ENHANCEMENT OF FUNDAMENTAL PHOTOSYNTHETIC PROPERTIES, GROWTH AND YIELD IN MR219 AND MR263 RICE VARIETIES VIA EARLY-STAGE CO_2 ENRICHMENT BEFORE TRANSPLANTING

By

AZZAMI ADAM BIN MUHAMAD MUJAB

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

September 2022

FP 2022 63

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

ENHANCEMENT OF FUNDAMENTAL PHOTOSYNTHETIC PROPERTIES, GROWTH AND YIELD IN MR219 AND MR263 RICE VARIETIES VIA EARLY-STAGE CO_2 ENRICHMENT BEFORE TRANSPLANTING

By

AZZAMI ADAM MUHAMAD MUJAB

September 2022

Chairman : Muhammad Nazmin bin Yaapar, PhD
Faculty : Agriculture

Controlled environment systems such as glasshouses regularly utilise elevated CO_2 (eCO_2) to boost yield and quality in the production of high-value crops. Although this approach is quite commonly practised in commercial horticulture, its implementation on major crops such as rice is technically not feasible, especially elevating CO_2 throughout the production field for the entire life cycle of the crop. During the early stage of rice plant development, the structure of the leaf is sensitive to environmental factors, including responses to CO_2 levels. In this project, the response of rice seedlings exposed to eCO_2 only during the initial nursery phase before field transplant can have a lasting impact until the harvest period was investigated. The study aims include understanding the effects of early-stage eCO_2 treatment on rice growth, leaf stomatal properties, photosynthetic performance and yield components at the rice seedling stage and mature stage. This experiment used two local rice varieties, namely MR219 and MR263. Rice plants were grown in a two-stage procedure. First, seedlings were grown in DIY ambient CO_2 (400 ppm) and elevated CO_2 (~800 ppm) chambers for 24 days and then transplanted to a rain shelter structure where the plants were grown to harvest. The eCO_2 source came from the fermentation of a mixture of sugar, distilled water, and baker's yeast (*Saccharomyces cerevisiae*) granules. The first experiment showed that eCO_2 priming had significantly increased the seedling height (38-42%), the number of leaves (26-30%), leaf thickness (22-38%), leaf length (8-32%) and dry weight (58-69%) for MR219 and MR263 varieties. In general, eCO_2 treatment resulted in a larger stomatal complex (14-46%) and stomatal pore area dimensions (62-64%) with reduced stomatal density (11-19%) than aCO_2-grown leaves also in both varieties. Moreover, the intrinsic water use efficiency (iWUE) of eCO_2 leaves was also 38-68% higher in both MR219 and MR263. In terms of photosynthetic performance, the maximum assimilation rate (A_{max}), maximum Rubisco carboxylation rate (V_{cmax}), maximum electron transport rate (J_{max}), the quantum yield of PSII

(ΦPSII), and quantum yield of CO_2 assimilation (ΦCO_2) were significantly higher for eCO_2 rice seedlings than aCO_2 for both rice varieties. In the second experiment, significant photosynthetic parametres enhancement (A_{max}, J_{max}, ΦPSII, ETR, ΦCO_2) were quantified in eCO_2 MR263 flag leaves but not in MR219. Interestingly, both rice varieties' seedlings when exposed to eCO_2 maintained a significantly higher V_{cmax} (> 10%) during the mature phase of plant development than plants grown continuously under aCO_2. In terms of yield components, both varieties exposed to early-stage eCO_2 treatment showed a significantly 14-27% higher filled spikelet number per panicle, 3% higher 1000-grain weight, 11.5-12.5% increase in tillers and 10-12% panicles numbers per plant with significantly 5-6% lower plant height. The yield potential shows an increase of 4-7% for MR219 and MR263 eCO_2-treated seedlings compared to aCO_2. In conclusion, brief and targeted eCO_2 enhancement during the seedlings phase demonstrates a promising way of improving plant growth development, photosynthetic properties and rice yield performance. CO_2 priming has been suggested as a potential strategy for improving the productivity of rice crops, especially in regions where maintaining elevated CO_2 levels throughout the entire crop life cycle is not feasible or practical. By exposing rice plants to elevated CO_2 levels during their early growth stages, farmers may be able to take advantage of the benefits of CO_2 priming without having to maintain elevated CO_2 levels throughout the entire crop life cycle and, in turn, increase farmers' income. This study can contribute to the development of more sustainable and efficient agricultural practices that can meet the growing demand for food.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

PENINGKATAN SIFAT FOTOSINTETIK ASAS, PERTUMBUHAN DAN HASIL DALAM VARIETI PADI MR219 DAN MR263 MELALUI PENGAYAAN CO_2 PERINGKAT AWAL KEPADA SEMAIAN SEBELUM DIPINDAHKAN

Oleh

AZZAMI ADAM BIN MUHAMAD MUJAB

September 2022

Pengerusi : Muhammad Nazmin bin Yaapar, PhD
Fakulti : Pertanian

Sistem persekitaran terkawal seperti rumah kaca kerap menggunakan CO_2 tinggi (eCO_2) untuk meningkatkan hasil dan kualiti dalam pengeluaran tanaman bernilai tinggi. Walaupun pendekatan ini agak biasa diamalkan dalam hortikultur komersial, pelaksanaannya pada tanaman utama seperti padi secara teknikalnya tidak boleh dilaksanakan, terutamanya meningkatkan CO_2 di seluruh ladang pengeluaran untuk sepanjang kitaran hayat tanaman. Semasa peringkat awal perkembangan pokok padi, struktur daun adalah sensitif terhadap faktor persekitaran, termasuk tindak balas terhadap paras CO_2. Dalam projek ini, tindak balas anak benih padi yang terdedah kepada eCO_2 hanya semasa fasa awal sebelum pemindahan ladang boleh memberi impak yang berpanjangan sehingga ke dalam tempoh penuaian telah dikaji. Kajian ini bertujuan untuk memahami kesan rawatan eCO_2 di peringkat awal terhadap pertumbuhan padi, sifat stomata daun, prestasi fotosintesis dan komponen hasil pada peringkat anak benih padi dan peringkat matang. Eksperimen ini menggunakan dua jenis padi tempatan iaitu MR219 dan MR263. Pokok padi ditanam dalam dua peringkat prosedur. Pertama, anak benih ditanam dalam ruang ambien DIY (aCO_2) dan CO_2 tinggi (~800 ppm) selama 24 hari dan kemudian dipindahkan ke struktur perlindungan hujan di mana tumbuhan ditanam sehingga penuaian. Sumber eCO_2 yang digunakan berasal daripada penapaian campuran gula, air suling, dan butiran yis pembakar (*Saccharomyces cerevisiae*). Eksperimen pertama menunjukkan bahawa rawatan eCO_2 telah meningkatkan ketinggian anak benih dengan ketara (38-42%), bilangan daun (26-30%), ketebalan daun (22-38%), panjang daun (8-32%) dan berat kering (58-69%) untuk varieti MR219 dan MR263. Secara amnya, rawatan eCO_2 menyebabkan stomata kompleks yang lebih besar (14-46%) dan dimensi kawasan liang stomata (62-64%) dengan ketumpatan stomata yang berkurangan (11-19%) daripada daun aCO_2 juga untuk kedua-dua varieti. Selain itu, kecekapan penggunaan air intrinsik (iWUE) daun eCO_2 juga adalah 38-68% lebih tinggi untuk MR219 dan MR263.

Dari segi prestasi fotosintesis, kadar asimilasi maksimum (A_{max}), kadar karboksilasi Rubisco maksimum (V_{cmax}), kadar pengangkutan elektron maksimum (J_{max}), hasil kuantum PSII (ΦPSII), dan hasil kuantum asimilasi CO_2 ($ΦCO_2$) adalah ketara lebih tinggi untuk anak benih padi eCO_2 daripada aCO_2 untuk kedua-dua varieti padi. Dalam eksperimen kedua, peningkatan parameter fotosintesis yang ketara (A_{max}, J_{max}, ΦPSII, ETR, $ΦCO_2$) diperoleh dalam daun pengasuh eCO_2 MR263 tetapi tidak pada MR219. Menariknya, kedua-dua anak benih varieti padi apabila terdedah kepada eCO_2 mengekalkan V_{cmax} yang jauh lebih tinggi (> 10%) semasa fasa matang berbanding tanaman yang ditanam secara berterusan dengan aCO_2. Dari segi komponen hasil, kedua-dua varieti yang terdedah kepada rawatan eCO_2 peringkat awal menunjukkan bilangan bulir biji padi terisi yang ketara 14-27% lebih tinggi bagi setiap tangkai, berat 1000 biji 3% lebih tinggi, peningkatan 11.5-12.5% dalam bilangan anak pokok dan peningkatan 10-12% bilangan tangkai bagi setiap rumpun dengan ketinggian pokok 5-6% lebih rendah dengan ketara berbanding aCO_2. Potensi hasil menunjukkan peningkatan sebanyak 4-7% untuk anak benih MR219 dan MR263 yang dirawat eCO_2 berbanding dengan aCO_2. Secara kesimpulannya, rawatan peningkatan CO_2 yang disasarkan semasa fasa awal anak benih padi mampu menjanjikan peningkatan pertumbuhan tanaman padi, tambahbaik ciri-ciri fotosintetik dan prestasi hasil padi. Rawatan eCO_2 pada peringkat awal ini dicadangkan sebagai strategi yang berpotensi untuk meningkatkan produktiviti tanaman padi, ini memandangkan mengekalkan tahap CO_2 yang tinggi sepanjang kitaran hidup tanaman padi adalah tidak praktikal. Petani mungkin dapat mengambil keuntungan dari manfaat dengan kaedah ini tanpa perlu mengekalkan tahap CO_2 yang tinggi sepanjang kitaran hidup tanaman padi dan pada masa yang sama dapat meningkatkan pendapatan petani. Kajian ini dapat menyumbang kepada pembangunan amalan pertanian yang lebih mampan dan efisyen yang dapat memenuhi permintaan makanan yang semakin meningkat.

ACKNOWLEDGEMENTS

First and foremost I would like to take this opportunity to express my utmost appreciation to my dedicated supervisor, Dr Nazmin Yaapar. Thank you for allowing me to gain invaluable experiences in conducting my Master's study. Also, thank you for the productive discussions, valuable teaching and shared a lot of her expertise, research insight and ideas for my research. I owed my indebtedness and gratitude to Dr Mashitah Jusoh for her encouragement, insightful comments and give suggestions and feedback in improving my research. I would like to thank MARDI, UPM, and the University of Sheffield, UK for providing research facilities to conduct my Master's study. To my colleagues from Genbank & Seed Centre MARDI, thank you for your support and advice. They have been there from the start until the finishing end of my Master's study. Last but not least, I would like to dedicate my heartfelt thanks to my beloved and wonderful wife, daughter, parents and family members, who deserve special attention for their unconditional love, supports and encouragement that have kept me going on until the end.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Muhammad Nazmin Yaapar, PhD
Senior Lecturer
Faculty of Agriculture
Universiti Putra Malaysia
(Chairman)

Mashitah Jusoh, PhD
Senior Lecturer
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

Muhammad Saiful Ahmad Hamdani, PhD
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 11 May 2023

Declaration by the Graduate Student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software

Signature: ______________________ Date: ______________

Name and Matric No: Azzami Adam Muhamad Mujab

Declaration by Members of the Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature:	
Name of Chairman of Supervisory Committee:	Dr. Muhammad Nazmin Yaapar
Signature:	
Name of Member of Supervisory Committee:	Dr. Mashitah Jusoh
Signature:	
Name of Member of Supervisory Committee:	Associate Professor Dr. Muhammad Saiful Ahmad Hamdani

TABLE OF CONTENTS

Page

CHAPTER

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

%	percentage
3-PGA	3-phosphoglyceric acid
A/C_i	Assimilation versus intercellular CO_2 response curve
A400	Assimilation rate at 400 ppm CO_2
aCO_2	Ambient Carbon Dioxide
A_{max}	Maximum rate of assimilation
ATP	Adenosine triphosphate
$C_6H_{12}O_6$	Glucose
C_i	Intercellular Carbon Dioxide
cm	Centimetre
CO_2	Carbon dioxide
CO_2_R	Carbon dioxide reference
D	Dimension
DAS	Day after sowing
eCO_2	Elevated Carbon Dioxide
ETC	Electron transport chain
ETR	Electron transfer rate
ETR_{max}	Maximum electron transfer rate
Eq.	Equation
FACE	Free-Air Carbon dioxide Enrichment
FAO	Food and Agriculture Organization
g	Gram
G3P	Glyceraldehyde-3-phosphate
GMC	Guard mother cells
g_s	Stomatal conductance

g_{smax}	Maximum stomatal conductance
H^+	Hydrogen ion
IG	Interveinal gap
IRGA	Infra-red gas analyser
200IRRI	International rice research institute
iWUE	Intrinsic water use efficiency
$iWUE_{max}$	Maximum intrinsic water use efficiency
J_{max}	Maximum light and CO2 saturated electron transport rate
kPa	Kilopascal
l	Litre
LED	Light-emitting diode
LRC	Light response curve
m	Meter
MARDI	Malaysian Agricultural Research and Development Institute
mm	Millimetre
mm^{-2}	Millimetre square
MOP	Muriate of potash
MR	MARDI Rice
NADPH	Nicotinamide adenine dinucleotide phosphate
nm	Nanometer
NPK	Nitrogen, phosphorus, and potassium
O_2	Oxygen
^oC	Degree Celsius
OECD	Organisation for Economic Co-operation and Development
PAR	Photosynthetically active radiation
PFD	Photon flux density
PPFD	Photosynthetic photon flux density

ppm	Part per million
PSI	Photosystem I
PSII	Photosystem II
PVC	Polyvinyl chloride
Rd	Dark respiration
rpm	Revolutions per minute
Rubisco	Ribulose-1,5-bisphosphate carboxylase-oxygenase
RuBP	Ribulose-1,5-bisphosphate
SCA	Stomatal complex area
SCL	Stomatal complex length
SCW	Stomatal complex width
SD	Stomatal density
SMC	Subsidiary mother cells
SPA	Stomatal pore area
SPAD	Soil plant analysis development
TE	Trace element
TPU	Triose phosphate utilization
TSP	Triple superphosphate
UN	United nation
V_{cmax}	Maximum Rubisco carboxylation rate
W	Width
α	Alpha
β	Beta
µmol	Micromole
$\mu mol\ m^{-2}\ s^{-1}$	Micromol per meter square per second
ΦCO_2	Quantum yield of CO2 assimilation

$\Phi CO_{2,2500}$	Quantum yield of CO2 assimilation at 2500 µmol photon m^{-2} s^{-1}
ΦPSII	Quantum yield of Photosystem II
$\Phi PSII_{2500}$	Quantum yield of Photosystem II at 2500 µmol photon m^{-2} s^{-1}
Φ	Phi

CHAPTER 1

INTRODUCTION

1.1 Background

Rice (*Oryza sativa* L.) is indeed an important cereal for its role as the staple food for almost half of the world's population (Sekhar, 2018). GRiSP (2013) reported that over half of the world's population relies on rice for at least 20% of their daily caloric intake. However, rice production is not keeping pace with the demand stemming from the ever-rising global human population. As a result, agricultural productivity is in the need to improve remarkably to cater for the hungry people who are going to reach 9.9 billion by 2050, an increase of more than 25% from the current population of around 7.8 billion (PRB, 2021) .

CO_2 is one of the substrates that limits photosynthesis, particularly in the C3 plant system living at the current CO_2 level. Thus increasing CO_2 levels in crop production has been employed as a way to enhance the carboxylation rate of photosynthesis while minimizing photorespiration through oxygenation reaction suppression of Rubisco (Bhagat et al., 2014). This simple method increases photosynthesis efficiency which generally results in better plant performance that leads to a higher yield (Sakai et al., 2019; Usui et al., 2016). In the Free-Air Carbon dioxide Enrichment (FACE) experiment, elevated CO_2 (eCO_2) will promote the net photosynthetic of the plant and thus plant productivity, according to Long et al., 2004 and Leakey et al., 2009. eCO_2 also has been used widely for many years as a CO_2 gas fertilizer to increase photosynthetic performance and yield in vegetables and high-value crops grown in greenhouses (Bisbis et al., 2018).

1.2 Problem Statement

The CO_2 enrichment method is relatively common in commercial horticultural crop production, due to the massive areas involved in major food crops such as rice, it is technically not feasible to elevate CO_2 throughout the whole rice crop life cycle. In addition, large-scale manipulation of atmospheric CO_2 levels is not practical or economically feasible. Furthermore, rice is a unique crop that is typically grown in flooded paddies, which complicates attempts to manipulate CO_2 levels. The flooded fields make it difficult to regulate CO_2 levels within the rice canopy, as the water covering the fields can trap and release CO_2 at different rates, making it difficult to maintain consistent CO_2 levels. Given these limitations, CO_2 priming is suggested as a potential alternative to continuous CO_2 elevation for rice crops.

Early-stage CO_2 enrichment or CO_2 priming is a technique that involves exposing crops to elevated levels of carbon dioxide (CO_2) for a short period during their early growth stages. The idea behind this technique is that by subjecting plants to higher concentrations of CO_2 early on, they can become more efficient at utilizing CO_2 throughout their life cycle, even when grown under normal CO_2 concentrations. This technique can help to increase rice yields and improve crop productivity more practically and sustainably.

1.3 Objectives

In this study, we aim to investigate the effects of early-stage CO_2 enrichment on fundamental photosynthetic properties, growth, and yield in two rice varieties, MR219 and MR263. The objective of this study is:

1. To evaluate how eCO_2 influences rice seedling establishment before they could be transplanted into the field for MR219 and MR263 rice varieties.
2. To assess the efficacy of growing rice in eCO_2 during the seedling stage in improving rice harvest components in both MR219 and MR263 rice varieties.

The results of this study could have significant implications for rice production and food security in the face of climate change. By identifying a potential method for enhancing the efficiency of photosynthesis and improving growth and yield in rice plants, this study may contribute to the development of more sustainable and efficient agricultural practices that can meet the growing demand for food.

REFERENCES

Abzar, A., Nizam, M., Said, M., Juliana, W., Ahmad, W., Mohtar, W., & Yusoff, W. (2017). Elevated CO_2 concentration enhance germination, seedling growth and vigor of rice. *Ecology,Environment and Conservation*, *23*(3), 41–45.

Ainsworth, E. A., & Long, S. P. (2005). What have we learned from 15 years of free-air CO_2 enrichment (FACE)?A meta-analytic review of the responses of photosynthesis, canopy properties and plant production to rising CO_2. *New Phytologist*, *165*, 351–372.

Ainsworth, E. A., & Rogers, A. (2007). The response of photosynthesis and stomatal conductance to rising [CO_2]: Mechanisms and environmental interactions. *Plant, Cell and Environment*, *30*(3), 258–270. https://doi.org/10.1111/j.1365-3040.2007.01641.x

Ainsworth, E. A., Rogers, A., & Leakey, A. D. B. (2008). Targets for crop biotechnology in a future high-CO_2 and high-O_3 world. *Plant Physiology*, *147*(1), 13–19. https://doi.org/10.1104/PP.108.117101

Alberts, B., Johnson, A., Lewis, J., Raff, M., Roberts, K., & Walter, P. (2002). *Chloroplasts and Photosynthesis*. Molecular Biology of the Cell; Garland Science. https://www.ncbi.nlm.nih.gov/books/NBK26819/

Aranjuelo, I., Erice, G., Sanz-sáez, A., Abadie, C., Gilard, F., Gil-quintana, E., Avice, J., Ucbn, I., Biologie, I. De, & Basse-normandie, U. D. C. (2015). Differential CO_2 effect on primary carbon metabolism of flag leaves in durum wheat (*Triticum durum* Desf .). *Plant Cell and Environment*, *38*, 2780–2794. https://doi.org/10.1111/pce.12587

Bacon, M, A. (2004). *Water Use Efficiency in Plant Biology* (A. Bacon, M (ed.)). CRC Press.

Badger, M. R., & Price, G. D. (2003). CO_2 concentrating mechanisms in cyanobacteria: molecular components, their diversity and evolution. *Journal of Experimental Botany*, *54*(383), 609–622. https://doi.org/10.1093/JXB/ERG076

Beerling, D. J., McElwain, J. C., & Osborne, C. P. (1998). Stomatal responses of the “living fossil” *Ginkgo biloba* L. to changes in atmospheric CO_2 concentrations. *Journal of Experimental Botany*, *49*(326), 1603–1607. https://doi.org/10.1093/jxb/49.326.1603

Bergmann, D. C., & Sack, F. D. (2007). Stomatal development. *Annual Review of Plant Biology*, *58*(December 2006), 163–181. https://doi.org/10.1146/annurev.arplant.58.032806.104023

Berry, M. P. (2013). Lodging Resistance in Cereals Lodging. In P. Christou (Ed.), *Sustainable Food Production* (pp. 1096–1110). Springer Science. https://doi.org/10.1007/978-1-4614-5797-8

Bertolino, L. T., Caine, R. S., Gray, J. E., & Gray, J. E. (2019). Impact of Stomatal Density and Morphology on Water-Use Efficiency in a Changing World. *Frontiers in Plant Science*, *10*(March). https://doi.org/10.3389/fpls.2019.00225

Bhagat, K. P., Kumar, R. A., Ratnakumar, P., Kumar, S., Bal, S. K., & Agrawal, P. K. (2014). Photosynthesis and associated aspects under abiotic stresses environment. *Approaches to Plant Stress and Their Management*, 191–205. https://doi.org/10.1007/978-81-322-1620-9_10

Bisbis, M. B., Gruda, N., & Blanke, M. (2018). Potential impacts of climate change on vegetable production and product quality – A review. *Journal of Cleaner Production*, *170*, 1602–1620. https://doi.org/10.1016/j.jclepro.2017.09.224

Bishop, K. A., Betzelberger, A. M., Long, S. P., & Ainsworth, E. A. (2015). Is there potential to adapt soybean (*Glycine max* Merr.) to future [CO_2]? An analysis of the yield response of 18 genotypes in free-air CO2 enrichment. *Plant Cell and Environment*, *38*(9), 1765–1774. https://doi.org/10.1111/pce.12443

Black, C. ., Tu, Z.-P., Counce, P. A., Yao, P.-F., & Angelov, M. N. (1995). An integration of photosynthetic traits and mechanisms that can increase crop photosynthesis and grain production. *Photosynthesis Research*, *46*, 169–175.

Bowes, G. (1991). Growth at elevated CO_2 : photosynthetic responses mediated through Rubisco. *Plant Cell and Environment*, *14*, 795–806.

Brestic, M., & Zivcak, M. (2013). PSII fluorescence techniques for measurement of drought and high temperature stress signal in crop plants: Protocols and applications. In G. R. Rout & A. B. Das (Eds.), *Molecular Stress Physiology of Plants* (pp. 87–131). Springer Dordrecht. https://doi.org/10.1007/978-81-322-0807-5_4

Broberg, M. C., Högy, P., Feng, Z., & Pleijel, H. (2019). Effects of Elevated CO_2 on Wheat Yield : Non-Linear Response and Relation to Site Productivity. *Agronomy*, *9*(243), 1–18.

Broeckx, L. S., Fichot, R., Verlinden, M. S., & Ceulemans, R. (2014). Seasonal variations in photosynthesis, intrinsic water-use efficiency and stable isotope composition of poplar leaves in a short-rotation plantation. *Tree Physiology*, *34*(7), 701–715. https://doi.org/10.1093/treephys/tpu057

Buckley, C. R., Caine, R. S., & Gray, J. E. (2020). Pores for Thought: Can Genetic Manipulation of Stomatal Density Protect Future Rice Yields? *Frontiers in Plant Science*, *0*, 1783. https://doi.org/10.3389/FPLS.2019.01783

Bunce, J. A. (2017). Variation in yield responses to elevated CO_2 and a brief high temperature treatment in quinoa. *Plants*, *6*(3), 442–453. https://doi.org/10.3390/plants6030026

Carmo-silva, E., Andralojc, P. J., Scales, J. C., Driever, S. M., Mead, A., Lawson, T., Raines, C. A., & Parry, M. A. J. (2017). Phenotyping of field-grown wheat in the UK highlights contribution of light response of photosynthesis and flag leaf longevity to grain yield. *Journal of Experimental Botany*, *68*(13), 3473–3486. https://doi.org/10.1093/jxb/erx169

Chan, C. S., & Daud, A. H. (2016). *Manual Teknologi Pencedungan Padi Secara Mekanikal*. Institut Penyelidikan dan Kemajuan Pertanian Malaysia.

Chaturvedi, A. K., Bahuguna, R. N., Shah, D., Pal, M., & Krishna, S. V. (2017). High temperature stress during flowering and grain filling offsets beneficial impact of elevated CO_2 on assimilate partitioning and sink-strength in rice. *Scientific Reports*, *April*, 1–13. https://doi.org/10.1038/s41598-017-07464-6

Cheng-Jiang Ruan, Hong-Bo Shao, & Jaime A. Teixeira da Silva. (2012). A critical review on the improvement of photosynthetic carbon assimilation in C3 plants using genetic engineering. *Critical Reviews in Biotechnology*, *32*(1), 1–21. https://ripe.illinois.edu/sites/ripe.illinois.edu/files/2018-06/A critical review on the improvement of photosynthetic carbon assimilation in C3 plants using genetic engineering.pdf

Croft, H., Chen, J. M., Luo, X., Bartlett, P., Chen, B., & Staebler, R. M. (2017). Leaf chlorophyll content as a proxy for leaf photosynthetic capacity. *Global Change Biology*, *23*(9), 3513–3524. https://doi.org/10.1111/ijlh.12426

Demirel, Y. (2014). Thermodynamics and Biological Systems. *Nonequilibrium Thermodynamics*, 485–562. https://doi.org/10.1016/B978-0-444-59557-7.00011-4

Ding, Y., Fromm, M., & Avramova, Z. (2012). Multiple exposures to drought “train” transcriptional responses in Arabidopsis. *Nature Communications*. https://doi.org/10.1038/ncomms1732

Driscoll, S. P., Prins, A., Olmos, E., Kunert, K. J., & Foyer, C. H. (2006). Specification of adaxial and abaxial stomata, epidermal structure and photosynthesis to CO_2 enrichment in maize leaves. *Journal of Experimental Botany*, *57*(2), 381–390. https://doi.org/10.1093/jxb/erj030

Ent, S. Van Der, Wees, S. C. M. Van, & Pieterse, C. M. J. (2009). Phytochemistry Jasmonate signaling in plant interactions with resistance-inducing beneficial microbes. *Phytochemistry*, *70*(13–14), 1581–1588. https://doi.org/10.1016/j.phytochem.2009.06.009

ESRL. (2021). *Trends in atmospheric carbon dioxide-monthly average Mauna Loa CO_2*. Global Monitoring Laboratory. www.esrl.noaa.gov/gmd/ccgg/trends/

Ethier, G. J., & Livingston, N. J. (2004). *On the need to incorporate sensitivity to CO_2 transfer conductance into the Farquhar – von Caemmerer – Berry leaf*.

Evans, J. R. (2013). Improving Photosynthesis. *Plant Physiology*, *162*(4), 1780. https://doi.org/10.1104/PP.113.219006

Fageria, N. K. (2007). Yield Physiology of Rice. *Journal of Plant Nutrition*, *30*(6), 843–879. https://doi.org/10.1080/15226510701374831

FAO. (2016). *The State of Food and Agriculture: Climate Change, Agriculture and Food Security*.

FAO. (2020). *Production/Yield quantities of rice, paddy in Malaysia*. http://www.fao.org/faostat/en/#country/131

Gamage, D., Thompson, M., Sutherland, M., Hirotsu, N., Makino, A., & Seneweera, S. (2018). New insights into the cellular mechanisms of plant growth at elevated atmospheric carbon dioxide concentrations. *Plant Cell and Environment*, *41*(6), 1233–1246. https://doi.org/10.1111/pce.13206

Garcia, D., Zhao, S., Arif, S., Zhao, Y., Chau, L., & Huang, D. (2021). Seed priming technology as a key strategy to increase crop plant production under adverse environmental conditions. *Preprints*, *September*, 1–35. https://doi.org/10.20944/preprints202109.0364.v1

Ge, S., Sang, T., Lu, B. R., & Hong, D. Y. (1999). Phylogeny of rice genomes with emphasis on origins of allotetraploid species. *Proceedings of the National Academy of Sciences of the United States of America*, *96*(25), 14400–14405. https://doi.org/10.1073/pnas.96.25.14400

Gimenez, C., Gallardo, M., & Thompson, R. B. (2013). Plant–Water Relations´. In *Reference Module in Earth Systems and Environmental Sciences* (Issue May, pp. 1–8). Elsevier. https://doi.org/10.1016/B978-0-12-409548-9.05257-X

Goel, S., & Agarwal, D. (2014). Carbon Dioxide. In *Encyclopedia of Toxicology: Third Edition* (Third Edit, Vol. 1). Elsevier. https://doi.org/10.1016/B978-0-12-386454-3.00269-4

Gratani, L. (2014). Plant Phenotypic Plasticity in Response to Environmental Factors. *Advances in Botany*, *2014*, 1–17. https://doi.org/10.1155/2014/208747

Gray, J. E., Holroyd, G. H., Van Der Lee, F. M., Bahrami, A. R., Sijmons, P. C., Woodward, F. I., Schuch, W., & Hetherington, A. M. (2000). The HIC signalling pathway links CO_2 perception to stomatal development. *Nature*, *408*(6813), 713–716. https://doi.org/10.1038/35047071

GRiSP. (2013). Rice Almanac. In *IRRI, Los Baños, Philippines*. https://doi.org/10.1093/aob/mcg189

Hanley, M., Fenner, M., Whibley, H., & Darvill, B. (2004). Early plant growth : identifying the end point of the seedling phase. *New Phytologist*, *163*, 61–66. https://doi.org/10.1111/j.1469-8137.2004.01094.x

Haworth, M., Marino, G., & Centritto, M. (2018). An introductory guide to gas exchange analysis of photosynthesis and its application to plant phenotyping and precision irrigation to enhance water use efficiency. *Journal of Water and Climate Change*, *October*, 1–23. https://doi.org/10.2166/wcc.2018.152

Haworth, M., Marino, G., Loreto, F., & Centritto, M. (2021). Integrating stomatal physiology and morphology : evolution of stomatal control and development of future crops. *Oecologia*, *197*(4), 867–883. https://doi.org/10.1007/s00442-021-04857-3

Heineke, D., & Scheibe, R. (2009). Photosynthesis: The Calvin Cycle. *ELS*. https://doi.org/10.1002/9780470015902.A0001291.PUB2

Herrmann, H. A., Schwartz, J. M., & Johnson, G. N. (2020). From empirical to theoretical models of light response curves - linking photosynthetic and metabolic acclimation. *Photosynthesis Research*, *145*(1), 5–14. https://doi.org/10.1007/S11120-019-00681-2/figures/4

Hilker, M., & Schmülling, T. (2019). Stress priming, memory, and signalling in plants. *Plant Cell and Environment*, *42*(3), 753–761. https://doi.org/10.1111/pce.13526

Hilker, M., Schwachtje, J., Baier, M., Balazadeh, S., Isabel, B., Geiselhardt, S., Hincha, D. K., Kunze, R., Mueller-roeber, B., Rillig, M. C., Rolff, J., Romeis, T., Schm, T., Steppuhn, A., Dongen, J. Van, Whitcomb, S. J., Wurst, S., Zuther, E., & Kopka, J. (2015). Priming and memory of stress responses in organisms lacking a nervous system. *Biological Reviews*. https://doi.org/10.1111/brv.12215

Hincha, D. K., & Zuther, E. (2014). Introduction: Plant Cold Acclimation and Freezing Tolerance. In *Plant Cold Acclimation: Methos and Protocols, Methods in Molecular Biology* (Vol. 1166, pp. 255–277). Springer Science. https://doi.org/10.1007/978-1-4939-0844-8

Hogy, P., Wieser, H., Kohler, P., Schwadorf, K., Breuer, J., Franzaring, J., Muntifering, R., & Fangmeier, A. (2009). Effects of elevated CO_2 on grain yield and quality of wheat : results from a 3-year free-air CO2 enrichment experiment. *Plant Biology*, *11*, 60–69. https://doi.org/10.1111/j.1438-8677.2009.00230.x

Honda, S., Ohkubo, S., San, N. S., Nakkasame, A., & Tomisawa, K. (2021). Maintaining higher leaf photosynthesis after heading stage could promote biomass accumulation in rice. *Scientific Reports*, 1–11. https://doi.org/10.1038/s41598-021-86983-9

Hu, S., Chen, W., Tong, K., Wang, Y., Jing, L., Wang, Y., & Yang, L. (2022). Response of rice growth and leaf physiology to elevated CO_2

concentrations : A meta-analysis of 20-year FACE studies. *Science of the Total Environment*, *807*(151017), 1–13. https://doi.org/10.1016/j.scitotenv.2021.151017

Huang, M. Y., Wong, S. L., & Weng, J. H. (2021). Rapid Light-Response Curve of Chlorophyll Fluorescence in Terrestrial Plants: Relationship to CO_2 Exchange among Five Woody and Four Fern Species Adapted to Different Light and Water Regimes. *Plants 2021, Vol. 10, Page 445*, *10*(3), 445. https://doi.org/10.3390/plants10030445

Hubbart, S., Bird, S., Lake, J. A., & Murchie, E. H. (2013). Does growth under elevated CO_2 moderate photoacclimation in rice? *Physiologia Plantarum*, *148*(2), 297–306. https://doi.org/10.1111/j.1399-3054.2012.01702.x

Hussain Zainudin, P. M D Mokhtar, A., Amzah, B., Hashim, M., & Ghafar, B. A. (2012). Six MARDI popular rice varieties. In *Buletin Teknologi MARDI* (Vol. 1, pp. 1–10).

Hussain Zainudin, P. M. D., Sunian, E., Shaari, A., Ismail, A., Abdullah, S., Omar, O., Hashim, H., Ramli, A., Mohd Yusof, M. N., Misman, S. N., & Mokhtar, A. (2012). MR 263 new rice variety for moderate fertile area. In *Buletin Teknologi MARDI* (Vol. 1, pp. 33–40).

IPCC. (2013). Summary for Policymakers. In T. F. Stocker, D. Qin, G. K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, & P. M. Midgley (Eds.), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 3–29). Cambridge University Press.

IRRI. (2015a). *Crop calendar*. IRRI Rice Knowledge Bank.

IRRI. (2015b). *Steps to successful rice production.* International Rice Research Institute.

Jablonski, L. M., Wang, X., & Curtis, P. S. (2002). Plant reproduction under elevated CO_2 conditions: A meta-analysis of reports on 79 crop and wild species. *New Phytologist*, *156*(1), 9–26. https://doi.org/10.1046/j.1469-8137.2002.00494.x

Jagadish, S. V. K., Bahuguna, R. N., & Djanaguiraman, M. (2016). Implications of High Temperature and Elevated CO_2 on Flowering Time in Plants. *Frontiers in Plant Science*, *7*(913). https://doi.org/10.3389/fpls.2016.00913

Jitla, D. S., Rogers, G. S., Seneweera, S. P., Basra, A. S., Oldfield, R. J., & Conroy, J. P. (1997). Accelerated Early Growth of Rice at Elevated CO_2 (Is It Related to Developmental Changes in the Shoot Apex?). *Plant Physiology*, *115*, 15–22. https://doi.org/10.1104/pp.115.1.15

Johnson, M. P. (2016). Photosynthesis. *Essays in Biochemistry*, *60*(3), 255–273. https://doi.org/10.1042/EBC20160016

Kachroo, A., & Robin, G. P. (2013). Systemic signaling during plant defense. *Current Opinion in Plant Biology*, *16*(4), 527–533. https://doi.org/10.1016/j.pbi.2013.06.019

Kalaji, H. M., Goltsev, V., . K. Z., uk-Golaszewska, Zivcak, M., & Brestic, M. (2017). *Chlorophyll fluorescence : understanding crop performance : basics and applications*. CRC Press.

Kalaji, H. M., Goltsev, V. N., Zuk-Golaszewska, K., Zivcak, M., & Brestic, M. (2017). *Chlorophyll fluorescence : understanding crop performance : basics and applications*. CRC Press.

Kalaji, H. M., Jajoo, A., Oukarroum, A., Brestic, M., Zivcak, M., Samborska, I. A., Cetner, M. D., Łukasik, I., Goltsev, V., & Ladle, R. J. (2016). Chlorophyll a fluorescence as a tool to monitor physiological status of plants under abiotic stress conditions. *Acta Physiologiae Plantarum*, *38*(4). https://doi.org/10.1007/s11738-016-2113-y

Kaul Wattal, R., Hameed Siddiqui, Z., Wattal, R. K., & Siddiqui, Z. H. (2015). Effect of Elevated Levels of Carbon Dioxide on the Activity of RuBisCO and Crop Productivity. *Crop Production and Global Environmental Issues*, 241–256. https://doi.org/10.1007/978-3-319-23162-4_10

Kim, H. Y., Lieffering, M., Miura, S., Kobayashi, K., & Okada, M. (2001). Growth and nitrogen uptake of CO_2 -enriched rice under field conditions. *New Phytologist*, *150*, 223–229.

Kimball, B. A. (2016). Crop responses to elevated CO_2 and interactions with H2O, N, and temperature. *Current Opinion in Plant Biology*, *31*, 36–43. https://doi.org/10.1016/j.pbi.2016.03.006

Kirkpatrick, K. (2018). *Investigating Hop Enzymes*. https://www.researchgate.net/figure/The-chemical-equation-of-photosynthesis_fig1_327920538

Kobata, T., Yoshida, H., Masiko, U., & Honda, T. (2014). Spikelet Sterility is Associated with a Lack of Assimilate. *Crop Ecology & Physiology*, *105*(6), 1821–1831. https://doi.org/10.2134/agronj2013.0115

Kobayashi, K., Okada, M., Kim, H. Y., Lieffering, M., Miura, S., & Hasegawa, T. (2006). Paddy Rice Responses to Free-Air [CO_2] Enrichment. *Managed Ecosystems and CO2*, *187*, 87–104. https://doi.org/10.1007/3-540-31237-4_5

Lake, J. A., Quick, W. P., Beerling, D. J., & Woodward, F. I. (2001). Signals from mature to new leaves. *Nature*, *411*(6834), 154. https://doi.org/10.1038/35075660

Lake, Janice A., Woodward, F. I., & Quick, W. P. (2002). Long-distance CO_2 signalling in plants. *Journal of Experimental Botany*, *53*(367), 183–193. https://doi.org/10.1093/jexbot/53.367.183

Lambers, H., & Oliveira, R. S. (2019). Photosynthesis, Respiration, and Long-Distance Transport: Photosynthesis. In *Plant Physiological Ecology* (pp. 11–114). Springer International Publishing. https://doi.org/10.1007/978-3-030-29639-1_2

Leakey, A. D. B., Ainsworth, E. A., Bernacchi, C. J., Rogers, A., Long, S. P., & Ort, D. R. (2009). Elevated CO_2 effects on plant carbon, nitrogen, and water relations: Six important lessons from FACE. *Journal of Experimental Botany*, *60*(10), 2859–2876. https://doi.org/10.1093/jxb/erp096

Leegood, R. C. (2013). Photosynthesis. *Encyclopedia of Biological Chemistry: Second Edition*, 492–496. https://doi.org/10.1016/B978-0-12-378630-2.00049-9

Lemmens, E., Deleu, L. J., Brier, N. De, Man, W. L. De, Proft, M. De, Prinsen, E., & Delcour, J. A. (2019). The Impact of Hydro-Priming and Osmo-Priming on Seedling Characteristics , Plant Hormone Concentrations , Activity of Selected Hydrolytic Enzymes , and Cell Wall and Phytate Hydrolysis in Sprouted Wheat (*Triticum aestivum* L .). *ACS Omrga*, *4*, 22089−22100. https://doi.org/10.1021/acsomega.9b03210

Li, J., Liu, X., Cai, Q., Gu, H., Zhang, S., Wu, Y., & Wang, C. (2008). Effects of Elevated CO_2 on Growth, Carbon Assimilation, Photosynthate Accumulation and Related Enzymes in Rice Leaves during Sink-Source Transition. *Journal of Integrative Plant Biology*, *50*(6), 723–732. https://doi.org/10.1111/j.1744-7909.2008.00666.x

Li, R., Li, M., Ashraf, U., Liu, S., & Zhang, J. (2019). Exploring the Relationships Between Yield and Yield-Related Traits for Rice Varieties Released in China From 1978 to 2017. *Frontiers in Plant Science*, *10*(May), 1–12. https://doi.org/10.3389/fpls.2019.00543

Li, Yansheng, Yu, Z., Liu, X., Mathesius, U., & Wang, G. (2017). Elevated CO_2 Increases Nitrogen Fixation at the Reproductive Phase Contributing to Various Yield Responses of Soybean Cultivars. *Frontiers in Plant Science*, *8*(1546). https://doi.org/10.3389/fpls.2017.01546

Li, Yuting, Lam, S. K., Han, X., Feng, Y., Lin, E., Li, Y., & Hao, X. (2017). Effects of elevated CO_2 on rice grain yield and yield components: Is non-flooded plastic film mulching better than traditional flooding? *European Journal of Agronomy*, *85*, 25–30. https://doi.org/10.1016/J.EJA.2017.01.003

Liu, B. B., Li, M., Li, Q. M., Cui, Q. Q., Zhang, W. D., Ai, X. Z., & Bi, H. G. (2018). Combined effects of elevated CO_2 concentration and drought stress on photosynthetic performance and leaf structure of cucumber (*Cucumis sativus* L.) seedlings. *Photosynthetica*, *56*(3), 942–952.

https://doi.org/10.1007/s11099-017-0753-9

Liu, S., Waqas, M. A., Wang, S. H., Xiong, X. Y., & Wan, Y. F. (2017). Effects of increased levels of atmospheric CO_2 and high temperatures on rice growth and quality. *PLoS ONE*, *12*(11). https://doi.org/10.1371/journal.pone.0187724

Lobo, F. A., Barros, M., Dalmagro, H., Dalmolin, Â., Pereira, W., de Souza, É., Vourlitis, G., & Rodríguez Ortíz, C. (2013). Fitting net photosynthetic light-response curves with Microsoft Excel-a critical look at the models. *Photosynthetica*, *51*(3), 445–456. https://doi.org/10.1007/s11099-013-0045-y

Lombardozzi, D. L., Smith, N. G., Cheng, S. J., Dukes, J. S., Sharkey, T. D., Rogers, A., Fisher, R., & Bonan, G. B. (2018). Triose phosphate limitation in photosynthesis models reduces leaf photosynthesis and global terrestrial carbon storage. *Environmental Research Letters*, *13*(7), 074025. https://doi.org/10.1088/1748-9326/AACF68

Long, S. P., Ainsworth, E. A., Rogers, A., & Ort, D. R. (2004). Rising Atmospheric Carbon Dioxide: Plants FACE the Future. *Annual Review of Plant Biology*, *55*(1), 591–628. https://doi.org/10.1146/annurev.arplant.55.031903.141610

Long, S. P., Zhu, X. G., Naidu, S. L., & Ort, D. R. (2006). Can improvement in photosynthesis increase crop yields? *Plant, Cell & Environment*, *29*(3), 315–330. https://doi.org/10.1111/J.1365-3040.2005.01493.X

Lv, C., Huang, Y., Sun, W., Yu, L., & Zhu, J. (2020). Response of rice yield and yield components to elevated [CO_2]: A synthesis of updated data from FACE experiments. *European Journal of Agronomy*, *112*(July 2019), 125961. https://doi.org/10.1016/j.eja.2019.125961

Mahesh, H. B., Shirke, M. D., Singh, S., Rajamani, A., Hittalmani, S., Wang, G., & Gowda, M. (2016). Indica rice genome assembly, annotation and mining of blast disease resistance genes. *BMC Genomics*, *17*(242), 1–12. https://doi.org/10.1186/s12864-016-2523-7

MARDI. (2000). *Padi varieti MR 219* (p. 4).

MARDI. (2010). *Memperkenalkan varieti padi baru MR 263* (p. 4).

Masle, J. (2000). The effects of elevated CO_2 concentrations on cell division rates, growth patterns, and blade anatomy in young wheat plants are modulated by factors related to leaf position, vernalization, and genotype. *Plant Physiology*, *122*(4), 1399–1415. https://doi.org/10.1104/pp.122.4.1399

Medlyn, B. E., De Kauwe, M. G., Lin, Y. S., Knauer, J., Duursma, R. A., Williams, C. A., Arneth, A., Clement, R., Isaac, P., Limousin, J. M., Linderson, M. L., Meir, P., Martin-Stpaul, N., & Wingate, L. (2017). How do leaf and ecosystem measures of water-use efficiency compare? *New*

Phytologist, *216*(3), 758–770. https://doi.org/10.1111/nph.14626

Medrano, H., Tomás, M., Martorell, S., Flexas, J., Hernández, E., Rosselló, J., Pou, A., Escalona, J. M., & Bota, J. (2015). From leaf to whole-plant water use efficiency (WUE) in complex canopies: Limitations of leaf WUE as a selection target. *Crop Journal*, *3*(3), 220–228. https://doi.org/10.1016/j.cj.2015.04.002

Ministry of Agriculture and Agro-Based Industry Malaysia. (2019). *Agrofood Statistics 2018*.

Moldenhauer, K., Counce, P., & Hardke, J. (2018). Rice Growth and Development. In J. Hardke (Ed.), *Rice Production Handbook* (pp. 9–20). University of Arkansas Division of Agriculture.

Murchie, E. H., & Lawson, T. (2013). Chlorophyll fluorescence analysis: A guide to good practice and understanding some new applications. *Journal of Experimental Botany*, *64*(13), 3983–3998. https://doi.org/10.1093/jxb/ert208

Muthayya, S., Sugimoto, J. D., Montgomery, S., & Maberly, G. F. (2014). An overview of global rice production, supply, trade, and consumption. *Annals of the New York Academy of Sciences*, *1324*(1), 7–14. https://doi.org/10.1111/nyas.12540

Nakamoto, H., Zheng, S., Tanaka, K., Yamazaki, A., Furuya, T., Iwaya-inoue, M., Fukuyama, M., Nakamoto, H., Zheng, S., Tanaka, K., Yamazaki, A., Furuya, T., Iwaya-inoue, M., & Fukuyama, M. (2015). Effects of Carbon Dioxide Enrichment during Different Growth Periods on Flowering, Pod Set and Seed Yield in Soybean Effects of Carbon Dioxide Enrichment during Different Growth Periods on Flowering, Pod Set and Seed Yield in Soybean. *Plant Production*, *7*(1), 11–15. https://doi.org/10.1626/pps.7.11

Nakano, H., Yoshinaga, S., Takai, T., & Sanoh, Y. A.-. (2017). Quantitative trait loci for large sink capacity enhance rice grain yield under free-air CO_2 enrichment conditions. *Scientific Reports*, *March*, 1–10. https://doi.org/10.1038/s41598-017-01690-8

Nature Education. (2014). *Structure of a chloroplast | Learn Science at Scitable*. https://www.nature.com/scitable/content/structure-of-a-chloroplast-14705175/

NOAA Research. (2021). *Trends in Atmospheric Carbon Dioxide*. National Oceanic & Atmospheric Administration. https://gml.noaa.gov/ccgg/trends/graph.html

OECD, & FAO. (2020). *OECD‑FAO Agricultural Outlook 2020‑2029*.

Onofre, S. B., Bertoldo, I. C., Abatti, D., & Refosco, D. (2017). Chemical Composition of the Biomass of Saccharomyces cerevisiae - (Meyen ex E. C. Hansen, 1883) Yeast obtained from the Beer Manufacturing

Process. *International Journal of Environment, Agriculture and Biotechnology*, *2*(2), 558–562. https://doi.org/10.22161/ijeab/2.2.2

Pandey, V., Sharma, M., Deeba, F., Maurya, V. K., Gupta, S. K., Singh, S. P., Mishra, A., & Nautiyal, C. S. (2017). Impact of Elevated CO_2 on Wheat Growth and Yield under Free Air CO_2 Enrichment. *American Journal of Climate Change*, *6*, 573–596. https://doi.org/10.4236/ajcc.2017.64029

Parul, S. S. (2017). *Rice technical manual for extension officers*. FAO.

Peterhansel, C., Horst, I., Niessen, M., Blume, C., Kebeish, R., Kürkcüoglu, S., & Kreuzaler, F. (2010). Photorespiration. *The Arabidopsis Book / American Society of Plant Biologists*, *8*, e0130. https://doi.org/10.1199/TAB.0130

Pozo, M. J., Verhage, A., García-andrade, J., García, J. M., & Azcón-aguilar, C. (2009). *Priming Plant Defence Against Pathogens by Arbuscular Mycorrhizal Fungi*. 123–135.

PRB. (2021). *World Population Data Sheet*.

Pribil, M., & Leister, D. (2017). Photosynthesis. *Encyclopedia of Applied Plant Sciences*, *1*, 90–95. https://doi.org/10.1016/B978-0-12-394807-6.00156-8

Prior, S. A., Pritchard, G. S., & Runion, B. G. (2004). Leaves and the Effects of Elevated Carbon Dioxide Levels. In *Encyclopedia of Plant and Crop Science*. https://doi.org/10.1081/e-epcs

Pritchard, G. S., Rogers, H. H., Prior, A. S., & Peterson, M. C. (1999). Elevated CO2 and plant structure: a review. *Global Change Bilology*, *5*, 807–837.

Quebbeman, J. A., & Ramirez, J. A. (2016). Optimal allocation of leaf-level nitrogen: Implications for covariation of Vcmax and Jmax and photosynthetic downregulation. *Journal of Geophysical Research: Biogeosciences*, *121*(9), 2464–2475. https://doi.org/10.1002/2016JG003473

Raines, C. A. (2003). The Calvin cycle revisited. *Photosynthesis Research*, *75*, 1–10.

Rivera-Méndez, Y. D., Romero, H. M., Rivera-Méndez, Y. D., & Romero, H. M. (2017). Fitting of photosynthetic response curves to photosynthetically active radiation in oil palm. *Agronomía Colombiana*, *35*(3), 323–329. https://doi.org/10.15446/agron.colomb.V35N3.63119

Robertson, E. J., & Leech, R. M. (1995). Significant Changes in Cell and Chloroplast Development in Young Wheat Leaves (T*riticum aestivum* cv Hereward) Grown in Elevated CO_2,'. *Plant Physiology*, *107*, 63–71.

Robertson, E. J., Williams, M., Harwood, J. L., Lindsay, J. C., Leaver, C. J., & Leech, R. M. (1995). Mitochondria Increase Three-Fold and

Mitochondrial Proteins and Lipid Change Dramatically in Postmeristematic Cells in Young Wheat Leaves Grown in Elevated CO_2,’. *Plant Physiology*, *108*, 469–474.

Saad, A., Badrulhadza, A., Sariam, O., Azmi, M., Yahya, H., Siti Norsuha, M., & Maisarah, M. S. (2014). *Pengurusan Perosak Bersepadu Tanaman Padi Ke Arah Pengeluaran Berlestari*. MARDI.

Sadeghi, H., Khazaei, F., Yari, L., & Sheidaei, S. (2011). Effect of Seed Osmopriming On Seed Germination Behavior and Vigor of Soybean (*Glycine Max* L.). *Journal of Agricultural and Biological Science*.

Sage, R. F., Way, D. A., & Kubien, D. S. (2008). Rubisco , Rubisco activase , and global climate change. *Journal of Experimental Botany*, *59*(7), 1581–1595. https://doi.org/10.1093/jxb/ern053

Sakai, H., Tokida, T., Usui, Y., Nakamura, H., & Hasegawa, T. (2019). Yield responses to elevated CO_2 concentration among Japanese rice cultivars released since 1882. *Plant Production Science*, *22*(3), 352–366. https://doi.org/10.1080/1343943X.2019.1626255

Sakurai, G., Iizumi, T., Nishimori, M., & Yokozawa, M. (2014). *How much has the increase in atmospheric CO_2 directly affected past*. 1–5. https://doi.org/10.1038/srep04978

Sani, E., Herzyk, P., Perrella, G., Colot, V., & Amtmann, A. (2013). Hyperosmotic priming of Arabidopsis seedlings establishes a long-term somatic memory accompanied by specific changes of the epigenome. *Genome Biology*, *14*(R59), 1–23.

Sarena, C. O., Ashraf, S., & Siti Aiysyah, T. (2019). The Status of the Paddy and Rice Industry in Malaysia. In *Khazanah Research Institute*. http://www.krinstitute.org/assets/contentMS/img/template/editor/20190409_RiceReport_Full Report_Final.pdf

Sarkar, S. (2020). *Factors Affecting Photosynthesis*. https://surendranathcollege.ac.in/new/upload/suranjana_sarkarfactors affecting photosynthesis2020-05-02factors affecting photosynthesis.pdf

Sekhar, C. S. C. (2018). *Climate change and rice economy in Asia : Implications for trade policy. Background paper for The State of Agricultural Commodity Markets (SOCO) 2018*.

Senatore, A., Lania, I., Corrente, G. A., & Basile, A. (2020). CO_2 capture by bacteria and their enzymes. *Advances in Carbon Capture*, 407–429. https://doi.org/10.1016/B978-0-12-819657-1.00018-9

Seneweera, P. S., Basra, S. A., Barlow, W. E., & Conroy, P. J. (1995). Diurna1 Regulation of Leaf Blade Elongation in Rice by CO_2 Is It Related to Sucrose-Phosphate Synthase Activity? *Plant Pysiology*, *108*(4), 1471–1477.

Seneweera, P. S., Conroy, P. J., Ishimasru, K., Ghannoum, O., Okada, M., Lieffering, M., Kim, Y. H., & Kobayashi, K. (2002). Changes in source–sink relations during development influence photosynthetic acclimation of rice to free air CO_2 enrichment (FACE). *Functional*, *29*, 945–953.

Seneweera, S., Milham, P., & Conroy, J. (1994). Influence of Elevated CO_2 and Phosphorus Nutrition on the Growth and Yield of a Short-duration Rice (*Oryza sativa* L. Cv. Jarrah). *Australian Journal Plant Physiology*, *21*, 281–292.

Shi, Z., Chang, T. G., Chen, F., Zhao, H., Song, Q., Wang, M., Wang, Y., Zhou, Z., Wang, C., Zhou, S. C., Wang, B., Chen, G., & Zhu, X. G. (2020). Morphological and physiological factors contributing to early vigor in the elite rice cultivar 9 , 311. *Scientific Reports*, *10*(14813), 1–16.

Simkin, A. J., López-Calcagno, P. E., & Raines, C. A. (2019). Feeding the world: improving photosynthetic efficiency for sustainable crop production. *Journal of Experimental Botany*, *70*(4), 1119–1140. https://doi.org/10.1093/JXB/ERY445

Singer SD, Chatterton S, Soolanayakanahally RY, Subedi U, Chen G, Acharya SN. (2020).Potential effects of a high CO_2 future on leguminous species. Plant-Environment Interactions. 1:67–94. https://doi.org/10.1002/pei3.10009

Singh, S. K., & Reddy, V. R. (2015). Response of carbon assimilation and chlorophyll fluorescence to soybean leaf phosphorus across CO_2 : Alternative electron sink, nutrient efficiency and critical concentration. *Journal of Photochemistry and Photobiology B : Biology*, *151*, 276–284. https://doi.org/10.1016/j.jphotobiol.2015.08.021

Singh, S. K., & Reddy, V. R. (2018). Co-regulation of photosynthetic processes under potassium deficiency across - CO_2 levels in soybean : mechanisms of limitations and adaptations. *Photosynthesis Research*, *0*(0), 0. https://doi.org/10.1007/s11120-018-0490-3

Slot, M., & Winter, K. (2017). Photosynthetic acclimation to warming in tropical forest tree seedlings. *Journal of Experimental Botany*, *68*(9), 2275–2284. https://doi.org/10.1093/JXB/ERX071

Smith, N. G., Keenan, T. F., Prentice, I. C., Wang, H., & Crous, K. Y. (2019). Global photosynthetic capacity is optimized to the environment. *Ecology Letters*, *22*, 506–517. https://doi.org/10.1111/ele.13210

Spreitzer, R. J., & Salvucci, M. E. (2002). Rubisco: structure, regulatory interactions, and possibilities for a better enzyme. *Annual Review of Plant Biology*, *53*, 449–475. https://doi.org/10.1146/annurev.arplant.53.100301.135233

Springer, C. J., & Ward, J. K. (2007). Flowering time and elevated atmospheric carbon dioxide. *New Phytologist*, *176*, 243–255.

Stinziano, J. R., Adamson, R. K., & Hanson, D. T. (2019). Using multirate rapid A/Ci curves as a tool to explore new questions in the photosynthetic physiology of plants. *New Phytologist*, *222*(2), 785–792. https://doi.org/10.1111/NPH.15657

Taiz, L., & Zeiger, E. (2010). Photosynthesis: Physiological and Ecological Considerations. *Plant Physiology*.

Taylor, G., Ceulemans, R., Ferris, R., Gardner, S. D. L., & Shao, B. Y. (2001). Increased leaf area expansion of hybrid poplar in elevated CO_2. From controlled environments to open-top chambers and to FACE. *Environmental Pollution*, *115*(3), 463–472. https://doi.org/10.1016/S0269-7491(01)00235-4

Thilakarathne, C. L., Tausz-Posch, S., Cane, K., Norton, R. M., Fitzgerald, G. J., Tausz, M., & Seneweera, S. (2015). Intraspecific variation in leaf growth of wheat (*Triticum aestivum*) under Australian Grain Free Air CO_2 Enrichment (AGFACE): Is it regulated through carbon and/or nitrogen supply? *Functional Plant Biology*, *42*(3), 299–308. https://doi.org/10.1071/FP14125

Thinh, N. C., Kumagai, E., Shimono, H., & Kawasaki, M. (2018). Effects of elevated atmospheric CO_2 concentration on morphology of leaf blades in Chinese yam. *Plant Production Science*, *21*(4), 311–321. https://doi.org/10.1080/1343943X.2018.1511377

Thompson, M., Gamage, D., Hirotsu, N., Martin, A., & Seneweera, S. (2017). Effects of elevated carbon dioxide on photosynthesis and carbon partitioning: A Perspective on root sugar sensing and hormonal crosstalk. *Frontiers in Physiology*, *8*(AUG), 578. https://doi.org/10.3389/FPHYS.2017.00578/BIBTEX

Tomimatsu, H., & Tang, Y. (2016). Effects of high CO_2 levels on dynamic photosynthesis: carbon gain, mechanisms, and environmental interactions. *Journal of Plant Research*, *129*(3), 365–377. https://doi.org/10.1007/s10265-016-0817-0

Tsutsumi, K., Konno, M., Miyazawa, S., & Miyao, M. (2014). Sites of action of elevated CO_2 on leaf development in rice : Discrimination between the effects of elevated CO_2 and nitrogen deficiency. *Plant and Cell Physiology*, *55*(2), 258–268. https://doi.org/10.1093/pcp/pcu006

Tuzet, A. J. (2011). Stomatal Conductance, Photosynthesis,and Transpiration, Modeling. In Jan Gliński, J. Horabik, & J. Lipiec (Eds.), *Encyclopedia of Agrophysics. Encyclopedia of Earth Sciences Series: Vol. Part 4* (p. 855). Springer Science. https://doi.org/10.1007/978-90-481-3585-1

UN. (2019). *World Population Prospects 2019: Vol. II: Demogr*.

Uprety, D. C., Dwiivedi, N., & Mohan, R. (2002). Effects of elevated carbon dioxide concentration on the stomatal parameters of rice cultivars. *Photosynthetica*, *40*(2), 315–319.

Usui, Y., Sakai, H., Tokida, T., Nakamura, H., Nakagawa, H., & Hasegawa, T. (2016). Rice grain yield and quality responses to free-air CO_2 enrichment combined with soil and water warming. *Global Change Biology*, *22*(3), 1256–1270. https://doi.org/10.1111/GCB.13128

Valentine, A., Ruzvidzo, O., Kleinert, A., Kang, Y., & Bennedito, V. (2013). Infrared gas analysis technique for the study of the regulation of photosynthetic responses. *Methods in Molecular Biology*, *1016*, 261–269. https://doi.org/10.1007/978-1-62703-441-8_19

Vijay, D., & Roy, B. (2013). Rice (Oryza sativa L .). In A. K. B. & A. B. M. Roy, Bidhan (Ed.), *Breeding, Biotechnology and Seed Production of Field Crops*. New India Publishing Agency.

Wei, H., Kong, D., Yang, J., & Wang, H. (2020). Light Regulation of Stomatal Development and Patterning: Shifting the Paradigm from Arabidopsis to Grasses. *Plant Communications*, *1*(2), 100030. https://doi.org/10.1016/J.XPLC.2020.100030

Wei, X., & Huang, X. (2018). Origin, taxonomy, and phylogenetics of rice. In Jinsong Bao (Ed.), *Rice: Chemistry and Technology* (4th ed., pp. 1–29). AACCI. Published by Elsevier Inc. in cooperation with AACC International. https://doi.org/10.1016/B978-0-12-811508-4.00001-0

Wiszniewska, A. (2021). Priming strategies for benefiting plant performance under toxic trace metal exposure. *Plants*, *10*(4). https://doi.org/10.3390/plants10040623

Woodward, F. I., & Kelly, C. K. (1995). The influence of CO_2 concentration on stomatal density. *New Phytologist*, *131*, 311–327.

Wostrikoff, K., & Stern, D. B. (2009). Rubisco. *The Chlamydomonas Sourcebook 3-Vol Set*, *2*, 303–332. https://doi.org/10.1016/B978-0-12-370873-1.00017-4

Wu, Z., Chen, L., Yu, Q., Zhou, W., Gou, X., Li, J., & Hou, S. (2019). Multiple transcriptional factors control stomata development in rice. *New Phytologist*, *223*(1), 220–232. https://doi.org/10.1111/NPH.15766

Xu, Z., Jiang, Y., Jia, B., & Zhou, G. (2016). Elevated-CO_2 Response of Stomata and Its Dependence on Environmental Factors. *Frontiers in Plant Science*, *7*(May), 1–15. https://doi.org/10.3389/fpls.2016.00657

Xu, Z., Shimizu, H., & Ito, S. (2014). Effects of elevated CO_2, warming and precipitation change on plant growth, photosynthesis and peroxidation in dominant species from North China grassland. *Planta*, *239*, 421–435. https://doi.org/10.1007/s00425-013-1987-9

Yaapar, M. N. (2017a). *The control of stomatal properties in rice (Oryza sativa L.) and their influence on photosynthetic performance* (Issue July). Faculty of Science, The University of Sheffield.

Yaapar, M. N. (2017b). *The control of stomatal properties in rice (Oryza sativa L.) and their influence on photosynthetic performance* (Issue July). The University of Sheffield.

Yahia, E. M. (2018). Postharvest physiology and biochemistry of fruits and vegetables. *Postharvest Physiology and Biochemistry of Fruits and Vegetables*, 1–476. https://doi.org/10.1016/C2016-0-04653-3

Yahia, E. M., Carrillo-lópez, A., Barrera, G. M., Suzan-Azpiri, H., & Bolanos, M. Q. (2019). Photosynthesis. In *Postharvest Physiology and Biochemistry of Fruits and Vegetables* (pp. 47–72). Elsevier Inc. https://doi.org/10.1016/B978-0-12-813278-4.00003-8

Yang, Y., Zhu, K., Xia, H., Chen, L., & Chen, K. (2014). Comparative proteomic analysis of indica and japonica rice varieties. *Genetics and Molecular Biology*, *37*(4), 652–661.

Yoshida, S. (1981). *Fundamentals of rice crop science*.

You-ding, C., Xu, Z., Xin-qiao, Z., & Gum-hua, C. (2007). Preliminary studies on thickness of nondestructive rice (*Ovza sativa* L.) Leaf Blade. *Agricultural Sciences in China*, *6*(7), 802–807.

Zeier, J. (2013). New insights into the regulation of plant immunity by amino acid metabolic pathways. *Plant, Cell and Environment*, *36*(12), 2085–2103. https://doi.org/10.1111/pce.12122

Zheng, Y., Li, F., Hao, L., Yu, J., Guo, L., Zhou, H., Ma, C., Zhang, X., & Xu, M. (2019). Elevated CO_2 concentration induces photosynthetic down-regulation with changes in leaf structure, non-structural carbohydrates and nitrogen content of soybean. *BMC Plant Biology*, *19*(255), 1–18.

Zhu, X.-G., Long, S. P., & Ort, D. R. (2010). Improving Photosynthetic Efficiency for Greater Yield. *Annual Review of Plant Biology*, *61*(1), 235–261. https://doi.org/10.1146/annurev-arplant-042809-112206