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Multi-site monitoring network of canopy micrometeorology and environmental stresses of rice for the climate change adaptation evaluation
（Abstract of the Interim Report）

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1. Introduction

The occurrence of extreme weather events and the progress of global warming are concerned to be a threat to crop production. Their effects need to be detected which helps adaptation strategy. Research and development regarding the adaptation strategies are being promoted in several fields of study such as agricultural meteorology, crop science and breeding. However, the climate of rice production areas in the world is diverse, and most of the quantitative evaluations of versatility and effectiveness is still unclear. To solve these problems systematically, it is essential to elucidate the mechanism of each adaptation measure leading to the reduction of heat stresses based on the canopy temperature, and it is necessary to conduct wide-area cultivation trials and accurate canopy micrometeorology monitoring.

The sub-Saharan Africa (SSA) is recognized as the most vulnerable region to the global climate change. This is because most of the population rely on agriculture with limited production infrastructure (e.g., lack of irrigation system, poor soil) and little external inputs. Therefore, it is a critical challenge for the food security in SSA to develop suitable adaptation measures to the changing field environments and to quantify their impacts.

2. Research Objectives

This research project addresses a comprehensive monitoring of heat stresses and paddy micrometeorology of rice by the monitoring network (MINCERnet) to elucidate the mechanism of the effect of the introducing various climate change adaptation measures through the changes in plant growth and physiology and canopy micrometeorological conditions. Research on two sub-themes were conducted:

(1) Multi-site monitoring heat stress in hot spots of rice cultivation areas in the world for evaluating the efficacy of adaptation strategies

1) to conduct field trials using standard cultivar (IR64) and early-morning-flowering cultivar (IR64-*qEMF3*) to elucidate the effect of early-morning-flowering (EMF) trait on micrometeorology inside the canopy and sterility, 2) to conduct drainage experiment to elucidate the effect of EMF trait under the drought stress condition, and 3) to conduct the detailed analysis of yield components to examine the effects of EMF trait on retaining grain yield through reduction in spikelet sterility under the hot field condition in Myanmar and Philippines sites; and

(2) Monitoring the effect of adaptation measures on heat stress and productivity of rice in climate-change-vulnerable environment

1) to elucidate the effect of early-morning-flowering trait, silica (Si) fertilization, and water-saving management on the canopy temperature, heat stress and productivity of rice under unstable hydrological environment in Africa, and 2) to introgress the early-morning-flowering QTL-*qEMF3* into leading varieties in Madagascar and Sri Lanka.

3. Research Methods

(1) Multi-site monitoring heat stress in hot spots of rice cultivation area in the world for evaluating the efficacy of adaptation strategies

Cultivation trials under flooded paddy fields were conducted at the monitoring sites using IR64, IR64-*qEMF3* and N22 and the micrometeorology inside and above the canopy were monitored with MINCER at the flowering period. In the drainage experiment, the paddies were drained at one week before flowering and drought stress was taken to the rice plants at flowering. In the Myanmar and Philippines sites, varieties of IR64 and IR64-*qEMF* were grown in the experimental field to head genotypes to the different temperature regimes. At maturity, 12 plants were harvested per plot, and six plants having intermediate panicle number were used for the determination of yield and yield components.

(2) Monitoring the effects of counter measures on heat stress and productivity of rice in climate-change-vulnerable environment

Three-year field trials were conducted to evaluate the effect of IR64-*qEMF3* and Si fertilization on two different water management: continuously flooded (Flood) and partially drained at pre-heading to heading period (Drained) in the northern region of Ghana and northwestern region of Madagascar.

BC_4F_2 plants derived from a backcross with BG251GSR as well as BC_3F_1, BC_4F_1, and BC_2F_1 plants derived from a backcross with Bg300, FOFIFA160, and X265, respectively were grown with parental varieties in the paddy field at Tsukuba in summer season in 2021. Before heading stage, marker-assisted selection was conducted to select a near-isogenic line carrying *qEMF3* in the BG251GSR background (BG251GSR-*qEMF3*). Then, at heading stage, the flowering time in the selected BG251GSR-*qEMF3* and BG251GSR was investigated. Also, each plant in Bg300, FOFIFA160, and X265 was backcrossed with each parental variety. Genotype was analyzed with Illumina Infinium 7K SNP chip for BG251GSR-*qEMF3* and the plants in which backcrossing was successful.

4. Results and Discussions

(1) Multi-site monitoring heat stress in hot spots of rice cultivation area in the world for evaluating the efficacy of adaptation strategies

Although some sites were unable to conduct experiments due to lockdowns and some missing data occurred, with the global spread of COVID-19, we were able to accumulate monitoring data on canopy micrometeorology in paddy fields and sterility at sites with diverse climates.

Panicle temperature associated with heat induced sterility at flowering stage differed from temperatures at the nearest weather station and temperatures above the canopy, and the differences in temperatures varied depending on climatic conditions. It was demonstrated for the first time in the world that the induction of heat induced sterility can be quantitatively evaluated using panicle temperature as an indicator, and the effectiveness of each adaptation strategy variety can be assessed. The heat tolerant variety (N22) showed consistently lower sterility than the standard variety (IR64). The early-morning-flowering variety (IR64-*qEMF3*) was able to lower the temperature inside the canopy and panicle temperature at flowering by 1.5 to 3.0°C compared to the standard variety (IR64), and was similarly able to avoid high temperatures at flowering in the drought stress experiment. The effect of reducing sterility by introducing high-temperature flowering was not as clear as with the high-tolerance variety (N22), suggesting that microclimatic factors other than avoidance of high temperatures at flowering (low wind speed and high humidity conditions) may have an effect on pollination stability.

Analysis of field trial results under extreme heat and extreme drought conditions in Myanmar and the Philippines demonstrated the effect of introducing early-morning-flowering on reducing heat induced sterility, indicating that early-morning-flowering lines can maintain early-morning-flowering characteristics even under drought stress conditions. Our results suggest that the integration of an early-morning-flowering QTL (*qEMF3*) and a drought-tolerant QTL is necessary to improve rice productivity under high temperature and drought stress conditions.

(2) Monitoring the effects of counter measures on heat stress and productivity of rice in climate-change-vulnerable environment

We consistently observed earlier peak flowering time of NIL-*qEMF3* than IR64 by 75–91 min. irrespective of water management and across 3 years. With this change, the inner-canopy temperature during the peak flowering time was reduced by 0.09-0.34 °C in the flooded condition and by 0.32-0.54 °C in the drained condition .The greater effect in the drained condition was because the difference in inner-canopy temperature between the flooded and drained conditions were enlarged (the inner-canopy temperature during the daytime was higher in the drained condition than the flooded condition) from the peak flowering time of NIL-*qEMF3* to that of IR64. This is a unique observation under open-field conditions that the impact to reduce the inner-canopy temperature by introducing *qEMF* is greater at the water-saving management condition. However, despite such a clear impact of water management and *qEMF* on the inner-canopy temperature at flowering, there were no clear effects detected on either grain yield or spikelet sterility. The effect of Si application was consistent with a significant yield gain by 9% across 3 years.

We selected the plant as BG251GSR-*qEMF3* that carries approximately 2.7Mb genomic segments including *qEMF3* derived from the donor variety, IR64-*qEMF3* and in which genetic background was almost BG251GSR. At heading, flowering time of BG251GSR-qEMF3 differed each day depending on the climates, but consistently flowered 40 minutes to 2 hours earlier than BG251GSR. Therefore, we conclude that the development of BG251GSR-*qEMF3* was successful. Regarding other variety backgrounds, we advanced back-crossed generation and collected the BC_4F_1, BC_3F_1, and BC_5F_1 seeds in the Bg300, X265, and FOFIFA160 genetic backgrounds, respectively. By genotyping with 7K SNP chip for BC_5F_1 plants in FOFIFA160 background, we confirmed that only 3.6Mb genomic region including *qEMF3* was heterozygous and other regions were homozygous with FOFIFA160. Therefore, we selected it as a candidate for FOFIFA160-*qEMF3*.