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Responses of red rice paddy under low nutrient supply in type B tidal swamp

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ABSTRACT

Low soil fertility can constrain the paddy red rice yield. One of the efforts to increase paddy red rice production at the Tidal swamp area is using iron toxicity tolerant varieties. The objectives of this research were (i) to evaluate the agronomic responses of red paddy rice to low nutrient supply to determine the sensitive character and (ii) to identify the tolerant and nutrient-efficient variety under low nutrient supply in a tidal swamp area. The experiment was conducted at Tidal Swamp Area Type B, Telang Sari Village, Banyuasin District, South Sumatra Province. The experimental design was Split Plot with five replications. Nutrient supply was the main plot, and the Varieties (Inpara 7; Inpago 7, Aek Sibundong, and Telang Sari) were the subplot. The nutrient supply treatments were H1: standard fertilizer rate and H2: low nutrient supply, which is 30% of the standard rate. The results showed that Inpago 7 and Inpara 7 were potential varieties at low nutrient supply. The sensitive characteristics of the varieties evaluated were chlorophyll content, number of tillers, grain weight, and percentage of empty grain for growth and production characters.

Conflict of interest: The authors declare that they have no conflicts of interest.

Introduction

Recent developments have led to suboptimal land use as a substitute for marginal land converted for non-agricultural purposes. The suboptimal land area in Indonesia is estimated at 123.1 million ha of dry land and 33.4 million ha of swamp land. Based on the existing swamp area, 20.1 million ha (60.2%) is tidal land[1,2]. The main obstacles faced in cultivating rice plants in low tides are the water system that is still not controlled, the high content of Fe elements, and the availability of nutrients[3,4].

Red rice plant growth was inhibited in soil types with a pH of less than 5.6, mainly due to the lack of macro elements and the toxicity of Al and Fe. Fe poisoning is a complex physiological symptom caused by physical conditions, nutrients, physiological properties, and plant growth medium containing excessive Fe[5]. The solubility of iron from Fe+3 to Fe+2 ions can potentially cause poisoning in rice and reduce production by an average of 60%[6,7]. Meanwhile, one way to overcome problems on marginal land is to use plants that are tolerant of environmental stress and are nutrient efficient[8].

Nutrient-efficient plant varieties can produce higher yields in soil conditions with limited nutrient content than other varieties[9,10]. Selection of nutrient-efficient plant varieties on marginal land can be made by comparing yields under low and optimum (normal) nutrient conditions[11,12]. Varieties with the slightest reduction in yield under nutrient-deficient conditions compared to optimum conditions are considered tolerant varieties and carry nutrient-efficient characteristics[10,13,14]. The nutrient uptake by roots is an essential factor that determines nutrient efficiency when planted in media nutrient-deficient [15,16].

This study aims to evaluate the agronomic response of red rice at low nutrient supply to obtain the most sensitive characteristics and to identify tolerant and nutrient-efficient varieties in low nutrient supply conditions..

Method

The study was conducted in tidal land of Type B, Telang Sari Village, Tanjung Lago District, Banyuasin Regency, South Sumatra, with a Split Plot Design with five replications and ten plant samples. The main plot (main plot) of the Red Rice variety consisted of the Inpara 7, Inpago 7, Aek Sibundong, and Telang Sari varieties. At the same time, the sub-plots were the nutrient supply standard for fertilization (H1: 100% with the standard 300 kg fertilization rate ha-1Urea, 100 kg ha-1SP36, 50 kg ha-1KCl) and low nutrient supply (H2: 30% standard dose of Urea, SP36, and KCl fertilization).

The soil used has pH-H2O 4.6, pH-KCl 4.00, C organic 4.78%, total nitrogen (N) 0.45%, P total 31.20 mg 100g-1P2O5, K total 13.28 mg 100g-1K2O, Ca 3.57 me100g -1, Fe 345.67 ppm, H 0.48 me100g -1 soil, CEC 30.45 me100g -1, texture clay 28.15%, Sand 9.35%, Dust 62.35%, Al-dd 7.25 me100g -1 and Na 12.75 me100g -1.

Red rice seeds were planted using the table system (direct seed sowing) on plots measuring 3 x 2 m, with a distance between plots of 1 m. The number of research plots is 40 plots. Maintenance of pests and diseases is carried out chemically using pesticides, the research area is fenced with plastic, and traps are installed to avoid rats. Harvesting is done after 80% of the grains on the panicles have turned yellow.

Observations were made, including plant height (cm), chlorophyll content (by immersion method), the total number of tillers and productive tillers, Fe content in roots and the crown (using Atomic Absorbent Spectro (AAS), root dry weight, shoot dry weight, the weight of grain per clump, the weight of grain per plot and percentage of empty grain. The data were analyzed for variance with the F test to determine whether the treatment affected the observed variables; if it was real, it was continued with the BNJ test at $\alpha = 5$ %.

Results and Discussion

The results of variance (Table 1) showed that the nutrient supply treatment in several varieties of Red Rice had a significant to a very significant effect on the observed variables, including plant height, total tiller number, number of productive tillers, chlorophyll content, root Fe content, crown Fe content, and dry weight.

Table 1. The results of the variance of the influence of varieties and the treatment of nutrient supply on the observed variables

Observed variables	F_{count}		
	Main tile	**Subsidiary tile**	**Interaction**
Plant height	62.54**	79.46**	3.50*
Root Fe content	61.11**	130.70**	13.33**
Crown Fe content	64.43**	125.03**	13.39**
Chlorophyll Content	639.80**	15.32**	1.48tn
Number of productive tillers	81.06**	104.28**	2.49tn
Number of tillers	88.41*	84.24**	1.17tn
Grain weight per clump	312.85**	142.72**	4.39*
Percentage of empty grain per clump	75.04**	9.28**	1.02tn
Grain weight per plot	130.30**	44.52**	1.35 tn
F table 5%	**7.71**	**3.01**	**3.01**
F table 1%	**71.2**	**4.72**	**4.72**

Note: tn = not significantly different, * = significantly different, ** = very significantly different

Plant Height, Number of Tillers (Total and Productive), and Chlorophyll Content

Based on observations of plant height in the nutrient supply treatment in Table 2, data were obtained on the decrease in plant height at low nutrient supply (H2), especially the Telang Sari variety compared to the Inpara 7, Inpago7 and Aek Sibundong varieties. The plant crown is a part that is sensitive to low nutrient conditions. Limited nutrient supply can inhibit plant growth, and the varieties generally planted also have plant height; leaf chlorophyll is very significant at low nutrient conditions (H2) except for Inpara 7 and Inpago 7; the decrease is not significant (Table 2). Limited nutrient supply causes plants to lack nutrients which results in disruption of plant growth; the lack of nutrient supply resulted in a decrease in plant height, plant dry weight, and leaf chlorophyll content[17-20].

Tidal land, where the research location is often submerged (due to high tides), also affects the decrease in chlorophyll content due to the increase in Fe nutrient tides which causes the absorption of macronutrients to be disrupted by plants. Iron toxicity in lowland rice has been associated with the reduction of Fe to its 2+ form for uptake by crop plants[21]. Furthermore, the effects of deficiency and excess of zinc on morphophysiological traits have revealed cross talk between micro- and macronutrients, leading to variations in macroelement concentrations, including reduced levels of Fe in certain conditions[22]. There was a decrease in the amount of chlorophyll in plants under submerged stress[23-25]. A high chlorophyll content would maintain a high rate of photosynthesis during the seed-filling stage so that the resulting assimilation increases[26,27].

Table 2 shows that the number of total tillers and productive tillers decreased with the treatment of limited nutrient supply. Limited nutrient supply (H2) gave the total number of tillers and productivity ranged from 15.20 – 24.20 and 14.20 – 23.60, respectively. The Inpara 7 and Inpago 7 varieties had more productive tillers, and fewer tillers decreased in conditions of low (limited) nutrient supply, indicating that both varieties were tolerant and efficient compared to the Telang Sari variety. Based on the research results, the nutrient supply affects growth during vegetative growth, ultimately affecting crop yields[28,29]. The number of tillers indicates red rice plant performance on efficiency and tolerance at high Fe conditions[6,30]. Additionally, the omission of nitrogen and phosphorus has been reported to reduce the total number of tillers in rice[31]. This decrease in tiller number has been linked to the death of some tillers due to their failure in competition for light and nutrients[32]. Furthermore, the content of endogenous growth-inhibitory hormone abscisic acid decreased, and the number of tillers per plant increased after double nitrogen compensation[33]. It has also been observed that the percentage of reproductive tillers is a very plastic trait, depending on the growing conditions[34].

Table 2. Plant height, total tiller number, number of productive tillers, and chlorophyll content of nutrient supply treatment for red rice

Nutrient supply	Varieties (V)				Average
	Telang Sari	Inpara 7	Inpago 7	Aek Sibundong	
	…………...Plant height (cm) …………...				
H1: 100%	74.50b	83.80de	85.70e	78.00c	80.5
H2: 30 %	65.40a	80.20c	82.00cd	73.80b	75.35
Average	69.95a	82.00bc	83.85c	75.90b	
	…………...Total Number of Tillers (Till)……………..				
H1: 100%	19.20b	26.40e	24.60cd	23.40c	23.40y
H2: 30 %	15.20a	24.20cd	21.60bc	21.00b	20.50x
Average	17.20a	25.30c	23.10b	22.20b	
	………………Total Number of Productive Tillers (Till)……………..				
H1: 100%	18.40b	25.20e	23.80d	23.00d	22.6y
H2: 30 %	14.20a	23.60d	21.00c	20.00c	19.7x
Average	16.30a	24.40d	22.40c	21.50b	
	…………...Chlorophyll Content (mg g-1)……………..				
H1: 100%	15.89b	16.93c	16.72c	17.40c	16.74y
H2: 30 %	13.63a	15.67b	15.63b	15.90b	15.21x
Average	14.76a	16.30b	16.18b	16.65b	

Note: Numbers in the same column and row followed by the same letter mean that they are not significantly different based on the 5% BNJ test

Grain Weight per Clump, Grain Weight per Plot, and Percentage of Void Grain

Grain weight per plot of red rice paddy at standard nutrient supply (H1) ranged from 3.62-4.27 kg, while production per plot of low nutrient supply rice plant (H2) ranged from 3.02-3.9 kg (Table 3). The weight of grain per clump and plot was related to the number of productive tillers, the weight of grain per clump, and the number of populations related to the ability to grow plants per plot, physiological mechanisms underlying the high yield potential[35]. There was a decrease in production per clump and plot due to the low nutrient supply; although it produced productive tillers also had a high percentage of empty grain. The element N is essential for plants because it is a constituent element of amino acids, proteins, nucleic acids, and chlorophyll which plays a role in carbohydrate synthesis as assimilate will affect generative growth and the formation of all components of red rice yields[36]. The number of tillers correlated with the number of panicles, which would determine grain weight per clump[37].

Table 3. Grain weight per clump, grain weight per plot, percentage of empty grain in the treatment of rice nutrient supply for red rice

Nutrient supply	Varieties (V)				Average
	Telang Sari	Inpara 7	Inpago 7	Aek Sibundong	
	…………... Grain Weight per Clump (g) …………...				
H1: 100%	31.00b	38.87d	36.70d	33.90c	35.12y
H2: 30 %	24.04a	34.38c	31.20b	30.02b	29.91x
Average	27.52a	36.63d	33.95c	31.96b	
	…………... Grain Weight per Plot (kg)……………..				
H1: 100%	3.62b	4.27c	4.09c	4.00c	4.00y
H2: 30 %	3.02a	3.90b	3.63b	3.64b	3.55x
Average	3.32a	4.08c	3.86b	3.82b	
	……………… Percentage of Empty Grain (%)……………..				
H1: 100%	13.78b	7.38a	5.17a	9.18a	8.88x
H2: 30 %	22.48d	16.76c	14.36bc	13.45bc	16.76y
Average	18.13b	12.07a	9.77a	11.31a	

Note: Numbers in the same column and row followed by the same letter mean that they are not significantly different based on the 5% BNJ test

The percentage of empty grain per clump of red rice ranged from 13.45 – 22.48% at low nutrient supply (H2), while at standard nutrient supply (H1), 5.17 to 13.78 %. There was a very significant effect on the percentage of empty grains per clump, where the low nutrient supply caused the percentage of empty grain per clump to increase (Table 3); plant growth and photosynthetic ability were inhibited due to low nutrient supply, which would affect panicle filling, but the Inpara 7 and The Inpago 7 tolerates no significant downgrade. Nitrogen is also required to synthesize chlorophyll, a photosynthetic pigment[38]. N deficiency can result in low photosynthetic activity.

Root Fe Content, Root Fe Content, Root Dry Weight, and Root Dry Weight

Table 4 shows that the tolerant varieties, namely Inpara 7 and Inpago 7 varieties at low nutrient supply, experienced a slight decrease in dry weight. In contrast, for those with susceptible varieties at low nutrient supply, a decrease in dry weight (root dry weight and shoot dry weight) was more significant, ranging from 3.69 – 5.04 g and 10.53 – 14.71 g. The tolerant varieties will carry out more photosynthesis and can produce more significant dry matter[39,40]. The soil N, P, and K nutrient uptake significantly increased crown dry weight[41].

Tidal lands often experience submerged stress; therefore, the low nutrient supply affects the dry weight of red rice plants because the increase in Fe nutrients affects the availability of macronutrients, but for tolerant and nutrient-efficient varieties, this does not affect much. The rice varieties have elongated properties during submersion, so food reserves are reduced and affect dry weight so that sufficient nutrients are needed[42,43]. Susceptible varieties will experience physiological disturbances due to inundation, affecting growth in both the vegetative and generative phases[44].

Table 4. Crown Fe content, root Fe content, root dry weight, and shoot dry weight in red rice nutrient supply treatment

Nutrient supply	Varieties (V)				Average
	Telang Sari	Inpara 7	Inpago 7	Aek Sibundong	
	………….. Crown Fe Content (mg g-1) …………..				
H1: 100%	4.14d	2.18b	2.88c	1.73a	2.73x
H2: 30 %	4.88e	2.70bc	3.62d	3.59d	3.70 y
Average	4.51c	2.44a	3.25b	2.66a	
	………….. Root Fe Content (mg g-1)……………..				
H1: 100%	3.81b	5.96	4.90cd	4.24c	4.73y
H2: 30 %	2.00a	5.18	4.56cd	3.99b	3.93x
Average	2.91a	5.57c	4.73b	4.12b	
	………………. Root Dry Weight (g)……………..				
H1: 100%	4.48b	6.31c	6.02c	4.63b	5.36y
H2: 30 %	3.69a	5.04b	4.82b	4.18a	4.43x
Average	4.48b	6.31c	6.02c	4.63b	5.36y
	………….. Shoot Dry Weight (g)……………..				
H1: 100%	12.07b	14.55d	15.78d	13.07bc	13.87
H2: 30 %	10.53a	13.45c	14.71d	11.49a	12.55
Average	11.30a	14.00b	15.25b	12.28a	

Note: Numbers in the same column and row followed by the same letter mean that they are not significantly different based on the 5% BNJ test

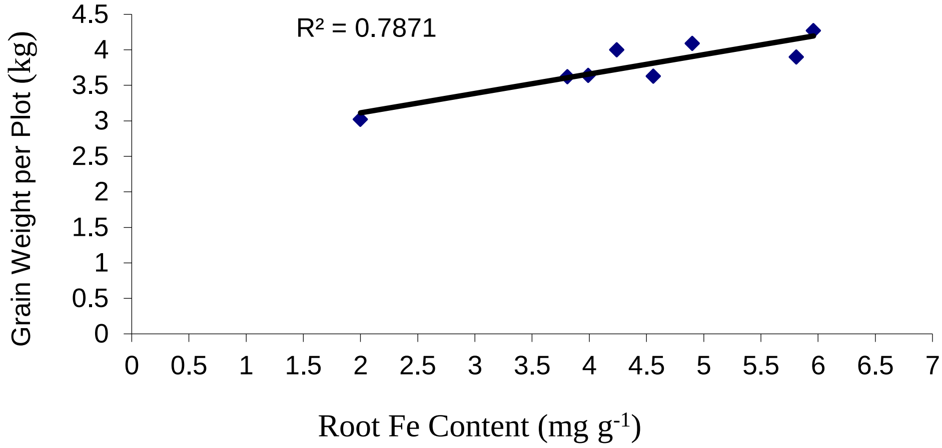

Fig 1.Relationship of root Fe content with grain weight per red rice plant plot

Low nutrient supply also affects the absorption of Fe levels in the roots and canopy (Table 4); tolerant varieties have higher levels of Fe absorbed by roots than susceptible varieties, as well as the levels of Fe in the crown for sensitive varieties will absorb more Fe. in the canopy compared to varieties that are tolerant and nutrient efficient, both at standard nutrient supply and low nutrient supply. The Fe content of roots and plant crowns determines the potential (tolerant) varieties for plants in the tides.

Fe content in plant tissue planted on tidal land determines the efficiency of nutrient absorption to determine the tolerance of varieties. The higher the level of Fe absorbed by the roots (R^2 = 0.7871), the weight of grain per plot produced by red rice plants was greater (Fig 1), while the higher the entry of Fe content into the canopy tissue (R^2 = 0.805) had a negative correlation with the weight of grain per plot (Fig 2). On the other hand, the higher the absorption of excessive Fe in the plant canopy, the correlation with the percentage of empty grain (Fig 3). According to Zhao et al[45], increased Fe^{2+} solubility can inhibit root growth and interfere with nutrient uptake. The higher levels of Fe enter the plant canopy tissue, it will cause inhibition of plant growth. Furthermore, Boussadia et al[38] explained that the greater the absorption of macronutrients by the roots, the higher the photosynthetic ability and the supply of photosynthate for grain development.

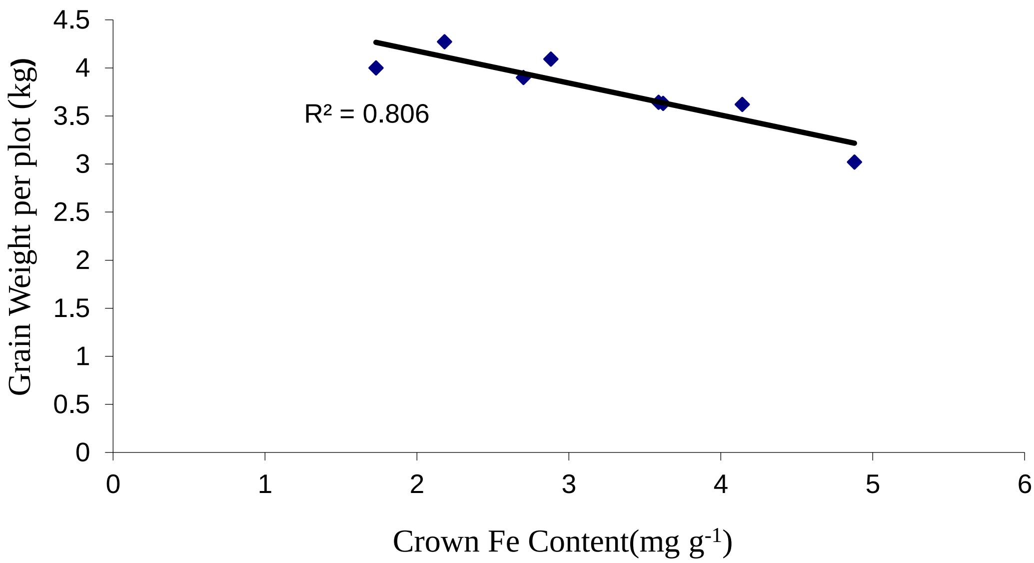

Fig 2.Relationship between crown Fe content and grain weight per plot of red rice plants

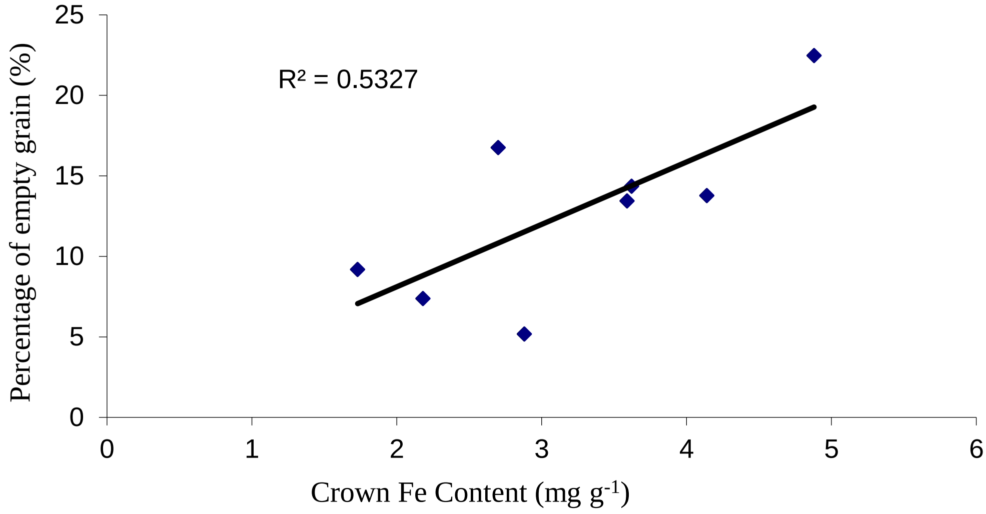

Fig 3.Correlation between crown Fe content and percentage of empty grain in red rice plants

Conclusion

Red rice varieties have different responses to low nutrient supply; based on all the characters evaluated, Inpara 7 and Inpago 7 are considered the most tolerant and nutrient-efficient, while Telang Sari is the most susceptible. Red rice's sensitive characteristics can be used as characters evaluated on tidal land for tolerant varieties and nutrient efficiency.

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Author contributions

All authors contributed to the study's conception and design. Material preparation by [**Asmawati**], [**Laili Nisfuriah**], and [**Gamal Abdul Nasser**]. Data collection was performed by [**Rosmiah**], [**Rastuti Kalasari**] and [**Marlina**]. Data analysis were performed by [**Ida Aryani**], [**Neni Marlina**], and [**Joni Rompas**]. The first draft of the manuscript was written by [**Asmawati**] and [**Dali**]. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.