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GROWTH AND YIELD IMPROVEMENT OF MR219 AND SRI MALAYSIA 1 RICE VARIETIES EMPLOYING TARGETED CO2 ENRICHMENT REGIMES

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By

SALIHI MOHAMMAD SADIQ

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Rice (*Oryza sativa* L.) is one of the most important members of the *Poaceae* family as this crop has been the staple food for people in various nations, especially in Asian countries. Current climate changes and increasing carbon dioxide (CO_2) concentration in the atmosphere have varying global impacts on crop performance. As CO_2 is one of the limiting factors in photosynthesis, any addition of this gas can increase carboxylation activity, hence increases productivity and yield. Thus, this research was conducted to study the effects of elevated CO_2 (eCO_2) CO_2 on rice seedlings' growth and establishment for MR219 and Seri Malaysia1 varieties before transplanted into the field, and the efficacy of eCO_2 to improve rice harvest components in both varieties. The study used a novel approach where the rice plants were treated with high CO_2 only during their early vegetative stage before being transplanted into the field. The source of CO_2 for eCO_2 condition was obtained from baker's yeast fermentation which was 600 to 800 µmol mol^{-1}, for the ambient CO_2 (aCO_2) it was 410 µmol mol^{-1} to 415 µmol mol^{-1} and control at field condition. Rice seedlings were grown in a nested design with 15 replication for four weeks in a growth chamber under LED lights (white, red, and blue. The seedlings in the control treatment were grown in the field. After four weeks, the seedlings grown in growth chambers were transplanted to the field and arranged in a rain shelter in a two factorial randomized complete block design (RCBD) with four blocks. Leaf properties of rice seedlings, for instance, leaf length, leaf

number per plant, and leaf area were increased by 9.20%, 10.28%, and 25.67% respectively in eCO_2 compared to control. Similarly, general growth properties were also increased, such as seedling height was increased by 18.25% and seedling dry weight by 34.21% under eCO_2 compared to control. Moreover, results from the field experiment also demonstrated that the growth properties of rice such as plant height and plant dry weight were also increased in the eCO_2 compared to the control by 5.29% and 43.84%, respectively. Tiller-panicle properties also increased in eCO_2 treatment than control such as tiller number per plant, panicle number per plant, and panicle length that increased by 18.38%, 20.96%, and 14.15%, respectively. The non-productive tiller number per plant was also decreased by 30.53%. Moreover, rice grain properties also demonstrated significant improvement under eCO_2 conditions compared to control. Filled grain per panicle and grain yield was increased by 15.30% and 47.48%, respectively. The non-filled grain per panicle was decreased by 42.04% under eCO_2 conditions compared to control. In conclusion, this experiment has demonstrated that eCO_2 treatment on rice seedlings enhanced seedling and plant growth, as well as grain yield of rice. This study suggested that temporary eCO_2 treatment on rice seedlings has the potential to enhance rice production thus can help farmers to earn a higher income and improve their living standard.

Abstrak tesis yang dikemukakan kepada Senat of Universiti Putra Malaysia sebagai memenuhi keperluan untuk Doktor Falsafah

PENINGKATAN PERTUMBUHAN DAN HASIL VARIETI PADI MR219 DAN SRI MALAYSIA1 MENGGUNAKAN PENGURUSAN PENGAYAAN CO_2 BERSASAR

Oleh

SALIHI MOHAMMAD SADIQ

Mei 2021

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Padi (*Oryza sativa* L.) adalah salah satu ahli keluarga *Poaceae* yang paling penting kerana tanaman ini telah menjadi makanan ruji bagi orang-orang di pelbagai negara, terutama di negara-negara Asia. Perubahan iklim semasa dan peningkatan kepekatan karbon dioksida (CO_2) di atmosfera mempunyai kesan global yang berbeza terhadap prestasi tanaman. Oleh kerana CO_2 adalah salah satu faktor pembatas dalam fotosintesis, penambahan gas ini dapat meningkatkan aktiviti karboksilasi, sekaligus meningkatkan produktiviti dan hasil. Oleh itu, penyelidikan ini dilakukan untuk mengkaji kesan CO_2 tinggi (600-800 µmol ml^{-1}) (eCO_2) berbanding CO_2 ambien (400 µmol ml^{-1}) (aCO_2) terhadap pertumbuhan dan pembentukan anak benih padi untuk varieti MR219 dan Seri Malaysia1 sebelum dipindahkan ke ladang, dan keberkesanan eCO_2 untuk meningkatkan komponen penuaian padi untuk kedua varieti tersebut. Kajian ini menggunakan pendekatan baru di mana tanaman padi dirawat dengan CO_2 tinggi hanya pada peringkat vegetatif awal sebelum dipindahkan ke ladang. Anak benih padi ditanam dalam reka bentuk bersarang dengan 15 ulangan selama empat minggu di ruang pertumbuhan di bawah lampu LED (putih, merah, dan biru). Sumber CO_2 untuk keadaan eCO_2 diperoleh daripada penapaian yis roti. Anak benih dalam rawatan kawalan ditanam di ladang. Selepas empat minggu, anak benih yang ditanam di ruang pertumbuhan dipindahkan ke ladang dan disusun dalam rumah pelindung hujan dalam reka bentuk blok lengkap dua faktorial (RCBD) dengan empat blok. Sifat daun anak benih padi, misalnya, panjang daun, jumlah daun per pokok, dan luas daun masing-masing meningkat sebanyak 9.20%, 10.28%, dan 25.67% dalam eCO_2 dibandingkan dengan kawalan. Begitu juga, sifat pertumbuhan umum meningkat, seperti tinggi anak benih meningkat 18.25% dan berat kering anak benih sebanyak 34.21% di bawah eCO_2 berbanding kawalan. Selain itu, hasil eksperimen di lapangan juga menunjukkan bahawa sifat

pertumbuhan padi seperti tinggi tanaman dan berat kering tanaman juga meningkat dalam eCO_2 dibandingkan dengan kawalan masing-masing sebanyak 5.29% dan 43.84%. Sifat anakan-panikel juga meningkat dalam rawatan eCO_2 daripada kawalan seperti jumlah anakan per pokok, jumlah panikel per pokok, dan panjang panikel yang masing-masing meningkat sebanyak 18.38%, 20.96%, dan 14.15%. Jumlah anakan tidak produktif per pokok juga menurun sebanyak 30.53%. Selain itu, sifat bijirin padi juga menunjukkan peningkatan yang ketara dalam keadaan eCO_2 berbanding dengan kawalan. Bijian yang diisi per panikel dan hasil bijirin masing-masing meningkat sebanyak 15.30% dan 47.48%. Bijian yang tidak berisi per panikel menurun sebanyak 42.04% dalam keadaan eCO_2 berbanding dengan kawalan. Sebagai kesimpulan, eksperimen ini telah menunjukkan bahawa rawatan eCO_2 pada anak benih padi meningkatkan pertumbuhan anak benih dan pokok serta hasil bijian padi. Kajian ini menunjukkan bahawa rawatan eCO_2 sementara pada anak benih padi berpotensi meningkatkan pengeluaran padi seterusnya dapat membantu petani memperoleh pendapatan yang lebih tinggi dan meningkatkan taraf hidup mereka.

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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:

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Declaration by the Members of Supervisory Committee

This is to certify that:

- The research conducted and the writing of the thesis were under our supervision.
- Supervision of responsibilities as slated in Rule 41 in Rule 2003 (Revision 2012-2013) was adhered to.

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LIST OF ABBREVIATIONS

%	Percent
ºC	Degree Celcius
aCO_2	Ambient CO_2
ANOVA	Analysis of variance
C_3	C_3 photosynthesis
C_4	C_4 photosynthesis
Ca	Calcium
CH_4	Methane
cm	centimeter
cm^2	centimeter square
CO_2	Carbon dioxide
CTGC	Carbon dioxide Temperature Gradient Chamber
DAS	Day after sowing
DAT	Day after transplanting
DC	Direct current
DW	Distilled water
E	Est
eCO_2	Elevated Carbon dioxide
FACE	Free-air Carbon Dioxide Enrichment
FAO	Food and Agriculture Organisation
Fe	Iron
g	gram

GHG	Greenhouse Gas
H_2O	Water
H_2O_2	Hydrogen peroxide
H_2SO_4	Sulfuric acid
HI	Harvest index
K	Potassium
Kg	Kilogram
LAI	Leaf Area Index
LED	Light-Emitting Diode
LSD	Least Significant Differences
m	meter
MARDI	Malaysia Agriculture Research Development Institute
Mg	Magnesium
mm	millimeter
Mn	Manganese
N	Nitrogen, North
N_2O	Nitrogen oxide
Na	Sodium
NO_2	Nitrogen dioxide
NPK	Nitrogen/ Phosphorus/ Potassium
OTC	Open Top Chamber
P	Phosphorus
PAR	Photosynthetic Active Radiation

PFD	Photon Flux Density
ppm	Parts per million
RCBD	Randomized Complete Block Design
RubP	Rubisco
SAS	Statistical Analysis Software
SPAD	Soil Plant Analysis Development
UPM	Universiti Putra Malaysia
V	Volt
Zn	Zinc

CHAPTER 1

GENERAL INTRODUCTION

Rice is a semi-aquatic annual grass plant with 22 species belonging to the *Oryza* genus, 20 of which are wild. The two most common rice species for human consumption are *Oryza sativa* L. and *Oryza glaberrima* L. According to Muthayya et al. (2014), *Oryza sativa* is the most common rice type that becomes the staple food for nearly 3.5 billion people worldwide.

Rice has been a staple food for humans for centuries. It is one of the world's most important crops and the primary source of nutrition for a large number of people in Asian countries (Wang et al., 2011). Furthermore, rice is consumed by more than half of the world's population, and all rice is produced and consumed in Asian countries (Abazar et al., 2017 and Jing et al., 2016), where more than 60% of the world's population lives (Khush, 2005). Rice is no longer just a staple food in Asia; it has become a staple food in Africa, Latin America, and Australia (Maity et al., 2019 and Seneweera et al., 2011).

The population of rice-producing and consuming nations has lately increased significantly, possibly requiring an urgent need to fulfill half of the world's food demand. According to Khush (2005), hence a need to expand rice production by 40% by 2030 due to the increasing population in several nations and a lack of staple food, leading people in the developing world to go malnutrition. Moreover, in the same study, there is an estimation by the researcher whereby the world population mainly in the developing countries will be increased significantly and reach 8 billion people by 2025. Currently, it is needed globally to have a high yield and quality of rice plants to produce sufficient food for the world population. Therefore, there is an urgent need to increase rice production to meet the global population demand. The fight has been ongoing to increase rice production in the same or less amount of arable land. Rice production has been at a plateau; thus, new methods are desirable to solve this issue.

In this regard, eCO_2 has been shown to improve photosynthesis, which is generally associated with a higher yield. Additional production input, on the other hand, must also be kept under control, and traditional Carbon Dioxide (CO_2) tanks are unaffordable and expensive, particularly for small-scale farmers in developing countries. As a consequence, a less expensive eCO_2 method based on renewable sources is implemented to reduce costs and increase rice production.

Global warming is a controversial modern climatic phenomenon that is the primary cause of the significant increase of CO_2 levels in the atmosphere (Wang

et al., 2011). Carbon dioxide levels in the atmosphere are higher now than at any time (Long et al., 2004). Currently, CO_2 in the atmosphere is 417 μmol mol^{-1}, and it is being predicted to double by the end of this century (Long et al., 2004).

Crop physiological and yield performance have changed as a result of the global increase in temperature induced by eCO_2 concentration. Plants' most important response to higher CO_2 levels in the atmosphere is to increase their growth and yield (Wohlfahrt et al., 2018). Despite its reputation as a greenhouse gas that contributes to global warming, CO_2 has been shown to increase photosynthesis and crop water use efficiency such as rice (Hasegawa et al., 2013).

Most of the previous decade`s work focused on the plant physiological responses to elevate the CO_2 level (Taylor et al., 2014.) Elevated CO_2 significantly increased the growth and germination rate of the rice seedling, as well as eCO_2, had effects on the vigorousity and germination speed which increased from 83% to 92% in rice (Abzar et al., 2017). Guo (2015) also stated that eCO_2 stimulates the mineral uptake through roots and upward transport of minerals in rice plants.

According to Zhao (2019), eCO_2 helped to increase the lodging resistance at the late grain filling stage. Other studies demonstrated that eCO_2 affects the yield of the plants, especially rice such as eCO_2 concentration and the temperature has strongly affected yield, methane (CH_4), and nitrous oxide (N_2O) emissions in rice (Wang et al., 2018). Elevated CO_2 enhances photosynthesis, thus increase the yield of the rice (Hesagawa et al., 2013). Whereas some of the researchers reported that, traditional flooded rice grown under eCO_2 tends to increase the spikelet number per panicle from 24% to 27% whereby the degeneration of spikelet number per panicle was reported to be 60% to 69% (Liu et al., 2017). The biomass and grain were increased, but nitrogen (N) concentration in rice grain was decreased in eCO_2 condition (Lieffering et al., 2004). In addition, Cheng (2009) has reported that eCO_2 significantly increased grain weight in brown rice. Rice grain quality was also affected only in eCO_2 conditions or in the combination with heat stress by increasing the rice chalkiness, changes in the amylose content, and reducing protein and grain mineral nutrients (Chaturvedi et al., 2017).

Since CO_2 is one of the determining factors in photosynthesis, any increase in CO_2 leads to an increase in carboxylation activity. The present study used a new approach wherein eCO_2 enriches the rice plant only during its early vegetative stage before being transplanted into a regular cultivation field, as opposed to the normal method where CO_2 is continuously supplied to the systems. Two rice varieties which are, MR219 more recent and improved variety, and Sri Malaysia1 an older variety were selected in order to evaluate the effects of different level of atmospheric CO_2 on growth and performance of varieties developed in different area.

The objectives of the experiments were as follows:

1- To evaluate how eCO_2 influence rice seedling establishment before they could be transplanted into the field for MR219 and Sri Malaysia 1 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 Sri Malaysia 1 rice varieties.

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