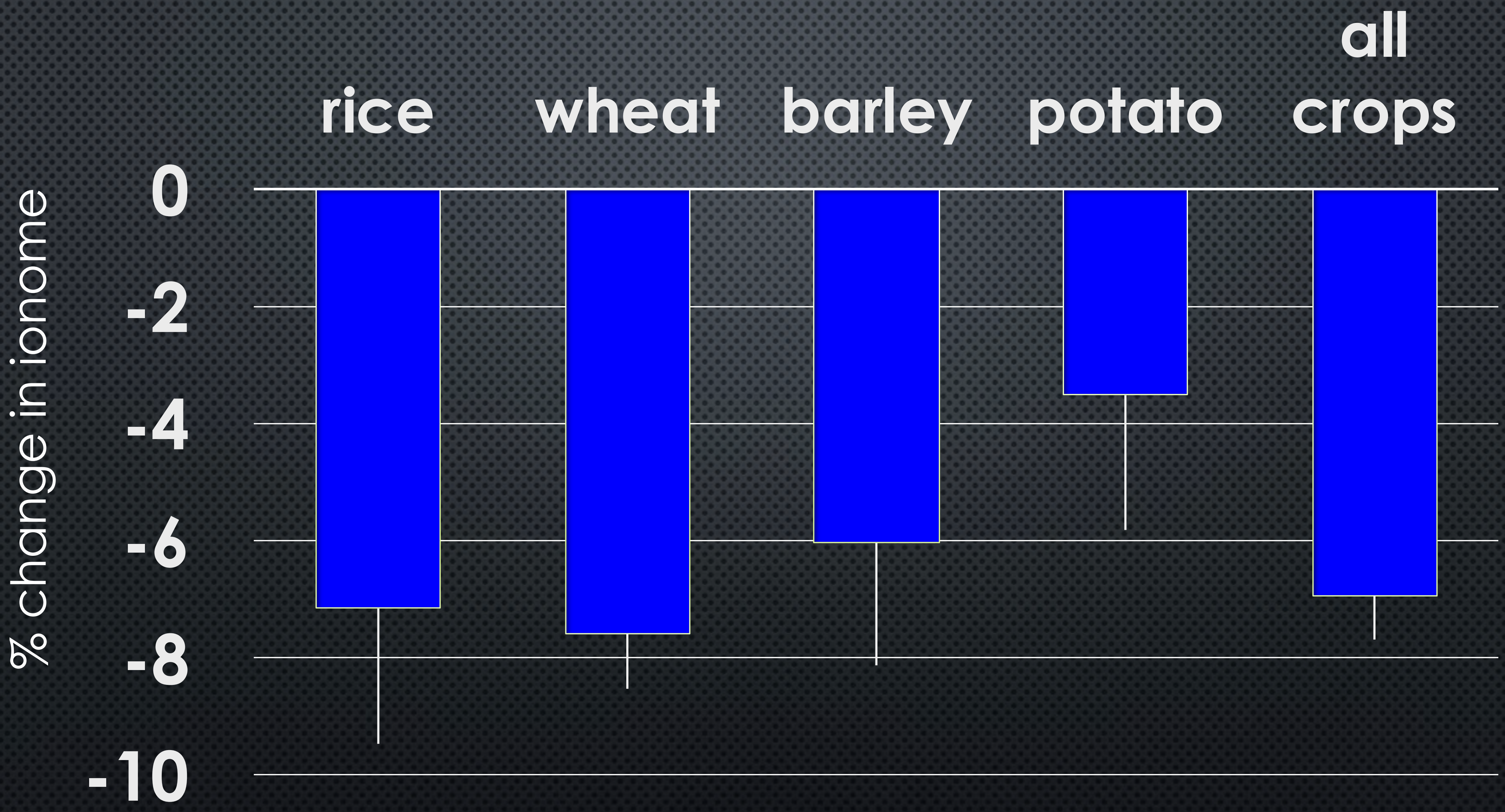
Locations of the FACE and Open Top Chamber (OTC) centers, which report concentrations of minerals in foliar or edible tissues, are shown as white dots inside colored circles. The area of a circle is proportional to the total number of observations (counting replicates) generated by the center. If the mean change is negative (decline in mineral content), the respective circle is blue; otherwise, it is red. The figure reflects data on 21 minerals in 57 plant species and cultivars. The shaded region (between 35 N and S latitudes) represents tropics and subtropics.

Loladze, I. (2014) Hidden shift of the ionome of plants exposed to elevated CO2 depletes minerals at the base of human nutrition. eLife, 1–30. doi:10.7554/eLife.02245



*The **ionome** is the mineral and trace element composition of an organism*

Loladze, I. (2014). Hidden shift of the ionome of plants exposed to elevated CO2 depletes minerals at the base of human nutrition. eLife, 1–30. doi:10.7554/eLife.02245



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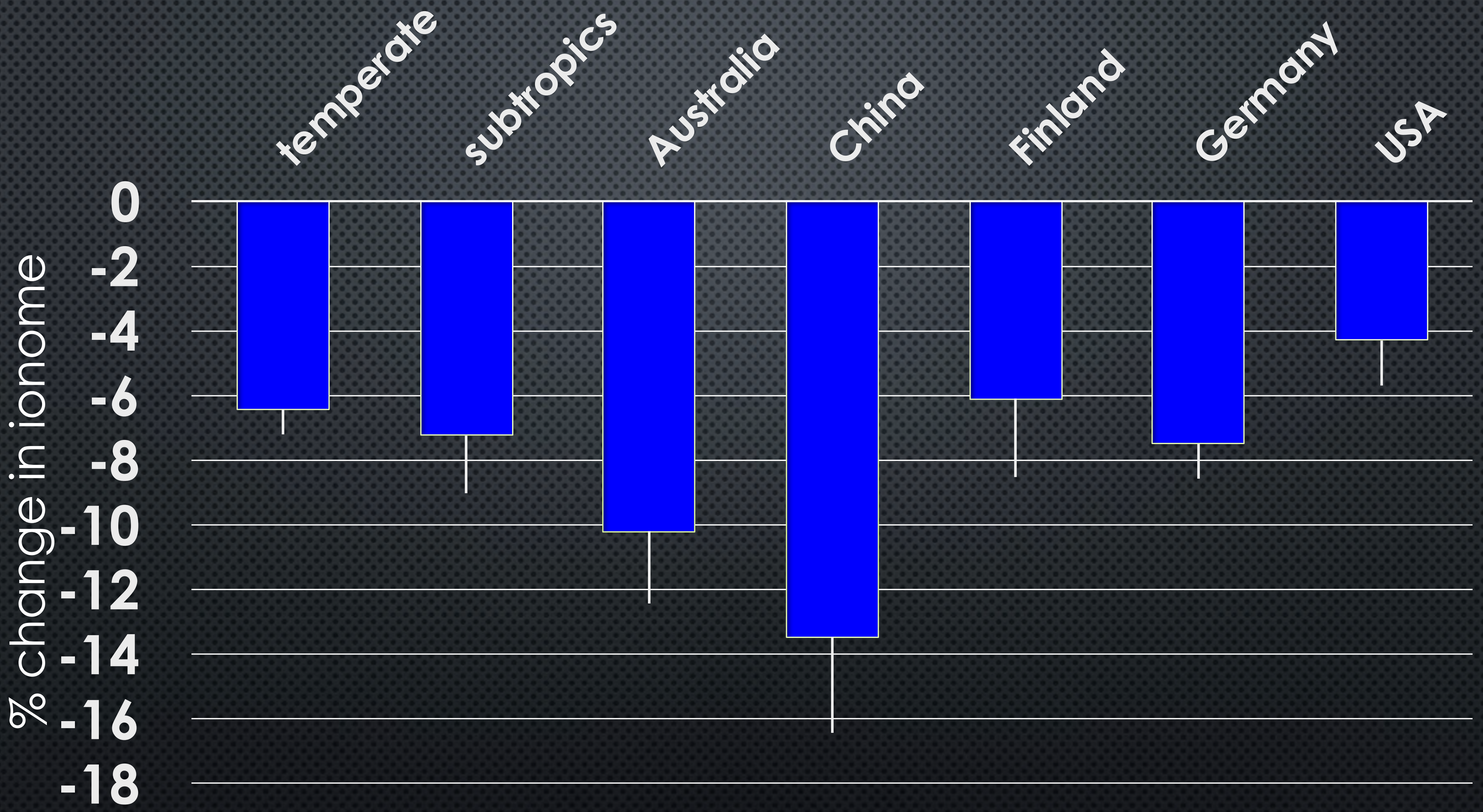

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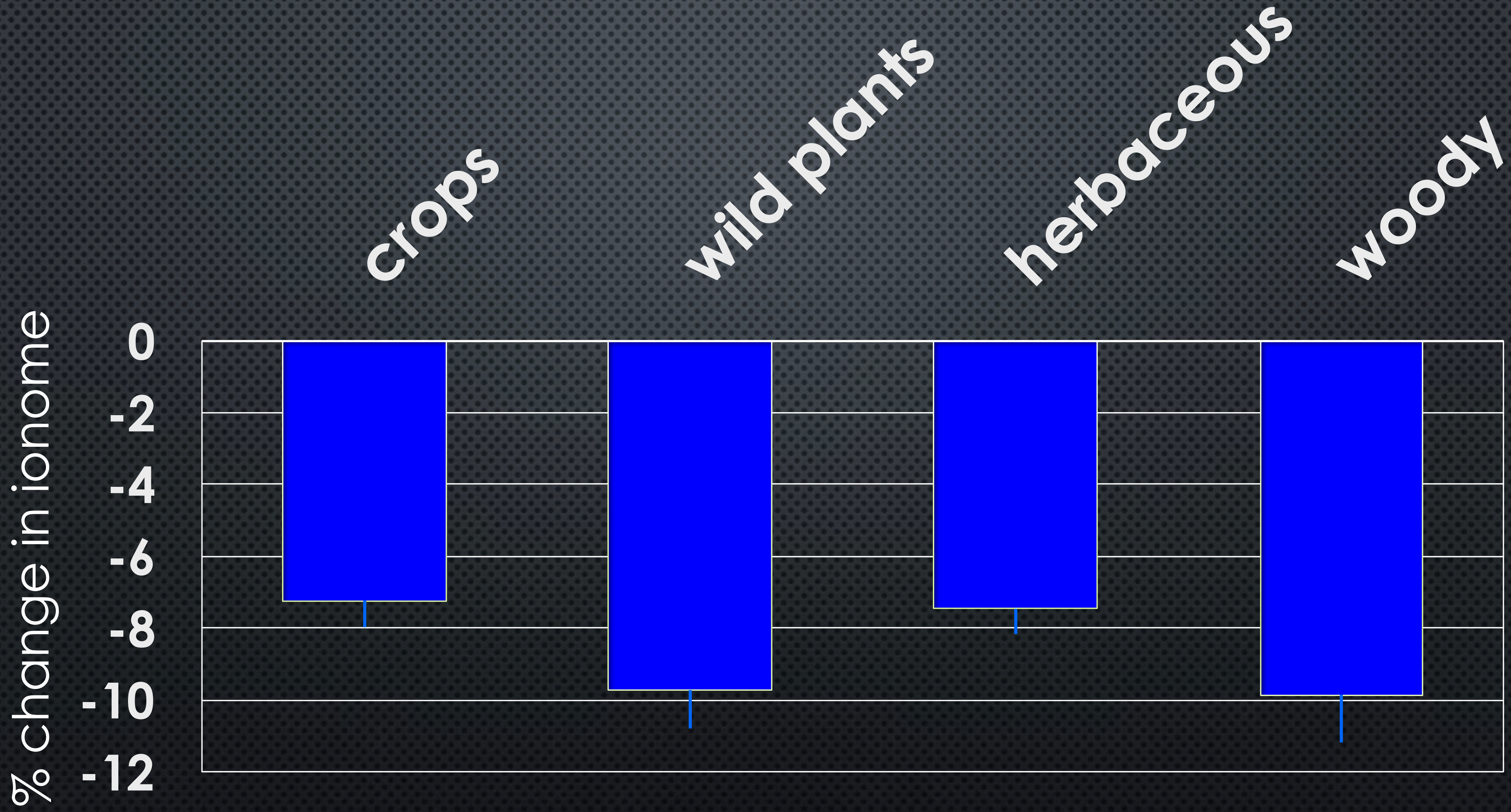


Loladze, I. (2014). Hidden shift of the ionome of plants exposed to elevated CO_2 depletes minerals at the base of human nutrition. eLife, 1–30. doi:10.7554/eLife.02245

THE EFFECT OF ELEVATED CO2 ON B VITAMINS IN RICE

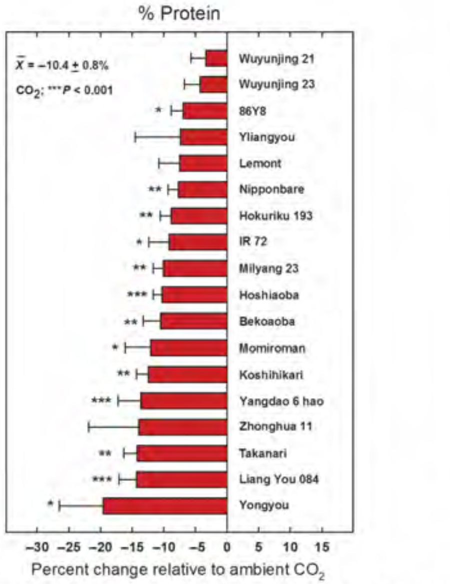


Fig. 1. Average reduction in grain protein at elevated relative to ambient $[CO_2]$ for 18 cultivated rice lines of contrasting genetic backgrounds grown in China and Japan using FACE technology. A country by $[CO_2]$ effect on protein reduction was not significant (P = 0.26). Bars are ±SE. *P < 0.05 and **P < 0.01 (see Methods for additional details).

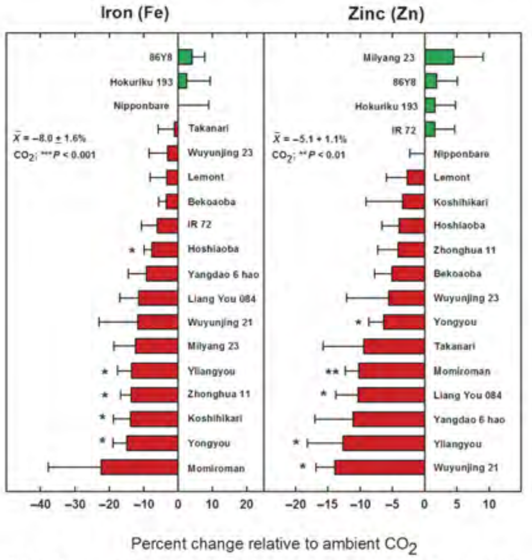


Fig. 2. Average reduction in grain micronutrients, iron (Fe), and zinc (Zn) concentration at elevated relative to ambient $[CO_2]$ for 18 cultivated rice lines of contrasting genetic backgrounds grown in China and Japan using FACE technology. A country by $[CO_2]$ effect was not significant for either micronutrient [P = 0.17 and 0.10 for iron (Fe) and zinc (Zn), respectively] so data from both locations are shown. Bars are ±SE. *P < 0.05 and **P < 0.01 for a given cultivar. CO_2; **P < 0.01 is based on all cultivars (see Methods for additional details).

SCIENCE ADVANCES | RESEARCH ARTICLE

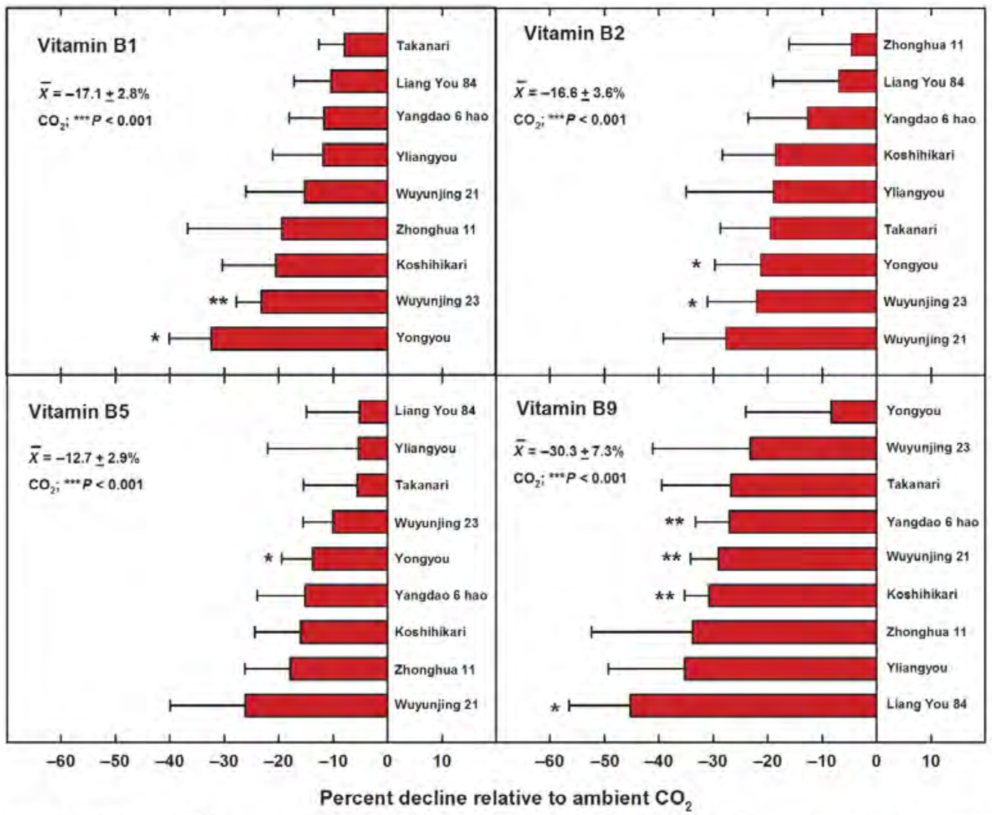


Fig. 3. CO_2-induced reductions in vitamins B1 (thiamine), B2 (riboflavin), B5 (pantothenic acid), and B9 (folate) by cultivar. No significant effect was observed for vitamin B6 (pyridoxine), and results are not shown. Analysis was conducted only for the China FACE location. Bars are ±SE. *P < 0.05 and **P < 0.01 for a given cultivar. CO_2; **P < 0.01 is based on all cultivars (see Methods for additional details).

Zhu, Kobayashi, … Ziska (2018). Carbon dioxide (CO2) levels this century will alter the protein , micronutrients , and vitamin content of rice grains with potential health consequences for the poorest rice-dependent countries. *Science Advances*, *4*(5), 1–9.

THE EFFECT OF ELEVATED CO2 ON PLANT CAROTENOIDS

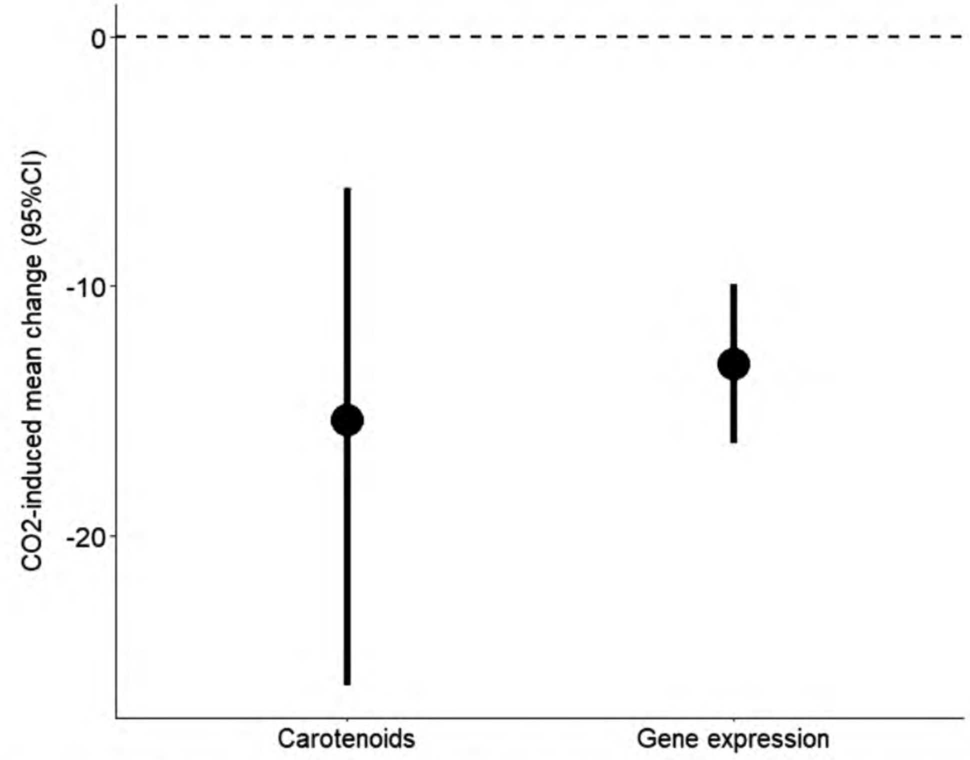
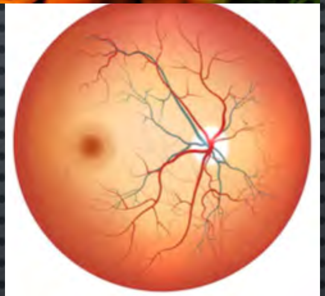


Figure 1. Elevated CO_2 effects on 1) carotenoid levels in plants (% change), and 2) the expression of genes involved in the carotenoid synthesis in *A. thaliana* (Log2FC values). The error bars indicate 95% confidence intervals.



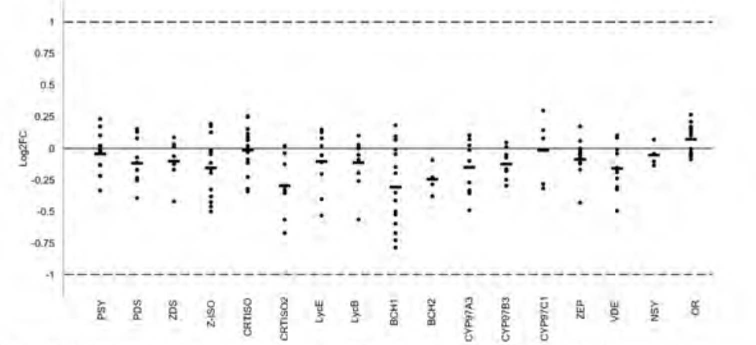


Figure 2. Log2FC values across nine CO_2 studies for *A. thaliana*. For each gene indicated along the x-axis, Log2FC values from individual datasets are plotted as dots. The mean Log2FC value for each gene is indicated as a short bar.

Loladze, I., Nolan, J. M., Ziska, L. H., & Knobbe, A. R. (2019). Rising Atmospheric CO2 Lowers Concentrations of Plant Carotenoids Essential to Human Health: A Meta-Analysis. *Molecular Nutrition & Food Research*, 63(15), e1801047.

FINAL THOUGHTS

- Biofortification and soil enrichment improve crop quality. However:

- Incentives in the Agriculture are based on YIELD.
- Farmers are paid for *Food* Quantity but NOT *Food Quality*
- As atmospheric CO2 levels keep rising, the nutrient density of most crops and wild plants will keep declining

- If we can change incentives to pay farmers for improved crop quality, we can start mitigating the negative effect of rising CO2 on plant quality and human nutrition