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Climate change adaptation and mitigation strategy through submergence tolerance in rice

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Abstract. The aim of this study is to identify rice cultivars which have capacity to survive in submergence condition and result low CH_4 emissions. The study was conducted at research station of Indonesian Agricultural Environment Research Institute (IAERI) during 2 seasons consecutively. Six rice varieties were used during rainy season (RS) 2015/2016 and 12 rice varieties during dry season (DS) 2016. During flash flooding, rice plants were 10 days submerged for 90 cm from the soil surface. The flash flooding was conducted during vegetative phase of the plant. Result showed that some varieties could not survive due to flash flooding. Some rice varieties could survive but severe, stagnant and lost the yield. Inpago 9 and Inpari 30 resulted highest yield compared to others varieties during RS 2015/2016 and DS 2016, respectively. Grain yields of Inpago 9 and Inpari 30 were approximately around 5.38 and 5.29 Mg ha^{-1}, respectively. Ciherang and Inpara 5 showed lowest CH_4 emissions during RS 2015/2016 and DS 2016 approximately 108 and 78.3 kg C ha^{-1} season^{-1}, respectively. Varieties that could survive in flash flood condition as well as mitigate CH_4 emission were Ciherang, Inpago 8, Inpari 30 and Inpara 5.

1. Introduction

Nowadays, the world has to face the main threats of food security due to climate change impact and overpopulation. The global food production should be produced more than 70% in order to meet the world's food demand [1]. On the other hand, the effort to achieve the food resilience faces the impact of climate change. Climate change impacts, e.g., drought and floods became more common throughout the world. Future agricultural farming system should have the capabilities to be adapted to abiotic and biotic stress as consequences of climate change impacts.

Submergence was causing low rice production and estimated the losses around US $1B every year from 10 – 15 million ha of paddy fields in South and South East Asia [2]. Although rice is a semiaquatic plant, but waterlogged causes some damages for plant grown due to slow diffusion supply of oxygen from atmosphere to soil. Indonesian Agency for Agricultural Research and Development released rice varieties tolerant short-duration flash flooding. Finding rice capability of surviving under flash flooding then recover after the water recedes is one of the efforts to meet the food demand because plant growth and grain yield is affected by excess water as the major constraint to productivity in rice fields [3].

However, flooded rice field is one of methane (CH_4) contributors because excess water in the rice fields inhibit adequate oxygen supply from the atmosphere to the rhizosphere, which leads to anaerobic condition as potential condition of CH_4 production [4]. There are three processes of CH_4 released from flooded soils: diffusion, ebullition and through rice plant. Mostly (90%) of CH_4 emission from flooded rice fields to atmosphere is released through intracellular space of rice plant, namely aerenchyma. CH_4 is one of three greenhouse gases from rice fields that contributes to the global warming and it has global warming potentials (GWP) 25 times more potent that of CO_2 [5].

Selecting high yielding rice cultivars with low CH_4 transport capacity is one of potential options to reduce CH_4 emissions from rice fields without any yield loss [6]. Based on the best of our knowledge, there are lack studies regarding high yielding rice cultivars with low CH_4 emissions under submergence condition for adaptation and mitigation strategies of climate chance in paddy fields. Thus, the aim of this study is to identify the rice varieties which have capacity to survive in submergence condition and result low CH_4 emissions.

2. Material and methods

2.1 Study site
The experiment was conducted during the rainy season (RS) 2015/2016 and the dry season (DS) 2016 at the experimental farm of Indonesian Agricultural Environment Research Institute (IAERI) that located in Pati, Central Java (6°46′39.7' S and 111°11′53.0' E). The soil type is categorized as silt loam, aeric endoaquepts. The total rainfall, minimum and maximum air temperature of the study site was < 1500 mm, 24°C and 40°C; respectively and it was recorded from IAERI weather station.

Table 1. Rice varieties that used during RS 2015/2016 and DS 2016

RS 2015/2016	DS 2016
1. Situbagendit	1. Inpara 3
2. Towuti	2. Inpara 4
3. Batutegi	3. Inpara 5
4. Inpago 8	4. Inpara 8
5. Inpago 9	5. Inpari 29
6. Ciherang	6. Inpara 30
	7. Inpago 8
	8. Inpago 9
	9. Ciherang
	10. Situbagendit
	11. Towuti
	12. Batutegi

2.2 Field experiment
The crops were established by direct seeding and transplanting during the rainy season (RS) 2015/2016, and the dry season (DS) 2016, respectively. The field was ploughed thoroughly with the depth of puddling around 10 cm and conducted 5 days before transplanting. Rice seedlings were transplanted at 21 days old with 20 cm x 20 cm plant spacing.

The experiment was arranged with treatments of different rice varieties (Table 1). When the rice plants were 37 days old after sowing and 44 days old after transplanting, the plots were submerged for 10 days in the submergence condition with water depth of 90 cm above the soil level in the plots. The rate of fertilizer applications were 120 kg N ha^{-1} (urea), 60 kg P_2O_5 ha^{-1} (super phosphate), 90 kg K_2O ha^{-1} (potassium chloride) and 5 Mg compost ha^{-1}. The basal fertilizer was applied 60 kg ha^{-1} of super phosphate during the day of transplanting or sowing, while compost was applied 5 days before basal fertilizer application. Urea and K_2O fertilizers were split into 3 applications at rates of 40 and 30kgha^{-1} for each application, respectively.

2.3 Gas emissions measurement
The CH_4 flux measurements were conducted using closed chamber which measured 50 cm length x 50 cm width x 100 cm height that covered four hills of rice plants. Four gas samples from each chamber were typically collected on each sampling day during 06:00–08:00 in the morning with 5 minute intervals (5, 10, 15 and 20 minutes). Gas samples were collected by using syringes, then directly brought to laboratory and analyzed by a gas chromatograph (GC) with a flame ionization detector (FID).
CH_4 fluxes were calculated using an equation as follows [7]:

$$E = \rho \, x \, \frac{\Delta C}{\Delta t} \, x \, \frac{V}{A} \, x \, \frac{273.2}{T + 273.2}$$

where
E   = CH_4 flux (mg m^{-2} min^{-1})
ρ   = gas density (0.714 mg cm^{-3})
Δc/Δt   = rate of increase of CH_4 concentration over time (ppm/min)
V   = volume of chamber (m^3)
A   = area of chamber (m^2)
T   = the average of air temperature inside the chamber during gas sampling (°C).

3. Results and discussion

3.1 Grain yield
The six and twelve rice cultivars tested during the RS 2015/2016 and the DS 2016, respectively, showed different survival behavior in yield (Table 2). During the RS, Inpago 9 resulted the highest rice yield approximately 5.38 Mg ha^{-1}, while Batutegi resulted the lowest yield approximately 3.46 Mg ha^{-1}. Each variety have their own ability responding excess water, some of them are still sensitive to complete submergence. The poorest survival was observed during DS 2016, whereas 8 varieties were dead (Inpara 3, Inpara 8, Inpago 9, Ciherang, Situbagendit, Towuti, Batutegi and Inpago 8) due to the flash flooding. The major cause of plant growth inhibition or even dead during the flash flooding is limitation oxygen (O_2) supply to the submerged rice plant tissues as result of low gas diffusion into the water or even soil and rapid O_2 consumption of soil microorganism [8]. During submerged, production of toxic substances such as Fe_2^+, Mn_2^+, and H_2S may affect severe plants damage [9]. The highest yield during DS was found on Inpari 30 approximately 5.29 Mg ha^{-1}. Inpari 30 showed the least damage and the best survival at the end of the submergence treatment because no significant effect of submergence to plant tiller number was observed (data not presented). The strategy of rice plant to survive under low-oxygen quiescence syndrome is to preserve carbohydrates through suppressed shoot elongation under flash-flood conditions then the rice plant regenerate its normal growth during de-submergence by using preserved carbohydrates [8].

3.2 CH_4 emission
Seasonal CH_4 emissions during the RS 2015/2016 and the DS 2016 are shown in Table 2. The rice varieties that still survived after flash flooding and resulted lowest CH_4 emissions are Ciherang and Inpara 5 during the RS and DS approximately 108 and 78.3 kg kg C ha^{-1} season^{-1}, respectively. The CH_4 emission could be different among rice cultivars due to growth duration as well as growth performance, such as weight of biomass, number of plant tillers and root distribution [10]. In addition, many factors affect CH_4 emission from rice cultivars such as size of the root space, supply of organic matter and oxidation rate in the rhizosphere [11]. Ciherang resulted lowest CH_4 emission during the RS but could not survive during the DS. During DS, Inpago 8 and Ciherang could not survive after flash flooding and still emit high CH_4 emission most likely because Inpago 8 and Ciherang contain high dead rice plant materials. The plant residues were returned to the soil and undergo decomposition. CH_4 emission is end product of the organic matter degradation, microbial processes

and the result of rice plants under anaerobic conditions [12]. Anaerobic condition, including submerged soil, emits 80% of atmospheric CH_4 as result of methanogenic bacteria during the anaerobic organic matter decomposition [13]. Rice plant influence the production of CH_4 emission because it provides substrate for methanogenic bacteria through root exudates, decaying root tissues and to a lesser extent, litter fall from above ground parts [14].

Table 2. CH_4 emission, grain yield and index of yield per emission during RS 2015/2016 and DS 2016

Rice varieties	CH_4 Emission (kg C ha^{-1} Season^{-1})	CH_4 Emission (mg CO_2eq ha^{-1} Season^{-1})	Grain Yield (mg ha^{-1})	Index of Yield per Emission
RS 2015/2016				
Situbagendit	157.8	4.42	4.82	1.092
Towuti	367.7	10.30	3.72	0.362
Batutegi	312.4	8.75	3.46	0.395
Inpago 8	146.7	4.11	4.60	1.119
Inpago 9	239.7	6.71	5.38	0.801
Ciherang	108.8	3.05	5.08	1.668
DS 2016				
Inpara 3*	12.0	0.34	0.00	0.000
Inpara 4	112.9	3.16	0.01	0.002
Inpara 5	78.3	2.19	2.16	0.985
Inpara 8*	78.6	2.20	0.00	0.000
Inpari 29	94.0	2.63	0.01	0.003
Inpari 30	139.9	3.92	5.29	1.351
Inpago 9*	514.7	14.41	0.00	0.000
Ciherang*	373.1	10.45	0.00	0.000
Situbagendit*	105.2	2.94	0.00	0.000
Towuti*	102.8	2.88	0.00	0.000
Batutegi*	71.8	2.01	0.00	0.000
Inpago 8*	31.7	0.89	0.00	0.000

*: rice plants could not survive after flash flooding

3.3 Index of yield per emission
The highest index of yield per emission during the RS is Ciherang while during the DR is Inpari 30. The higher value of yield per emission from different varieties means that the treatments give more advantages to produce more rice as well as mitigate GHG emission. During the RS, Ciherang could survive after flash flooding but could not survive during the DS most likely because water to be used for submergence was muddier so inhibit the photosynthesis so it makes less of light intensity and CO_2 availability [15].

4. Conclusion
The varieties that could survive after the flash flood condition as well as mitigate CH_4 emission were Ciherang, Inpago 8, Inpari 30 and Inpara 5. Using index of yield per emission make easier to know the high yielding rice varieties and the curtailment of the methane emission fluxes.

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